Colorado State University

rco
RADIATION CONTROL OFFICE
ENVIRONMENTAL HEALTH SERVICES

Radiation Control Office

Radiation Safety Training

Module 7 - Irradiators

OUTLINE

- PERTINENT RULES AND REGULATIONS
- CASE HISTORIES
- CSU IRRADIATORS AND ACCELERATORS
- OTHER IRRADIATORS AND ACCELERATORS

RECORDS

Survey and calibration reports

- Retained for 3 years

Surveys to determine the dose from external sources to assess individual dose equivalents

- Retained until termination of each pertinent license or registration

Testing of entry control devices for very high radiation areas

- Must include the date, time, and results of each such test of function
- Retained for 3 years

Records of tests for leakage or contamination of sealed sources

- Shall be kept in units of microcurie(s)
- Retained for 5 years

TESTING FOR LEAKAGE OR CONTAMINATION OF SEALED SOURCES

Sealed sources not in storage

- Shall be leak tested every 6 months
- Shall be tested when damage is suspected
- Alpha sealed sources shall be leak tested every 3 months

Determination of Leakage

- Contamination in excess of 185 Bq (0.005 millicuries)
- Contamination in excess of 185 Bq resulting from the decay of radium

The RCO performs all sealed source leak tests.

Leaking source(s)

- Shall immediately be withdrawn from use
- Action will be taken to prevent the spread of contamination
- The leaking sealed source shall be repaired or disposed of

ENTRANCE AND ACCESS TO HIGH RADIATION AREAS

- One or more of the following is required:
  - A device, upon entry, reduces the deep dose equivalent to 0.1 rem or less in 1 hour at 30 centimeters (1 foot) from the source
  - A device that energizes a visible or audible alarm signal alerting the individual entering the area and the supervisor of the activity
  - Entryways that are locked, except during periods when access to the areas is required, with positive control over each individual entry.
  - Continuous direct or electronic surveillance may be used if it prevents unauthorized entry
  - Can apply for alternative measures
- While open prevents operation of the source
- Controls cannot prevent individuals from leaving the area
- Not required:
  - Areas with packages that will be shipped within 3 days
  - Areas with patients containing radioactive material
- Parts 5, 6 or 9 requirements meet these requirements

ENTRANCE AND ACCESS TO HIGH RADIATION AREAS

- 100 mrem (1 mSv) in 1 hour at 30 centimeters
- A sign bearing the radiation symbol and the words “CAUTION (OR DANGER) RADIOACTIVE MATERIAL”

CONTROL OF ACCESS TO VERY HIGH RADIATION AREAS

- 500 rem (5 Gy) in 1 hour at 1 meter
- Authorized access only
  - **Does not apply to:**
    - Diagnostic X-Ray Units
    - Self-shielded irradiators
- Parts 5, 6 or 9 requirements meet these requirements

CONTROL OF ACCESS TO VERY HIGH RADIATION AREAS (IRRADIATORS)

- **Applies to Non-self-shielded Irradiators**
  - **Does not apply to:**
    - Teletherapy
    - Industrial Radiography
    - Self-shielded irradiators
- **Entrance Devices**
  - **Automatically prevent inadvertent entry**
  - **Deliberate entry only after reducing radiation levels below 1 mSv (0.1 rem)/hr**
  - **Prevent operation when open**
  - **Additional Required Devices:**
    - **Secondary device to reduce radiation levels below 1 mSv (0.1 rem)/hr if primary fails**
    - **Visible and audible alarms alerting the individual and another authorized individual that is:**
      - **Physically present**
      - **Familiar with the activity**
      - **Prepared to render or summon assistance**

CONTROL OF ACCESS TO VERY HIGH RADIATION AREAS (IRRADIATORS)

- **Liquid Shield**
  - **Integrity Must be Monitored**
  - **Signal if Not Adequate**
- **Visible and Audible Alarms**
  - **Comes on Before Operation**
  - **Allows Time to Evacuate Area**
  - **Labeled Emergency Stop Switch in Area to Prevent Operation of Source**
- **Procedures to Assure No Personnel in Area Before Operation**
  - **Administrative**
  - **Devices**
- **Required Measurements**
  - **Below 0.1 rem/h Before Entry**
- **Testing of Entry Control Devices**
  - **Prior to Operation if Not Continued From Previous Day**
  - **Prior to Resumption of Operation After Unintentional Interruption**
  - **Submitted Schedule for Periodic Tests**
  - **Operations Not Allowed if Not Functioning**

CONTROL OF ACCESS TO VERY HIGH RADIATION AREAS (IRRADIATORS)

- **Control Devices Cannot Prevent Individuals From Leaving Area**
- **Entry and Exit Portals (Not Intended for Individuals)**
  - **Warn Against Inadvertent Entry**
  - **Exit Portals Must Detect and Signal the Presence of Loose Radioactive Material**
- **Use in a Variety of Position or Location (Fields, Outside)**
  - **May Apply for Alternative Measures not Feasible**
    - **Application Must Provide**
      - **Personnel Protection Equivalent to Requirements**
      - **Must Include Entry Preventing Interlock Control Ensuring Absence of High Radiation Levels**

