	Fax de:
To: US NRC R1 Fax.No. 610-337-5269/ 610-337-5393	**International Cyclotrons Inc.** José Marti Street # 56 Floral Park Hato Rey, P.R. 00918
Date: 05/18/2009	
Attention: Betsy Ullrich	L-4

Docket No. 03037882

Mail Control No: 143067

License No. ~~5231352~~ 52-31352-01

Thanks,

Sonia Rodríguez

International Cyclotrons, Inc.

47 PAGES

143067

NMSS/RGN1 MATERIALS-002

ICI INTERNATIONAL CYCLOTRONS, INC.	Training Record of Personnel & Associates	SOP #	SOP-ADM-100
		Revision #	0.0
		Implementation Date:	
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		Department:	

TRAINING RECORD FORM

INSTRUCTOR:	DURATION:	DATE:
Sonia Rodríguez	15 minutos	09-25-08

SUBJECT: Cyclotron Room Exposure Rate Survey Beam-on

NAME (PLEASE PRINT)	SIGNATURE	INITIALS	SOCIAL SECURITY NO. OR EMPLOYEE NO.
José O. Ramos	[signature]	JOR	N/A

N/A JOR 09/25/08

INTERNATIONAL CYCLOTRONS, INC.	Training Record of Personnel & Associates	SOP #	SOP-ADM-100
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TRAINING RECORD FORM

INSTRUCTOR:	DURATION:	DATE:
Sonia Rodriguez	20 minutos	09-24-08

SUBJECT: Cyclotron Exposure Rate and Contamination Survey

NAME (PLEASE PRINT)	SIGNATURE	INITIALS	SOCIAL SECURITY NO. OR EMPLOYEE NO.
Jose O. Ramos	[signature]	JOR	N/A

NA 09/24/08 JOR

ICI INTERNATIONAL CYCLOTRONS, INC.	Training Record of Personnel & Associates	SOP #	SOP-ADM-100
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TRAINING RECORD FORM

INSTRUCTOR: Sonia Rodriguez	DURATION: 15 Minutos	DATE: 05-25-08

SUBJECT: Exhaust Systems Check

NAME (PLEASE PRINT)	SIGNATURE	INITIALS	SOCIAL SECURITY NO. OR EMPLOYEE NO.
Sosé O. Ramos	[signature]	SOC	N/A

NA SOC 29/5/08

ICI INTERNATIONAL CYCLOTRONS, INC.	Training Record of Personnel & Associates	SOP #	SOP-ADM-100
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TRAINING RECORD FORM

INSTRUCTOR:	DURATION:	DATE:
Sonia Rodriguez	10 minutos	09-25-08

SUBJECT: Area Monitor Alarm Set point Check

NAME (PLEASE PRINT)	SIGNATURE	INITIALS	SOCIAL SECURITY NO. OR EMPLOYEE NO.
Jose O. [illegible]	[signature]	JOL	N/A

N/A JOL 09/25/08

ICI INTERNATIONAL CYCLOTRONS, INC.	Training Record of Personnel & Associates	SOP #	SOP-ADM-100
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TRAINING RECORD FORM

INSTRUCTOR:	DURATION:	DATE:
Sonia Rodríguez	15 minutos	09-24-08

SUBJECT:

Area Monitor Check

NAME (PLEASE PRINT)	SIGNATURE	INITIALS	SOCIAL SECURITY NO. OR EMPLOYEE NO.
José O. Ramos	[signature]	SOR	N/A

N/A SOR 09/24/08

INTERNATIONAL CYCLOTRONS, INC.

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TRAINING RECORD FORM

INSTRUCTOR:	DURATION:	DATE:
Sonia Rodríguez	15 minutos	09-24-08

SUBJECT:
Wipe Test for Removable Contaminator

NAME (PLEASE PRINT)	SIGNATURE	INITIALS	SOCIAL SECURITY NO. OR EMPLOYEE NO.
José O. Ramos	[signature]	SOL	N/A

NA SOL 09/24/08

INTERNATIONAL CYCLOTRONS, INC.	Training Record of Personnel & Associates	SOP #	SOP-ADM-100
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TRAINING RECORD FORM

INSTRUCTOR: Sonia Rodríguez	DURATION: 15 minutos	DATE: 09-25-08

SUBJECT: Radiation Survey Instrument (Constancy Check)

NAME (PLEASE PRINT)	SIGNATURE	INITIALS	SOCIAL SECURITY NO. OR EMPLOYEE NO.
José O. Ramos	[signature]	SOL	N/A

N/A SOR 09/25/08

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TRAINING RECORD FORM

INSTRUCTOR: Sonia Rodríguez

DURATION: 25 minutos

DATE: 09-25-08

SUBJECT: Ordering/Receiving Radioactive Materials

NAME (PLEASE PRINT)	SIGNATURE	INITIALS	SOCIAL SECURITY NO., OR EMPLOYEE NO.
José O. Ramos	[signature]	JOR	N/A

NA JOR 09/25/08

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TRAINING RECORD FORM

INSTRUCTOR:	DURATION:	DATE:
Sonia Rodríguez	15 minutos	09-24-08

SUBJECT: Handling of Radioactive Materials

NAME (PLEASE PRINT)	SIGNATURE	INITIALS	SOCIAL SECURITY NO. OR EMPLOYEE NO.
José O. Rivos	[signature]	JOR	N/A

N/A JOR 09/24/08

ICI INTERNATIONAL CYCLOTRONS, INC.	Training Record of Personnel & Associates	SOP #	SOP-ADM-100
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TRAINING RECORD FORM

INSTRUCTOR:	DURATION:	DATE:
Sonia Rodríguez	35 minutos / 40 minutos	09-26-08

SUBJECT: GMP (training)

NAME (PLEASE PRINT)	SIGNATURE	INITIALS	SOCIAL SECURITY NO. OR EMPLOYEE NO.
José O. Ramos	[signature]	SoL	N/A

N/A SoL 09/26/08

INTERNATIONAL CYCLOTRONS, INC.	Training Record of Personnel & Associates	SOP #	SOP-ADM-100
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TRAINING RECORD FORM

INSTRUCTOR:	DURATION:	DATE:
Sonia Rodríguez	20 minutos	09-24-08

SUBJECT: Dose Calibrator Calibration

NAME (PLEASE PRINT)	SIGNATURE	INITIALS	SOCIAL SECURITY NO. OR EMPLOYEE NO.
José O. Ramos	[signature]	SOR	N/A

NA SOR 09/24/08

INTERNATIONAL CYCLOTRONS, INC.	Training Record of Personnel & Associates	SOP #	SOP-ADM-100
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TRAINING RECORD FORM

