chem 5390

Advanced X-ray Analysis

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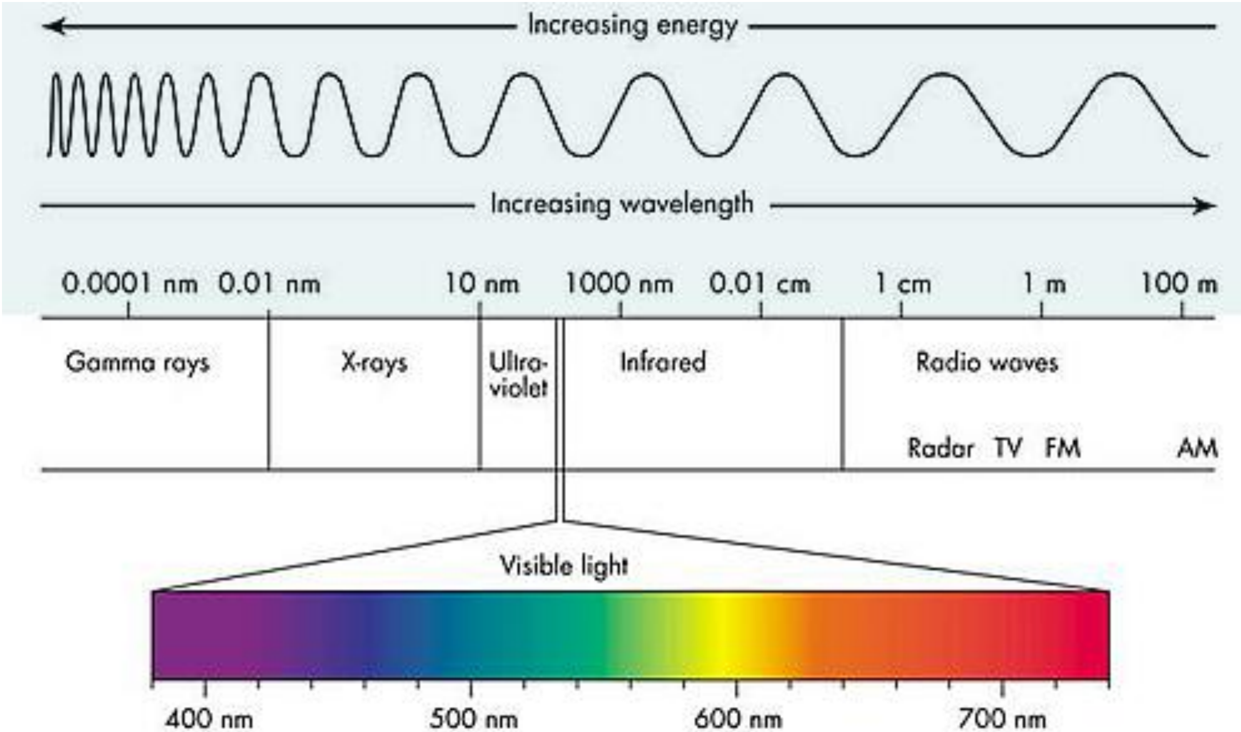
XRD Safety and Hazards



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X-Ray Absorption in Human Tissue

When X-ray photons interact with matter -- human tissue in this discussion -- some of the photons are absorbed by the tissue. Many analytical x-ray machines produce X-rays up to 50 or 60 kV. Over this energy range, bone absorbs roughly five times the energy that muscle absorbs and about ten times that of fat. This is significant since the hands are mainly muscle and bone. They are therefore more susceptible to X-ray injury.

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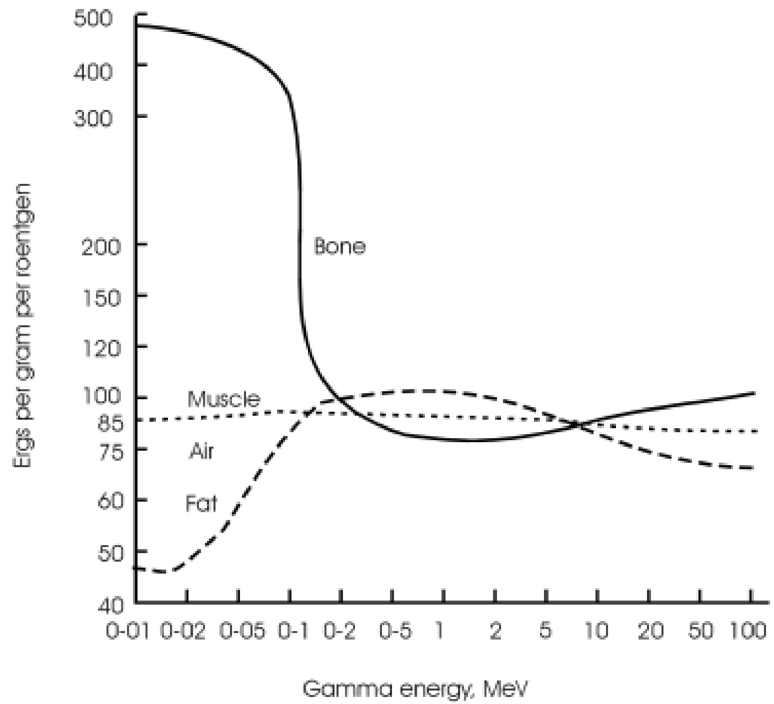
The figure shows the absorption characteristics for bone, muscle, and fat, as a function of the gamma (or X-ray) energy.



