RADIATION SAFETY TRAINING

(12/21/93)

I) RADIATION PHYSICS

A) Basic Physics Review

The atom is made up of a nucleus of protons and neutrons, surrounded by a cloud of electrons. The number of protons and electrons determine the chemical nature of the atom. The number of neutrons determines if the atom is stable or radioactive.

All isotopes of a particular element have the same atomic number (number of protons) but different atomic mass (number of neutrons). Because all isotopes of an element have the same atomic number, their chemical nature is identical. However, the radioactive nature of the isotopes vary.

Unstable (or radioactive) isotopes emit energetic particles and/or electromagnetic (EM) radiation in the form of photons. All radioactive isotopes eventually decay to stable isotopes.

Stable isotopes can be made radioactive (activated) by bombardment with energetic protons in particle accelerators or neutrons in nuclear reactors.

Radioactive decay is a disintegration process by which a radioactive isotope radiates energy in order to become a stable isotope.

Radioactive decay is random when observed for short periods. Only by observing over long periods of time does a regular pattern emerge. This pattern of decay we call the physical half-life.

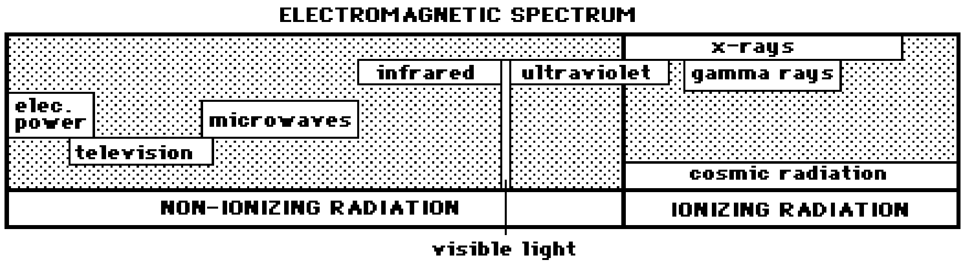
The half-life is defined as the time required for half of the atoms of a particular isotope to decay. The value of the half-life is specific to the isotope and may vary from microseconds to thousands of years.

The half-life has been determined for each isotope, and can be used to perform decay calculations.

As a rule, whenever an isotope has undergone 10 half-lives, enough atoms will have decayed to make the radiation field emitted indistinguishable from the "background" level.

B) Types of Radiation and Characteristics

EM radiations (photons) differ in frequency, wavelength and energy. The EM spectrum diagram below shows the break point between ionizing radiation and non-ionizing radiation. This training program will discuss only ionizing radiation. By definition, ionizing radiation has sufficient energy to disrupt the structure of an atom, causing the formation of charged ion pairs. These ions can cause chemical changes (damage) in human tissue.



Ionizing radiation falls into two categories: directly ionizing and indirectly ionizing. Ionizing radiation emitted may be photons (EM) or particles.

Alpha radiation is directly ionizing. Alpha particles are Helium nuclei consisting of two protons and two neutrons. They have a charge of +2, a mass of 4 AU (atomic units), and are very energetic, on the order of 3 to 5 MeV (million electron volts; particle energy is measured in the eV or electron volt).

The large charge and great mass makes them readily interact with matter, giving them a short range (a few centimeters in air). They are of no concern as an external radiation hazard, but can be a hazard if alpha emitting isotopes enter the body through contamination.

Beta particles are directly ionizing energetic electrons emitted from the atom as a spectrum of energies. The average energy of the betas emitted is about 1/3 of the maximum energy beta emitted. The mass of the beta is 1/1800 of an AU and it has a charge of + (positron) or - 1. The range of a beta is dependent on it's energy and the material it is traveling in. For example; a P-32 beta has a range in air of about 7 meters.

Bremsstrahlung (x-rays) and gamma rays are photons with no mass or charge. Photons are emitted at a discrete energy which depends on the isotope. They are indirectly ionizing EM radiations with no charge or mass.

The range of EM radiation is theoretically infinite. Depending on the energy of the photon, a half-value layer may be determined for a specific shielding material that defines the thickness required to reduce the radiation field intensity by one half.

