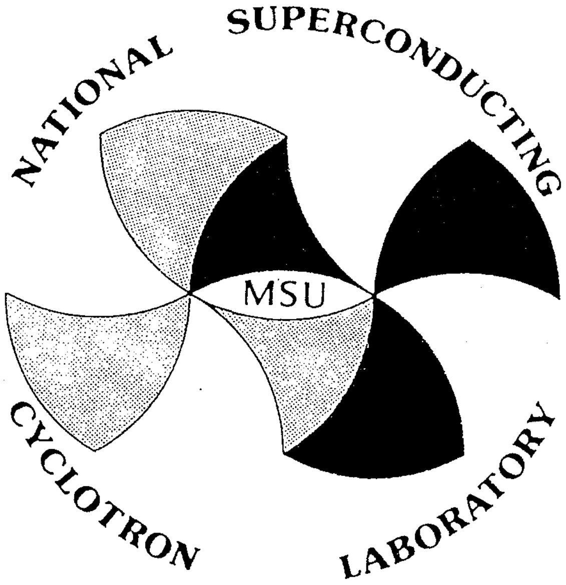
NATIONAL SUPERCONDUCTING CYCLOTRON LABORATORY

MICHIGAN STATE UNIVERSITY



RADIATION SAFETY MANUAL

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MSUCP-38

INTRODUCTION

The lab does not contain restricted areas and all lab staff are free to go from non-radiation areas to radiations areas. Therefore, it is necessary to monitor the radiation exposure of everyone, even though many members of the staff will receive little or no radiation exposure whatsoever. The lack of restricted areas necessitates classifying all lab staff as radiation workers, who must read this manual and sign a statement that they have done so. Visiting users need to be knowledgeable in radiation protection and sign a statement to that effect.

The first section of this radiation manual contains general information of concern to all laboratory staff and visiting users. This information is intended to ensure a basic understanding of radiation safety. The second section contains additional detailed information for accelerator operators, maintenance and experimental staff, and visiting users. An understanding of this material is essential to the safety of all people working in the cyclotron and experimental vaults.

The radiation safety rules and procedures contained in this manual are based upon the U.S. Nuclear Regulatory Commision Guides, code of Federal Regulations (10CFR Parts 19&20), and the Michigan Department of Public Health-Division of Radiological Health Regulations- "Ionizing Radiation Rules Governing Radioactive Materials and Electronic Product Radiation".

A good reference on the effects of low-level ionizing radiation can be found in the February, 1982 issue of Scientific American: "The Biological Effects of Low-Level Ionizing Radiation" by A.C. Upton (in cyclotron library). For additional information, contact the Laboratory Radiation Safety Officer, Reg Ronningen, or the Laboratory Health Physicist, Rich Lassin. Questions may also be addressed to the University's Radiation Safety Officer, Warren Malchman, at the Office of Radiation, Chemical, and Biological Safety (302 N. Kedzie Phone: 355-0153).

Please give comments or suggestions regarding this manual to Rich Lassin.

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I. ALL LABORATORY STAFF AND VISITING USERS

Ionizing Radiation

The radiation from accelerators and radioactive materials is classified as ionizing radiation. This is in contrast to non-ionizing radiation, such as visible light and radio waves, which do not ionize the material through which they pass. Ionizing radiation removes electrons from atoms. The result of ionization is the production of free electrons with their negative charges and ionized atoms with positive charges.

Ionized atoms are much more active chemically than neutral atoms. These chemically active atoms can form compounds that interfere with the process of cell division and metabolism. The degree of damage suffered by an individual exposed to ionizing radiation is a function of several factors: type of radiation involved, intensity of the radiation, its associative energy, and length of exposure.

Here at the NSCL, ionizing radiation can be classified according to its source: primary radiation, secondary or stray radiation, and induced radioactivity. The beam of particles which is accelerated by the cyclotron is classified as the primary radiation. When the primary beam strikes a target or any other material along its path, secondary radiation or stray radiation is produced.

When the accelerator beam is turned off, the primary and secondary radiation cease; however, other radiation hazards due to induced radioactivity may exist. The atoms of materials irradiated may have been excited to an unstable state or new unstable atoms may have been produced. The unstable atoms will return to a more stable state after a time described by a characteristic half-life and with the emission of radiation. The radiation emitted may consist of electrons, positrons, alpha particles, x-rays, or gamma rays, or combinations of these rays and particles.

Primary and Secondary Radiation

Primary radiation always consists of charged particles because the charge is necessary for the accelerating process. The primary radiation exists as the "internal beam" inside the machine, and as the "external beam" which emerges from the accelerator. The external beam is focussed to a small diameter and directed onto a target. For these reasons, the primary radiation occupies a very small volume, and its energy is very concentrated. Obviously, any exposure to this primary radiation (the beam itself), would be dangerous, but this is not considered a significant hazard since the beam is restricted to the cyclotron and beam lines and can only exist under vacuum conditions.

The primary particles, as a result of their charge and the consequent strong interaction with the electrons of the material through which they pass, have poor penetrating power and can be absorbed by small amounts of material.

The distance traveled by such a charged particle as it slows down and eventually stops in a material is called its range. The range depends on the composition of the impacted material as well as the nuclear charge and the initial speed of the accelerated particle. Stray particles from high energy beams can pass through the walls of aluminum vacuum pipes (a few millimeters thick) which carry the beam to the target. Nevertheless, the secondary radiation produced from the interaction of the primary beam striking matter is of concern because of the abundant secondary radiation produced which can be very penetrating (i.e. neutrons and gamma rays).