Energy absorption per roentgen of various tissues.
(From O. Glasser, *Medical Physics*, Vol. II)

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Injuries

Injuries are generally characterized by the clinical symptoms manifested (burns, swelling, and so on), and the estimated dose. There are short-term and long-term injuries.

Short-Term Injuries

Short-term injuries are generally manifested by soreness, reddening of the skin, swelling, inflammation, and tissue breakdown characteristic of second and third degree burns. Most often these signs do not begin until several days after the accident.

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Figure 1 shows the fingers of an accident victim about 1 month after his exposure, and Figure 2 was taken 3½ months after exposure.

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Long-Term Injuries

Many long term injuries are due to the progression of short-term damage. Despite initial treatment of the injury, the tissue may be damaged beyond recovery, sometimes necessitating the removal of the damaged tissue (such as a finger). Cancer and cataracts, in the case of eye exposure, are also considered potential (latent) long-term injuries.

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Dose Definitions

"Absorbed dose" of any ionizing radiation is the energy imparted to matter by ionizing particles per unit mass of irradiated material at the place of interest. The unit of radiation absorbed dose is the "rad." 1 rad is 100 erg/gram.

"RBE dose" is equal numerically to the product of the absorbed dose in rads and an agreed factor RBE (relative biological effectiveness) whose values for ICRP (International Commission on Radiological Protection). The "rem" (roentgen equivalent [in] man) is the unit of RBE dose.

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Dose Limits

Maximum Permissible Dose Equivalent for Occupational Exposure

Dose to whole body	**5 rem per year**
Skin of whole body	**50 rem per year**
Hands	**50 rem per year**
Pregnant women (with respect to fetus)	**0.5 rems in gestation period**

[Note that average background radiation in U.S. is 0.36 rem per year.]

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Sample Dose Calculation

Using a Mo X-ray tube at 50 kV and 40 mA, and assuming:

Most of the energy radiated is at the Mo Kα1 spike of 17 kV, and that the bremsstrahlung is small by comparison,

1 amp = 6.3 E18 e-/sec (then 40 mA = 2.52 E17 e-/sec)

1 eV = 1.6 E-12 erg/e- (then 17 kV = 2.72 E-8 erg/e- (Mo Kα1))

The total Mo Kα1 X-ray power radiated (17 kV, 40 mA) is 6.8 E9 erg/sec.

The X-ray tube is 65 mm diameter with four 16 mm diameter windows. The area of one window is 201 mm^2. The area of a 65 mm diameter sphere, centered on the X-ray focal spot, is 3,318 mm^2.
The ratio of the area of half of one window to the area of the sphere is 0.031 to 1.

(Depending on the target orientation, it is presumed that only 50% of the X-rays generated exit the window.)The total MoKα1 X-ray power exiting through one window is:

(6.8 E9 erg/sec) X 0.031 - 2.1 E8 erg/sec

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Sample Dose Calculation

If a hand were covering that window and the X-rays were totally absorbed in the hand in a column of flesh and bones 30 mm tall and 101 mm^2 in cross-section area, then 3.0 cm^3 or ~3.0 gram would receive the dose.

The dose received by the irradiated portion of the hand would be (2.1 x E8 erg/sec)/(3.0 gram) or 7.1 E7 erg/gram or about 7.1 E5 rems for every second of exposure!

Compared to 75 rems per year maximum allowed occupational exposure to the hands, this is about 9500 times the annual dose limit to the hand every second!

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Minimizing Exposure

How can exposure to radiation be minimized?

