X-ray Radiation and Safety: What Everyone Should Know

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Outline

1. Basics of X-ray Diffraction
2. Where are the X-rays
3. General X-ray Safety
    - -definitions
    - -procedures
    - -videos
    - -handouts
4. At the Instrument
5. Some Software Instruction

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Personnel Training

All personnel involved in the installation, maintenance, repair or use of analytical X-ray units must be registered with the Radiation Safety Office. Prior to beginning work with an analytical unit, the user shall attend a radiation safety training session provided by the Radiation Safety Office. This session is intended to provide basic safety information and to introduce the administrative procedures of the Safety Office at Rigaku Americas Corporation.

Detailed instructions on the operations, hazards and radiation warning devices of a specific analytical unit , must be provided by the owner of the equipment. Before starting to work on an analytical unit, make sure you receive specific instruction on the unit's operation from the person responsible for the unit.

General Radiation

- **Radiation** is energy in transit in the form of high speed particles and electromagnetic waves. We encounter electromagnetic waves every day. They make up our visible light, radio and television waves, ultra violet (UV), and microwaves with a spectrum of energies. These examples of electromagnetic waves do not cause ionizations of atoms because they do not carry enough energy to separate molecules or remove electrons from atoms.

General Radiation

- **Ionizing radiation** is radiation with enough energy so that during an interaction with an atom, it can remove tightly bound electrons from their orbits, causing the atom to become charged or ionized. Ionizing radiation deposits energy at the molecular level, causing chemical changes which lead to biological changes. These include cell death, cell transformation, and damage which cells cannot repair. Effects are not due to heating.

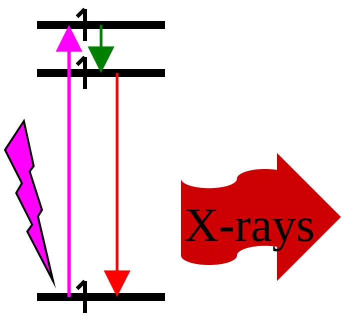
General Radiation

- **X-rays are a form of ionizing radiation.** They are electromagnetic waves emitted by energy changes in electrons. These energy changes are either in electron orbital shells that surround an atom (Rigaku FRE+ or Micromax 007HF generators) or in the process of slowing down (synchrotron).

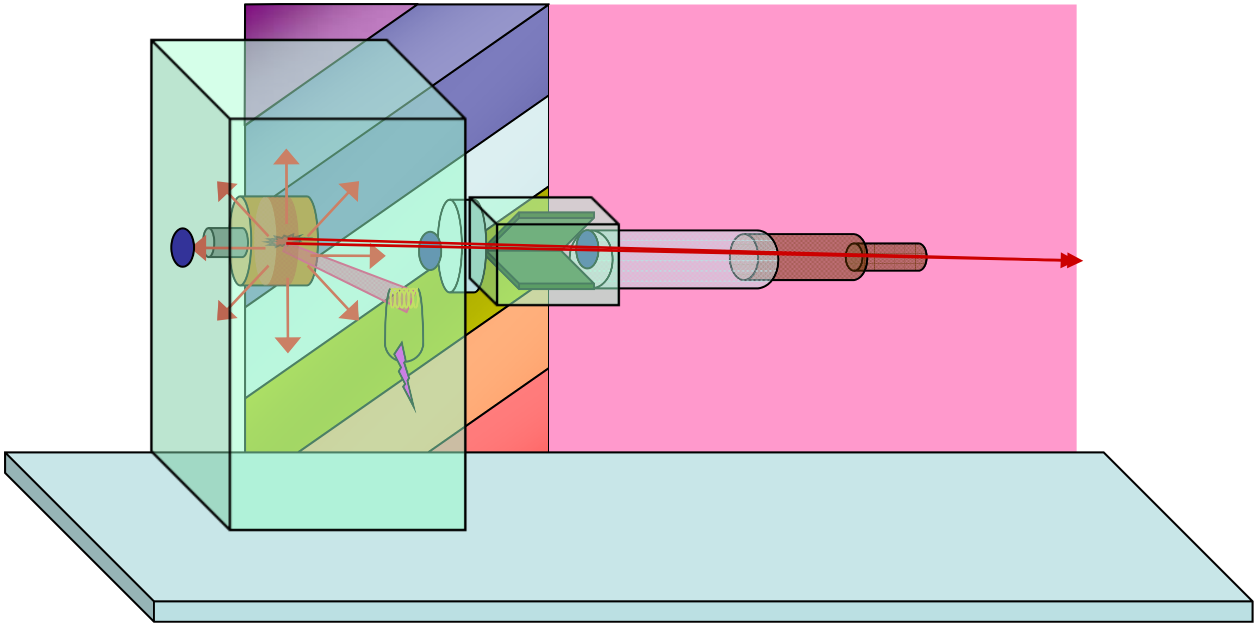
General X-ray

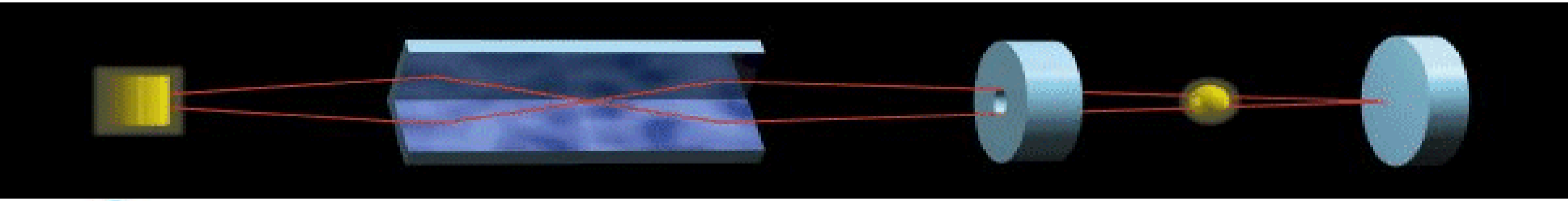
- X-rays are produced from the excitation of electrons followed by the cascading of these electrons back down to the ground state
- The typical X-rays used in crystallography range from **0.6 to 2.5Å**
- Your instrument ideally emits X-rays of only one wavelength (**1.54Å** or **0.7107Å)** out of the end of the collimator:

  But other wavelengths are produced while the primary wavelength is being produced