Neutrons are indirectly ionizing particles with no charge, but with a mass of 1 AU. They are produced only in particle accelerators, nuclear reactors, and isotopic neutron generators. The energy of the neutron is dependent on it's source, and neutrons may be found as a spectrum of energies. They are shielded with low Z materials such as water or borated polyethylene.

C) Radiation Interaction with Matter and Attenuation (Shielding)

Radiation shielding is a matter of attenuation. Particles or EM radiation deposit energy in the shielding material and are thereby attenuated. Energy deposited in the shield cannot be absorbed in tissue. This reduces the radiation hazard.

The ranges of various particulate radiations are well known. These values can be used to determine the type and thickness of material required to reduce or stop particulate radiation.

Alpha particles, due to their mass and charge, readily interact with matter and are stopped by a single sheet of notebook paper.

Low Z materials should be used to shield beta particles. For example: all P-32 betas will be attenuated in 0.8 cm. of Lucite. In general, 1.0 cm. of Lucite is sufficient to absorb any beta radiation.

Using high Z materials to shield betas may result in Bremsstrahlung production, replacing the beta hazard with an x-ray hazard.

The range of EM radiation is theoretically infinite. Shielding is accomplished by use of the half-value layers. A half-value layer is the thickness of a material necessary to reduce the radiation intensity by 50%. Lead, concrete, or steel are the best shielding materials for photons. See the diagram in the Appendix.

II) RADIATION UNITS

The Curie (Ci) is the unit of radioactivity. It is equal to 3.7×10^{10} (nuclear) disintegrations per second (dps) or 2.22×10^{12} disintegrations per minute (dpm). The international unit used is the Becquerel (Bq) which is equal to 1 dps.

Because the Ci is so large and the Bq is so small, we often use prefixes to define levels of activity. Examples of these prefixes follow:

(m) milli (10^{-3})	(K) kilo (10^{3})
(u) micro (10^{-6})	(M) mega (10^{6})
(n) nano (10^{-9})	(G) giga (10^{9})
(p) pico (10^{-12})	(T) tera (10^{12})

The Roentgen (R) is the unit of radiation exposure (ionization in air). The R (or mR) is the unit usually seen on the meter face of Geiger counters.

The Rad (Roentgen Absorbed Dose) and Gy (the Gray is equal to 100 Rads) are the units of absorbed energy dose. The Rad is most often used in medical applications.

The Rem (Roentgen Equivalent Man) and Sv (the Sievert is equal to 100 Rem) are indexes of biological harm relating the damage done by various energetic particles and EM radiations. The Rem is also called the unit of risk. Dosimetry reports (reports of absorbed dose) are always expressed in mRem.

QF (quality factors) are used to relate the RBE (relative biological effectiveness) of different types of radiation. Rad (or R) x QF = Rem. Quality factors are as follows: 1 for beta, gamma, and x-rays, 10 for neutrons, and 20 for alpha particles.

Radiation exposure field measurements are expressed in mR/hr dose rates.

III) DETECTION AND MEASUREMENT

Ionizing radiation is not detectable with the human senses. Radiation survey instruments are therefore used to determine the presence of radiation fields.

Geiger Mueller (or GM) detectors are the most common type of survey instrument. They detect the ion pairs formed when beta, gamma or x-ray radiation cause ionizations in the gas in the detector. GM survey meters read out in mR/hr or cpm. See the diagram in the Appendix.

The accuracy of GM survey meters depends on the energy of the radiation being measured. They are used to detect betas and gamma photons. GM METERS WILL NOT DETECT THE LOW ENERGY BETAS PRODUCED BY TRITIUM.

Solid scintillator detectors utilize a solid NaI crystal with a photo multiplier tube. These instruments are most useful in detecting gamma radiation. The thickness of the NaI crystal determines the energy efficiency of the detector. Thin crystals are used to detect low energy gammas like I-125. See the diagram in the Appendix.

Liquid scintillation counting (or LSC) uses photo multiplier tubes to amplify light produced by a radioactive sample immersed in a vial of liquid scintillation cocktail. LSC is used to count wipe samples for contamination. See the Appendix for an LSC diagram.