INSTRUCTOR: Sonia Rodriguez	DURATION: 35min	DATE: 09-26-08
SUBJECT: GMP (training)		

NAME (PLEASE PRINT)	SIGNATURE	INITIALS	SOCIAL SECURITY NO. OR EMPLOYEE NO.
Jose O. Ramos	[signature]	SOR	N/A

N/A SOR 09/26/08

ICI INTERNATIONAL CYCLOTRONS, INC.	Training Record of Personnel & Associates	SOP #	SOP-ADM-100
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TRAINING RECORD FORM

INSTRUCTOR:	DURATION:	DATE:
Sonia Rodriguez	20 minutes	09-26-08

SUBJECT: Emergency Response
Activity Transfer Delay

NAME (PLEASE PRINT)	SIGNATURE	INITIALS	SOCIAL SECURITY NO. OR EMPLOYEE NO.
José O. Ramos	[signature]	JOL	N/A

N/A JOL 9/26/08

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TRAINING RECORD FORM

INSTRUCTOR: Sonia Rodriguez	DURATION: 15 minutos	DATE: 09-25-08

SUBJECT: Emergency Response
Loss, theft or Damage of Radioactive Sources

NAME (PLEASE PRINT)	SIGNATURE	INITIALS	SOCIAL SECURITY NO. OR EMPLOYEE NO.
José O. Ramos	[signature]	JOR	N/A

NA JOR 9-25-08

INTERNATIONAL CYCLOTRONS, INC.	Training Record of Personnel & Associates	SOP #	SOP-ADM-100
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TRAINING RECORD FORM

INSTRUCTOR: Sonia Rodriguez	DURATION: 15 minutes	DATE: 09-26-08

SUBJECT: Emergency Response Injuries To Personnel Involving Radioactive Contamination

NAME (PLEASE PRINT)	SIGNATURE	INITIALS	SOCIAL SECURITY NO. OR EMPLOYEE NO.
Sor G. Ramos	[signature]	SGR	N/C

N/A SGR 09/26/08

INTERNATIONAL CYCLOTRONS, INC.	Training Record of Personnel & Associates	SOP #	SOP-ADM-100
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TRAINING RECORD FORM

INSTRUCTOR:	DURATION:	DATE:
Sonia Rodríguez	15 minutos	09-26-08

SUBJECT: Emergency Response
Injuries to Personnel from Possible External in Excess of Limits

NAME (PLEASE PRINT)	SIGNATURE	INITIALS	SOCIAL SECURITY NO. OR EMPLOYEE NO.
José O. Ramos	[signature]	JOR	N/A

N/A JOR 09/26/08

INTERNATIONAL CYCLOTRONS, INC.	Training Record of Personnel & Associates	SOP #	SOP-ADM-100
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TRAINING RECORD FORM

INSTRUCTOR: Sonia Rodriguez	DURATION: 15 minutos	DATE: 09-26-08
SUBJECT: Emergency Response Release of Airborne Radioactivity		

NAME (PLEASE PRINT)	SIGNATURE	INITIALS	SOCIAL SECURITY NO. OR EMPLOYEE NO.
José G. Lenos	[signature]	JGL	N/A

N/P JGL 09/26/08

INTERNATIONAL CYCLOTRONS, INC.	Training Record of Personnel & Associates	SOP #	SOP-ADM-100
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TRAINING RECORD FORM

INSTRUCTOR: Sonia Rodriguez	DURATION: 15 minutos	DATE: 09-26-08

SUBJECT: Emergency Response Spills of Radioactive Material

NAME (PLEASE PRINT)	SIGNATURE	INITIALS	SOCIAL SECURITY NO. OR EMPLOYEE NO.
José O. Ramos	[signature]	JOR	N/A

N/A JOR 09/26/08

INTERNATIONAL CYCLOTRONS, INC.	Training Record of Personnel & Associates	SOP #	SOP-ADM-100
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TRAINING RECORD FORM

INSTRUCTOR: Sonia Rodriguez	DURATION: 20 minutos	DATE: 09-26-08

SUBJECT: Emergency Response
Fire and Impending Natural Disaster

NAME (PLEASE PRINT)	SIGNATURE	INITIALS	SOCIAL SECURITY NO. OR EMPLOYEE NO.
Jose O. Ramos	[signature]	SOL	N/A

NA SOL 09/26/08

ICI INTERNATIONAL CYCLOTRONS, INC.	Training Record of Personnel & Associates	SOP #	SOP-ADM-100
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TRAINING RECORD FORM

INSTRUCTOR: Sonia Rodriguez	DURATION: 25 minutos	DATE: 09-25-08

SUBJECT: Emergency Response
Target, Processing Equipment and Ventilation System Failure

NAME (PLEASE PRINT)	SIGNATURE	INITIALS	SOCIAL SECURITY NO. OR EMPLOYEE NO.
Jose O. [illegible]	[signature]	JOL	N/A

N/A JOL 09/25/08

INTERNATIONAL CYCLOTRONS, INC.	Training Record of Personnel & Associates	SOP #	SOP-ADM-100
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TRAINING RECORD FORM

INSTRUCTOR: Sonia Rodríguez	DURATION: 40 minutos	DATE: 09-24-08

SUBJECT: Radiation Safety Training

NAME (PLEASE PRINT)	SIGNATURE	INITIALS	SOCIAL SECURITY NO. OR EMPLOYEE NO.
Jose O. Ramos	[signature]	JOR	N/A

N/A JOR 09/24/08

ICI INTERNATIONAL CYCLOTRONS, INC.	Training Record of Personnel & Associates	SOP #	SOP-ADM-100
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TRAINING RECORD FORM

INSTRUCTOR:	DURATION:	DATE:
Sonia Rodriguez	20 minutes	09-26-08

SUBJECT:

Visitor and Temporary Worker Exposure Monitoring

NAME (PLEASE PRINT)	SIGNATURE	INITIALS	SOCIAL SECURITY NO. OR EMPLOYEE NO.
Jose G. Ramos	[signature]	JGR	N/A

φ/A JGR 09/26/08

INTERNATIONAL CYCLOTRONS, INC.	Training Record of Personnel & Associates	SOP #	SOP-ADM-100
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TRAINING RECORD FORM

INSTRUCTOR:	DURATION:	DATE:
Sonia Rodríguez	15 minutos	09-25-08

SUBJECT:

Exposure Monitoring for The General Public

NAME (PLEASE PRINT)	SIGNATURE	INITIALS	SOCIAL SECURITY NO. OR EMPLOYEE NO.
José O. Ramos	[signature]	JOR	N/A

N/A JOR 09/25/08

ICI INTERNATIONAL CYCLOTRONS, INC.	Training Record of Personnel & Associates	SOP #	SOP-ADM-100
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TRAINING RECORD FORM

INSTRUCTOR: Sonia Rodríguez	DURATION: 20 minutos	DATE: 09-25-08

SUBJECT: Personnel Exposure Monitoring

NAME (PLEASE PRINT)	SIGNATURE	INITIALS	SOCIAL SECURITY NO. OR EMPLOYEE NO.
José O. Ramos	[signature]	SOR	N/A

N/A SOR 09/25/08

ICI INTERNATIONAL CYCLOTRONS, INC.