Neutrons are electrically neutral and do not have a well defined range or stopping distance as charged particles do. This is why the accelerators and experimental areas are surrounded by thick shielding walls.

A certain amount of radiation is absorbed as it travels through the shielding. If the shielding is made thicker or a denser material is used, a greater fraction of the radioactivity will be absorbed. It is not possible to completely shield an experiment. Therefore, some radiation will always survive and emerge from the shielding. In providing shielding, the factors which affect tolerable exposure levels are operating and working schedules and permissible exposure limits.

A secondary radiation that is produced in the cyclotron even when no ion beam is present is x-rays. X-rays arise whenever high speed electrons strike solid matter. X-rays are produced in the cyclotron when the electrostatic deflectors and the dees are struck by electrons. The X-rays are a particular hazard to persons working around the accelerator on trouble-shooting tasks.

Table I. lists the various types of ionizing radiation which are created in the laboratory and their major sources.

TABLE I. IONIZING RADIATIONS RESULTING FROM CYCLOTRON OPERATION

Radiation	Sources
Primary ion beam	Entire beam path, accelerator and beam line inside vacuum system
Neutrons, gamma-rays and other secondary radiations	Beam stops, probes, slits, targets, dees, and deflectors
X-rays	Dees and deflectors when voltage is applied Also, deflector test stand, RPMS Wien filter, ion sources, etc.
Induced radioactivity from primary beams	Beam stops, probes slits, targets, dees and deflectors and ion sources
Induced radioactivity from secondary radiations (Neutrons)	Vacuum chamber walls and ion source components and various cyclotron components

External and Internal Hazard

Injury, as a result of being irradiated, is caused mainly by ionizations within the tissues of the body. There are two main potential hazards connected with work with radioactivity: external exposure to radiation and internal deposition of radioactive materials.

1. External hazards arise when the radiation source is external to the body and the body is penetrated by ionizing radiation emitted from the source. These radiations may be X-rays, gamma rays, neutrons, alpha particles, or beta particles. Beta particles, do not normally penetrate beyond the skin layer, but when sufficiently intense, can cause skin damage.Half-inch plexiglass is an effective shield for most beta radiations.

Alpha particles, because of their higher mass, slower velocity, and greater electrical charge compared to beta particles are capable of traveling only a few centimeters in air and rarely penetrate the outer layer of the skin. X-rays, gamma rays, and neutrons, on the other hand, are very penetrating. These radiations are of primary importance when evaluating external radiation exposure.

Exposure to external radiation may be controlled by limiting the working time in the radiation field, by working at a distance from the source of radiation, and by inserting shielding between the worker and the source.

2. Internal hazards arise when radiation is emanating from internal deposits of radioactive material within the body. Although external hazards are primarily caused by x-rays, gamma rays and neutrons, all forms of radiation, including alpha and beta particles, can cause internal hazards. Alpha particles have a high ionization potential and can cause severe damage to internal organs and tissues when they are injected or inhaled. Once these particles get into the body, deleterious effects occur more readily as there is no protective dead-skin layer to shield the organs and tissues. Radioactive material may gain access to the body by ingestion, inhalation, or by absorption through a cut or break in the skin. The internal hazard is not limited to ingesting large amounts at one time. Often a chronic hazard can arise from small accumulations over a long period of time.

It is known that many elements, if taken into the body, will concentrate in certain body ogans. For example, iodine will concentrate in the thyroid; strontium, calcium, radium, and plutonium will concentrate in bone. This latter group contains the most hazardous of radioactive elements. Most of them have long effective half-lives and remain deposited in the bones for long periods of time. The bone marrow contains blood-forming tissues which are very sensitive to radiation. The amount of damage caused by deposits of radioactive materials in the bones depends on the amount of radioactive material that has become "fixed", and the type(s) of radiations emitted. If the deposit is small, the natural repair process of the body may overcome whatever damage is done. But, if the deposit is substantial, sufficient damage may be caused to interfere with proper body function. Thus, a disease such as leukemia or osteosarcoma may develop later on in life.

Protection of personnel against internal deposits of radioactive material is facilitated by the judicious use of protective clothing such as gloves, coveralls, impervious plastic suits, and respiratory equipment. Good housekeeping procedures and adequate care in handling radioactive materials are imperative.

Personnel Monitoring

Film badges must be worn routinely by all laboratory staff. The badges are changed and processed every month. When visiting other facilities where radiation exposure is possible, an exposure report should be mailed to Michigan State University in order to keep an up to date record of your lifetime, occupational radiation exposure. Do not bring your NSCL badge when you visit other facilities. A complete report on exposure history can be obtained from the Laboratory's radiation safety officer, Reg Ronningen, or from the Laboratory's Health Physicist, Rich Lassin. Complete radiation histories are also available at the University's Office of Radiation, Chemical, and Biological Safety (302 N. Kedzie Phone: 355-0153).

In addition to radiation badges, pocket chambers or pocket dosimeters should be used during more hazardous operations. Their advantage over film badges is that they can be read immediately. At their discretion, group leaders may prescribe the use of these instruments by individuals or by groups during specific operations. The readings obtained are for the individuals guidance only. The radiation film badge remains the official and legal record of the radiation exposure received.

Radiation Dose Units

The RAD and the REM are the two main radiation units used when assessing radiation dose. The RAD (Radiation Absorbed Dose) refers to the energy deposition by any type of radiation in any type of material. Specifically, one RAD equals 100 ergs of energy deposition per gram of absorber. The REM (Radiation Equivalent Man) takes into account the biologic effectiveness of different radiation. Some types of radiation cause more ionizations in tissue than other types. For example, one RAD of alpha particles is twenty times more effective in its ability to ionize than one RAD of gamma rays. To account for these differences a number called a quality factor (QF) is used in conjunction with the radiation absorbed dose in order to determine the dose in REM :

Dose in REMS = Dose in RADS X QF

The dose rate is proportional to the radiation flux (number of particles or photons per square centimeter per second) and is expressed in REM/hour or MILLIREM/hour. Your radiation film badge readings are reported in MILLIREM.