CDPHE SECTION 20 ACCELERATORS

PARTICLE ACCELERATORS AND THERAPEUTIC RADIATION MACHINES IN THE HEALING ARTS

- **Human use**
  - Only Under the Direct or General Supervision of, a Licensed Practitioner
    - Of the Healing Arts
    - Meets the Required Training
    - Meets the Required Experience
- **Veterinary Use**
  - Only Under the Direct or General Supervision of a Licensed Veterinarian.
- **Names and Training of Operators**
  - Current Operator Information Shall be Kept on file at the Facility
  - Former Operator Information Shall be Retained for a Period of at Least Two (2) Years

CDPHE SECTION 20 ACCELERATORS

- Written Safety Procedures and Rules
  - Shall be Developed by a Radiation Therapy Physicist
  - Shall be Available in the Control Area
  - Shall Include Any Restrictions for Safe Operation
  - The Operator Shall be Able to Demonstrate Familiarity With These Rules and the Procedures for Contacting the Radiation Therapy Physicist
- Operating Procedures
  - Shall Specifically Address How the Radiation Therapy Physicist is Contacted for Problems or Emergencies
  - Shall Address Specific Actions, If Any, to be Taken Until the Radiation Therapy Physicist Can be Contacted
- Exposing Individuals to the Useful Beam
  - Only for Medical Therapy Purposes
  - Only if Ordered in Writing by a Licensed Practitioner of the Healing Arts Who Meets the Required Training Requirements
  - This Provision Specifically Prohibits Deliberate Exposure of an Individual for Training, Demonstration or Other Non-Healing-Arts Purposes.

CDPHE SECTION 20 ACCELERATORS

- If Required Surveys Indicate Any Radiation Levels in Excess of the Respective Limit (RH 20.4.1.1)
  - The Registrant Shall Lock the Control in the "OFF" Position
  - Not Use the Unit
- Door Opened While the Machine Is Activated
  - The Air Kerma Rate at a Distance of One Meter From the Source Shall be Reduced to Less Than 1 mGy (100 mrad) Per Hour
- Patient Held in Position for Radiation Therapy
  - Mechanical Supporting or Restraining Devices Shall be Used
- Tube Housing Assembly
  - Shall Not Be Held by an Individual During Operation Unless
    - The Assembly is Designed to Require Such Holding
    - The Peak Tube Potential of the System Does Not Exceed 50 kV
    - The Holder Shall Wear Protective Gloves and Apron of Not Less than 0.5 Millimeters Lead Equivalency at 100 kV

CDPHE SECTION 20 ACCELERATORS

- Each Facility Location
  - Shall Possess Appropriately Calibrated Portable Monitoring Equipment
    - As a minimum
      - Shall Include a Portable Radiation Measurement Survey Instrument Capable of Measuring Dose Rates Over the Range 10 µSv (1 mrem) Per Hour to 10 mSv (1000 mrem) Per Hour
      - The Survey Instrument(s) Shall be Operable and Calibrated as Required
- Therapeutic Machines 500 kV and Above
  - Absorbed Dose Due to Leakage
    - Outside Maximum Sized Useful Beam, But Within 2 Meters
      - 0.2% or the Average of 0.1% of the Absorbed Dose on the Central Axis
    - One Meter From Electron Path
      - Not Exceed 0.5% of the Absorbed Dose on the Central Axis

RULES AND REGULATIONS CDPHE SECTION 20 ACCELERATORS

- Leakage Air Kerma Limits
  - any position **5 centimeters from the tube housing** assembly shall **not exceed 1 mGy (100 mrad) in any one hour**.
  - **>50 to <500 kV Systems**
    - at a distance of **1 meter from the target** in any direction shall **not exceed 1 cGy (1 rad) in any one hour**. In addition, the air kerma rate at a distance of **5 centimeters from the surface of the tube housing** assembly shall **not exceed 30 cGy (30 rad) per hour**.
  - escaping from the **filter slot** shall **not exceed 1 cGy (1 rad) per hour at one meter under any operating conditions**
  - When any **door** referred to in RH 20.7.15.3 **is opened** while the x-ray tube is activated, the air kerma rate at a distance of **one meter from the source** shall be reduced to **less than 1 mGy (100 mrad) per hour**.

RULES AND REGULATIONS CDPHE SECTION 19 IRRADIATORS

Part 19

- requirements for the issuance of a license
- sources containing radioactive materials in irradiators
- irradiate objects or materials using gamma radiation.
- requirements for operating irradiators.
- apply to panoramic irradiators that have either dry or wet storage
- apply to underwater irradiators in which both the source and the product being irradiated are under water
- irradiators whose dose rates exceed 5 grays (500 rads) per hour at 1 meter from the source(s) in air or in water

Do not Apply To

- self-contained dry-source-storage irradiators
- the irradiation of materials for nondestructive testing purposes
- gauging
- open-field (agricultural) irradiations

RULES AND REGULATIONS CDPHE SECTION 19 IRRADIATORS

- Must have an independent backup access control to detect personnel entry while the sources are exposed. Detection of entry while the sources are exposed must cause the sources to return to their fully shielded position and must also activate a visible and audible alarm to make the individual entering the room aware of the hazard.