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TRAINING RECORD FORM

INSTRUCTOR:	DURATION:	DATE:
Sonia Rodriguez	30 minutos	09-25-08

SUBJECT:

Decontamination (Personnel and Equipment

NAME (PLEASE PRINT)	SIGNATURE	INITIALS	SOCIAL SECURITY NO. OR EMPLOYEE NO.
Jose O. Cosas	[signature]	SOL	N/A

N/A SOL 09/25/08

INTERNATIONAL CYCLOTRONS, INC.	Training Record of Personnel & Associates	SOP #	SOP-ADM-100
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TRAINING RECORD FORM

INSTRUCTOR: Sonia Rodríguez	DURATION: 30 minutos	DATE: 09-25-08

SUBJECT: Disposal of Radioactive Waste

NAME (PLEASE PRINT)	SIGNATURE	INITIALS	SOCIAL SECURITY NO. OR EMPLOYEE NO.
Jose O. Ramos	[signature]	SOR	N/A

N/A SOR 09/25/08

INTERNATIONAL CYCLOTRONS, INC.	Training Record of Personnel & Associates	SOP #	SOP-ADM-100
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TRAINING RECORD FORM

INSTRUCTOR:	DURATION:	DATE:
Sonia Rodriguez		09-26-08

SUBJECT: Storage of Radioactive Components and Waste

NAME (PLEASE PRINT)	SIGNATURE	INITIALS	SOCIAL SECURITY NO. OR EMPLOYEE NO.
Jose O. Lucas	[signature]	JOL	N/A

N/A 09/26/08 JOL

INTERNATIONAL CYCLOTRONS, INC.	Training Record of Personnel & Associates	SOP #	SOP-ADM-100
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TRAINING RECORD FORM

INSTRUCTOR:	DURATION:	DATE:
Sonia Rodríguez	20 minutos	09-24-08

SUBJECT:

Shipping of Radioactive Materials

NAME (PLEASE PRINT)	SIGNATURE	INITIALS	SOCIAL SECURITY NO. OR EMPLOYEE NO.
Sosé O. Laros	[signature]	SOL	N/A

N/A SOR 09/24/08

INTERNATIONAL CYCLOTRONS, INC.	Training Record of Personnel & Associates	SOP #	SOP-ADM-100
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TRAINING RECORD FORM

INSTRUCTOR: Sonia Rodríguez	DURATION: 25 minutos	DATE: 09-26-08

SUBJECT: Leak Testing Sealed Sources

NAME (PLEASE PRINT)	SIGNATURE	INITIALS	SOCIAL SECURITY NO. OR EMPLOYEE NO.
José O. Lanns	[signature]	SOL	N/A

N/A SOL 09/26/08

INTERNATIONAL CYCLOTRONS, INC.	Training Record of Personnel & Associates	SOP #	SOP-ADM-100
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TRAINING RECORD FORM

INSTRUCTOR:	DURATION:	DATE:
Sonia Rodriguez	30 minutos	09-25-08

SUBJECT:

Target and Delivery line Maintenance

NAME (PLEASE PRINT)	SIGNATURE	INITIALS	SOCIAL SECURITY NO. OR EMPLOYEE NO.
Jose O. [illegible]	[signature]	SOR	N/A

N/A SOR 09/25/08

INTERNATIONAL CYCLOTRONS, INC.	Training Record of Personnel & Associates	SOP #	SOP-ADM-100
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TRAINING RECORD FORM

INSTRUCTOR:	DURATION:	DATE:
Sonia Rodríguez	20 minutos	09-26-08

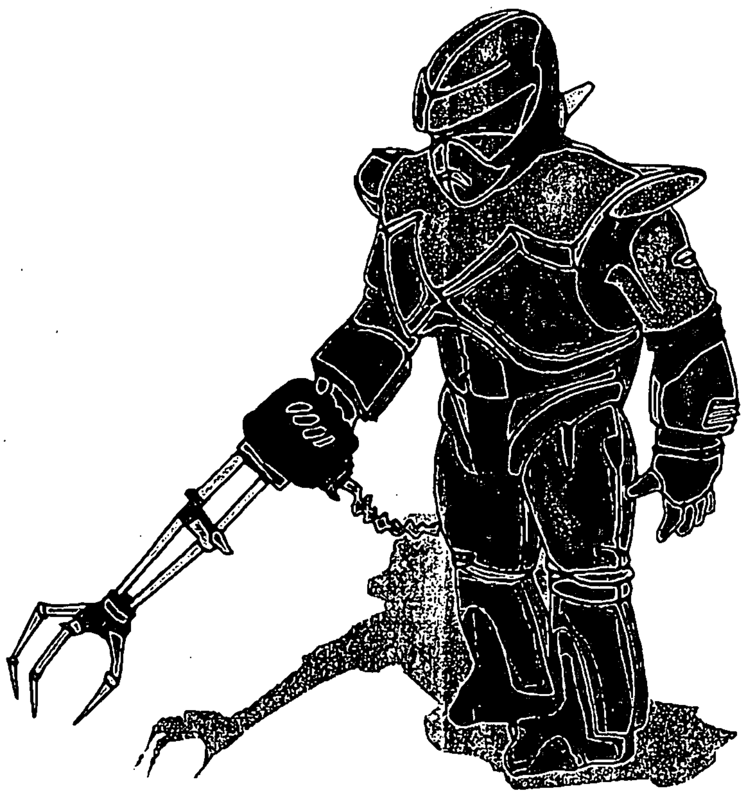
SUBJECT: Ventilation System Maintenance

NAME (PLEASE PRINT)	SIGNATURE	INITIALS	SOCIAL SECURITY NO. OR EMPLOYEE NO.
José G. Ramos	[signature]	JGR	N/A

NA SR 09/26/08

5

Principals of Radiation Protection



Introduction-Principals of Radiation Protection

The principal of radiation protection is to protect workers and the general public from radiation exposure, to minimize radiation hazard, and to maintain radiation exposure to As Low As Reasonably Achievable (ALARA). Radiation protection is responsibility of everyone who is involved with utilization of radiation sources.