The dose rate can be estimated by using an ion chamber when the radioactive source is a gamma or X-ray emitter. The ion chamber is also useful in estimating dose for most beta radiations. In the case of alpha particles and neutrons, special detectors are required.

Maximum Permissible Exposure

It is generally accepted that there is no lower limit of exposure to ionizing radiation which does not cause some biologic effect. However, exposure standards have been established and set at a level where apparent injury during a normal lifetime is not expected. This limit is called the "maximum permissible exposure".

Maximum permissible exposure to external radiation is given in Table II. However, personnel should not completely disregard exposures at or below these limits. It is the responsibility of each individual to keep his exposure to all radiation as low as practical and to avoid all exposures to radiation when such exposures are unnecessary.

TABLE II. MAXIMUM PERMISSIBLE EXPOSURES TO EXTERNAL RADIATION IN MILLIREM FOR RADIATION WORKERS

Part of Body	Weekly	Quarterly	Yearly
Whole Body, Head and Trunk, Active Blood Forming Organs, Lens of Eye, or Gonads.	100	1,250	5,000
Hands & Forearms, Feet and Ankles.	1,500	18,750	75,000
Skin of Whole Body.	600	7,500.	30,000

The weekly values, as quoted in Table II, are average values. As a working guide, the recommended weekly whole body exposure limit for laboratory staff is 100 millirem/week (40 Hours).

The calendar quarter limits are mandatory with the following exception allowed by both federal and state regulations: when there is documented evidence that a worker's previous exposure is low enough, the MSU Radiation Safety Officer, Warren Malchman, may permit a dose of up to three rems in one calendar quarter. The State of Michigan Regulations require the annual dose to be less than five rems in all circumstances. In addition, a worker's accumulated dose may not exceed 5(N-18) rems, where N is the person's age in years, i.e. the lifetime occupational dose may not exceed an average of five rems for each year above the age of 18.

Female Staff of Child Bearing Age

A special situation arises when a radiation worker becomes pregnant. Under these conditions, radiation exposure could also involve exposure to the embryo or fetus. A number of studies have indicated that the embryo or fetus is more sensitive than the adult, particularly during the first three months of pregnancy. This can be a problem since many women are unaware of their pregnancy during the first month or two of gestation. Hence, the NRC (Nuclear Regulatory Commission) and the State of Michigan requires that <u>all</u> occupationally exposed women be instructed concerning the health protection problems associated with prenatal radiation exposure and sign a statement that they are familiar with the risks involved as stated in the NRC Regulatory Guide 8.13.

There are relatively few positions in the laboratory where radiation levels are high enough such that a fetus would receive 500 millirem before birth (maximum permissible exposure during gestation period is 500 millirem). If a radiation worker is pregnant, or is planning to become pregnant, she should discuss her exposure history with the laboratory's Radiation Safety Officer or Health Physicist. By doing so, a complete assessment or her radiation exposure potential can be made. If appropriate, a change in work assignment or location may be required in order to assure a low-radiation, exposure potential. It is the female radiation worker's responsibility to notify the Radiation Safety Officer, Reg Ronningen, or Health Physicist, Rich Lassin, about her pregnancy or planned pregnancy.

Exposure of Non-Radiation Workers

Visitors to the laboratory who are not classified as radiation workers by their employers must not receive a radiation dose in excess of:

A. Two millirems in any one hour.
B. 500 millirem in any one calender year.
C. 100 millirem in any seven consecutive days.

Warning Signs

Signs are used to mark areas where hazardous radiation levels could exist. In addition, entrance to any room containing radioactive material should be labeled with the radiation caution symbol and the phrase "caution radioactive materials". The terms "radiation area" and "high radiation area" are defined here and should be used whenever appropriate on warning signs.

A "radiation area" means any area accessible to personnel in which radiation exists at such a level that a major portion of the body could receive a dose of five millirem or more in one hour or 100 millirem in any five consecutive days. Properly worded signs should be posted to designate the area as restricted for access.

A "high radiation area" means any area accessible to personnel in which there exists radiation at such levels that a major portion of the body could receive 100 millirems in one hours time. Ropes or fences should be used in addition to warning signs to clearly mark the restricted area.

TABLE III. DEFINITION OF RADIATION WARNING SIGNS

Amount of radiation	Designation
Any radioactive material or radiation	Caution or Danger "Radioactive Material" or "Radiation"
5 to 100 mrem/hour	Caution or Danger "Radiation Area"
100 mrem/hour or greater	Caution or Danger "High Radiation Area"

Tours

There is a need to exercise considerable caution to see that visitors are not inadvertentently exposed to radiation. Please note the exposure limits for non-radiation workers given above. Also, remember that the exposure limits for individuals under 18 years of age are one tenth (10%) of the occupational limit. This means that these individuals cannot receive a dose in excess of 125 millirem in any calender quarter or 500 millirem in any calender year. If you are going to be taking members of your family or friends through the lab, it is advised that you check with Rich Lassin or Reg Ronningen in regards to radiation safety. The receptionist will issue you a tour badge so that a record will be made of your visitor's radiation exposure while at the lab.