Where are the X-rays? Rotating Anode/Confocal Optic Systems





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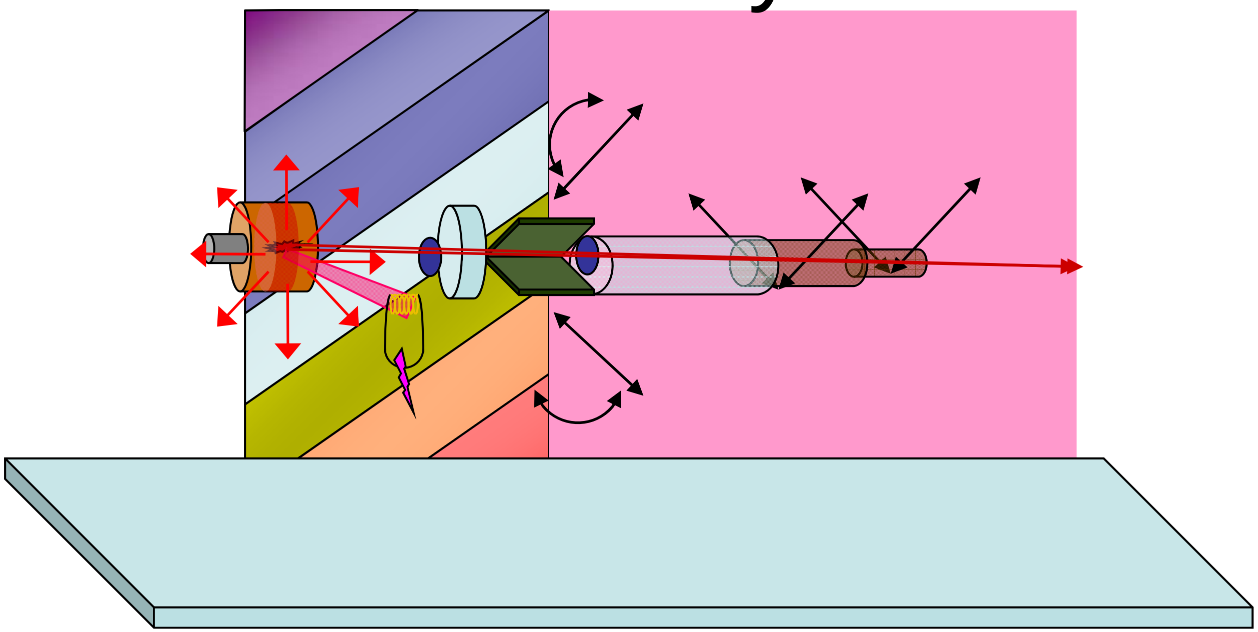
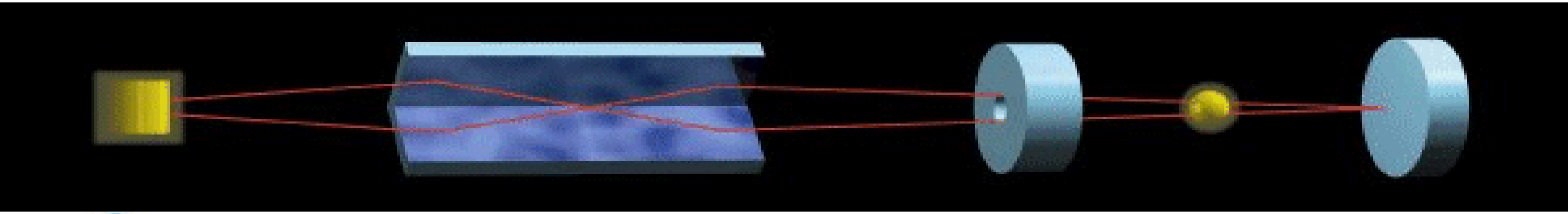
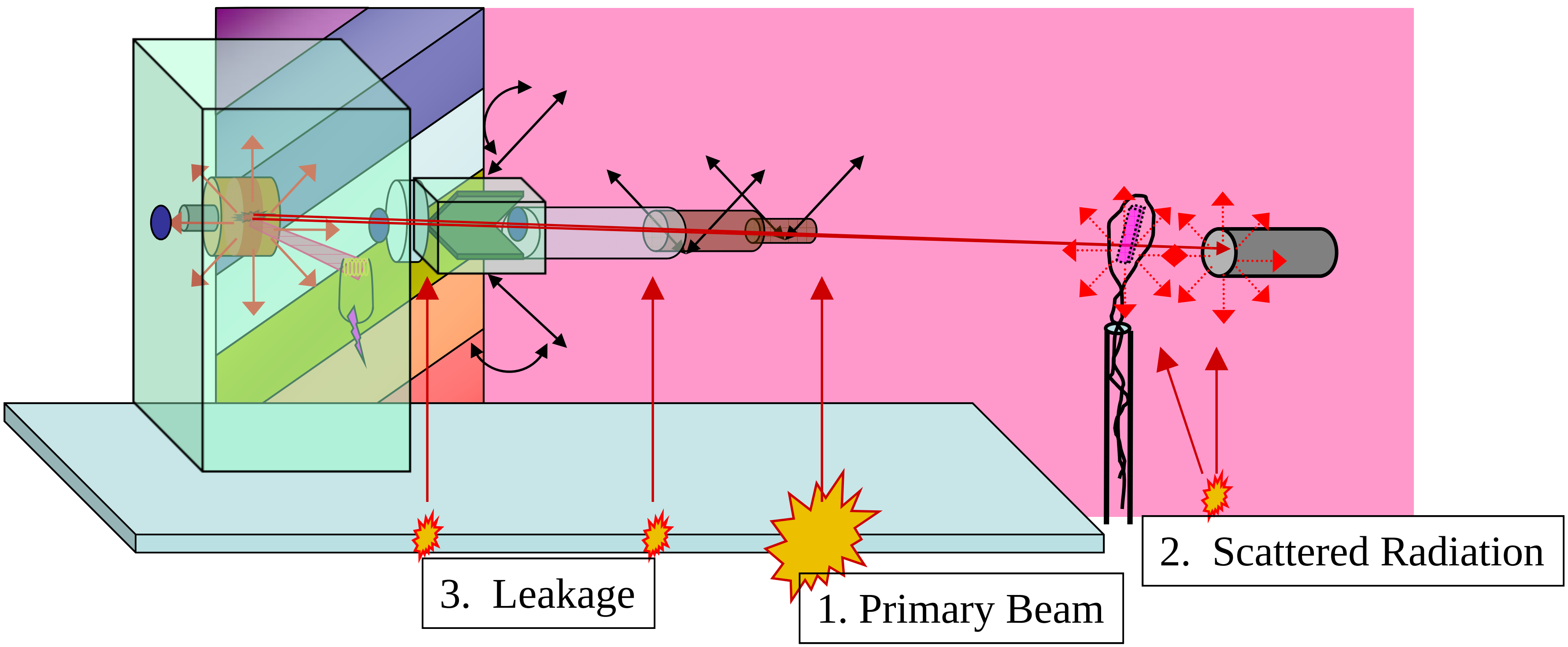




Three Regions of High Exposure Concern

1. **Primary Beam**
   The critical radiation exposure problem with analytical X-ray equipment is the primary beam. Exposure to the primary beam can cause localized acute exposure. Consequently, the analytical operator must never intentionally place any part of their body in the primary beam. Typically, these beams are relatively "soft" X-rays resulting in maximal energy deposition in epithelial tissues. Erythema or reddening of the skin can occur when skin is acutely exposed to 300 R (much less than a second). Radiation burns may occur from longer exposures.
2. **Scattered Radiation**
   When the primary beam intersects a material such as a sample or elements of the X-ray unit including the beam stop, some of the radiation is scattered out of the primary beam. While these radiation fields are considerably less intense than the primary beam, they still represent a potential hazard. Scattered radiation fields can be measured by the analytical operators with a survey meter.
3. **Leakage**
   Some radiation may leak around the tube housing structure. State law requires that source housing construction shall be that when all the shutters are closed the leakage radiation must not exceed that of radiation limits for the general public.

Rotating Anode Systems: What are the danger areas?



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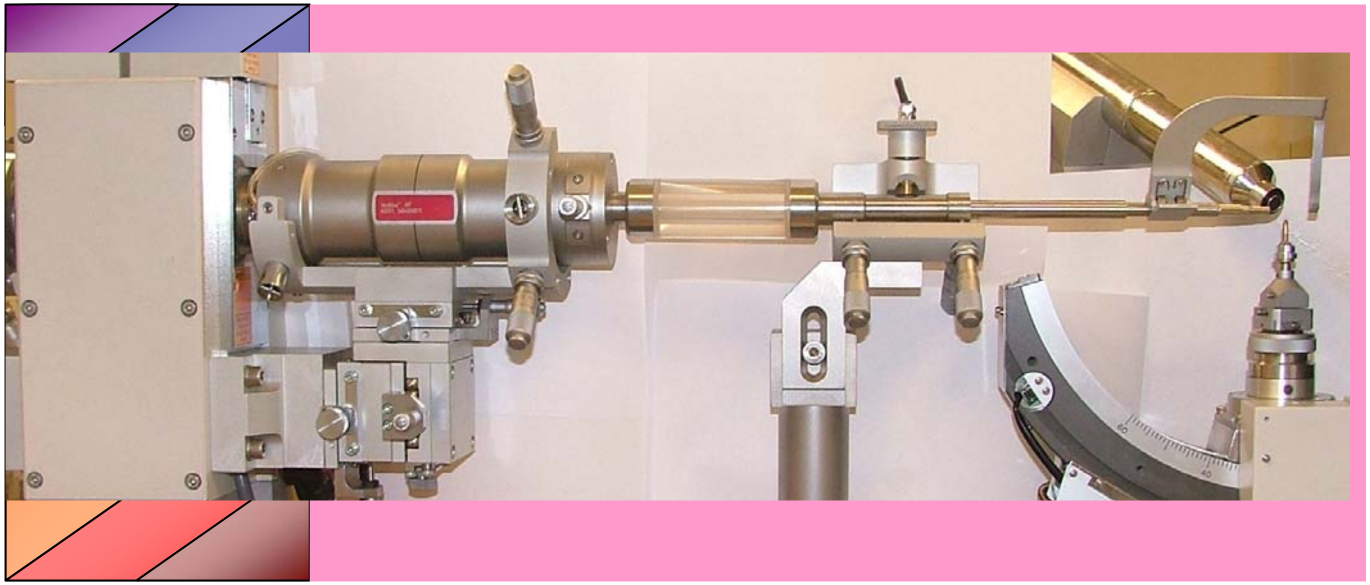