1. External Radiation Protection

Limiting the duration of an exposure period, increasing distance between the external radiation source and the person, and placing a shielding material between the external radiation source and the person can reduce external radiation.

1.1. Time, Distance, and Shielding

Time:
Minimizing the time of exposure can reduce radiation exposure. Practice runs without source may help to reduce exposure times when an actual experiment is performed. If limitation of the stay time in the vicinity of an external radiation source is not possible due to the required time to perform a given task, then other means of exposure reduction should be utilized.

Distance:
Distance is a simple, inexpensive, and very effective way of dose reduction. If a distance between a person and a source is doubled (increased by 2) then the exposure rate is decreased by 4. This is called the "Inverse Square Law".

Example. An exposure rate is 100 mR/h at 1 meter. What is the expected exposure at 2 meter, 3 meter, and 4 meter?

RD2=rd2, where R: exposure rate at distance D, r: exposure rate at distance d, and D, d: distances from a fixed point source.

at 2 meters, (100 mR/hr)(12m2)=I(22m2), r=(100 mR/hr)/4=25 mR/hr.

at 3 meters, r=(100 mR/hr)/9=11.11 mR/hr.

at 4 meters, r=(100 mR/hr)/16=6.25 mR/hr.

Shielding:
Shielding is to place a material, which will interact with radiation between a source and a person (or location of interest) to reduce exposure. Alpha radiation requires no shielding. High Beta radiation can be effectively shielded by low atomic number material such as lucite and plastic. Gamma and x-rays require a high-density material such as lead. Shielding can be very effective to reduce exposure but it may be more expensive. Shielding material selection is dependant on the type and energy of radiation.

Safety Office can provide assistance if a problem persists. It is easy to remove contamination in workbench tops if the work area is covered with plastic backed absorbent pad. Application of a new pad and discarding the contaminated absorbent pad into a radioactive waste container takes care of the contamination. This is one of the reasons all radioactive material handling areas such as bench tops should be covered with plastic backed absorbent pads.

Personnel contamination such as on clothing, shoes, or a part or whole body should be approached in such a way to prevent spreading of contamination and keeps away from wounds. Water and mild soap should be used initially. If harsher methods are needed due to stubborn contaminants, an evaluation should be made to avoid embedding the contaminant deeper into the skin.

If contamination is fixed and not removable, the contaminated area should be marked accordingly. An evaluation should be made based on the isotope amount, half-life, radiation type, occupancy of the area, etc, to correct contamination. It may be practical to wait for decay, or, to remove the contaminated area/equipment. After decontamination, the result and its effectiveness must be verified by re-survey.

2.2. Good Laboratory Practices

A. Eating, drinking, smoking: No eating, drinking, smoking or application of cosmetics is permitted in a radioisotope laboratory.
B. Wash Hands: Wash hands after handling radioisotope and before doing other work.
C. Pipetting: Pipetting by mouth is prohibited.
D. Protective Clothing: Always use rubber or plastic gloves when handling radioisotope. Lab coats shall be worn in the laboratory and left in the laboratory. They shall not be used for other work, sent to another area, or released for cleaning until demonstrated to be free of contamination.
E. Confine the Activity: Always work over trays or work surfaces lined with an absorbent material. Keep and transport radioisotope doubly contained.
F. Labeling: Label radioisotope containers with your name, date, radionuclide and its quantity.
G. Before Leaving: Clean up and monitor your work area and yourself at the end of each work period before leaving the laboratory. Remove any contamination found and monitors the area to ensure successful decontamination.
H. Waste Disposal: All radioactive wastes and contaminated materials shall be placed in the properly labeled radioactive waste containers. No radioactive material shall be placed in the regular waste. Waste log shall be on the waste container or near by.
I. Counting Room: Take only prepared samples into the counting room. No potentially contaminated material or apparatus is permitted in the counting room or area.
J. Hoods: Materials, which could become airborne, must be stored and used in an approved hood or glove box.
K. Security: Secure all radioactive materials when laboratory is unoccupied or when authorized radiation workers are not present.
L. Personnel Monitoring: Wear assigned personnel dosimeters whenever working with radioactive material.
M. Sewer Disposal: No radioactive waste shall be placed into the sewer system without authorization from the Radiation Safety Office.
N. Radiation Exposure: No one shall cause any person unnecessary exposure to radiation.

3. Radiation Exposure Limits

5. Characteristics of Ionizing Radiation

Ionizing radiation consists of subatomic particles or electromagnetic waves that are energetic enough to detach electrons from atoms or molecules, ionizing them. The occurrence of ionization depends on the energy of the impinging individual particles or waves, and not on their number. An intense flood of particles or waves will not cause ionization if these particles or waves do not carry enough energy to be ionizing. Roughly speaking, particles or photons with energies above a few electron volts (eV) are ionizing.

Examples of ionizing particles are energetic alpha particles, beta particles, and neutrons. The ability of electromagnetic waves (photons) to ionize an atom or molecule depends on their wavelength. Radiation on the short wavelength end of the electromagnetic spectrum - ultraviolet, x-rays, and gamma rays - is ionizing.

Ionizing radiation comes from radioactive materials, x-ray tubes, particle accelerators, and is present in the environment. It has many practical uses in medicine, research, construction, and other areas, but presents a health hazard if used improperly. Exposure to radiation causes microscopic damage to living tissue, resulting in skin burns and radiation sickness at high doses and cancer, tumors and genetic damage at low doses.

With respect to ionizing radiation, "dose" is a macroscopic concept describing the total energy deposited in tissue, and tissue-doses are expressed in energy-units per gram of irradiated tissue.

The biologically important characteristics of low-LET radiation are that its energy is carried through tissue by high-speed electrons, and that the transfers of this energy occur along paths (tracks) in extremely localized or concentrated fashion.

One need only consider the common fever in order to ponder the very high probability that the biological potency of ionizing radiation is related to its spatial concentration along tracks, rather than to its meager addition of energy to cells. A dose of 400 cGy (400 rads) is equivalent in heat to only 4.184 x 10^-3 joules per gram of tissue -- enough to provoke a mini-fever of 0.001 degree Centigrade -- yet 400 cGy of ionizing radiation to the whole body, acutely delivered, will kill about half the humans exposed to it.

Ionizing radiation as a toxic agent differs fundamentally from toxic substances, which can be introduced to a solution slowly and diluted to a lower and lower uniform concentration. By contrast, for low-LET radiations such as X-rays and beta particles, the minimal unit is the primary ionization track left by a single high-speed electron. The electron cannot be subdivided, and it cannot make its delivery of energy more gentle by diluting it evenly throughout the whole cell; the initial transfer of energy occurs very abruptly and very close to the primary track.