A point of particular concern is that undergraduate student workers are generally not adequately informed of the potential dangers throughout the lab whether it be radiation, high voltage or mechanical hazards. Undergraduate students are therefore not to bring visitors nor give tours of the lab.

II. ACCELERATOR OPERATIONS AND EXPERIMENTAL USERS: CONTENTS

II. ACCELERATOR OPERATORS AND EXPERIMENTAL USERS

This section of the manual supplements the first section and provides basic information of concern to accelerator operators and experimentalists. For more information regarding the effects of radiation and safe radiation procedures, consult the following:

Shapiro, J. "Radiation Protection". Harvard University Press, 1981.
NCRP Report No. 32, "Radiation Protection in Educational Institutions".
Code of Federeal Regulations, (10CFR Parts 19&20). Standards for Protection Against Radiation and Information to Workers.
Michigan Department of Public Health, Division of Radiological Health, Ionizing Radiation Rules Governing Radioactive Material and Electronic Product Radiation.
"Health Physics Practices at Research Accelerators", R. Thomas, LBL-4655 (1976).

Copies of the above references are available, on a loan basis, from MSU's Office of Radiation, Biological, and Chemical Safety, ORCBS (phone: 355-0153). Questions about any safety related matter are also welcome by Reg Ronningen or Rich Lassin.

Entering Shielded Vaults

Experimenters and cyclotron operators should acquaint themselves with the distribution of cyclotron produced radiation and radioactive components inside the various vaults in order to reduce the possibility of unnecessary exposure to radiation. One class of hazardous objects is probes, beam stops, slits, etc. containing induced radioactivity. Another class is the neutron radiation that is present in occupiable areas when the accelerator is running, such as in an idle experimental area or on top of the roof shielding. If there is any doubt about the conditions present, the operator should be consulted and a portable radiation meter should be used when entering a vault. Note that survey meters used for neutrons differs from those used for gamma rays.

Workers who rarely enter the vaults or are unfamiliar with the recent radiation history of the machine should see the operator and seek assistance, if necessary, in order to assure their safety while at work in the vault.

Activation of Targets and Accelerator

The target which is intentionally being irradiated will become radioactive. Any other material such as vacuum chamber walls which the beam strikes or which is exposed to intense secondary radiation, may also become radioactive. The induced radioactivity may cover a wide range in intensity and half-life and come from many radioactive isotopes. Cyclotrons have high neutron yields and produce higher intensities of induced activity than do some other accelerators. The intensity following shutdown under normal conditions may be sufficient to overexpose a person in a matter of minutes. Whenever possible, repairs and other maintenance tasks should be scheduled after an overnight or weekend shutdown, when the radiation levels are much lower. Surveys should be made to evaluate the radiation hazard before doing target changes, maintenance, reconfigurations, etc.

Activation of cooling water and other cooling media in targets may be a problem. Since the main, water cooling system for the laboratory extends into portions of the building which is occupied during accelerator operation, any radioactivity induced into this water system is a hazard. Consequently, any water-cooled apparatus in which the primary beam may enter the water, must be provided with a separate, closed cooling-loop and heat exchanger. In these cases, the irradiated water will become radioactive and shielding of the holding tanks will probably be required.

Airborne Radioactive Materials

1. Some oxygen and nitrogen atoms in the air may become radioactive when they are struck by the primary or secondary radiations, especially neutrons. This is a normal occurrence, and is handled by exchanging the activated air via the exhaust fans.
2. Radioactive gases produced in targets may escape into the room as a result of contaminant failure or improper venting of pumps. This may be difficult to distinguish from above without the use of detectors that identify the specific radionuclides present
3. Contamination may be present in particulate or dust form, possibly the result of a ruptured, powder target or flaking of the target while under irradiation. If this occurs, air fans should be turned off to prevent the spread of the dust. This form of contamination is not normal and should be treated as an accident, as described in subsequent sub-sections.

Safety Interlocks and Accelerator Procedures

Interlock Systems: Interlocks are electrical circuits which can turn off or keep off electrical power in the event of a hazardous situation. Here at the NSCL, the cyclotron has many interlocked subsystems. Each interlock is intended to protect personnel or equipment in the event of a specific malfunction or improper operating condition.

Each of the individual interlock functions opens or closes a pair of electrical contacts, either directly or through a relay. Many pairs of contacts in series must be closed in order to operate the cyclotron. Often, subsystems have smaller, series chains which culminate in a single pair of contacts in the main interlock chain. Ideally, the interlock system is "fail safe" in the sense that defects or component failures within the chain itself, will prevent operation of the cyclotron.

The radiation interlock system is a very important part of the overall interlock network. This system has two main functions: prevent access to unsafe radiation areas resulting from cyclotron operations, and prevent or stop cyclotron operations if such operations produce unsafe radiation levels in an occupied area.

The various target areas are grouped into separated shielded rooms (vaults) so that experimenters can work in one vault while the beam is directed to another vault. The radiation interlock system prevents the beam from accidentally being misdirected to an occupied room. Neutron detectors are strategically placed throughout the facility so that the neutron flux can be monitored. Special attention should be made to the neutron flux in the South Vault when an experiment is in progress in the North Vault (S-320). When certain beams are run (i.e. lithium) at high currents to the S-320 spectrograph (North Vault), high neutron fluxes can be encountered in the South Vault, especially in the northwest corner as the shielding (wall thickness) is rather thin. If you need to work in this area under these conditions, please contact the Radiation Safety Officer, Reg Ronningen, or Health Physicist, Rich Lassin. If neither can be contacted, see the operator on duty.

The other major components of the radiation interlock system are the shield doors, neutron plugs, and beam stops.