- A radiation monitor must be provided to detect the presence of high radiation levels in the radiation room of a panoramic irradiator before personnel entry.

- Before the sources move from their shielded position in a panoramic irradiator, the source control must automatically activate conspicuous visible and audible alarms to alert people in the radiation room that the sources will be moved from their shielded position. The alarms must give individuals enough time to leave the room before the sources leave the shielded position.

RULES AND REGULATIONS CDPHE SECTION 19 IRRADIATORS

- Each radiation room at a panoramic irradiator must have a clearly visible and readily accessible control that would allow an individual in the room to make the sources return to their fully shielded position.

- Each entrance to the radiation room of a panoramic irradiator and each entrance to the area within the personnel access barrier of an underwater irradiator must have a sign bearing the radiation symbol and the words, "CAUTION (OR DANGER) RADIOACTIVE MATERIAL". Panoramic irradiators must also have a sign stating "GRAVE DANGER, VERY HIGH RADIATION AREA", but the sign may be removed, covered, or otherwise made inoperative when the sources are fully shielded.

RULES AND REGULATIONS CDPHE SECTION 19 IRRADIATORS

- The radiation dose rate in areas that are normally occupied during operation of a panoramic irradiator may not exceed 0.02 millisievert (2 millirem) per hour at any location 30 centimeters or more from the wall of the room when the sources are exposed.

- The radiation dose rate at 1 meter from the shield of a dry-source-storage panoramic irradiator when the source is shielded may not exceed 0.02 millisievert (2 millirem) per hour and at 5 centimeters from the shield may not exceed 0.2 millisievert (20 millirem) per hour.

RULES AND REGULATIONS CDPHE SECTION 19 IRRADIATORS

- The mechanism that moves the sources of a panoramic irradiator must require a key to actuate. Actuation of the mechanism must cause an audible signal to indicate that the sources are leaving the shielded position. Only one key may be used at any time, and only one operator or facility management may possess it. The key must be attached to a portable radiation survey meter by a chain or cable. The lock for source control must be designed so that the key may not be removed if the sources are in an unshielded position. The door to the radiation room must require the same key.

RULES AND REGULATIONS CDPHE SECTION 19 IRRADIATORS

- If electrical power at a panoramic irradiator is lost for longer than 10 seconds, the sources must automatically return to the shielded position.

- The lock on the door of the radiation room of a panoramic irradiator may not be deactivated by a power failure.

- During a power failure, the area of any irradiator where sources are located may be entered only when using an operable and calibrated radiation survey meter.

RULES AND REGULATIONS CDPHE SECTION 19 IRRADIATORS

Training

Before an individual is permitted to operate an irradiator without a supervisor present, the individual must be instructed in:

1). The fundamentals of radiation protection applied to irradiators (including the differences between external radiation and radioactive contamination, units of radiation dose, Department dose limits, why large radiation doses must be avoided,

2). The requirements of Parts 4, 10 and 19 of these regulations that are relevant to the irradiator;

RULES AND REGULATIONS CDPHE SECTION 19 IRRADIATORS

3). The operation of the irradiator;

4). Those operating and emergency procedures listed in RH 19.19 that the individual is responsible for performing; and

5). Case histories of accidents or problems involving irradiators.

6). Shall pass a written test on the instruction received consisting primarily of questions based on the licensee's operating and emergency procedures that the individual is responsible for performing and other operations necessary to safely operate the irradiator without supervision. Items 1-5 above.

7). Must have received on-the-job training or simulator training in the use of the irradiator as described in the license application. The individual shall also demonstrate the ability to perform those portions of the operating procedures that he or she is to perform.

RULES AND REGULATIONS CDPHE SECTION 19 IRRADIATORS

The licensee shall have and follow written operating procedures for:

1). Operation of the irradiator or accelerator, including entering and leaving the radiation room; This also includes all emergency procedures applicable to the irradiator in question;

2). Use of personnel dosimeters;

3). Surveying the shielding of panoramic irradiators.

RULES AND REGULATIONS CDPHE SECTION 19 IRRADIATORS

- Irradiator operators shall wear either a film badge or a thermoluminescent dosimeter (TLD) while operating a panoramic irradiator. Each film badge or TLD must be assigned to and worn by only one individual. Film badges must be processed at least monthly, and TLD's must be processed at least quarterly.

- Other individuals who enter the radiation room of a panoramic irradiator shall wear a dosimeter, which may be a pocket dosimeter. For groups of visitors, only two people who enter the radiation room are required to wear dosimeters. If pocket dosimeters are used to meet the requirements of this paragraph, a check of their response to radiation must be done at least annually. Acceptable dosimeters must read within "30 percent of the true radiation dose.

RULES AND REGULATIONS CDPHE SECTION 19 IRRADIATORS

Both an irradiator operator and at least one individual, who is trained on how to respond and prepared to promptly render or summon assistance if the access control alarm sounds, shall be present onsite:

1). Whenever the irradiator is operated using an automatic product conveyor system; and

2). Whenever the product is moved into or out of the radiation room when the irradiator is operated in a batch mode.