5.1 Primary and Secondary Electrons

Gamma rays and X-rays are photons, which injure cells and cell-nuclei by ejecting an electron from a molecule or atom and putting it into high-speed motion; we will take account of the three

As the primary electron is creating its ionization track, it is setting secondary electrons into motion at irregular intervals. For example, a primary electron with an initial energy of about 300 KeV is producing secondary electrons at irregular intervals of a few hundred nanometers on the average (a few tenths of a micrometer). Of course, the energy-deposition events creating the secondary electrons, with some several tens of electron volts of energy-loss for each deposition-event, reduce the energy of the primary electron.

The amount of disturbance caused by a secondary electron depends on how much energy it acquired when it was ejected from its molecule by the primary electron

5.2 "Off-Center" Nuclear Traversals:

Obviously, not all primary tracks, which traverse a cell-nucleus go right through its full diameter. Although most tracks will be "off-center" (short chords, in the language of microdosimetry), one cannot assume that short chords menace a nucleus with fewer energy-transfers and with a lower chance of carcinogenic injury than do longer chords. When the primary electron is slow near the end of its track, and its LET has become high, an off-center track can pack more transfers of energy (more microzones of reactivity) into a nucleus than can a full-length chord when the electron's LET is still low. Thus, it would be biologically meaningless to introduce a distinction between off-center and central tracks, in the concept of the Least Possible Disturbance.

6. Types of radiation

Alpha (**α**) radiation consists of Helium-4 (^{4}He) nuclei and is stopped by a sheet of paper. Beta (**β**) radiation, consisting of electrons, is halted by an aluminium plate. Gamma (γ) radiation, consisting of energetic photons, is eventually absorbed as it penetrates a dense material. Neutron (**n**) radiation consists of free neutrons which are blocked using light elements, like hydrogen, which slow and/or capture them.

Various types of ionizing radiation may be produced by radioactive decay, nuclear fission and nuclear fusion, extremely hot objects via blackbody radiation, and by particle accelerators.

In order for a particle to be ionizing, it must both have a high enough energy and interact with the atoms of a target. Photons interact strongly with charged particles, so photons of sufficiently high energy also are ionizing. The energy at which this begins to happen with photons (light) is in the ultraviolet region of the electromagnetic spectrum; sunburn is one of the effects of ionization. Charged particles such as electrons, positrons, and alpha particles also interact strongly with electrons of an atom or molecule. Neutrons, on the other hand, do not interact strongly with electrons, and so they cannot directly cause ionization by this mechanism. However, fast neutrons will interact with the protons in hydrogen (in the manner of a billiard ball hitting another, sending it away with all of the first ball's energy of motion), and this mechanism produces proton radiation (fast protons). These protons are ionizing because of their strong interaction with electrons in matter. A neutron can also interact with an atomic nucleus, depending on the nucleus and the neutron's velocity; these reactions happen with fast neutrons and slow neutrons, depending on the situation. Neutron interactions in this manner often produce radioactive nuclei, which produce ionizing radiation when they decay, they then can produce chain reactions in the mass that is decaying, sometimes causing a larger effect of ionization.

and include burns and also cancer, through mutations. Human biology resists germline mutation by either correcting the changes in the DNA or inducing apoptosis in the mutated cell.

Non-ionizing radiation is thought to be essentially harmless below the levels that cause heating. Ionizing radiation is dangerous in direct exposure, although the degree of danger is a subject of debate. Humans and animals can also be exposed to ionizing radiation internally: if radioactive isotopes are present in the environment, they may be taken into the body. For example, radioactive iodine is treated as normal iodine by the body and used by the thyroid; its accumulation there often leads to thyroid cancer. Some radioactive elements also bioaccumulate.

7. Units

Weighting factors W_R for equivalent dose		
Radiation	**Energy**	w_R
x-rays, gamma rays, electrons, positrons, muons		1
neutrons	< 10 keV	5
	10 keV - 100 keV	10
	100 keV - 2 MeV	20
	2 MeV - 20 MeV	10
	> 20 MeV	5
protons	> 2 MeV	2
alpha particles, fission fragments, heavy nuclei		20

The units used to measure ionizing radiation are rather complex. The ionizing effects of radiation are measured by units of exposure:

- The coulomb per kilogram (C/kg) is the SI unit of ionizing radiation exposure, and measures the amount of radiation required to create 1 coulomb of charge of each polarity in 1 kilogram of matter.
- The roentgen (R) is an older traditional unit that is almost out of use, which represented the amount of radiation required to liberate 1 esu of charge of each polarity in 1 cubic centimeter of dry air. 1 Roentgen = 2.58×10^{-4} C/kg

However, the amount of damage done to matter (especially living tissue) by ionizing radiation is more closely related to the amount of energy deposited rather than the charge. This is called the absorbed dose.

- The gray (Gy), with units J/kg, is the SI unit of absorbed dose, which represents the amount of radiation required to deposit 1 joule of energy in 1 kilogram of any kind of matter.
- The rad (Roentgen absorbed dose), is the corresponding traditional unit which is 0.01 J deposited per kg. 100 rad = 1 Gy.

Equal doses of different types or energies of radiation cause different amounts of damage to living tissue. For example, 1 Gy of alpha radiation causes about 20 times as much damage as 1 Gy of x-rays. Therefore the equivalent dose was defined to give an approximate measure of the biological effect of radiation. It is calculated by multiplying the absorbed dose by a weighting factor W_R which is different for each type of radiation (see above table).

charged ions and restore them to a neutral electrical state. This reduces the current in the open chamber. When the current drops below a certain threshold, the alarm is triggered.

- Radioactive tracers for industry: Since radioactive isotopes behave, chemically, mostly like the inactive element, the behavior of a certain chemical substance can be followed by *tracing* the radioactivity. Examples:
  - Adding a gamma tracer to a gas or liquid in a closed system makes it possible to find a hole in a tube.
  - Adding a tracer to the surface of the component of a motor makes it possible to measure wear by measuring the activity of the lubricating oil.

Potential electricity generation through nanomaterials

Using layers of carbon nanotubes interlaced with gold and lithium hydride, has been shown to produce a current when the gold particles are hit by radiation, releasing electrons which can travel through the carbon nanotubes to the lithium hydride, and then to electrodes in order to generate electricity.[3]

8.2 Biological and medical applications of ionizing radiation

In biology, radiation is mainly used for sterilization, and enhancing mutations. For example, mutations may be induced by radiation to produce new or improved species. A very promising field is the sterile insect technique, where male insects are sterilized and liberated in the chosen field, so that they have no descendants, and the population is reduced.