The purpose of the beam stops are (1) prevent the beam from striking the target (2) prevent the beam from entering a beam-line or apparatus which is not prepared to accept the beam (3) read the beam intensity by measuring the electric current of the intercepted beam. A beam stop is water-cooled to safely remove the heat deposited by the beam, and is usually designed to minimize the induced radioactivity in order to facilitate maintenance of the device.

Several beam stops are located in the beamlines. Check with the operations staff for their locations.

A neutron plug (also known as a beam plug) is placed in a shielding wall where a beamline penetrates through the wall. Its primary purpose is to close the hole when the beamline is not in use to reduce the neutron flux and allow occupancy of the vault which does not contain the beam. The laboratory's neutron plugs are constructed of a wedge-shaped block of steel which is pushed by a pneumatic piston into the beamline. They are massive (several hundred pounds) and are built into the wall. They contain no cooling water and are not designed to withstand the primary beam. The beam must not be allowed to strike a closed neutron plug. If it does, a higher than normal neutron flux may be produced on the opposite side of the wall.

Finally, a set of yellow chains have been strategically placed throughout cyclotron work area. These chains also act as an interlock mechanism and have a twofold purpose. First, before the cyclotron can be made operational, all yellow chains must be fastened (secured) in a certain sequence which requires a physical inspection of all work areas in and about the K-500 and K-50 vaults. This is to assure that all areas are vacated before the beam is turned on. Secondly, the yellow, interlock chains act as a barrier keeping workers out of the main radiation areas. If any of these chains are unfastened during operations, the cyclotron will be shut-off immediately. These chains are an integral part of the radiation safety interlock system and it is prohibited for anyone to bypass these interlocks.

Vault Door Procedures

1. Entering accelerator vault
   - A. Turn off cyclotron dee voltage by pressing the "RF DC STOP" button on the console.
   - B. Open shield door for K-500 vault.
   - C. Enter with ion chamber survey meter and determine safe working time.
2. Closing accelerator vault
   - A. Sequentially secure all yellow chains and inspect vault for other people and be sure all are out before proceeding.
   - B. Close shield door.
3. Entering experimental vault
   - A. Insert beam stop
   - B. Close neutron plug.
   - C. Open shield door.
   - D. Enter vault with ion chamber survey meter.
4. Closing experimental vault - same as for accelerator vaults except that there are no yellow chains in the experimental areas.

The system is based upon the following assumptions:

1. If a shield door is open (i.e. not fully closed), the vault it serves can be occupied by people.
2. If a neutron plug is open, then dangerous radiation may pass through the plug.

The primary interlock condition is expressed as follows: If any neutron plug is open and the shield door for the corresponding vault is open, the cyclotron is interlocked off. This is implemented by turning off the RF amplifiers which provide voltage on the dees (rather than by turning off the ion source or some other means). If the interlock condition exists in any vault, the accelerator will shut off. This interlock condition is announced to the operator by a light which reads "Shield Door".

There is a redundant, protective system based on neutron monitors located in every vault. The monitors read the neutron flux continuously and produce an interlock signal if the flux is higher than a set threshold corresponding to five millirems per hour. If this signal appears from any vault with an open door, the cyclotron is interlocked off in the same way as described above. The interlock is announced to the operator by an indicator light which reads "Neutron Monitor".

This interlock system insures that people are excluded from any vault which contains the primary beam. Shield doors can be closed only by local controls designed so that the operator must be standing just outside the door holding a switch during most of the door closing operation. Before starting to close a door, the person is required to enter the vault and determine that no one is inside before closing the door. When the door begins to close, a siren and light system are automatically activated to give audible and visual warning for 20 seconds inside the vault. There is, in addition, an emergency switch inside every vault (bright red in color) which opens the shield door, shuts off the cyclotron, sounds a buzzer, and turns on a light in the control room indicating that this safety switch has been activated. The operator must then go to the shield door to reset the switch before the cyclotron can be restarted. All personnel who may work in the vaults should be familiar with the operation of the protective interlock system described above.

Warning Devices

In addition to interlocks to prevent inadvertent entry into hazardous areas during cyclotron operation, warning devices are utilized to inform people of the machine status. Lights, signs, and audible devices are used.

Status Indicators

The presence of a magnetic field in the K-500 or K-800 magnet is detected by a magnetic switch in the magnet yoke which turns on at a low magnetic field level, corresponding to approximately 300 amperes in the main coils. This activates a rotating red light just outside the K-500 door. This light indicates that stray magnetic fields large enough to pull on magnetic objects outside the yoke may be present. It is a good idea to remove any magnetic-type credit or bank cards along with your wristwatch before entering the vault when the magnet is on.

Status indicators for the radio-frequency system and other accelerator components are located in the control room. Additional remote indicators will be provided when necessary for safety reasons.

Maximum Permissible Contamination on Exposed Surfaces

In general, radioactive contamination is not permitted on exposed surfaces such as benchtops and floors. If any is found on such a surface, it must be removed as quickly as possible. Smear the suspected surface and count the wipe on a G-M pancake probe and NaI scintillator. If it is found that the radioactivity is removable, initiate decontamination procedures when the following limits have been exceeded:

1. Alpha Contamination: 220dpm/100 cm^2.
2. High Energy Beta or Gamma Emitters: 2200dpm/100 cm^2.
3. Low Energy Beta or Gamma Emitters: 22,000dpm/100 cm^2.

* dpm = disintegrations per minute.

The above contamination standards also apply to tools, clothing, and equipment. Skin contamination should not exceed 10% of the levels reported above.