- Irradiation of explosive material is prohibited.

RULES AND REGULATIONS CDPHE SECTION 19 IRRADIATORS

- Upon first entering the radiation room of a panoramic irradiator after an irradiation, the irradiator operator shall use a survey meter to determine that the source has returned to its fully shielded position. The operator shall check the functioning of the survey meter with a radiation check source prior to entry.
- Before exiting from and locking the door to the radiation room of a panoramic irradiator prior to a planned irradiation, the irradiator operator shall:

  1). Visually inspect the entire radiation room to verify that no one else is in it; and

  2). Activate a control in the radiation room that permits the sources to be moved from the shielded position only if the door to the radiation room is locked within a preset time after setting the control.

CASE HISTORIES

Case 1: FATAL RADIATION DOSE AT AN IRRADIATOR FACILITY IN NORWAY

Date of Incident: September 1982

Type of Irradiator: large, dry storage conveyor belt, continuous-mode type, operating 24 hours a day, unattended at night.

Activity and Type of Sources: 64,000 Ci, ^{60}Co

Failures or Procedural Errors:

- Conveyor belt jammed at night.
- Sources failed to automatically retract into the shielded position.
- First person arriving at work in the morning found a green indicator light (sources shielded) and an unlocked door interlock. The irradiator control panel had indicators which correctly showed the cobalt-60 sources to be exposed.
- Radiation monitor normally located in the maze was out for repair. A portable radiation monitor was available to the worker, but was not used.
- Worker entered the maze and exposure room while the source was in an unshielded position.
- Worker did not provide any information to the hospital to indicate that he may have been exposed to radiation.

Consequences:

- worker became ill soon afterwards, and went to the hospital.
- worker received a fatal radiation dose.

Mechanical failures or human errors can result in serious, even fatal overexposure. Remind employees of the potential seriousness of an overexposure. Individual safety features should not be relied upon to the exclusion of other safety features. All available information related to the position of the source should be checked before entering the exposure room.

CASE HISTORIES

CASE 2: SECURITY OF CONTROLS PANELS AND MECHANISMS

NRC received a report concerning security of the control and interlock system at a large irradiator facility. The report noted that the electro-pneumatic valve control panel was located on the roof of the facility, and that this area could be reached by anyone climbing onto the roof. Thus, an unauthorized person could conceivably tamper with the electro-pneumatic controls of the irradiator, disabling safety interlocks, or even raising the source itself into an unshielded position.

Facilities should be secured against unauthorized access at all times. For small, self-shielded irradiators, the storage locations should be kept locked at all times when authorized users are not present. For large irradiators, all areas associated with irradiator operations, particularly control and interlock systems, should be locked and secured against unauthorized access. Review facilities and security programs to ensure that adequate security is being provided.

CASE HISTORIES

CASE 3: THE RADIOLOGICAL ACCIDENT AT THE STIMOS PLANT, ITALY

Date of Incident: May 1975

Type of Irradiator: large, dry storage conveyer belt system

Activity of Source: source rod (~500 TBq (13,500 Ci))

Failures or Procedural Errors:

- Source was left in an exposed position inside the irradiation cell.
- Unskilled Worker entered the irradiation cell, by sliding through the maze on the conveyer belt.
- None of the conditions outlined in the safety protocal procedures was complied with.
- The worker was unaware of the irradiation danger, since his place of work was in the seed storage area outside the irradiation plant proper; he had not received training either in radiation protection or in the operating rules.
- There was no trained console operator present.
- The entrance to the irradiation cell through this access was not meant for personnel.
- The worker had been in the irradiation cell for a short time, presumably 1-4 minutes, with his head a few centimeters from the source rod.

Consequences:

- The absorbed dose was very high, i.e. over the mean lethal dose.
- Subsequent tests carried out by researchers with thermoluminescent dosimeters (TLDs) inserted into a plastic phantom and inserted on its surface showed that the range of doses delivered to various organs were as follows: 12-24 Gy to the brain; 8-20 Gy to the internal organs; 10-16 Gy to the gonads; and 12 Gy to the bone marrow.
- The worker was immediately admitted to the local hospital for treatment of erythema, nausea and fever, and then to the Pavia Hospital (Italy) for special blood analyses.
- After a few days, he was transferred to the Institut Curie in Paris for appropriate treatment of acute irradiation syndrome.
- The worker died 13 days after the exposure.

CASE HISTORIES

CASE 4: THE RADIOLOGICAL ACCIDENT IN SAN SALVADOR, EL SALVADOR

Date of Incident: 5 February 1989

Type of Irradiator: Sterilizing unit is loaded into fibreglass boxes and sent by a conveyor system to a shielded irradiation chamber. In this chamber, the boxes are pushed and pulled by a series of pistons on two levels around a rectangular source rack that can be raised from a shielding pool.

Activity and Type of Sources: ~ 620 Ci per pencil, the upper and lower modules of the source racks each have an array of 54 pencils, 14 of which contain ^{60}Co, while the rest are inert.