Radiation is also useful in sterilizing medical hardware or food. The advantage for medical hardware is that the object may be sealed in plastic before sterilization. For food, there are strict regulations to prevent the occurrence of induced radioactivity. The growth of a seedling may be enhanced by radiation, but excessive radiation will hinder growth.

Electrons, x rays, gamma rays or atomic ions may be used in radiation therapy to treat malignant tumors (cancer). Furthermore, just like in industrial application, x rays can also be used in radiography to create images of hard-to-image objects, such as inside one's body.

Tracer methods are used in nuclear medicine in a way analogous to the technical uses mentioned above.

9. Radiation

Radiation is all around us. It is naturally present in our environment and has been since the birth of this planet. Consequently, life has evolved in an environment which has significant levels of ionizing radiation. It comes from outer space (cosmic), the ground (terrestrial), and even from within our own bodies. It is present in the air we breathe, the food we eat, the water we drink, and in the construction materials used to build our homes. Certain foods such as bananas and brazil nuts naturally contain higher levels of radiation than other foods. Brick and stone homes have higher natural radiation levels than homes made of other building materials such as wood. Our nation's Capitol, which is largely constructed of granite, contains higher levels of natural radiation than most homes.

Levels of natural or background radiation can vary greatly from one location to the next. For example, people residing in Colorado are exposed to more natural radiation than residents of the east or west coast year. NRC regulations and radiation exposure limits (contained in Title 10 of the Code of Federal Regulations under Part 20) are consistent with recommendations of national and international scientific organizations and with practices in other developed nations.

10. Sources

10.1 Natural background radiation

Natural background radiation comes from four primary sources: cosmic radiation, solar radiation, external terrestrial sources, and radon.

10.1.1 Cosmic radiation

For more details on cosmic radiation, see Cosmic ray.

The Earth, and all living things on it, are constantly bombarded by radiation from outside our solar system. This cosmic radiation consists of positively-charged ions from protons to iron nuclei. The energy of this radiation can far exceed that which humans can create even in the largest particle accelerators (see ultra-high-energy cosmic ray). This radiation interacts in the atmosphere to create secondary radiation that rains down, including x-rays, muons, protons, alpha particles, pions, electrons, and neutrons.

The dose from cosmic radiation is largely from muons, neutrons, and electrons, with a dose rate that varies in different parts of the world and based largely on the geomagnetic field, altitude, and solar cycle. The cosmic-radiation dose rate on airplanes is so high that, according to the United Nations UNSCEAR 2000 Report (see links at bottom), airline flight crew workers receive more dose on average than any other worker, including those in nuclear power plants.

10.1.2 Solar radiation

While most of the Sun's output consists of light (solar radiation), particle radiation is also produced and varies with the solar cycle. These particles are mostly protons with relatively low energies (10-100 keV). Their average composition is similar to that of the Sun itself. This represents significantly lower energy particles than come from cosmic rays. Solar particles vary widely in their intensity and spectrum, increasing in strength after some solar events such as solar flares. Further, an increase in the intensity of solar cosmic rays is often followed by a *decrease* in the galactic cosmic rays, called a Forbush decrease after their discoverer, the physicist Scott Forbush. These decreases are due to the solar wind which carries the Sun's magnetic field out further to shield the earth more thoroughly from cosmic radiation.

The ionizing component of solar radiation is negligible relative to other forms of radiation on Earth's surface.

10.1.3 External terrestrial sources

Most materials on Earth contain some radioactive atoms, even if in small quantities. Most of the terrestrial non-radon-dose one receives from these sources is from gamma-ray emitters in the walls and floors when inside a house, or rocks and soil when outside. The major radionuclides of concern for **terrestrial radiation** are potassium, uranium, and thorium. Each of these sources has been decreasing in activity

Of lesser magnitude, members of the public are exposed to radiation from the nuclear fuel cycle, which includes the entire sequence from mining and milling of uranium to the disposal of the spent fuel. The effects of such exposure have not been reliably measured due to the extremely low doses involved. Estimates of exposure are low enough that proponents of nuclear power liken them to the mutagenic power of wearing trousers for two extra minutes per year (because heat causes mutation).[citation needed] Opponents use a cancer per dose model to assert that such activities cause several hundred cases of cancer per year, an application of the controversial Linear no-threshold model (LNT).[citation needed]

In a nuclear war, gamma rays from fallout of nuclear weapons would probably cause the largest number of casualties. Immediately downwind of targets, doses would exceed 300 Gy per hour. As a reference, 4.5 Gy (around 15,000 times the average annual background rate) is fatal to half of a normal population, without medical treatment.

Occupationally exposed individuals are exposed according to the sources with which they work. The radiation exposure of these individuals is carefully monitored with the use of pocket-pen-sized instruments called dosimeters.

Some of the radionuclides of concern include cobalt-60, caesium-137, americium-241, and iodine-131. Examples of industries where occupational exposure is a concern include:

- Airline crew (the most exposed population)
- Industrial radiography
- Medical radiology and nuclear medicine
- Uranium mining
- Nuclear power plant and nuclear fuel reprocessing plant workers
- Research laboratories (government, university and private)

11. Introduction to Biological Effects of Radiation

We tend to think of biological effects of radiation in terms of their effect on living cells. For low levels of radiation exposure, the biological effects are so small they may not be detected. The body has repair mechanisms against damage induced by radiation as well as by chemical carcinogens. Consequently, biological effects of radiation on living cells may result in three outcomes: (1) injured or damaged cells repair themselves, resulting in no residual damage; (2) cells die, much like millions of body cells do every day, being replaced through normal biological processes; or (3) cells incorrectly repair themselves resulting in a biophysical change.

The associations between radiation exposure and the development of cancer are mostly based on populations exposed to relatively high levels of ionizing radiation (e.g., Japanese atomic bomb survivors, and recipients of selected diagnostic or therapeutic medical procedures). Cancers associated with high dose exposure (greater than 50,000 mrem) include leukemia, breast, bladder, colon, liver, lung, esophagus, ovarian, multiple myeloma, and stomach cancers. Department of Health and Human Services literature also suggests a possible association between ionizing radiation exposure and prostate, nasal cavity/sinuses, pharyngeal and laryngeal, and pancreatic cancer.

The period of time between radiation exposure and the detection of cancer is known as the latent period and can be many years. Those cancers that may develop as a result of radiation exposure are person's direct offspring, or may appear several generations later, depending on whether the altered genes are dominant or recessive.