Radiation detection methods vary in counting efficiency for various isotopes. Counts per minute (cpm) are not the same as disintegrations per minute (dpm), but rather relate to one another as: cpm/efficiency = dpm.

Counting statistics are important in interpreting LSC results. The higher the count rate, the greater the accuracy and confidence of the count. A background count performed on a control blank vial is essential in interpreting results.

IV) RADIATION BIOLOGY

A) Natural Background and Man Made Radiation Doses

Each of us receive about 300 mRem/year from natural sources. These include solar cosmic radiation, radon (gases) from soils, and internal dose from K-40.

We also receive about 70 mRem from man made sources, primarily from medical applications.

Your altitude above sea level and the location and construction materials in your home can also can influence your background dose. For example: In Denver, the background dose is about twice the dose in San Francisco.

B) Internal verses External Exposure

External exposure is the passage of particulate or EM radiation into tissue from outside the body. Internal exposure results from isotopes which have been deposited inside the body. Internal deposition can only result from one of the four entry pathways: ingestion, inhalation,absorption through the skin and skin punctures.

The biological half-life of any deposited isotope is determined by it's residence time in the body, and varies with the chemical nature of the element.

The effective half-life is determined by the relationship between the biological half-life and the physical half-life. The effective half-life is used in calculating the absorbed dose to tissue from a deposited isotope.

C) Acute verses Chronic Doses and Effects

Chronic radiation doses are received over many years. The biological effects of chronic whole body doses up to regulatory limits (150 Rem over 30 years) have proven undetectable and may not exist.

Acute radiation doses are received in a few hours. The biological effects of acute whole body doses under 10 Rem have proven undetectable and may not exist. At acute doses of 10 to 75 Rem, temporary changes in blood cell chromosomes have been observed.

At acute doses of 75 to 300 Rem biological effects include erythema (skin reddening), and acute radiation syndrome (ARS - loss of hair, nausea, dehydration and possible death) have been observed. The LD 50/30 for humans (the lethal dose for 50% of a population exposed within 30 days without medical treatment) is 300 to 350 Rem.

At acute an dose of 550 Rem, 99% of those exposed may die.

D) Somatic verses Genetic Effects

Somatic effects occur in the person receiving the radiation dose. Somatic effects can be caused by acute or chronic exposure. Cancer is a somatic effect identified with radiation exposure.

Genetic effects occur in the descendants of the person receiving the radiation dose. Genetic effects can be caused by acute or chronic exposure. Mental retardation is a genetic effect identified with radiation exposure.

The BEIR V (Biological Effects of Ionizing Radiation) report (1990) from the National Academy of Sciences uses information from the Hiroshima and Nagasaki atomic bomb survivors to estimate somatic and genetic effects of radiation exposure.

It is estimated that the normal lifetime probability of cancer induction is about 25% from causes other than radiation exposure. The BEIR V report estimates that the probability of additional cancer risk is about 0.08%/Remfor continuous lifetime exposure.

The BEIR V report, also estimates the increased risk of mental retardation at 0.4%/Rem of fetal exposure during the 8 to 15 week segment of the gestation period.

E) Radiation Risk Models and the ALARA Concept

Because of the uncertainty of human health effects at low radiation doses, a number of dose/response models have been proposed. See the Appendix for a diagram of these models.

The linear model of dose response assumes a direct relationship between radiation dose and effects down to zero exposure.

The quadratic model indicates there may be limited risk present a low doses.

The threshold model assumes a "threshold" dose of about 10 Rem must be received in order to see any effects.

Most experts and regulators agree that the linear model presents the safest assumption of the risk relationship for radiation exposure. This view drives the ALARA concept which aims at keeping radiation exposures **A**s **L**ow **A**s **R**easonably **A**chievable.

F) Risk verses Benefit

While there are no unique risks associated with radiation exposure, it is well understood that there are substantial benefits resulting from radiation use.

A table of risks from radiation exposure as compared to "acceptable" risks in modern life can be found in the Appendix. This table rates radiation exposure as a limited risk compared to the risk of driving a car, smoking, swimming, etc.