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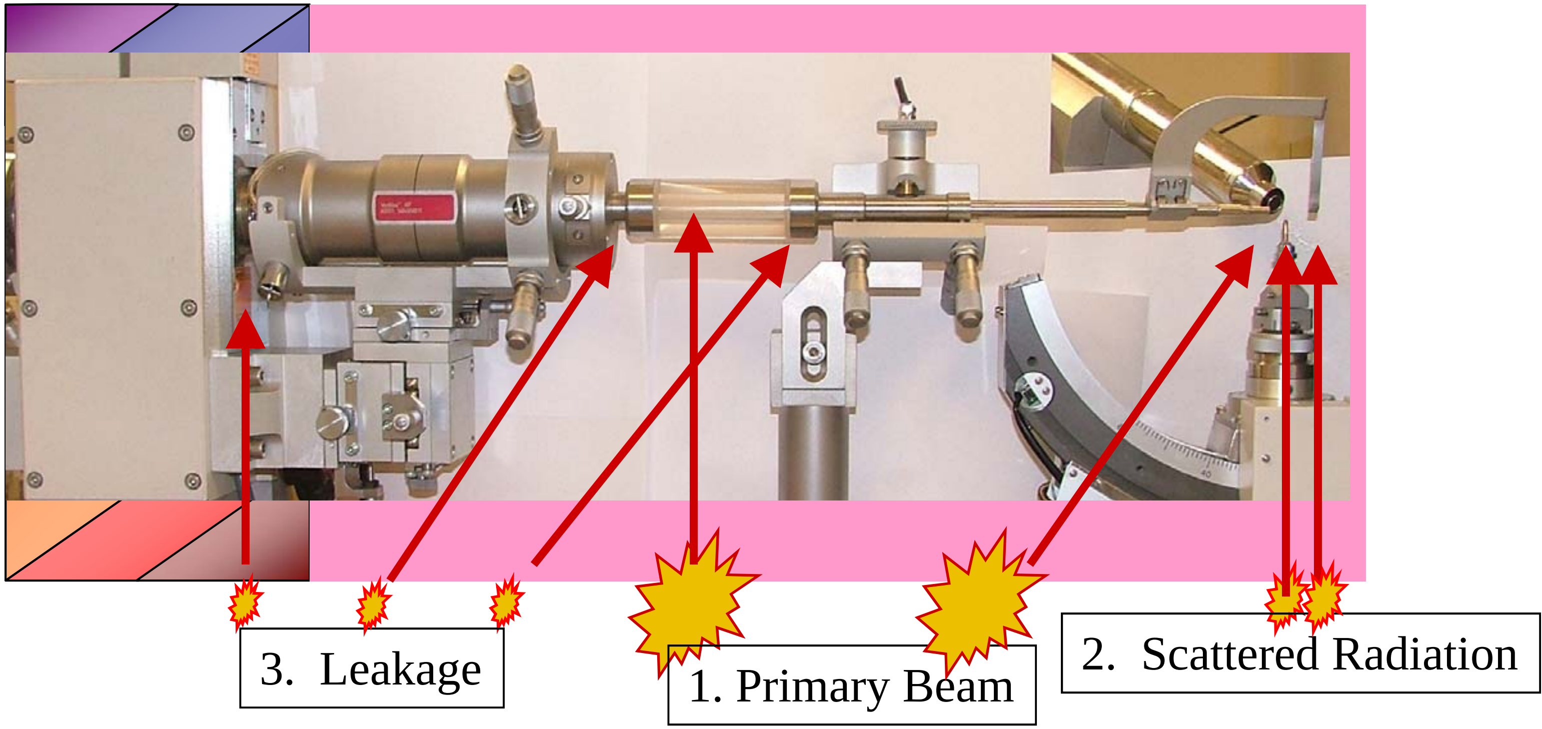


Emergency Procedures

If an exposure is suspected, do the following:

1. **Report all potential exposures of this kind immediately to your supervisor and/or person responsible for the analytical unit.**

2. **The supervisor in turn needs to immediately notify the Radiation Safety Office so that evaluation, corrective action and if necessary, medical evaluation can be initiated.**

Definitions

- Chronic vs. Acute dose
- Somatic vs. Genetic vs. Teratogenic effects
- Stochastic vs. Non-Stochastic effects
- Units of Radiation

Types of Exposure

- A **Chronic dose** means a person received a radiation dose over a long period of time.

- An **Acute dose** means a person received a radiation dose over a short period of time.

Effects of Exposure

- **Somatic effects** are effects from some agent, like radiation that are seen in the individual who receives the agent.
- **Genetic effects** are effects from some agent, that are seen in the offspring of the individual who received the agent. The agent must be encountered pre-conception.
- **Teratogenic effects** are effects from some agent, that are seen in the offspring of the individual who received the agent. The agent must be encountered during the gestation period.

Effects of Exposure

- **Stochastic effects** are effects that occur on a random basis with its effect being independent of the size of dose. The effect typically has no threshold and is based on probabilities, with the chances of seeing the effect increasing with dose. Cancer is a stochastic effect.
- **Non-stochastic effects** are effects that can be related directly to the dose received. The effect is more severe with a higher dose, i.e., the burn gets worse as dose increases. It typically has a threshold, below which the effect will not occur. A skin burn from radiation is a non-stochastic effect.

Common Units of Radiation

- The **Roentgen (R)** is a unit used to measure a quantity called exposure. This can only be used to describe an amount of gamma and X-rays, and only in air.
- One roentgen is equal to depositing in dry air enough energy to cause 2.58x 10^{-4} coulombs per kg. It is a measure of the ionizations of the molecules in a mass of air.
  - The main advantage of this unit is that it is easy to measure directly, but it is limited because it is only for deposition in air, and only for gamma and X-rays.

Common Units of Radiation

- The **rad** (radiation absorbed dose) is a unit used to measure a quantity called absorbed dose. This relates to the amount of energy actually absorbed in some material, and is used for any type of radiation and any material.
- One rad is defined as the absorption of 100 ergs per gram of material. The unit rad can be used for any type of radiation, but it does not describe the biological effects of the different forms of radiation.

Common Units of Radiation

- The **rem** (Roentgen equivalent man) is a unit used to derive a quantity called equivalent dose. This relates the absorbed dose in human tissue to the effective biological damage of the radiation.
- Not all radiation has the same biological effect, even for the same amount of absorbed dose. Equivalent dose is often expressed in terms of thousandths of a rem, or mrem.
  - (rem) = (rad) X (Q)
    - Where Q is the quality factor that is unique to the type of incident radiation

Common Units of Radiation

- The **sievert (Sv**) is a unit used to derive a quantity called equivalent dose. This relates the absorbed dose in human tissue to the effective biological damage of the radiation.
  - Not all radiation has the same biological effect, even for the same amount of absorbed dose. Equivalent dose is often expressed in terms of millionths of a sievert, or micro-sievert.
  - To determine equivalent dose
    - (Sv) = (Gy) x (Q)
    - One sievert is equivalent to 100 rem.

Other Units of Radiation

- The **curie(Ci)** is a unit used to measure a radioactivity. One curie is that quantity of a radioactive material that will have 37,000,000,000 transformations in one second. Often radioactivity is expressed in smaller units like: thousandths (mCi), millionths (uCi) or even billionths (nCi) of a curie. The relationship between becquerels and curies is: 3.7×10^{10} Bq in one curie.
- The **gray (Gy)** is a unit used to measure a quantity called absorbed dose. This relates to the amount of energy actually absorbed in some material, and is used for any type of radiation and any material. One gray is equal to one joule of energy deposited in one kg of a material. The unit gray can be used for any type of radiation, but it does not describe the biological effects of the different radiations. Absorbed dose is often expressed in terms of hundredths of a gray, or centi-grays. One gray is equivalent to 100 rads.
- The **Becquerel (Bq)** is a unit used to measure a radioactivity. One Becquerel is that quantity of a radioactive material that will have 1 transformations in one second. Often radioactivity is expressed in larger units like: thousands (kBq), one millions (MBq) or even billions (GBq) of a becquerels. As a result of having one Becquerel being equal to one transformation per second, there are 3.7×10^{10} Bq in one curie.

Federal Maximum Exposure Limits

Limits for Exposures	Exposure
Occupational Dose limit (US - NRC)	50 mSv/year (5 rem)
Occupational Exposure Limits for Minors (10%)	0.5 rem/year
Occupational Exposure Limits for Fetus	0.5 rem/9 months
Public dose limits (ouside radiation area)	1 mSv/year (0.1 rem)
Occupational Limits (eye)	15 rem/year
Occupational Limits (skin)	50 rem/year
Occupational Limits (extremities)	50 rem/year

ALARA: The above limits are the Maximum Permissible Doses allowed by regulation. However, all doses should be maintained As Low As Reasonably Achievable (ALARA).