CASE HISTORIES

Failures or Procedural Errors:

- A fault in the source rack being lowered automatically from the irradiation position triggered the source transit alarm.
- Source not fully shielded.
- A worker applied overpressure to the hydraulic hoist to force the source rack fully up so that it would then return to the fully down position (not recommended by the supplier).
- Worker manipulated the control system and induced the green source down light to go on.
- The radiation monitor in the irradiation chamber was removed 5 years before.
- Worker rapidly cycled buttons on control panel to simulate monitor detection of normal background levels so that the worker could open the irradiator door.
- Worker switched off power supply to the facility.
- Worker entered irradiator facility without survey instrument to check radiation levels.
- Worker tried to correct jammed box problem, then left to get help.
- Worker supplied power back to the facility.
- Worker returned with two other workers and assured them there was no danger.
- All three workers corrected the jamming problem by lifting the source rack via pulling on the hoist cable and lowering the source into the storage pool.
- The workers mentioned the source at the facility to the doctors but were diagnosed as having food poisoning and released with 3 day sick leave certificates.
- Another worker found the area in disarray, cleaned up and continued to operate the facility.
- The situation was reported to the manager by the worker, but no further action was taken.
- The source rack jammed again (within a week) and was corrected using the overpressure technique.
- The manager entered the facility to do QA and observed sources lying on the bottom of the pool. Longer exposure times were used, but no action was taken.
- Another failure occurred not allowing the sources to return to the shielded position.
- The radiation level was checked and found to be high. The overpressure technique was used again.
- The monitor showed lower levels of radiation, but these measurments were made outside of the irradiator door.
- Most of the sources fell into the storage pool, but four remained on the conveyor platform.
- Three workers entered the facility without checking radiation levels.
- The manager entered the facility to do an inspection.
- He retrieved the portable monitor and measured a dose rate above normal levels.
- None of the workers were wearing badges.

CASE HISTORIES

Consequences:

- The first worker began vomiting within leaving the irradiation facility.
- All three initial workers were taken to the hospital where all three were vomiting.
- Workers from the second exposure received doses between 90 and 220 mGy.

- The first worker returned to the emergency clinic within one week. He had nausea and was vomiting, had general erythema and burns to his legs and feet. His dose was estimated at 8.1 Gy whole body.
- Another of the workers that entered the facility during the first exposure was hospitalized and transferred to Mexico City. This worker had his leg amputated above the knee. His dose was estimated at 3.7 Gy.
- The third worker during the initial exposure had less extensive symptoms and returned to work with rehabilitation. His dose was estimated at 2.9 Gy.
- The first worker died 6.5 months later after amputation of his leg above the knee and pneumonia.

CASE HISTORIES

Case 5: THE RADIOLOGICAL ACCIDENT AT THE SOR-VAN IRRADIATION FACILITY, ISRAEL

Date of Incident: June 1990

Type of Irradiator: large water pool irradiator with a pneumatic hoist that uses pistons to push boxes through the irradiator on a conveyor

Activity and Type of Sources: 340,000 Ci, ^{60}Co

Failures or Procedural Errors:

- Transport jam of conveyor.
- The operator did not follow procedures to contact the supervisor.
- The operator decided that the source down signal on the control panel was correct and that the gamma radiation alarm was false.
- The operator entered the facility and disconnected the radiation monitor. The monitor functioning test was thus disabled.
- The operator released the second interlock by using a simulated trick. This would not have worked if the monitor had not been disconnected.
- The operator did not check the survey instrument attached to the keys to make sure it was working correctly before entering the facility. The instrument did not function on the low dose range he selected.
- Operator did not observe absence of Cerenkov radiation in the pool.
- Supervisor was contacted after exposure.
- The operator was not wearing a badge.
- Source down signal operated inadequately.
- A shroud recommended by the supplier to prevent jamming was not installed.

CASE HISTORIES

Consequences:

- Operator felt burning in eyes and a pounding sensation in head.
- Operator began to vomit.
- A second worker measured exposures of ~ 50 R/h.
- Operator estimated dose was 10-15 Gy.

- The operator died 36 days later.

CASE HISTORIES

Case 6: THE RADIOLOGICAL ACCIDENT AT THE IRRADIATION FACILITY IN NESVIZH, BELARUS

Date of Incident: October 1991

Type of Irradiator: large, dry storage sterilization overhead rail transport system operating 24 hr/day

Activity and Type of Sources: 800 kCi, ^{60}Co

Failures or Procedural Errors:

- The transport mechanism jammed.
- The operator was not wearing a badge.
- The control panel key was left in the control panel while entering the facility.
- The operator did not check to see if the sources were shielded until inside the irradiator after ~1min.
- Specified safe operating procedures were not followed and the safety features were circumvented.

Consequences:

- Operator developed an acute headache and pain in his joints and gonads and had difficulty breathing.
- A mean whole body dose of ~11Gy with localized areas up to 18Gy was estimated.
- The operator died 113 days later.