Although radiation-induced genetic effects have been observed in laboratory animals (given very high doses of radiation), no evidence of genetic effects has been observed among the children born to atomic bomb survivors from Hiroshima and Nagasaki.

12. Biological effects

The biological effects of radiation are thought of in terms of their effects on living cells. For low levels of radiation, the biological effects are so small they may not be detected in epidemiological studies. The body repairs many types of radiation and chemical damage. Biological effects of radiation on living cells may result in a variety of outcomes, including:

1. Cells experience DNA damage and are able to detect and repair the damage.
2. Cells experience DNA damage and are unable to repair the damage. These cells may go through the process of programmed cell death, or apoptosis, thus eliminating the potential genetic damage from the larger tissue.
3. Cells experience a nonlethal DNA mutation that is passed on to subsequent cell divisions. This mutation may contribute to the formation of a cancer.

Other observations at the tissue level are more complicated. These include:

1. In some cases, a small radiation dose reduces the impact of a subsequent, larger radiation dose. This has been termed an 'adaptive response' and is related to hypothetical mechanisms of hormesis.

12.1 Hormesis

Main article: Radiation hormesis

Radiation hormesis is the unproven theory that a low level of ionizing radiation (i.e. near the level of Earth's natural background radiation) helps "immunize" cells against DNA damage from other causes (such as free radicals or larger doses of ionizing radiation), and decreases the risk of cancer. The theory proposes that such low levels activate the body's DNA repair mechanisms, causing higher levels of cellular DNA-repair proteins to be present in the body, improving the body's ability to repair DNA damage. This assertion is very difficult to prove (using, for example, statistical cancer studies) because the effects of very low ionizing radiation levels are too small to be statistically measured amid the "noise" of normal cancer rates.

Therefore, the idea of radiation hormesis is considered unproven by regulatory bodies, which generally use the standard "linear, no threshold" (LNT) model, which states that risk of cancer is directly proportional to the dose level of ionizing radiation. The LNT model is safer for regulatory purposes because it assumes worst-case damage due to ionizing radiation; therefore, if regulations are based on it, workers might be over-protected, but they will never be under-protected.

Studies of occupational workers exposed to chronic low levels of radiation, above normal background, have provided mixed evidence regarding cancer and transgenerational effects. Cancer results, although uncertain, are consistent with estimates of risk based on atomic bomb survivors and suggest that these workers do face a small increase in the probability of developing leukemia and other cancers. One of the most recent and extensive studies of workers was published by Cardis et al. in 2005 [4].

The linear dose-response model suggests that any increase in dose, no matter how small, results in an incremental increase in risk. The linear no-threshold model (LNT) hypothesis is accepted by the Nuclear Regulatory Commission (NRC) and the EPA and its validity has been reaffirmed by a National Academy of Sciences Committee. (See the BEIR VII report, summarized in [5].) Under this model, about 1% of a population would develop cancer in their lifetime as a result of ionizing radiation from background levels of natural and man-made sources.

Ionizing radiation damages tissue by causing ionization, which disrupts molecules directly and also produces highly reactive free radicals, which attack nearby cells. The net effect is that biological molecules suffer local disruption; this may exceed the body's capacity to repair the damage and may also cause mutations in cells currently undergoing replication.

Two widely studied instances of large-scale exposure to high doses of ionizing radiation are: atomic bomb survivors in 1945; and emergency workers responding to the 1986 Chernobyl accident.

Approximately 134 plant workers and fire fighters engaged at the Chernobyl power plant received high radiation doses (70,000 to 1,340,000 mrem or 700 to 13,400 mSv) and suffered from acute radiation sickness. Of these, 28 died from their radiation injuries.

Longer term effects of the Chernobyl accident have also been studied. There is a clear link (see the UNSCEAR 2000 Report, Volume 2: Effects) between the Chernobyl accident and the unusually large number, approximately 1,800, of thyroid cancers reported in contaminated areas, mostly in children. These were fatal in some cases. Other health effects of the Chernobyl accident are subject to current debate.

12.4.1 Ionizing radiation level examples

Recognized effects of acute radiation exposure are described in the article on radiation poisoning. The exact units of measurement vary, but light radiation sickness begins at about 50–100 rad (0.5–1 gray (Gy), 0.5–1 Sv, 50–100 rem, 50,000–100,000 mrem).

Although the SI unit of radiation dose equivalent is the sievert, chronic radiation levels and standards are still often given in millirems, 1/1000th of a rem (1 mrem = 0.01 mSv).

The following table includes some short-term dosages for comparison purposes.

Level (mSv)	Duration	Description
0.001-0.01	Hourly	Cosmic ray dose on high-altitude flight, depends on position and solar sunspot

250	Acute	USA EPA voluntary maximum dose for emergency non-life-saving work [9]
260	Annual	Ramsar, Iran, natural background peak dose [10]
500	Annual	USA NRC occupational whole skin, limb skin, or single organ exposure limit
500	30 years	Exposure, long duration, Ural mountains, upper limit [11]
750	Acute	USA EPA voluntary maximum dose for emergency life-saving work [9]
500-1000	Acute	Low-level radiation sickness due to short-term exposure
500-1000	Detonation	World War II nuclear bomb victims[citation needed]
4500-5000	Acute	LD_{50} in humans (from radiation poisoning), with medical treatment.[10]

13. Monitoring and controlling exposure

Radiation has always been present in the environment and in our bodies. The human body cannot sense ionizing radiation, but a range of instruments exists which are capable of detecting even very low levels of radiation from natural and man-made sources.

Dosimeters measure an absolute dose received over a period of time. Ion-chamber dosimeters resemble pens, and can be clipped to one's clothing. Film-badge dosimeters enclose a piece of photographic film, which will become exposed as radiation passes through it. Ion-chamber dosimeters must be periodically recharged, and the result logged. Film-badge dosimeters must be developed as photographic emulsion so the exposures can be counted and logged; once developed, they are discarded. Another type of dosimeter is the TLD (Thermoluminescent Dosimeter). These dosimeters contain crystals that emit visible light when heated, in direct proportion to their total radiation exposure. Like ion-chamber dosimeters, TLDs can be re-used after they have been 'read'.

Geiger counters and scintillation counters measure the dose rate of ionizing radiation directly.