ANSI/HPS N43.2-2001 and Federal CFR

ANSI/HPS N43.2-2001

Federal Maximum Exposure Limits (areas)

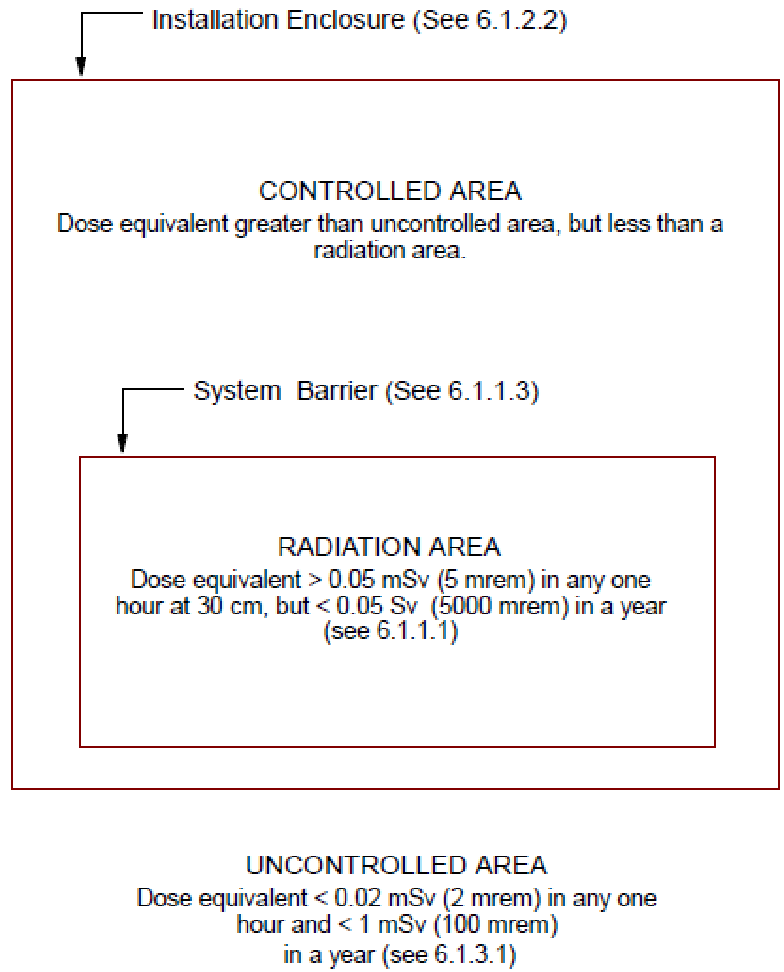


Fig. 1. Area Designations

Personnel Monitoring Ring/Badge Dosimeters

Operators of analytical X-ray equipment will be provided with a finger (ring) and body (badge) monitoring device. The dosimeter is designed to record information about the amount of radiation which you receive during the course of your work. However, it is important to note that the cross-sectional area of the primary radiation beam is usually small and that the monitoring device may not indicate the maximum exposure to the operator.

Dosimeter Use Practices

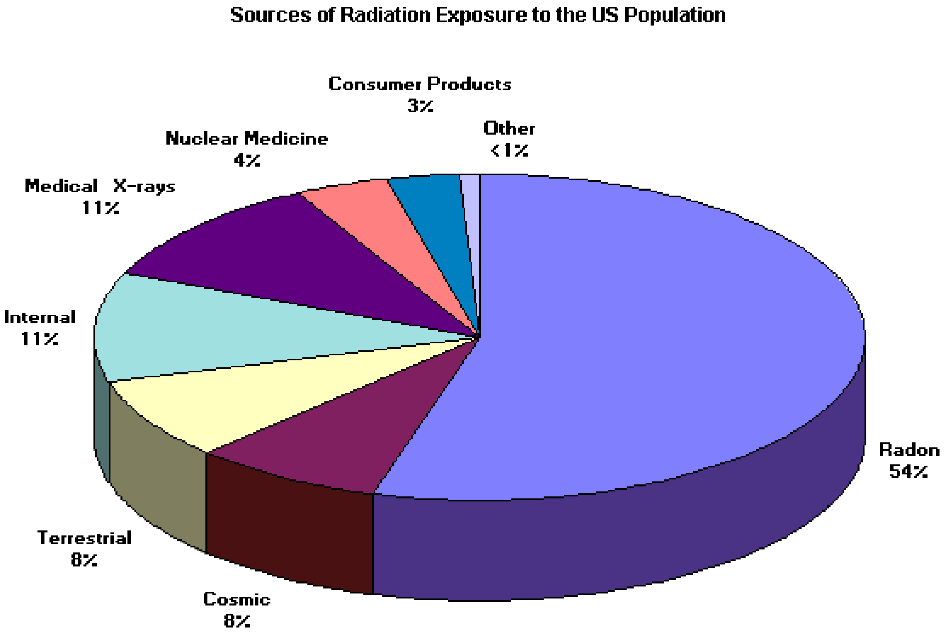
1. Ring/Badge dosimeters are issued for a specific period of time. The beginning and ending date is printed on the face of the dosimeter. At the end of each wear period, a replacement set will be issued through the ring/badge coordinator.
2. It is important to exchange the ring/badge dosimeter promptly so that exposures may be evaluated in a timely fashion. Prompt reading on the dosimeters will insure accurate information.
3. Chronic late ring/badge dosimeter returns may jeopardize your right to work with the instrumentation.
4. The ring dosimeter should be worn on the hand that will be nearest the primary beam. For example, if the operator sets up an experiment working mainly with the right hand, the ring dosimeter should be worn on the at hand.
5. When not wearing the dosimeters, do not store it in an area where it may receive a radiation exposure.

Dosimeter Use Practices (cont.)

6. Hand carry your badge through Airport Security…Do not allow it to be X-rayed!
7. If you lose your ring or badge dosimeter, promptly inform your Radiation Safety Officer for a replacement. If the lost dosimeter is subsequently recovered, return it to the Radiation Safety Office for processing and continue to wear the replacement dosimeter.
8. If your dosimeter is damaged, return it to the Radiation Safety Office for replacement.
9. Do not lend your ring or badge dosimeter to another person; and do not wear another person's dosimeter.
10. Do not wear your dosimeter during personal medical procedures involving nuclear medicine or X-ray radiation. The exposure recorded by the dosimeter must be restricted to your occupational exposure. If you inadvertently wear the dosimeter while being exposed to radiation for medical reasons, promptly report this to the Radiation Safety Office and obtain a replacement dosimeter.

Annual estimated average effective dose equivalent received by a member of the population of the United States.

Source	Average annual effective dose equivalent		
	(mrem)	(µSv)	**(percent of total)**
Natural			
Inhaled (Radon and Decay Products)	200	2	55%
Cosmic Radiation	27	0.27	8%
Terrestrial Radiation	28	0.28	8%
Other Internally Deposited Radionuclides	39	0.39	11%
Cosmogenic Radioactivity	1	10	0%
Total Natural	**300**	**3**	**82%**
Artificial			
Medical X ray	39	0.39	11%
Nuclear medicine	14	0.14	4%
Consumer products	10	0.1	3%
Other			
Occupational	0.9	1	<0.3
Nuclear Fuel Cycle	<1	1	<0.03
Fallout	<1	1	<0.03
Miscellaneous	<1	1	<0.03
Total Artificial	**63**	**0.63**	**18%**
Total Artificial and Natural	**360**	**3.6**	**100**



Typical Exposure and Dose

Source of Exposure	Exposure (Range)
Average Dose to US public from All sources	360 mrem/year
Average Dose to US Public From Natural Sources	300 mrem/year
Average Dose to US Public From Medical Sources	53 mrem/year
Average Dose to US Public from Weapons Fallout	< 1 mrem/year
Average Dose to US Public From Nuclear Power	< 0.1 mrem/year
Coal Burning Power Plant	0.165 mrem/year
X-rays from TV set (1 inch)	0.500 mrem/hour
Airplane ride (39,000 ft.)	0.500 mrem/hour
Nuclear Power Plant (normal operation at plant boundary)	0.600 mrem/year
Natural gas in home	9 mrem/year
Average Natural Background	0.008 mR/hour (0.006-0.015)
Average US Cosmic Radiation	27 mrem/year
Average US Terrestrial Radiation	28 mrem/year
Terrestrial background (Atlantic coast)	16 mrem/year
Terrestrial background (Rocky Mountains)	40 mrem/year
Cosmic Radiation (Sea level)	26 mrem/year
Cosmic Radiation (Denver)	50 mrem/year
Background Radiation Total (East, West, Central US)	46 mrem/year (35-75)
Background Radiation Total (Colorado Plateau)	90 mrem/year (75-140)
Background Radiation Total (Atlantic and Gulf in US)	23 mrem/year (15-35)
Radionuclides in the body (i.e., potassium)	39 mrem/year
Building materials (concrete)	3 mrem/year
Drinking Water	5 mrem/year
Pocket watch (radium dial)	6 mrem/year

