

RADIATION SAFETY IN THE X-RAY DIFFRACTION LAB AT UTC

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PART 1—FUNDAMENTALS OF RADIATION SAFETY

Radiation is transmitted energy in the form of high-speed particles and electromagnetic waves. We encounter relatively harmless radiation every day, including visible light, radio and television waves, ultra violet (UV), and microwaves.

Planck's law,

$$E = hc/\lambda ,$$

where h is Planck's constant and c is the velocity of light, describes the inverse relationship between the wavelength (λ) of electromagnetic radiation and its energy (E). Basically, the shorter the wavelength the more energetic the radiation.

X rays are of sufficiently short wavelength so as to be diffracted by the closely spaced atoms of a crystal and are consequently useful for diffraction studies of crystal structure. Due to their short wavelength, they are also dangerously energetic. X rays are a form of ionizing radiation and are capable of displacing tightly bound electrons from their orbits, causing atoms to become charged. Because X rays penetrate and cause damage to tissues, they pose a health hazard.

A modern X-ray diffraction system is not hazardous if it is used correctly. Safety devices are built into the instrument that make it very difficult for anyone to be exposed to the X-ray beam. Despite safety devices, it is important to be careful when using the instrument. Never put any part of the body in the expected path of the X-ray beam.

To help ensure their safety, users of the X-ray diffraction system **MUST** be familiar with pertinent radiation safety considerations, **MUST** follow normal operating procedures that minimize the potential for accidental exposure to X rays, and **MUST** know what to do in the event of accidental exposure.

ALARA The overall objective of radiation safety is to keep exposure "as low as reasonably achievable" (ALARA). This objective was a fundamental consideration in the design of our X-ray diffraction system (Philips Analytical X-Ray). More importantly, each user of the instrument is responsible to keep the dose to themselves and to the people around them ALARA. All users of the instrument **MUST** take this responsibility very seriously, particularly in light of uncertainties that exist concerning the long-term stochastic health effects of radiation, even in low doses.

Precautions In striving for ALARA doses of radiation, users of the X-ray diffractometer should (1) minimize the amount of time they spend near the X-ray source, (2) keep themselves as distant from the X-ray source as is practically possible, and (3) use appropriate shielding.

Time In some respects, radiation dose is cumulative. Reducing the amount of time spent near a source of radiation results in a proportionate reduction in total dose. Those that operate the diffractometer should spend as little time as possible near the X-ray generator.

Distance Radiation intensity varies inversely with the square of the distance from the source, i.e. the *inverse square law*,

$$I \approx 1/d^2 .$$

Hence, doubling the distance to the source (d) reduces the intensity of radiation (I) to one quarter; tripling the distance to the source reduces the intensity of radiation to one ninth. A radiation source with an exposure rate of 100 mR/hr at a distance of 10 centimeters has an exposure rate of only 1 mR/hr at 100 centimeters, which is little more than an arm's length away.

For much of its routine operation, our diffractometer is controlled remotely by a computer. With the exception of opening and closing the shutter, the operator need not be closer than a few meters from the X-ray generator during analysis.

Shielding Our diffraction system has a completely shielded X-ray tube and optical path and is equipped with a shutter that automatically

closes if shielding is out of place or if other safety circuits malfunction. The instrument meets German regulations, which are most stringent on "built-in" provisions for radiation safety (Philips Analytical X Ray, 930901, 3rd ed.).

Operators of our instrument **MUST** be familiar with its shielding and its shutter interlock system (Part 2 of this document), including mechanical aspects of its operation and roles of microswitches. Operators **MUST** employ these safety features at all times.

To help ensure that the instrument can be operated safely, shielding and the shutter interlock system are checked periodically.

Units used to quantify radiation

X rays are produced by energy changes in electrons, rather than by radioactive decay. None the less, the present discussion of units will begin with radioactivity.

Becquerel (Bq) and Curie (Ci)

The SI (Standard International) unit of radioactivity is the Becquerel (Bq), which is equivalent to 1 nuclear disintegration per second. Another unit, perhaps more common than the Bq, is the Curie (Ci), which is equivalent to 3.7×10^{10} disintegrations per second.

Radiation is quantified in terms of *dose*, and *dose equivalent*. Gamma and X-rays are also quantified in terms of *exposure*.

Roentgen (R)

The Roentgen (R), named after the man that discovered X rays in 1895, is a unit of *exposure* that describes the number of ionizations in an amount of air due to gamma and X rays. One Roentgen produces 2.58×10^{-4} coulombs (C) of electric charge per kilogram (kg) of air.

Rad and Gray (Gy)

Dose, also referred to as absorbed dose, describes the amount of energy absorbed by a material. A common unit of dose is the rad (Radiation Absorbed Dose). One rad equals 100 ergs of energy absorbed per gram of material. The SI unit of dose is the Gray (Gy). One Gray equals 100 rad.