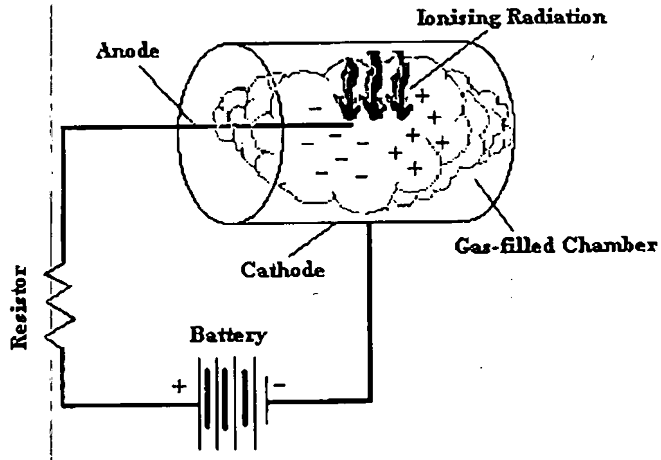
13.1 Limiting exposure

There are four standard ways to limit exposure:

Time: For people who are exposed to radiation in addition to natural background radiation, limiting or minimizing the exposure time will reduce the dose from the radiation source.

Distance: Radiation intensity decreases sharply with distance, according to an inverse square law.

Shielding: Barriers of lead, concrete, or water give effective protection from radiation formed of energetic particles such as gamma rays and neutrons. Some radioactive materials are stored or handled underwater or by remote control in rooms constructed of thick concrete or lined with lead. There are special plastic shields which stop beta particles and air will stop alpha particles. The effectiveness of a material in shielding radiation is determined by its halve value thicknesses, the thickness of material that reduces the radiation by half. This value is a function of the material itself and the energy and type of ionizing radiation.



There are various types of particle counting instruments filled with gas:

i. **Ionisation chamber counters (no secondary ions are produced)**
ii. **Proportional counters (secondary ions are produced but the number is proportional with initial energy of the radiation)**
iii. **Geiger-Müller counters (secondary ions are produced in large numbers and the number of ions is no longer proportional with radiation energy)**

The main difference between these 3 types of counters simply depends on the voltage used for charging the condenser.

14.2.2 Solid and Liquid Scintillation Detectors

A scintillation counter is a transducer that changes the kinetic energy of an ionizing particle into a flash of light. The flashes of light are viewed electronically by photomultiplier tubes. The output pulses may be amplified, sorted by size, and counted.

Different scintillation materials (NaI (Tl), CsI (Tl) crystals, plastics, or liquids) are used to detect different types of radiation.

Scintillation counters are widely used in our radiation protection program for bioassays, swipes, and laboratory experiment samples. Liquid scintillation counters have a very good detection threshold since the scintillation liquid and sample are practically mixed together.

When using a particle counting instrument, one must remember to measure a background first. The net number of counts is then obtained by subtracting the background from the actual number of counts produced by the source. Due to statistical processes for both nuclear disintegration and measurement itself, subtraction of background is trivial (simple) only when the counting rates are much

When the difference between sample measurement and background (net counts) is smaller that DL, the result of the measurement is NOT considered statistically significant and the result should be expressed as a minimum detectable activity (MDA).

$$\mathbf{MDA(Bq/sample)} = \frac{\mathbf{DL\ (cpm)}}{\mathbf{DE * 60\ s}}$$

MDA is not a characteristic of the sample measured, but is a characteristic of the instrument's limit for detecting radioactivity. That is why results should be expressed as "less than MDA (Bq)". Such a result indicates that the radioactivity of the sample is less than the capability of the instrument for detecting radioactivity.

Nevertheless, this kind of result can be quite informative. It will indicate whether an instrument is appropriate for specific applications. For example, an instrument's MDA might equal the release criteria for contaminated surfaces. Thus, any source whose activity is detected by the instrument cannot be released.

Example:

A tritium contamination occurred in a laboratory. A swipe of 100 cm^2 was taken and measured with a liquid scintillation counter for 1 minute.

a) Considering a swipe efficiency of 10% and a detection efficiency of 55%. Determine the result of a measurement when the number of counts for the sample is 750 with a background of 41.

b) Decide to clean the area and swipe again. In the same conditions, determine the result of the measurement if the new reading is now 60 counts and the new background is 39.

Answer:

a) The detection limit DL is:

$$\mathbf{DL\ (cpm)} = \frac{\mathbf{3 + 4.65 * \sqrt{41}}}{\mathbf{1\,(min)}} = \mathbf{32.8cpm}$$

The difference between sample (750 cpm) and background (41 cpm) is 709 cpm, which is more than 32.8 cpm. Therefore, the result is statistically significant. The activity and the uncertainty can now be calculated as:

$$\mathrm{A(Bq/sample)} = \frac{709\ (\mathrm{cpm})}{0.55 * 100 * 0.1 * 60\ \mathrm{s}} = 2.15\ \mathrm{Bq/cm^2}$$

Electronic dosimeters are also used for direct reading of dose. They are very useful for work in high radiation fields because of the alarm system they are equipped with. Alarms can be set for total dose, dose rate, and for superficial or deep dose.

Survey meters are particle counting instruments that have been calibrated to measure the dose. They are highly specialised and can only be used for the type of radiation (X-ray, gamma ray or neutrons) for which they have been calibrated. These instruments should never be used to measure dose outside the energy range or type of radiation for which they were calibrated.

14.4 Internal dosimetry

As was mentioned before, inhalation and ingestion are the main paths for internal irradiation of those working with radioactive materials. Therefore, special methods are required for measuring internal irradiation of personnel. At U of T, two internal dosimetry programs have been developed.

14.4.1 Iodine measurement

The Iodine bioassay program is based on the well-known fact that iodine radionuclides used in our laboratories (I-125 and I-131) tend to accumulate inside the thyroid. Both radionuclides are gamma emitters. Therefore, a gamma detector can be used to measure the iodine content of the person's thyroid. Proper calibration of the instrument is done using 'phantoms' that mimic human body composition, with fat and without fatty tissue. After gathering information about thyroid activity (in Bq) and the moment of iodine usage, we can estimate iodine uptake and intake. Then, we can compare these values with the annual allowable limit on intake (ALI) and estimate the dose received by the contaminated person.

14.4.2 Urinalysis

The scientific basis for this type of analysis is the fact that most of the radionuclides tend to be eliminated in body fluids. By measuring activity content in urine, we can estimate the uptake and the intake. The dose is estimated by comparing the intake with the ALI for that particular radionuclide.

Example:

a) During an iodine bioassay of a person using I-125, the result of a 2 minute measurement is 1200 counts (or 600 cpm). The background for a 2 minute measurement performed immediately before was 950 counts (or 475 cpm). Knowing the detection efficiency of the instrument for I-125 to be 1.42 % for a person without fat tissue, determine the content of I-125 in the person's thyroid.

b) What is the content of I-125 for a different person measured immediate after the first one, if the measured value is now 980 counts (or 490 cpm)?