Typical Exposure and Dose

Source of Exposure	Exposure (Range)
Chest X-ray	8 mrem (5-20)
Extemities X-ray	1 mrem
Dental X-ray	10 mrem
Head/neck X-ray	20 mrem
Cervical Spine X-ray	22 mrem
Lumbar spinal X-rays	130 mrem
Pelvis X-ray	44 mrem
Hip X-ray	83 mrem
Shoe Fitting Fluroscope (not in use now)	170 mrem
Upper GI series	245 mrem
Lower GI series	405 mrem
CT (head and body)	1,100 mrem
Therapeutic thyroid treatment (dose to the thyroid)	10,000,000 mrad
Therapeutic thyroid treatment (dose to the whole body)	7,000 mrem (5,000-15,000)
Earliest Onset of Radiation Sickness	75,000 mrad
Onset of hematopoietic syndrome	300,000 mrad (100,000 - 800,000)
Onset of gastrointestinal syndrome	1,000,000 mrad (500,000 - 1,200,000)
Onset of cerebrovacular syndrome	10,000,000 mrad (>500,000)
Thershold for cataracts (dose to the eye)	200,000 mrad
Expected 50% death without medical attention	400,000 mrad (300,000 - 500,000)
Doubling dose for genetic effects	100,000 mrad
Doubling dose for cancer	500,000 mrad
Dose for increase cancer risk of 1 in a 1,000	1,250 mrem
Consideration of theraputic abortion threshold (dose in utero)	10,000 mrem

Commonly Used Radioactive Elements

Americium -241: Used in many smoke detectors for homes and business...to measure levels of toxic lead in dried paint samples...to ensure uniform thickness in rolling processes like steel and paper production...and to help determine where oil wells should be drilled.

Cadmium -109: Used to analyze metal alloys for checking stock, sorting scrap.

Calcium - 47: Important aid to biomedical researchers studying the cell function and bone formation of mammals.

Californium - 252: Used to inspect airline luggage for hidden explosives...to gauge the moisture content of soil in the road construction and building industries...and to measure the moisture of materials stored in silos.

Carbon - 14: Helps in research to ensure that potential new drugs are metabolized without forming harmful by-products.

Cesium - 137: Used to treat cancers...to measure correct patient dosages of radioactive pharmaceuticals...to measure and control the liquid flow in oil pipelines...to tell researchers whether oil wells are plugged by sand...and to ensure the right fill level for packages of food, drugs and other products. (The products in these packages do not become radioactive.)

Chromium - 51: Used in research in red blood cell survival studies.

Cobalt - 57: Used in nuclear medicine to help physicians interpret diagnosis scans of patients' organs, and to diagnose pernicious anemia.

Cobalt - 60 : Used to sterilize surgical instruments...to improve the safety and reliability of industrial fuel oil burners...and to preserve poultry fruits and spices.

Copper - 67: When injected with monoclonal antibodies into a cancer patient, helps the antibodies bind to and destroy the tumor.

Curium - 244: Used in mining to analyze material excavated from pits slurries from drilling operations.

Iodine - 123: Widely used to diagnose thyroid disorders.

Iodine - 129: Used to check some radioactivity counters in vitro diagnostic testing laboratories.

Iodine - 131: Used to diagnose and treat thyroid disorders. (Former President George Bush and Mrs. Bush were both successfully treated for Grave's disease, a thyroid disease, with radioactive iodine.)

Iridium - 192: Used to test the integrity of pipeline welds, boilers and aircraft parts.

Iron - 55: Used to analyze electroplating solutions.

Krypton - 85: Used in indicator lights in appliances like clothes washer and dryers, stereos and coffee makers...to gauge the thickness of thin plastics and sheet metal, rubber, textiles and paper...and to measure dust and pollutant levels.

Nickel - 63: Used to detect explosives...and as voltage regulators and current surge protectors in electronic devices.

Phosphorus - 32: Used in molecular biology and genetics research.

Plutonium - 238: Has safely powered at least 20 NASA spacecraft since 1972.

Polonium - 210: Reduces the static charge in production of photographic film and phonograph records.

Promethium - 147: Used in electric blanket thermostats...and to gauge the thickness of thin plastics, thin sheet metal, rubber, textiles, and paper.

Radium - 226: Makes lightning rods more effective.

Selenium - 75: Used in protein studies in life science research.

Sodium - 24: Used to locate leaks in industrial pipelines...and in oil well studies.

Strontium - 85: Used to study bone formation and metabolism.

Technetium - 99m: The most widely used radioactive isotope for diagnostic studies in nuclear medicine. Different chemical forms are used for brain, bone, liver, spleen and kidney imaging and also for blood flow studies.

Thallium - 204: Measures the dust and pollutant levels on filter paper...and gauges the thickness of plastics, sheet metal, rubber, textiles and paper.

Thoriated tungsten: Used in electric arc welding rods in the construction, aircraft, petrochemical and food processing equipment industries. It produces easier starting, greater arc stability and less metal contamination.

Thorium - 229: Helps fluorescent lights to last longer.

Thorium - 230: Provides coloring and fluorescence in colored glazes and glassware.

Tritium: Used for life science and drug metabolism studies to ensure the safety of potential new drugs... for self-luminous aircraft and commercial exit signs... for luminous dials, gauges and wrist watches...and to produce luminous paint.

Uranium - 234: Used in dental fixtures like crowns and dentures to provide a natural color and brightness.

Uranium - 235: Fuel for nuclear power plants and naval nuclear propulsion systems...also used to produce fluorescent glassware, a variety of colored glazes and wall tiles.

Xenon - 133: Used in nuclear medicine for lung ventilation and blood flow studies.

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Adapted from Nuclear Energy Institute, 17706 I Street, N.W., Suite 400Washington, DC 20006-3708

Risks:
Reduced Life Expectancy

Health Risk	Est. life expectancy loss
Smoking 20 cigs a day	6 years
Overweight (15%)	2 years
Alcohol (US Ave)	1 year
All Accidents	207 days
All Natural Hazards	7 days
All Industries	60 days
Agriculture	320 days
Construction	227 days
Mining and quarrying	167 days
Manufacturing	40 days
Occupational dose (1 rem/yr)	51 days
Occupational dose (300 mrem/yr)	15 days

NRC Draft guide DG-8012, adapted from B.L Cohen and I.S. Lee, "Catalogue of Risks Extended and Updates", *Health Physics*, Vol. 61, September 1991.

Risks: 1 in a Million

Another way of looking at risk, is to look at the Relative Risk of *1 in a million chances of dying* of activities common to our society.

- Smoking 1.4 cigarettes (lung cancer)
- Eating 40 tablespoons of peanut butter
- Spending 2 days in New York City (air pollution)
- Driving 40 miles in a car (accident)
- Flying 2500 miles in a jet (accident)
- Canoeing for 6 minutes
- Receiving 10 mrem of radiation (cancer)

Adapted from DOE Radiation Worker Training, based on work by B.L Cohen, Sc.D.

Ways to Reduce Risk

There are 3 general ways to reduce exposure risk

- Time: Reduce the amount of time you are near the source of radiation

- Distance: Get as far away from the source as possible

- Shielding: Place something between you and the source to absorb approaching X-rays

Administrative Controls

Equipment Registration

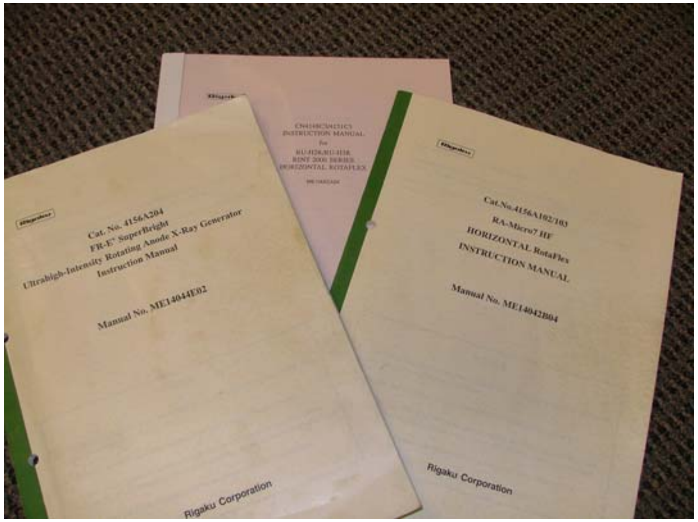
All analytical X-ray equipment shall be registered with the Radiation Safety Office. The Radiation Safety Office must be notified prior to initial use, if the unit is moved, modified or serviced.