CASE HISTORIES

Case 7: LINEAR ACCELERATOR ACCIDENT, ILLINOIS, USA

Date of Incident: February 1965

Type of Irradiator: linear accelerator using a conveyor belt system

Activity and Type of Sources: 10 MeV electrons

Failures or Procedural Errors:

- The bottom of the door providing access from the service room to the accelerator room had been sawn off to accommodate the conveyor belt.
- A worker entered the accelerator room on the conveyor near the output port while in operation without tripping any interlocks.

Consequences:

- Doses of 420-2400 Gy to various parts of the right hand, 3-290 Gy to various parts of the right foot, up to 290 Gy to various parts of the right leg, 2.45-3.25 Gy to the skin on the right side of the body and 0.002-0.05 Gy to the interior of the body were incurred.
- Serious radiation burns developed on the right hand and wrist as well as on the right leg. The right arm was amputated above the elbow 138 days later and the right leg was amputated just above the knee 6 months later.

CASE HISTORIES

Case 8: ACCELERATOR ACCIDENT, MARYLAND, USA

Date of Incident: December 1991

Type of Irradiator: accelerator to irradiate materials in carts using a chain drive system

Activity and Type of Sources: Maximum of 3 MV, 25 mA

CASE HISTORIES

Failures or Procedural Errors:

- Maintenance was performed to replace a plate. After maintenance the facility was operated to test the maintenance work. A worker entered the facility to check the assembly while the electron source was turned off. The accelerator potential, however was left on the high voltage terminal.
- The console meter read 0.090 mA which included a normal baseline reading of 0.040 mA. This indicated that there was approximately 50 mA of cold current.

The beam scanning electromagnet was still energized, since it is interlocked with the high voltage on the accelerator and is on whenever there is voltage in the machine.

- Flashing warning signals were ignored because it was common knowledge at the facility that these signals were connected to high voltage, not to a radiation detection device, as required.
- A chainlink entrance gate was unlocked and the padlock was removed previous to the accident.
- Two interlock photoelectric cell interlock systems, one at the entrance gate and one at the exit gate were not operable.
- An on/off switch had been installed on the first interlock without notification or permission of the regulatory authority and was turned off, intentionally bypassing a critical safety system.
- A pressure mat interlock system had been removed without approval.
- The operator deliberately passed beneath an interlock 1.22 m above the floor in the labyrinth.
- The operator felt the window for heat and placed his head at an oblique angle to the beam to inspect the window.
- The operator believed that there would be no radiation beam when the current was off.
- The operator thought he could save time by leaving the potential on so he could carry out further tests.

Consequences:

- The operator had been exposed to dark current.
- Three months after the accident the four digits of the right hand and most of the four digits of the left hand were amputated.

CASE HISTORIES

Case 9: ELECTRON ACCELERATOR ACCIDENT IN HANOI, VIET NAM

Date of Incident: November 1992

Type of Irradiator: Electron Accelerator

Activity and Type of Sources: 15 Mev

Failures or Procedural Errors:

- Cable and ventilation ducts were not angled.
- Inadequate roof and maze door shielding.
- No commissioning survey of the facility was done.
- No routine dose monitoring was done outside the accelerator.
- No appropriately calibrated monitoring equipment.
- No video monitoring system was installed in the facility.
- The control panel had no key switch, timer or dose control cut-out.
- There were no operational safety control devices to prevent entry when the facility was on.
- There was no audible or visual alarms installed.
- A physicist entered the facility while it was on to manipulate a sample.
- The physicist did not inform anyone of the accident or seek medical attention until 24 days after the accident.

Consequences:

•The right hand and two fingers of the left hand were amputated.

CASE HISTORIES

Case 10: LEAKAGE OF AN IRRADIATOR SOURCE – THE JUNE 1988 GEORGIA RSI INCIDENT

Date of Incident: June 1988

Type of Irradiator: Sterilization unit using a conveyor system

Activity and Type of Sources: 12.3 MCi, ^{137}Cs

Failures or Procedural Errors:

- The use of the capsules in a wet load, wet storage, dry irradiator mode of commercial irradiator operation was never envisioned during encapsulation.
- Capsules that were partially filled and later topped off potentially creating an internal pressure condition.
- Testing of the sources may have been inadequate.

Consequences:

- Elevated levels of ^{137}Cs chloride was dissolved in the pool from leaking sources.
- One employee had measurable contamination in his private automobile.
- Two other people had contamination on their residence carpets and articles of clothing.
- Several pinpoint contamination areas were found on the exterior surfaces of several shipping containers.
- The facility had several areas with contamination

CASE HISTORIES

Case 11: CHECHENIAN THEFT OF COBOLT-60

Date of Incident: Early 1999

Type of Irradiator: Unknown

Activity and Type of Sources: ?, Co-60 rods

Failures or Procedural Errors:

- Non secure rod sources resulting in three thieves stealing the rod sources.

Consequences:

- All three thieves died.
- Three others hospitalized.
- Grave concern about other unknown individuals that may have been affected.