V) ALLOWED OCCUPATIONAL AND NON-OCCUPATIONAL RADIATION DOSES

The allowed Total Effective Dose Equivalents (TEDEs) are published in Title 17, CCR (California Code of Regulations). The TEDEs includes both the external dose (from dosimeters) and internal dose (from bioassays):

The occupational (whole body) TEDE is not allowed to exceed 5,000 mRem/year or 1,250 mRem/qtr.

The (shallow) dose to the skin of the whole body is not allowed to exceed 50,000 mRem/year or 12,500 mRem/qtr.

The dose to the extremities (hands and forearms, feet and ankles) is not allowed to exceed 50,000 mRem/year or 12,500 mRem/qtr.

The dose to the lens of the eye is not allowed to exceed 15,000 mRem/year or 3,750 mRem/qtr.

The dose to any individual organ is not allowed to exceed 50,000 mRem/year or 12,500 mRem/qtr.

The fetal TEDE is not allowed to exceed 500 mRem during the 9 month gestation period.

The (whole body) TEDE for the general population is not allowed to exceed 100 mRem/year.

VI) RADIATION CONTROL METHODOLOGY

A) The ALARA Concept

Simply stated, the ALARA concept is the practice of maintaining radiation exposures to levels **A**s **L**ow **A**s **R**easonably **A**chievable. This philosophy is the basis of modern radiation protection.

B) Limiting External Radiation Exposure

The three basic elements to be considered in an external radiation protection program are time, distance, and shielding.

Radiation field measurements are always expressed as a rate, i.e. mRem/hr (or cpm). The amount of time spent in a radiation field should be kept to the minimum required to perform the task.

EM radiation follows the inverse square law. The intensity of the radiation field decreases with inverse square of the distance from the source. For example, standing twice as far from a source will reduce the radiation field intensity to 1/4 (2^2) of the original intensity.

Maintain the maximum distance possible from EM radiation sources that will still allow the work to be done. From a point source (such as a vial), a distance of a few centimeters will greatly reduce the dose to the extremities. Particulate radiations (alpha, beta and neutrons) obey the inverse square law but also have finite absorption ranges. While it is appropriate to maintain the maximum distance possible from particulate radiation sources, shielding is more effective in reducing dose. For particulate radiation, use a thickness of shielding at least 10% greater than the particle range in the shielding material.

Shielding is used to reduce field intensity by attenuating the energy of the radiation. Always use the appropriate shielding for the isotope being used.

C) Preventing Internal Radiation Exposure

Radioactive material (RAM) contamination is defined as: RAM dispersed in materials or places where it is unwanted.

Contamination may enter the body through four routes (or paths) of intake. These are: ingestion, inhalation, skin absorption, and through skin punctures.

Contamination control measures are used with all unsealed isotopes to prevent deposition of the isotope in the body.

Personal Protective Equipment (PPE) - Is used to prevent contamination of skin or clothing. PPE is required when handling unsealed RAM.

Labcoat - With sleeves long enough to cover the arms to the wrists, and long enough to cover the torso to the thighs. Wear with the closures fastened. Worm to protect the arms and torso.

Eye Protection - Worn to protect the eyes from splashes of radioactive and other hazardous materials.

Close Toed Shoes, Long Pants or a Long Dress - Worn to protect the feet and legs from splashes.

Disposable Gloves - Worn to protect the skin of the hands and wrists. Most effective if two pairs are worn at a time. Change the outer pair frequently.

Appropriate Bench Coverings - Used to prevent contamination of benches and hood surfaces.

Plastic Backed Disposable Paper - Defines and protects the RAM work area. "CAUTION - RAM" tape is used to secure the paper in place with the plastic side down. Replaced whenever damaged or contaminated.

Containment Trays - These shallow trays are used to contain RAM spills. They are available with disposable plastic liners to insure ease of decontamination.

Double Containment - Is the use of secondary containers (of sufficient volume) to contain all of the liquid should a RAM spill occur.