Administrative Controls

Operating Procedures

Detailed written operating procedures shall be available to each registered unit. These procedures shall include all routine operating conditions for which the instrument will be used. At a minimum this shall include: sample insertion and manipulation, equipment alignment, routine maintenance, as well as emergency procedures.

-User Manual is a good start for your procedures.



Administrative Controls

Safety Overrides

Under some circumstances it may be necessary to override the analytical unit's safety devices. All overrides must be approved in writing by the Radiation Safety Officer.

Safety Devices

Analytical units shall have the following safety devices as required by State Regulations.

- Unused ports shall be secure in a manner which will prevent accidental opening. Open beam units shall have a shutter over the port which cannot be opened unless a collimator or coupling has been connected.
- Safety interlocks shall not be used to de-activate the X-ray beam except in an emergency or during testing of the interlock system.

Warning Devices

- All units with an open beam configuration shall have an easily identified device located near the radiation source housing and labeled what gives a clear, visible indication of the X-ray generation status (on-off)
- Safety interlocks shall not be used to de-activate the X-ray beam except in an emergency or during testing of the interlock system.

Warning Labels

- A label which bears the following or similar words shall be placed on the X-ray source housing:

CAUTION - HIGH INTENSITY X-RAY BEAM

- A label which bears the following or similar wording shall be placed on the control console of each unit near any switch which energizes the source:

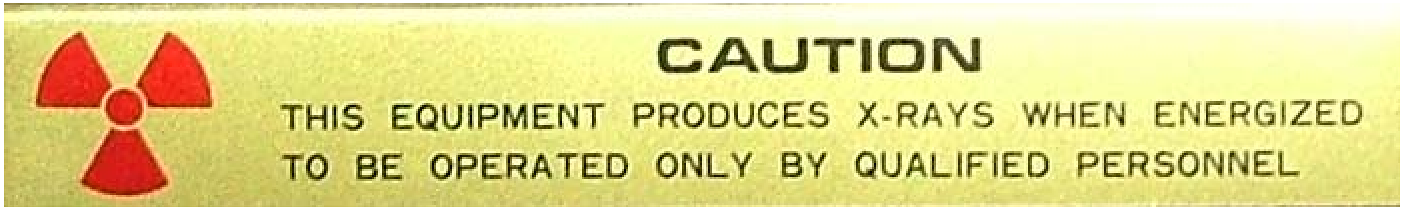
CAUTION - RADIATION

THIS EQUIPMENT PRODUCES

RADIATION WHEN ENERGIZED

Warning Labels

Warning Labels



Warning Lights

- An easily visible warning light labeled with these or similar words "X-RAY ON" shall be placed near any switch that energizes an X-ray source, and shall be illuminated only when the generator is energized, and have fail-safe characteristics.

Shutters

- Each port shall be equipped with a shutter that cannot be opened unless a collimator or a coupling device has been connected to the port.

Emergency Stop Buttons "Panic Buttons"

- All instruments are designed with a panic button which powers off the generator immediately upon activating.

- In an emergency, the *X-ray On* lamp can be jarred and the filament broken (if for example there is water on the floor).

Radiation Surveys

The Radiation Safety Office will perform a survey annually and following major repairs and/or system modifications. This survey will include inspection of all safety systems and a radiation exposure survey. The results of the survey will be kept on file in the Radiation Safety Office.

Users of analytical equipment should also routinely perform radiation surveys. The surveys should include monitoring for stray radiation in the immediate vicinity of the X-ray apparatus.

All labs should have a radiation survey meter readily available!!!

Survey Meter Instrumentation

Survey should be performed with a portable Geiger-Mueller survey instrument although the results are not necessarily quantitative. If accurate measurements are desired, the instrument should be calibrated with the source of low energy X-rays. Consideration should also be given to possible monitoring errors due to the cross-sectional area of the monitored radiation beam being smaller than the sensitive area of the survey meter.

When the Operator Should Perform a Radiation Survey

1. Upon installation of your instrument.

2. After any major changes in equipment configuration or minor system maintenance to insure that no unanticipated exposure hazards exist.

3. Following any maintenance requiring the disassembly or removal of local components.

4. During the performance of maintenance and alignment procedures.

5. When visual inspection of the local components in the system reveals an abnormal condition.

General Precautions

- Only Trained personnel shall be permitted to operate an analytical unit.
- Be familiar with the procedure to be carried out.
- Never expose any part of your body to the primary beam.
- Turn the X-ray beam OFF before attempting to make any changes to the experimental set-up (except for beam alignment)
- While the beam is on DO NOT attempt to handle, manipulate or adjust any object (sample, sample holder, collimator, etc.) which is in the direct beam path (except for beam alignment procedures).
- Examine the system carefully for any system modifications or irregularities.
- Follow the operating procedures carefully. DO NOT take short cuts!
- Never leave the energized system unattended in an area where access in not controlled.

General Precautions

- Survey the area frequently to evaluate scatter and leakage radiation fields.
- Never remove auxiliary shielding without authorization from the owner of the analytical equipment or Radiation Safety Officer.
- Never bypass safety circuits, such as interlocks.
- Report all unusual occurrences to the owner of the analytical unit for possible corrective actions.
- Only authorized, trained individuals as specified by the unit's owner and the Radiation Safety Office may repair, align or make modifications to the X-ray apparatus.

BRC FORM 203-1
(98)

Texas Department of Health
1100 West 49th Street
Austin, Texas 78756-3189

NOTICE TO EMPLOYEES

TEXAS REGULATIONS FOR CONTROL OF RADIATION

The Texas Department of Health has established standards for your protection against radiation hazards, in accordance with to the Texas Radiation Control Act, Health and Safety Code, Chapter 401.

YOUR EMPLOYER'S RESPONSIBILITY

Your employer is required to-

1. Apply these regulations to work involving sources of radiation.
2. Post or otherwise make available to you a copy of the Texas Department of Health regulations, licenses, certificates of registration, notices of violations, and operating procedures that apply to work you are engaged in, and explain their provisions to you.

YOUR RESPONSIBILITY AS A WORKER

You should familiarize yourself with those provisions of the regulations and the operating procedures that apply to the work you are engaged in. You should observe their provisions for your own protection and protection of your co-workers.

WHAT IS COVERED BY THESE REGULATIONS

1. Limits on exposure to radiation and radioactive material in restricted and unrestricted areas;
2. Measures to be taken after accidental exposure;
3. Personnel monitoring, surveys and equipment;
4. Caution signs, labels, and safety interlock equipment;
5. Exposure records and reports;
6. Options for workers regarding agency inspections; and
7. Related matters.

REPORTS ON YOUR RADIATION EXPOSURE HISTORY

1. The regulations require that your employer give you a written report if you receive an exposure in excess of any applicable limit as set forth in the regulations or in the license. The basic limits for exposure to employees are set forth in 25 Texas Administrative Code (TAC) §289.202(g), (h), and (i) (relating to Standards for Protection Against Radiation). These subsections specify limits on exposure to radiation and exposure to concentrations of radioactive material in air and water.

2. If you work where personnel monitoring is required by 25 TAC §282.202;
(a) your employer must give you a written report, upon termination of your employment, of your radiation exposures if you request the information on your radiation exposure; and
(b) your employer must furnish to you upon your written request, an annual written report of your exposure to radiation.

INSPECTIONS

All licensed or registered activities are subject to inspection by representatives of the Texas Department of Health. In addition, any worker or representative of the workers who believes that there is a violation of the Texas Radiation Control Act, the regulations issued thereunder, or the terms of the employer's license or registration with regard to radiological working conditions in which the worker is engaged, may request an inspection by sending a notice of the alleged violation to the Texas Department of Health. The request must set forth the specific grounds for the notice, and must be signed by the worker or the representative of the workers. During inspections, agency inspectors may confer privately with workers, and any worker may bring to the attention of the inspectors any past or present condition that the individual believes contributed to or caused any violation as described above.

POSTING REQUIREMENT

Copies of this notice shall be posted in a sufficient number of places in every establishment where employees are employed in activities licensed or registered, in accordance with 25 TAC §289.252 (relating to Licensing of Radioactive Material) and 25 TAC §289.226 (relating to Registration of Radiation Machine Use and Services), to permit employees to observe a copy on the way to or from their place of employment.