Equipment

Equipment such as glass-ware, tools, etc., used while working with radioactive materials should be kept separate from other equipment until decontaminated. Once this equipment is used with radioactive materials, it should not be used for other work nor sent out for repair until it is decontaminated. It is strongly recommended that a marked storage cabinet be provided for glass-ware, tools, etc., used in radioactive work.

Ventillation hoods used in conjunction with radioactive materials should have a flow rate greater than or equal to 100 linear feet per minute.

All work with long-lived isotopes should be done, whenever possible, over surfaces made of stainless steel, glass, or tile which can be decontaminated easily. Other surfaces should be protected by trays, heavy absorbent paper, or other easily removable material.

Vacuum Pump Exhaust

Exhaust from accelerator vacuum pumps may contain toxic, explosive, flammable, or radioactive gases. The radioactive gases may be absorbed in the vacuum system as the result of leakage from targets or from target failure.

Vacuum System Maintenance

Maintenance of vacuum systems and vacuum system components may be hazardous. The vacuum system, as well as pumps and pump oils, may become contaminated with radioactive materials. These radioactive materials may originate from targets that have been vaporized or burst during bombardment with the primary beam.

Therefore, vacuum pumps should be checked for radioactivity before they are repaired or disassembled. Special precautions should be followed when opening a vacuum system for decontamination or service, as material may be knocked loose or become airborne. The contaminated parts to be serviced should be removed in plastic bags. All service work or repairs on components should be performed in hoods or well ventillated areas. If needed, call the

Radiation Safety Officer, Reg Ronningen, or Health Physicist, Rich Lassin for assistance.

Movement of Radioactive Material from Controlled Areas

Workers must take care to avoid contaminating apparatus and the building with radioactive material. The following precautions are essential: 1.) All objects, except thin targets, removed from a target chamber or beam vacuum system must be checked for removable radioactivity. If necessary, the object should be decontaminated or sealed before further handling. 2.) Experimenters who need to move radioactive targets from the shielded vaults to the laboratory areas of the building must first discuss the procedures with the laboratory Radiation Safety Officer, Reg Ronningen. Also, no radioactive material is to leave the building without permission from either the Radiation Safety Officer or laboratory Health Physicist.

Surfaces inside the vacuum chamber are often found to carry radionuclides which have migrated from a source some distance away, and these radioactive materials are readily transferred to skin or anything else that touches the surface. Such removable activity has potential to become an internal radiation hazard and so is more of a serious health threat than the same amount of non-removable activity. The correct procedure to detect removable radioactivity is to wipe the surface with a tissue and count the sample with a G-M, NaI,or alpha particle counter. A counting rate above background indicates that removable contamination is present. If this is the case, the affected surfaces can often be wiped free of contamination before further work is done. Be sure to dispose of the radioactive wipes and tissues in the designated radioactive waste containers that are placed throughout the facility (see the Radiation Safety Officer if you need assistance).

"Sealed" radioactive sources may be taken from areas designated as controlled radiation areas for temporary use provided the following requirements are met:

1. The source container is free of removable contamination.
2. Radiation from the container is less than two mRem/hour at one meter from the center of the container and less than 20 mRem/hour at the surface.
3. The user signs out the source by filling in the source sign-out record.
4. All such encapsulated sources are tested for leaks by the Office of Radiation, Chemical and Biological Safety every six-months (alpha emitters every three months) providing that the activity is 100 microcuries or more for beta and/or gamma emitting material and 10 microcuries or more for alpha emitting material. If you find your source to be broken or leaking, do not use it and notify the RSO or HP.
5. No sources are to leave the building without permission.

Machining Radioactive Materials

When a radioactive part is sent to the machine shop or welding area, it is the responsibility of the sender to check the part for radioactivity. If the part is found to be radioactive, it must be tagged as such and the activity and type of radiation should be noted. Machining of these parts should be done in a well-ventillated area and in such a manner as to minimize radioactive contamination of the tools, building, and worker.

Protective gloves, coveralls, and breathing apparatus may be required in certain instances. Notify the Radiation Safety Officer or Health Physicist of your plans in advance so that precautionary measures can be taken if necessary. If you have any questions about this or if you are not sure whether or not the parts you are working on are radioactive, call the above mentioned people (Reg Ronningen or Rich Lassin).

Storage of Radioactive Material

1. Sealed sources are kept in the hallway just outside the south entrance to the K-50 vault. There is a sign-out procedure required when you use one of these sources.
2. Very radioactive parts and large sources (neutron source) are kept in a cave just west of the K-50 cyclotron, near the helium liquifier.
3. Thin targets are kept in various storage areas (in vacuum or in air) in the target lab.
4. The Th-228 source for making alpha sources from radon, which eminates from the thorium, is kept in the collector box inside the ventillation hood in room 126.

Radiation at the surface of containers of any radioactive material should not exceed 20mR/hour, and the container should be kept in such a place that the radiation intensity at the nearest occupied area is 2mR/hour or less. Such containers should be kept in a place not readily accessible to unauthorized personnel when not in use and should be conspicuously labeled with radiation caution signs.

Radioactive gases or materials with radioactive gaseous daughters must be stored in gas-type containers and must be kept in areas with satisfactory ventillation, preferrably in approved ventillation hoods.

Shielded storage areas or storage containers should be provided for bombarded targets and other radioactive items. It may be desirable to store small, radioactive components from the cyclotron (i.e. beam slicers) in order to lower the background radiation levels during maintenance operations on the accelerator. Any nuts, bolts, and other small objects, removed during maintenance operations on the cyclotron, should be placed in marked containers. These objects may be reused providing that the level of induced radioactivity is not hazardous. Any radioactive components, which must be left exposed should be clearly labeled to indicate the severity of the hazard.