Liquid Waste Storage Cans - Used to store liquid radwaste, these metal cans are available from the campus storehouse.

Transport Containers - Usually a deep plastic tray with a snap fitting lid. Used to contain RAM being transported between laboratories.

Use of Disposables - It may be preferable to use disposable plastic pipette tips, petri dishes, centrifuge tubes, etc. to prevent problems associated with the decontamination of glassware. Will adversely affect the minimization of radioactive waste generation in the lab.

Appropriate Handling Tools - Serve the dual purpose of reducing hand contamination while reducing extremity dose. Includes tweezers, forceps, tongs, and shielded containers.

Laboratory Hygiene - Restrict eating, drinking, and use of cosmetics to areas at least 1 meter distant from RAM use or storage. Food and drink cannot be stored in refrigerators, freezers or cold rooms used for RAM storage. The best practice is to isolate food and RAM to separate rooms.

Trial Runs - Contamination can be prevented during experimental procedures by performing trial runs first with non-radioactive materials. Colored water works well because "contaminated" droplets show up easily.

Marking and Labeling - An essential contamination control measure. ALL RAM USE AREAS, EQUIPMENT, AND STORAGE CONTAINERS MUST BE MARKED WITH THE RADIATION TRIFOIL SYMBOL. Failure to mark RAM with the trifoil symbol is the most common cause of contamination spread.

Contamination Monitoring Methods - Radiation monitoring is required whenever RAM is being used. Failure to use these methods often result in a spread of contamination.

Survey Meter Monitoring - With the exception of tritium, virtually all beta and gamma emitters can be detected with a GM (Geiger Mueller) survey meter. GM survey meters are used to determine the rough location and gross nature of contamination. The appropriate GM survey method is to position the probe surface 1 to 2 cm. above the suspected surface and then slowly "paint" the area, listening for variations in the click rate.

Wipe monitoring - This method is used with all isotopes, and is the only reliable method for quantitative determination of contamination levels. Contamination levels are normally expressed in cpm/100 cm^2. Wipe methods involve wiping a surface with an wipe material (filter paper or Q-tips are favorites) and then counting the wipe in the LSC. A background (uncontaminated) wipe is counted as a blank control.

Record Keeping - Documentation is maintained on all surveys performed. The wipe analysis data is related to a survey map by means of numbers so that areas found to be contaminated can be identified and decontaminated. Records should be maintained until the RUA is terminated. The records should then be returned to ORS.

Decontamination - Decontamination of equipment or skin can be performed with simple soap and water washing. Decontaminate in a sink marked for RAM release to the sanitary sewer.

Emergencies - Report personnel or floor contamination incidents to ORS immediately. Isolate any RAM spill area to prevent the spread of contamination. Keep all involved personnel near the area until ORS staff respond to assist you. THE MOST IMPORTANT THING TO REMEMBER ABOUT A CONTAMINATION EMERGENCY IS TO CALL ORS RIGHT AWAY. The ORS office number is 3-8414. After hours call 9-911 and ask for UCB ORS.

D) Dosimetry

Dosimeters are small wearable devices that monitor and record your radiation dose. Your RUA may not require dosimetry.

Assigned dosimeters must be worn whenever in the presence of RAM or Radiation Producing Machines. Store dosimeters in an uncontaminated area free from radiation fields when they are not being worn.

Dosimeters must be exchanged on a timely basis. Report lost or contaminated dosimeters to ORS as soon as possible.

E) Radioisotope Handling Methods

Detailed information on handling specific isotopes can be found in "The Handbook for Safe Use of Radioisotopes" which appears as an appendix to the campus "Radiation Safety Manual."

F) Posting and labeling of Radiation Use Locations

Controlled areas are designated by a RAM Area sign. Uncontrolled areas cannot exceed a whole body dose rate of 2.0 mR/hr, 100 mR/week, or 500 mR/yr.

Posted Radiation Areas may have whole body dose rates between 5 and 100 mR/hr. High Radiation Areas may have whole body dose rates between 100 and 5000 mR/hr.