CASE HISTORIES

Case 12: BANGKOK THAILAND COBOLT-60 SOURCE BROKEN OPEN AT SCRAP YARD

Date of Incident: Week of 14 Feb 2000

Type of Irradiator: Cobolt Bomb

Activity and Type of Sources: 600-700 Ci, Co-60 cylinder

Failures or Procedural Errors:

•Non secure sources resulting in a scrap collector getting possession of the source.

Consequences:

- Approximately 10 individuals admitted to hospital.
- Five workers at the scrap yard were hospitalized over a weekend.
- Four waste collectors who removed the cylinder were placed in intensive care.
- Victims had sharp drops in their white blood-cell counts, blisters, skin burns and hair loss.

CASE HISTORIES

Case 13: MOSCOW RUSSIA INCIDENT

Date of Incident: 11/27/93

Type of Irradiator: Unknown

Activity and Type of Sources: 20 R/hr source

Failures or Procedural Errors:

- Non secure sources.

Consequences:

- General Director of a joint stock company was murdered when the source was placed under his chair.

CASE HISTORIES

Case 14: BOGATA COLUMBIA THEFT

Date of Incident: 7/15/98

Type of Irradiator: Unknown

Activity and Type of Sources: 30 Ci, Iridium

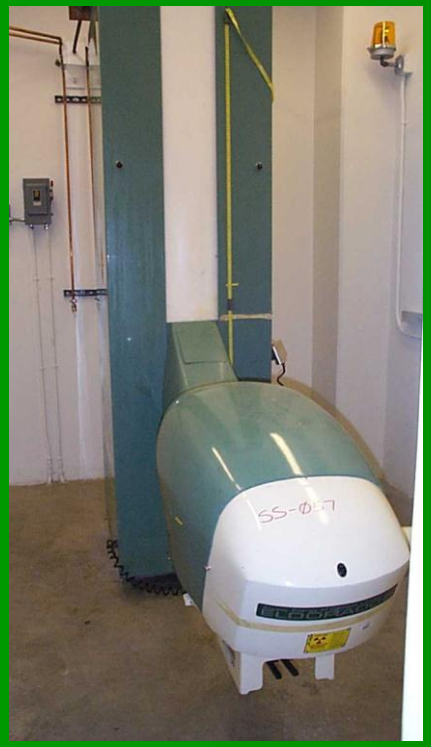
Failures or Procedural Errors:

•Unsecured material.

Consequences:

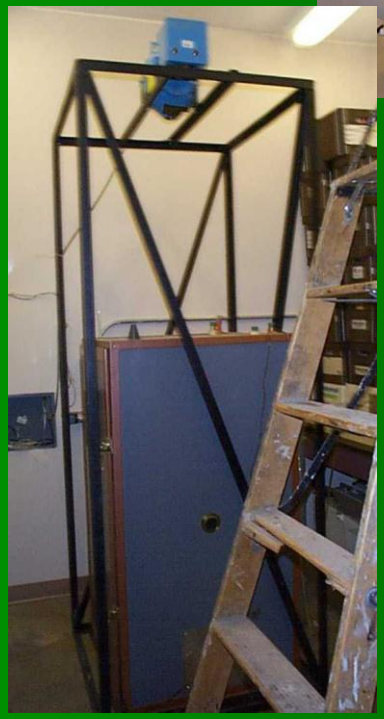
- A truck carrying the material was hijacked.
- Driver and technical assistant drugged.
- The material has not been recovered.