All containers that hold radioactive materials, should be clearly labeled. If the containers are used for storage or waste disposal, the label should state the isotope, activity (in mCi), and date the activity was measured. If the nuclides are unknown as is the case with induced radioactivity, the label should state that the exact radionuclides are unknown (e.g. "Activated Parts") and make a best approximation of gross activity (i.e. gross beta = 1.5 mCi; gross gamma = .001 mCi). Here, an efficiency will need to be assigned to the counter you are using in order to translate gross counts into activity (disintegrations). G-M counters have approximately a 10% efficiency for beta radiation and an approximate efficiency of 1% for gamma rays. G-M counters will not detect alpha particles. The NaI detector has about a 10% efficiency for gamma rays. The NaI detector will not detect beta or alpha radiations. Remember, that the disintegrations per minute = counts per minute/efficiency. This method will give a rough approximation of the true activity of your radioactive part.

Disposal of Radioactive Waste

All radioactive waste shall be disposed of separately from non-radioactive waste in special containers. Do not put radioactive liquids down drains.

1. Solid Waste Containers: The inner container is a plastic-lined, yellow cardboard box (supplied by ORCBS) which is kept inside a 48 gallon galvanized-steel trash can with lid. A 55 gallon drum with a plastic-lined cardboard box has been placed in the machine shop, North and South vaults, and K-50 vault in order to accomodate large or heavy radioactive waste. The smaller, galvanized-steel containers are located in the K-500 vault, the ion source rebuilding room, and the hot lab (Rm. 126). If additional containers are needed or if a container is full and needs to be emptied, call the laboratory's Health Physicist, Rich Lassin or ORCBS (355-0153).
2. Liquid Waste Containers: The lab does not normally need liquid radioactive waste containers. When one is needed the ORCBS will provide a five gallon carboy, which must be placed in a large plastic dishpan as a secondary protective container.
3. Waste Tag: Each container will be supplied with a yellow waste identification tag. The blanks must be filled in to identify the material in the waste container. Please write on the card the information for waste that you add. The term "mixed -" may be used to describe low-level radioactivity where the isotopes present are now known. Note that this is appropriate only if the waste does not emit alpha particles. Check with the alpha probe if in doubt.
4. Alpha-Emitters: These should be disposed of separately from other radioactive waste. Obtain a separate container and waste tag from ORCBS.
5. Personnel Safety: Labeling radioactive materials and areas for their use provides identification for the researcher and protects maintenance personnel from accidental exposure to radioactivity. As a laboratory member you are obligated to properly use, store and label all radioactive materials under your control. Labeling should include isotope, amount (in millicuries), and the date.

Approval to Obtain and Use Radionuclides

Requisitions for radioactive material must be initially approved by the MSU Radioisotope Committee. See Rich Lassin or call ORCBS (355-0153) in order to initiate this process. This committee's purpose is to assure that sources which require special handling procedures are treated properly and that essential records are sent to the university Office of Radiation, Chemical and Biological Safety, as required by government regulations.

This review will normally cause negligible delay for low-level sources similar to those already in our source inventory when used in normal ways. The intended usage of the radioactive material ordered must be written on the requisition form. Any special details about the use should be communicated to R. Lassin or R. Ronningen.

Projects involving quantities of radioactive material or procedures which imply a risk of significant radiation exposures will be reviewed by the Radiation Safety Officer, Office of Radiation, Chemical and Biological Safety. If warranted by the circumstances, the experimenter will be asked to apply to the MSU Radioisotopes Committee for review of the project before the source is approved for use.

Visiting users wishing to bring radioactive materials to the laboratory must request approval in writing from the ORCBS as indicated above.

Transfer of Radioactive Material

On-campus transfer of material between investigators on different projects shall be reported to the Office of Radiation, Chemical and Biological Safety (ORCBS) prior to transfer.

Shipment of any radioactive material off the MSU campus must have the prior consent and approval of the Office of Radiation, Chemical, and Biological Safety. Federal and state laws require that the shipper must obtain, through the MSU Office of Radiation, Chemical, and Biological Safety, the recipient's Nuclear Regulatory Commission or state license number prior to shipment of the material.

"By-product material" means any radioactive material yielded in or made radioactive by the exposure to special, nuclear (fissionable) material. All radioactive shipments, including cyclotron produced material, must be checked by the laboratory's Radiation Safety Officer or Health Physicist for compliance with Nuclear Regulatory Commission and state regulations covering the receipt and transfer of radioactive material. Visiting users must comply with all MSU radiation policies and procedures as stated above.

Procedures for Opening Radioactive Shipments

All packages containing radioactive materials must be inspected by the laboratory's Radiation Safety Officer or Health Physicist before they can be delivered to the user. If these people are not available when a radioactive shipment arrives, place the parcel in a safe and secure location until it can be properly nnspected. Do not attempt to open the parcel yourself.

Responsibilties

Operators and experimenters are directly responsible for compliance with all regulations governing radiation safety in the laboratory and for safe practices by other investigators or technicians who work under their supervision. They have the obligation to:

(1) Insure that individuals working under their control are properly supervised and have obtained the training required to enable safe working habits and the prevention of exposure to others or contamination of the surroundings. Inadequate supervision and lack of training have been cited in radiation lawsuits as indicative of negligence.

(2) Be aware of the known radiation hazards inherent in a proposed activity. If these hazards are not covered by the general program of laboratory safety, they are responsible for instructing personnel in safe practices or in directing personnel to sources of information concerning safe practices.