VII) UCB RADIATION SAFETY PROGRAM DOCUMENTS

You should read and be familiar with the documents in items A through E below. These documents define and explain the UCB Radiation Safety Program. If you are interested in the California regulations, copies of the Title 17, California Radiation Control Regulations and the UCB

Radioactive Materials License are available for review at the Office of Radiation Safety (ORS), 3rd Floor University Hall (3-8414).

A) A copy of the campus Radiation Safety Manual is available from your Principle Investigator (PI) or Lab Contact. This document gives instructions on how to obtain, modify or terminate an RUA. In the back of the manual is a copy of the Handbook for the Safe Use of Radioisotopes. This handbook gives specific information on precautions used in handling I-125, P-32, C-14, S-35 and H-3.

B) The laboratories RUA (Radiation Use Authorization) document should be posted in your work area. This document gives detailed information on the isotope(s) and activity of RAM authorized, the persons allowed to use the RAM, and the specific safety precautions required for their use.

C) A copy of the campus Radiation Safety Logbook is available from your Principle Investigator (PI) or Lab Contact. The logbook gives specific information on the UCB Radiation Safety Program.

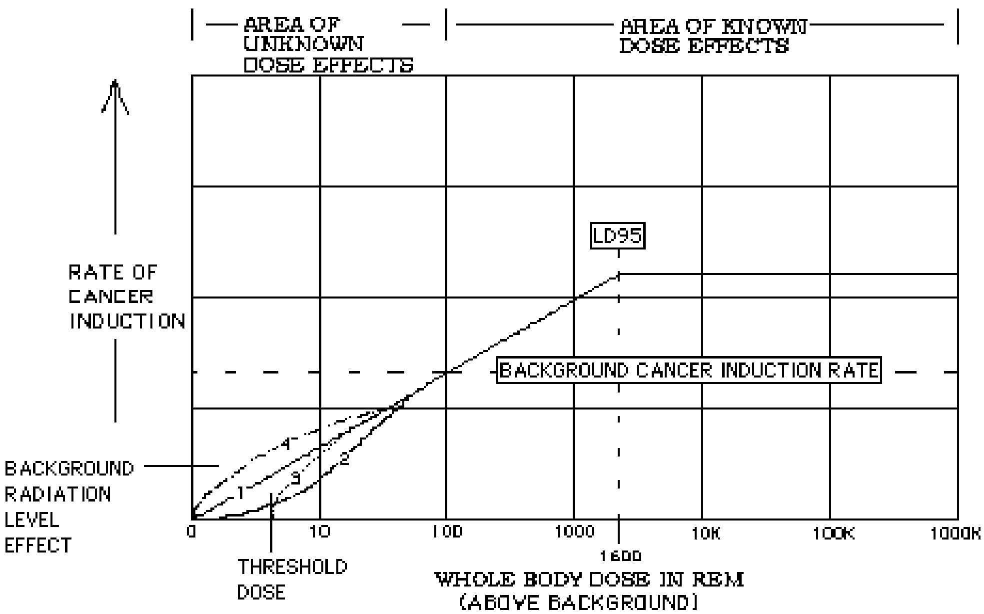
D) The Radiation Safety Procedure Poster (yellow poster) should be found posted in all areas designated on the RUA. The poster covers the basics of using RAM at UCB.

E) The Notice to Employees should be found posted in a conspicuous location in all buildings in which RAM is used. The poster covers the rights and responsibilities of RAM users under California law.

RAM USER TRAINING

Drawing A:

DOSE RESPONSE RELATIONSHIP (FOR CHRONIC EXPOSURE)



1) Linear Relationship (risk increases with dose)
2) Linear Quadratic (some risk with low dose)
3) Threshold Effect (no risk below threshold dose)
4) Low Dose Enhancement (enhanced risk at low dose)