Theoretical Intensity Calculations for Cu Kα radiation at 1.54 Angstrom

$$-\ln(I/I_o) = \mu t \qquad \mu = \rho \Sigma g_i (\mu/\rho)_i$$

		ex: N2(air)							
Intensity at front of material		10000	1000	100	100	100	100	atom	μ/ρ cm2/g
ntensity out back of material		1	1	1	50	90	99	H	0.40
V	ratio of I/Io	0.000100	0.001000	0.010000	0.500000	0.900000	0.990000	N	7.50
V	μ/ρ cm2/g	7.5	7.5	7.5	7.5	7.5	7.5	O	11.50
V	ρ g/cm3	0.001210	0.001210	0.001210	0.001210	0.001210	0.001210	Pb	232.00
V	μ cm−1	0.009075	0.009075	0.009075	0.009075	0.009075	0.009075		
V									
V	ln I/Io	-9.210340	-6.907755	-4.605170	-0.693147	-0.105361	-0.010050		
V	-ln I/Io	9.210340	6.907755	4.605170	0.693147	0.105361	0.010050		
Thickness of material in mm		10149	7612	5075	764	116	11		
		ex: water (body fluids)							
Intensity at front of material		10000	1000	100	100	100	100	atom	gi
ntensity out back of material		1	1	1	50	90	99	H	2/18
V	ratio of I/Io	0.000100	0.001000	0.010000	0.500000	0.900000	0.990000	O	16/18
V	Σgi(μ/ρ)i cm2/g	10.23	10.23	10.23	10.23	10.23	10.23		
V	ρ g/cm3	1.00	1.00	1.00	1.00	1.00	1.00		
V	μ cm−1	10.23	10.23	10.23	10.23	10.23	10.23		
V									
V	ln I/Io	-9.210340	-6.907755	-4.605170	-0.693147	-0.105361	-0.010050		
V	-ln I/Io	9.210340	6.907755	4.605170	0.693147	0.105361	0.010050		
Thickness of material in mm		9.00	6.75	4.50	0.68	0.10	0.01		
		ex: lead (beam stop)							
Intensity at front of material		10000	1000	100	100	100	100		1.00E+300
ntensity out back of material		1	1	1	50	90	99		1
V	ratio of I/Io	0.000100	0.001000	0.010000	0.500000	0.900000	0.990000		1.00E-300
V	μ/ρ cm2/g	232.00	232.00	232.00	232.00	232.00	232.00		232.00
V	ρ g/cm3	11.30	11.30	11.30	11.30	11.30	11.30		11.30
V	μ cm−1	2621.60	2621.60	2621.60	2621.60	2621.60	2621.60		2621.60
V									
V	ln I/Io	-9.210340	-6.907755	-4.605170	-0.693147	-0.105361	-0.010050		-690.78
V	-ln I/Io	9.210340	6.907755	4.605170	0.693147	0.105361	0.010050		690.78
Thickness of material in mm		3.51E-02	2.63E-02	1.76E-02	2.64E-03	4.02E-04	3.83E-05		2.63E+00

Walk In Radiation Enclosure


Rigaku
MiniFlex
EMERGENCY
Rigaku


X-RAYS ON
Rigaku
SmartLab
X-RAY DIFFRACTOMETER

LANDAUER®

Service Guide

Contents

Accredited by the National Institute of Standards and Technology through

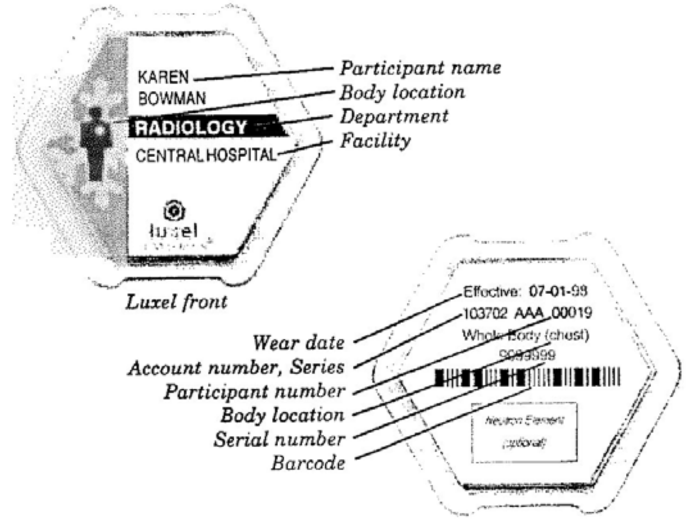
NVLAP®

Landauer, Inc.
2 Science Road
Glenwood, IL 60425
Phone: (800) 323-8830
Fax: (708) 755-7016
www.landauerinc.com

Welcome to Landauer Dosimetry Service

Your shipping container is designed to be reused to return your dosimeters to our laboratory. Included with each shipment is a packing list and a control dosimeter(s).

Personal identification is printed on each Luxel® dosimeter and laser etched on each TLD ring.



Dosimeters should be used beginning on the wear date or as close to that date as possible. Return all dosimeters, whether used or not used, at the end of each wear period.

Important! Do not tamper with dosimeter!

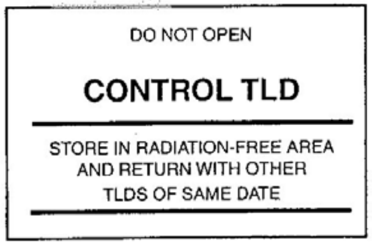
Control Dosimeters

A control dosimeter is included with each shipment (at no charge) to monitor possible radiation received in transit or storage. Do not use the control dosimeter for any other purpose.

A control dosimeter is supplied for each series in a series account. We can supply a master control to replace multiple series controls if all of your dosimeters are sent and stored at one location.

Store control dosimeters while not in use in a radiation free area with dosimeters of the same type and wear date.

Luxel Control



Ring Control

Return for Processing

At the end of the wear period, to process for exposure:

- ❑ snap Luxel® dosimeters out of their holders and return the dosimeters along with the Luxel control dosimeter(s) of the same wear date (retain the holders);
- ❑ return the complete TLD rings along with the ring control dosimeter(s) of the same wear date.

Unused Dosimeters

The filter component in the Luxel® dosimeter and the TLD chip in the ring is reusable, and is charged to you at each shipment. All dosimeters must be returned in order for you to receive credit for the chips and filter components.

When returning dosimeters that you wish to be reported as "unused," you must:

- ❑ list the dosimeters not used, and
- ❑ include a statement with an authorized signature verifying the dosimeters are unused.

Contaminated Dosimeters

Do not return to Landauer any dosimeter you suspect has been radioactively contaminated. Your Radiation Safety Officer should supply Landauer with an estimated dose for the individual whose dosimeter was contaminated.

Emergency Processing

Emergency processing is available for dosimeters suspected of receiving overexposure. Call Customer Service - Records at (708) 755-7000. Have the following available:

- ❑ account number;
- ❑ name and phone number of the person to be contacted with the dose reading(s);
- ❑ number and types of dosimeters being returned;
- ❑ means by which you are shipping the dosimeters;
- ❑ source of exposure;
- ❑ any other information you feel pertinent.

Enclose a note with the dosimeters with the name and phone number of the person to contact. Mark the outside of the package: *EMERGENCY PROCESSING*. Exposure readings for emergency dosimeters received by Landauer by 10:00 A.M. Central time will be phoned by 4:30 P.M. Central time.

LANDAUER®

Landauer, Inc. 2 Science Road Glenwood, Illinois 60425-1586
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www.landauerinc.com

luxel®

SAMPLE FACILITY
RADIATION SAFETY OFFICER
18930 SPRINGFIELD AVENUE
FLOSSMOOR IL 60422

RADIATION DOSIMETRY REPORT

ACCOUNT NO.	SERIES CODE	ANALYTICAL WORK ORDER	REPORT DATE	DOSIMETER RECEIVED	REPORT TIME IN WORK DAYS	PAGE NO.
103702	RAD	9874000125	07/17/98	07/13/98	5	1