The average person absorbs 360 mrad (millirads) of ionizing radiation annually, from natural and man-made sources. Due to cosmic sources, this dose of "background" radiation approximately doubles with each mile of elevation.

Rem and Sievert (Sv) Different types of radiation have different biological effects, even for the same absorbed dose. *Dose equivalent*, sometimes referred to as equivalent dose, relates absorbed dose in human tissue to effective biological damage. To derive dose equivalent, absorbed dose is multiplied by a factor Q , which is unique to the type of radiation. The rem (Roentgen Equivalent Man) is a common unit of dose equivalent; $1 \text{ rem} = 1 \text{ rad} \times Q$. The SI unit of dose equivalent is the Sievert (Sv); $1 \text{ Sv} = 1 \text{ Gy} \times Q$. Note that because $1 \text{ Gy} = 100 \text{ rad}$, $1 \text{ Sv} = 100 \text{ rem}$.

SI Prefixes SI prefixes are commonly used with these units. The milliroentgen (mR), for example, is one thousandths of a roentgen (0.001 R), just as the kiloBecquerel (kBq) is one thousand Becquerel (1,000 Bq).

Terms used to describe biological effects of radiation Being familiar with terminology used to describe biological effects of radiation constitutes an awareness of those effects. Users of the X-ray diffraction system **MUST** understand the meaning of the following terms.

Somatic, genetic, and teratogenic effects Somatic effects of radiation occur in the individual that received the dose. If offspring of the irradiated individual are effected, such effects are referred to as genetic or teratogenic. Genetic effects in an offspring are due to radiation received by the parent prior to conception and are caused by radiation-induced genetic aberrations in the parent. Teratogenic effects in an offspring are due to radiation received by the parent, effectively the fetus, during the gestation period. (See special note to pregnant women.)

Stochastic effects Stochastic effects of radiation are not directly related to the dose received. Stochastic effects involve chance or probability. Some forms of melanoma, for example, may occur as a stochastic effect of exposure to radiation from the sun. The conservative perspective on stochastic effects assumes no minimum threshold and that any amount of exposure may cause the effect.

Non-stochastic effects Nonstochastic effects are directly related to the dose received. Such effects typically have a threshold, below which the effect does not occur and above which the effect is more severe with higher doses. A skin burn due to radiation is a nonstochastic effect. Most of us have experienced a nonstochastic effect of high doses of solar radiation, the common sunburn.

The goal of radiation safety is to eliminate non-stochastic effects and to reduce the incidence of stochastic effects.

*Chronic
and
acute
dose*

The terms chronic and acute refer to the time period over which a dose is received. A chronic dose is received over a long period of time. An acute dose is received over a short period of time.

*A special note
to pregnant
women*

Rapidly growing, undifferentiated cells, as occur in a fetus, are particularly susceptible to damage (teratogenic effects) from ionizing radiation. Women that are pregnant or suspect that they are pregnant should take extreme precaution against exposure to ionizing radiation. Women in this condition should not operate the X-ray diffraction system or be near the instrument while X rays are generated.

*Normal
consequences
of accidental
exposure*

Accidental exposure to the collimated X-ray beam, as unlikely as it is, would probably be limited to small areas on the hands and arms. Furthermore, the copper $K\alpha$ X rays commonly used for diffraction studies are "soft" (of relatively low energy) and will normally penetrate no more than 2-4 cm into human tissue. Thus, accidental exposure will usually cause damage only to the skin and possibly bones that lie near the surface of the body. Little or no pain is normally felt at the time of exposure, although some people feel a tingling sensation. The tingling sensation is not the radiation, but rather the impact of ions on the skin from irradiated (ionized) air.

One to three hours after exposure, a first-degree burn may form on the skin where the dose was absorbed. The appearance of a burn may be followed by swelling and dull pain and, in some cases, blistering.

The eyes are particularly vulnerable to radiation damage. Exposure of soft X rays to the eyes may cause permanent cataracts.

Emergency procedures***What to do in the event of accidental exposure***

If a suspected exposure to radiation occurs, you should

1. Switch off the X-ray generator. (Press the "Off" buttons for either Power or HT.)
2. Do NOT take remedial action to correct the fault that caused the exposure.

Assessment of the absorbed dose is more difficult if the fault is corrected.

3. Put a sign on the instrument to indicate that it must not be used or altered in any way.
4. Notify Jonathan Mies, principal operator of the instrument, and/or Jack Pitkin, radiation safety officer (RSO), of the suspected exposure.

Jonathan Mies
Office: 105 Bretske Hall
Office phone: 425-4606
Home phone: 886-4926

Jack Pitkin
Office: 335 Grote Hall
Office phone: 425-4518

5. Exposed individual(s) should seek medical examination and treatment, if necessary, as soon as possible.