(3) Be aware of the various forms of radiation which are produced by the accelerator's operation and the known source of these radiations.

(4) Avoid any unnecessary exposure, either to themselves or to others working under them.

(5) Understand the risks associated with the possession, use, and shipment of all radioactive materials. Because federal and state regulations control the use and shipping of radioactive materials and other certain chemicals, they must be aware of these laws and comply with them. If you are not sure of the proper procedures, see the RSO or HP.

(6) Keep current working records of the receipt and disposition of radioactive material in their possession including use in research, waste disposal, transfer, storage, etc.

(7) Post warnings and restrict entry to areas that contain potentially hazardous radioactivity or chemicals.

(8) Notify the laboratory Radiation Safety Officer, Reg Ronnigen, or Health Physicist, Rich Lassin, of any personnel changes or changes of areas in which radioactive materials may be used or stored.

Some General Rules

1. Do not eat, drink, or smoke in radiation areas. "Eating" includes gum, candy, and beverages.
2. Refrigerators must not be used jointly for foods and radioactive materials.
3. Gloves should be worn during operations in which contamination of the hands is possible.
4. Do not pipette radioactive liquids by mouth.
5. Store and transport radioactive materials in such a manner as to prevent breakage or spillage.
6. Use ventillation hoods or glove boxes if the radioactivity can become airborne.
7. The individual(s) responsible for any contamination will be required to decontaminate the area of concern under the supervision of the laboratory's RSO or HP.
8. Regularly check your hands, clothing and shoes for contamination.
9. Always dispose of radioactive waste in a radioactive waste container.
10. Always wear your assigned film badge.
11. Women must receive a copy of the NRC Guide 8.13 (prenatal radiation exposure).

Radiological Health Emergency

The term "radiologic health emergency" applies to any incident pursuant to the use of radioactive substances that might produce radiation overexposure to individuals or cause contamination of personnel or areas.

The university's Radiation Safety Officer, Warren Malchman, should be notified of any radiologic health emergency along with the laboratory's Radiation Safety Officer, Reg Ronningen, and Health Physicist, Rich Lassin. During non-work hours, call the Department of Public Safety (5-2221) in the event of such emergencies.

Procedures in the Event of Accident or Suspected Hazard

Restrict entry to emergency personnel only. Call DPS (5-2221) if there is a potential for fire or explosion. Notify the laboratory RSO or HP of the problem.

Minor Spills

A. Confine spill
B. For liquid spills, use gloves and add absorbent papar onto the spill.
C. For dry spills, use protective gloves and thoroughly dampen area making sure not to spread contamination.
D. Notify laboratory RSO or HP.
E. RSO or HP will authorize resumption of work upon adequate decontamination procedures.

Major Spills

A. Everyone not involved vacate the area immediately.
B. If one's skin is contaminated, flush thoroughly with water.
C. Remove clothing if contaminated.
D. Switch off fans.
E. Prohibit access to contaminated area.
F. Notify Reg Ronningen or Rich Lassin (page). If neither can be contacted call ORCBS (355-0153). After hours, call DPS (5-2221).
G. Only trained personnel will be allowed to examine and/or clean up the contaminated area.
H. Resume work only after approval from those mentioned in item "F".

The individual responsible for the incident will be expected to do most of the clean up under the supervision of RSO and HP. If required, ORCBS will provide decontamination equipment and assistance. Additional questions that might arise should be directed to the ORCBS (355-0153).

Location of Monitoring Equipment

The following portable monitors are available for use by all employees. This equipment is located in the hallway outside Rm 142 just south of the control room. If you have any questions about using this equipment, see Reg Ronningen or Rich Lassin.

A. Four G-M counters (pancake-shaped probe). Use this for checking contamination.
B. One alpha particle probe (long rectangular probe). Use this with the corresponding Ludlum box. Determines alpha contamination. Does not detect beta particles, X-rays, or gamma rays with high efficiency
C. Four Victoreen ion chambers. Use this in order to estimate the dose (rough approximation of dose due to gamma rays)
D. One neutron-flux meter (Nuclear Chicago model 2673). Use this to determine neutron flux only. (10 neutrons/sq.cm/sec)=2.5mR/hour Does not detect alpha, beta, gamma or X-rays.
E. One low-energy X-ray pocket dosimeter (ion chamber).
F. Two gamma-ray pocket dosimeters (ion chamber).
G. One thermal-neutron pocket dosimeter.
H. Two dosimeter chargers.
I. One 2"X2" NaI high-energy detector (long tube without pistol grip). This is good for measuring gamma radiation. This probe will not detect beta or alpha particles.

These detectors are calibrated regularly, and this data are kept in Rm. 123. If you need further information, see Rich Lassin.

Conclusions

Radiation surveys are conducted regularly throughout the facility. Those areas that store, use or produce radiation are examined about once a week. These surveys examine contamination levels and exposure rates and are available for viewing in Rm 123 during regular working hours. Neutron surveys and calibration data on laboratory equipment are also kept in this room. If a radiation hazard is found to occur, an announcement will be made over the intercom and/or a notice will be placed on the bulletin board. If you have any questions about your work area, see Rich Lassin in Rm 123.

The laboratory is undergoing many new changes. Therefore, this manual will be updated periodically. It is required that all employees (students and staff) read this manual as a condition to employment and sign a statement that they have done so. Also, it has been tentatively agreed upon that at least once a year all employees will be instructed in radiation and laboratory safety. Lectures, discussions on hazards, and use of monitoring equipment will be covered. Notices will be posted when these lectures are scheduled. If you have any questions regarding the material presented in this manual, see Reg Ronningen or Rich Lassin.