① PARTICIPANT NUMBER	② NAME / ID NUMBER	BIRTH DATE	SEX	③ DOSIMETER	④ USE	⑤ RADIATION QUALITY	⑥ DOSE EQUIVALENT (MREM) FOR PERIODS SHOWN BELOW: DEEP DDE	EYE LDE	SHALLOW SDE	QUARTERLY ACCUMULATED DOSE EQUIVALENT (MREM): DEEP DDE	EYE LDE	SHALLOW SDE	YEAR TO DATE DOSE EQUIVALENT (MREM): DEEP DDE	EYE LDE	SHALLOW SDE	LIFETIME DOSE EQUIVALENT (MREM): DEEP DDE	EYE LDE	SHALLOW SDE	⑦ RECORDS FOR YEAR	⑧ INCEPTION DATE (MM/YY)
FOR MONITORING PERIOD:							06/01/98 - 06/30/98				QTR 2			1998						
000CC	CONTROL			J	CNTRL		M	M	M										6	6/80
	CONTROL			P	CNTRL		M	M	M											6/80
	CONTROL			U	CNTRL				M											6/80
00191	ADDISON JOHN			J	WHBODY	PN	90	90	90	90	90	90	100	100	100	200	200	200	6	6/80
	336235619	08/31/1944	M			P	60	60	60	60	60	60	70	70	70	170	170	170		
						NF	30	30	30	30	30	30	30	30	30	30	30	30		
14839	JORGENSON MIKE			P	WHBODY					160	160	160	470	470	470	860	860	860	6	1/90
	471740095	10/04/1968	M		NOTE		DOSIMETER PARTIALLY SHIELDED, NO EVALUATION POSSIBLE													
16784	THOMAS LEE			P	COLLAR	P	62	62	57										6	2/86
	384846378	11/22/1964	M	P	WAIST		M	M	M											2/86
					ASSIGN		2	62	57	N/A	N/A	N/A	2	112	107	1072	3192	3327		
					NOTE	⑨	ASSIGNED DOSE BASED ON EDE 1 CALCULATION													
00901	WALKER JANE			P	WAIST								30	30	30	100	100	150	6	1/90
	587336640	06/09/1960	F		NOTE		ABSENT													
50601	ZERR ROBERT			P	WHBODY		40	40	40	160	160	160	200	200	200	240	240	240	6	6/80
	982446591	07/15/1945	M		NOTE	⑩	CALCULATED													
				U	UFINGR				50			50			80			620		6/80

Dosimetry Report

At the end of each wear period, dosimeters are returned to our laboratory for processing, and a report is generated showing the type and amount of radiation exposure received by each participant. Explanation and remarks concerning the report can be found on the reverse side of each report. Explanation of some key items is described herein.

1. Within your account, each individual is identified by a unique number that is permanent.
2. Participant's personal information consisting of name, ID number, birth date, and sex. This information can be suppressed on "duplicate reports" for privacy and/or posting needs.
3. Landauer dosimeter.
4. The use or location on the body for which the dose is given.
5. Radiation type, and in some cases energy.
6. Dose Equivalent Columns - Current or accumulated exposures for deep, lens of eye and shallow dose equivalents. Bimonthly service will not have quarterly accumulation.
7. Number of times a current year report was generated for a participant.

8. The start of continuous Landauer service for a dosimeter.

9. Whole body exposures are carried for the person, rather than for individual whole body dosimeters. This example shows how a special dose calculation (EDE 1) can be applied to a participant who wears collar and waist dosimeters with a lead apron.

10. The dose for a dosimeter was from a calculation given by a customer, rather than from a Landauer dosimeter analysis.

Deep dose equivalent applies to external whole-body exposure and is the dose equivalent at a tissue depth of 1 cm (1,000 mg/cm^2).

Eye dose equivalent applies to the external exposure of the lens of the eye and is taken as the dose equivalent at a tissue depth of 0.3 cm (300 mg/cm^2).

Shallow dose equivalent applies to the external exposure of the skin or an extremity, and is taken as the dose equivalent at a tissue depth of 0.007 cm (7 mg/cm^2) averaged over an area of one square centimeter.

Internal exposure, if applicable, will be summed with Landauer external dose equivalents. Total effective dose equivalent is the sum of both the deep dose equivalent (for external exposure) and the committed effective dose equivalent (for internal exposure).

Minimum Dose Equivalent Reported - Dose equivalents for the current monitoring period below the minimum reportable quantity are recorded as "M". The minimum reportable quantity depends on the dosimeter type and quality of radiation.

Fetal Monitor Reporting is a reporting option that tracks exposure to the declared pregnant worker and the embryo/fetus. A separate page is generated showing the dose to the mother's dosimeter and the fetal dosimeter. And, every month a summary report shows estimated dose from conception to declaration, rolling exposure history by month for both mother and child, and accumulated fetal totals for the gestation period.

Notes - messages explaining any abnormalities, comments, or imaging and reanalysis results will appear on a separate line below all dosimeter exposure information.

Early Notification of Dose Above Specified Exposure Level

Landauer provides free notification by phone or fax when an individual's dose exceeds a specified exposure level. Landauer can code an account, a series, and/or specific individuals for specific notification levels. The default exposure notification levels are 20% of regulatory limits (e.g. Deep, Eye, Shallow, etc.) for any given wear period, or 50% of the cumulative maximum permissible dose.

Changes to Existing Service

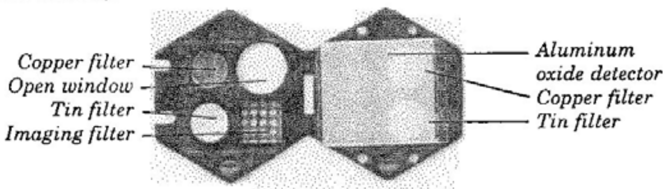
Once your service is established, you can quickly make changes using the *service change order* attached to the packing list. If the *service change order* is not available, we can fax you a copy. All written requests for change should always include your account number, series, participant number, and an authorized signature.

Allow us at least 25 days prior to the next wear date to make changes (note the date on the bottom of your *service change order*).

Luxel® Dosimeter

Luxel's optically stimulated luminescence (OSL) dosimeter measures radiation exposure due to x-ray, beta, and gamma radiation through a thin layer of aluminum oxide. After use, the aluminum oxide is stimulated with a laser light in our laboratory causing it to become luminescent in proportion to the amount of radiation exposure. The luminescence is measured and a report of exposure results is generated.

Inside the Luxel dosimeter is the OSL detector and filter packet. The dosimeter is enclosed in a water resistant blister pack, independent of the holder. Snap the dosimeter out of its holder and return for processing after each wear period (retain the holder).



Inside Luxel

Luxel dosimeters are available with custom backgrounds and have a variety of color coding options for series and exchange frequencies. A visual body location icon on each dosimeter indicates where it is to be worn.

The exposure range is 1 mrem to 1,000 rem for x and gamma radiation; 10 mrem to 1,000 rem for energetic beta. Detection outside these ranges can be provided.

Dose equivalents arising from exposures to x or gamma rays will have a deep, eye and shallow value reported. Depending on the energy of the x or gamma rays, these values may or may not be equal. Beta exposures are only reported as a shallow dose equivalent.

The dose of record is for a person, not a dosimeter, and is shown as *whole body*. When more than one whole body dosimeter is worn, an *assigned dose* equal to the highest dosimeter exposure is reported as the dose of record. The lens of eye dose is from the dosimeter worn closest to the eye.

Combined Neutron, X-Ray, Beta, and Gamma Service

The Fast Neutron (Neutrak® 144) detector is built into the Luxel® dosimeter. The exposure range is 20 mrem to 25 rem. One value is reported for deep, eye and shallow dose equivalent.

Ring Dosimeter

Landauer's thermoluminescent dosimeter (TLD) ring measures radiation exposure due to x-ray, beta, and gamma radiation with a lithium fluoride chip. After use, the chip is heated in our laboratory causing it to become luminescent in proportion to the amount of radiation exposure. The luminescence is measured and a report of exposure results is generated.

The TLD chip is safely encapsulated inside the identification cover. No separation of the TLD from the cover is possible, so the identity of the chip and the wearer is always maintained. The cover and TLD are independent of the ring base. Return the entire ring for processing after each wear period.

Ring cover

Identification is laser etched on the cover which permits the ring to be worn during scrub procedures. Rings can be cold sterilized in ethylene oxide and in disinfectants.

Rings are available in sizes small, medium, and large. Unless otherwise instructed, the medium size is sent. The color of the ring base changes each wear period.

The exposure range is 30 mrem to 1,000 rem for x and gamma radiation; 40 mrem to 1,000 rem for energetic beta. Detection outside these ranges can be provided.

The sum of the high energy x-ray, beta, and gamma radiation is reported as a shallow dose. If the ring dosimeter is exposed to radiation other than x-ray or gamma over 20 keV or high energy beta, the value recorded may require further interpretation on your part. Landauer will furnish, on request, adjustment factors for any specified energy level.

Sources of Information

University of Pittsburgh
Vanderbilt University
International Energy Agency, Division of Public Information
UCLA Radiation Safety Handout (8/92)
http://www.tdh.state.tx.us/ech/rad/pages/brc.htm
-Texas Department of Health, Bureau of Radiation Control
http://www.physics.isu.edu/radinf/index.html
http://www.physics.isu.edu/radinf/law.htm
-Idaho State University
http://liley.physics.swin.oz.au/~dtl/sp407/projrad/
-University of Swinburne Technology
http://www.umich.edu/~radinfo/
-University of Michigan
http://www.access.gpo.gov/nara/
-National Archives and Records Administration, Office of the Federal Register
http://www.dhs.ca.gov/rhb/
-California Department of Health Services, Radiologic Health Branch
http://www.hhmi.org/home/publication/3.html
http://www.ntis.gov/nac/index.html

THANK YOU FOR YOUR INTEREST

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