CSU IRRADIATORS AND ACCELERATORS



Co-60 Nominal
6,000 Ci
MRB Room 002

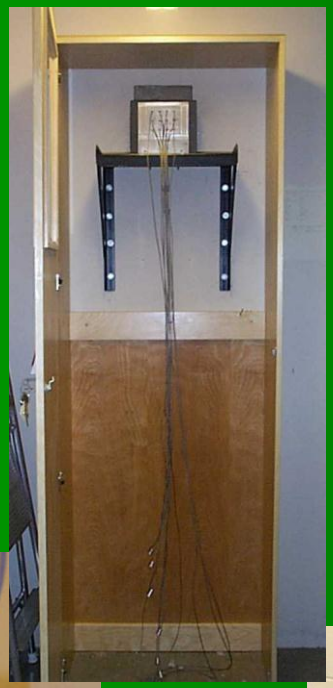
Cs-137 Nominal
600 Ci
MRB Room 006



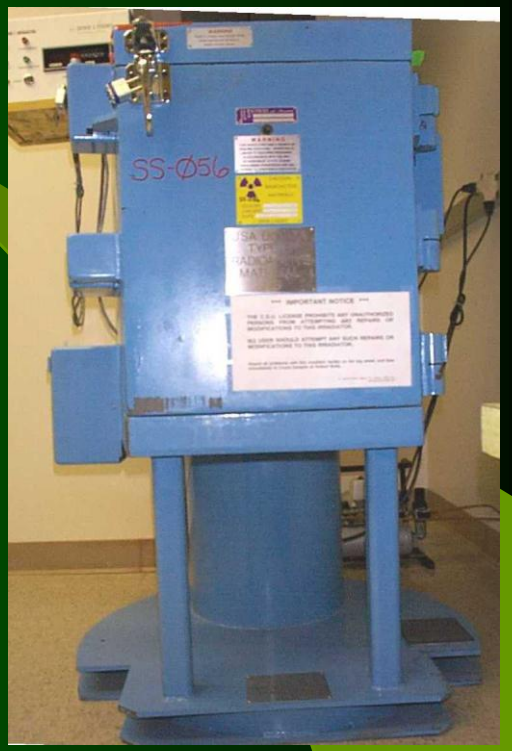
Cs-137 Nominal
6,000 Ci
MRB Room 004

Cs-137 Nominal
30 Ci
MRB Room 008

CSU IRRADIATORS AND ACCELERATORS



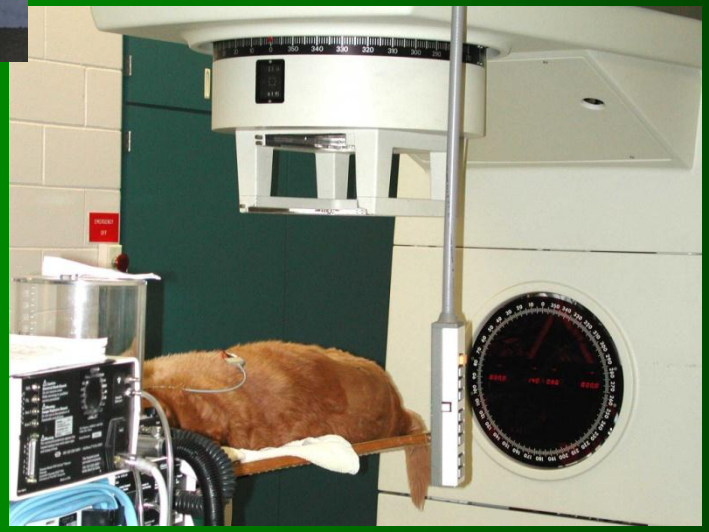
Cs-137 Nominal
12, 4 Ci Sources
MRB Room 10/12



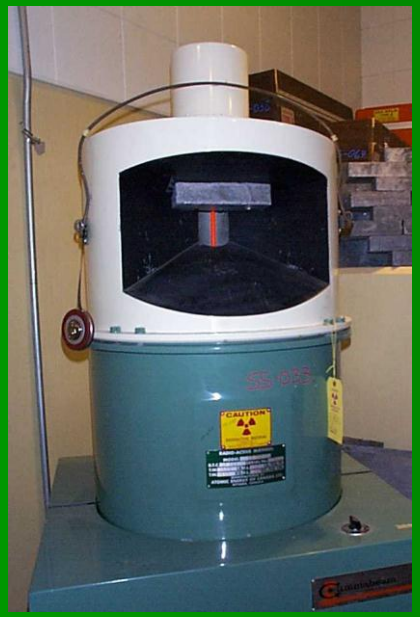
Cs-137 Nominal
6,000 Ci
MRB Room 470

Cs-137
Nominal 1.2 Ci
MRB Room
007

VTH Linear
Accelerator

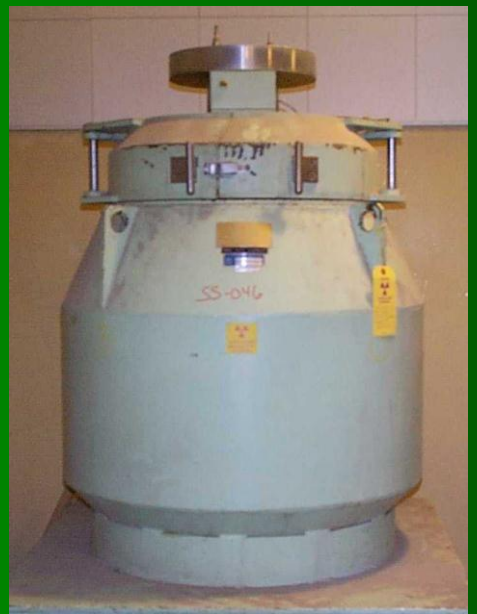


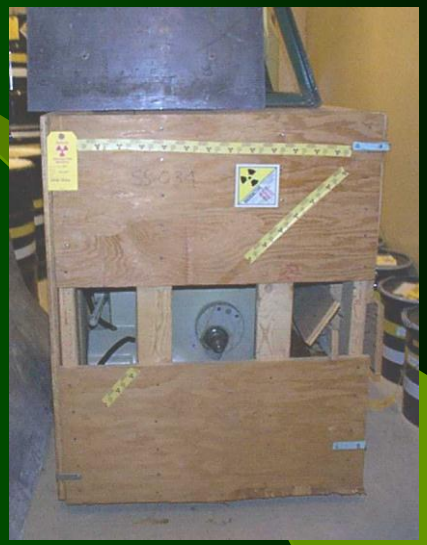
CSU IRRADIATORS AND ACCELERATORS



Co-60 Nominal
173 Ci
RSDF Storage

Co-60 Nominal
114 Ci
RSDF Storage





Co-60 Nominal
24 Ci
RSDF Storage

OTHER IRRADIATORS AND ACCELERATORS