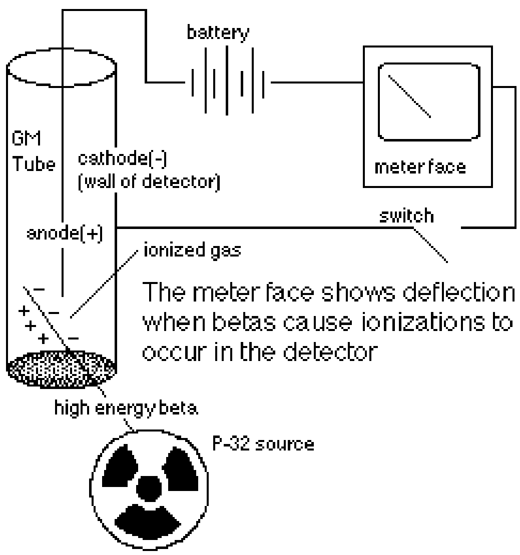
NOTE: LD 95 FOR ACUTE EXPOSURE IS 550 REM

RADIATION RISK AS COMPARED TO NORMALLY ACCEPTED RISKS

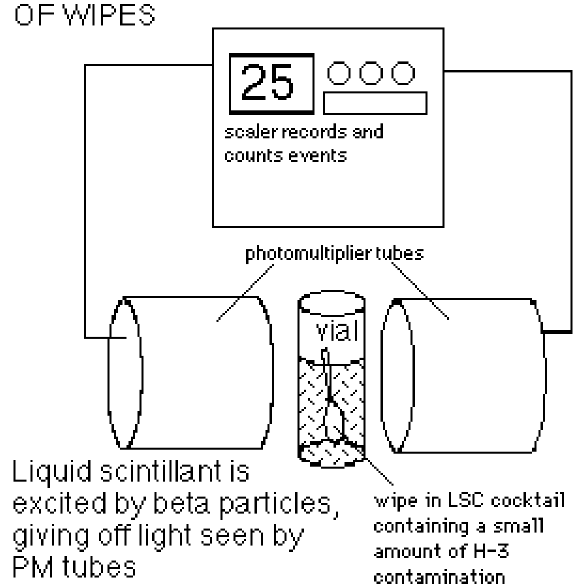
ACTIVITY	ESTIMATED NUMBER OF DAYS OF LIFE LOST
SMOKING 20 CIGARETTES PER DAY	2300
BEING 20% OVERWEIGHT	985
DRIVING AN AUTOMOBILE	200
BEING A SOCIAL DRINKER	130
ACCIDENTS IN THE HOME	95
DROWNING WHILE SWIMMING	41
BACKGROUND RADIATION OF 350 mRem/yr	8
AN OCCUPATIONAL EXPOSURE OF 1000 mRem	1

Drawing B:

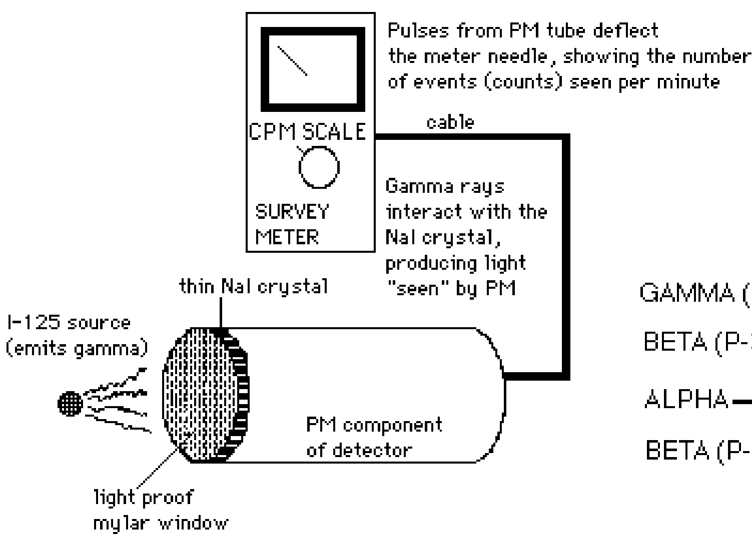
GEIGER MUELLER (GM) DETECTOR OPERATION



LIQUID SCINTILLATION COUNTING OF WIPES



NaI SCINTILLATION SURVEY METER OPERATION



SHIELDING MATERIALS AND STOPPING POWER FOR VARIOUS RADIATIONS