There are four physical factors that affect the exposure level in a "radiation field"

1. **Distance**
2. **Time**
3. **Shielding**
4. **Output factors (kV, mA)**

- **Exposure varies as the inverse square of the distance (assuming a point source, as from scattering)**
- **Exposure increases linearly with time**
- **Exposure is inversely exponential with the thickness of shielding.**
- **Exposure increases linearly with current (mA) and as the square of the potential (kV).**

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Dosimetry

An operator of analytical x-ray equipment is provided with an extremity monitoring device and any person coming in contact with equipment capable of exposing a major portion of the body shall be required to wear a whole-body monitoring device. Such devices are referred to as dosimeters. These portable devices are capable of measuring and registering the total accumulated exposure to ionizing radiation.

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Dosimetry

At the University of North Texas, thermoluminescent dosimeters (TLDs) in the form of ring badges and optically stimulated luminescence (OSL) whole-body badges may be issued to operators of analytical x-ray equipment. Thermoluminescent dosimeters contain crystalline materials (for example, CaF_2 with a Mn impurity or LF) that emit light if they are heated after having been exposed to radiation. The whole body badges contain a thin layer of aluminum oxide. After use, the aluminum oxide is stimulated with a laser light and the luminescence is measured. The amount of luminescence is proportional to the amount of radiation exposure.

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Dosimetry

Remember that dosimetry badges are to be worn only for work related to research and not for "checking" dental or medical doses.

The badges/rings are to be worn at all times when operating, or in the vicinity of, the analytical x-ray equipment. They should be stored in a location away from the equipment (and heat sources) to avoid exposure to the badges when they are not being worn. These badges are issued by, and returned to, the UNT Radiation Safety Office via the authorized user who supervises the worker.

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Equipment

The X-ray equipment manufactured today is much safer than that made before the 1970s. Major advances have been in the areas of:

- **interlocks**
- **enclosures**
- **shutters**
- **failsafe warning lights**
- **remote and computer controls**

The sealed X-ray tubes and the mechanical goniometers are basically unchanged.

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Equipment - Interlocks

Interlocks are a set of switches in a series, where EVERY switch must be closed in order for the X-rays to be generated and/or for a shutter to be opened. These switches are connected to doors, panels, and collimators, which if opened or removed, would create a radiation hazard for the user.

If any switch is opened while the X-rays are on or the shutter is open, the X-ray generator will immediately shut off and/or the shutter will close.

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Equipment - Enclosures

Enclosures are boxes, some having a transparent window, which contain the X-ray instruments so that stray or scattered X-rays do not escape into the room. Enclosures, along with interlocks, also prevent people from encountering the direct X-ray beam.

Equipment - Shutters

Shutters open and close a path for the X-ray beam. When a shutter is properly functioning and closed, no X-rays can pass beyond the shutter.

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Equipment - Warning Lights, Failsafe

Lights are used to indicate that the X-ray generator is turned on and that a shutter is open. These lights are 'failsafe' so that in the event of a lamp failure (e.g., broken filament) the X-ray generator will NOT turn on and the shutter will NOT open (and, in fact, if on or open, will shut off or close in the event of a lamp failure). Also, the X-ray generator will not turn back on nor the shutter open again without the user first taking action to do so.

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Equipment - Remote and Computer Controls

Remote and computer controls of X-ray instruments are major safety advances in that the user need not be anywhere near the instrument to operate it. Enclosures, interlocks and warning lights serve to prevent possible radiation exposure to anyone in the vicinity of the instrument.

Equipment - Safety Over-Rides

Any mechanical or electrical system can, by deliberate action, be made unsafe (e.g., using a key to over-ride the interlock system, using jumper wires to bridge an open switch, and/or mechanically opening or removing something). Such actions are reserved for service personnel in the repair or alignment of the instrument. Such actions should NEVER be done by users.

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Equipment - Repairs

Users are NEVER to attempt repairs or make non-trivial adjustments to instruments. If there is a problem, inform the instrument supervisor. Depending on the severity of the problem, in the absence of the supervisor, users should label the instrument as "down" and power it off. For lesser problems, if deemed safe to do so, label it and walk away.

If users encounter an instrument being repaired, stay back and do not touch it!

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Normal Operating Procedures

'Normal Operating Procedures' mean operating procedures for conducting suitable for analytical purposes with shielding and barriers in place. These do not include maintenance but do include routine alignment procedures. Routine and emergency radiation safety considerations are part of these procedures.

Normal operating procedures shall be written and available to all analytical x-ray equipment workers.

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One of the major causes of X-ray accidents has been taking short cuts in attempts to complete work more quickly. Most of these involved defeating interlocks, or modifications to the instruments, but still one must think through every task and procedure to recognize and avoid hazards.

Work smart!

Assignment

- **Do UNT Bridge Module:**
  “Radiation Safety Training”

You must make a copy of your successful completion of this training and give to Dr. Golden to continue in this course.