Medical Sources of Radiation

Professional Training Programs

Oak Ridge Associated Universities

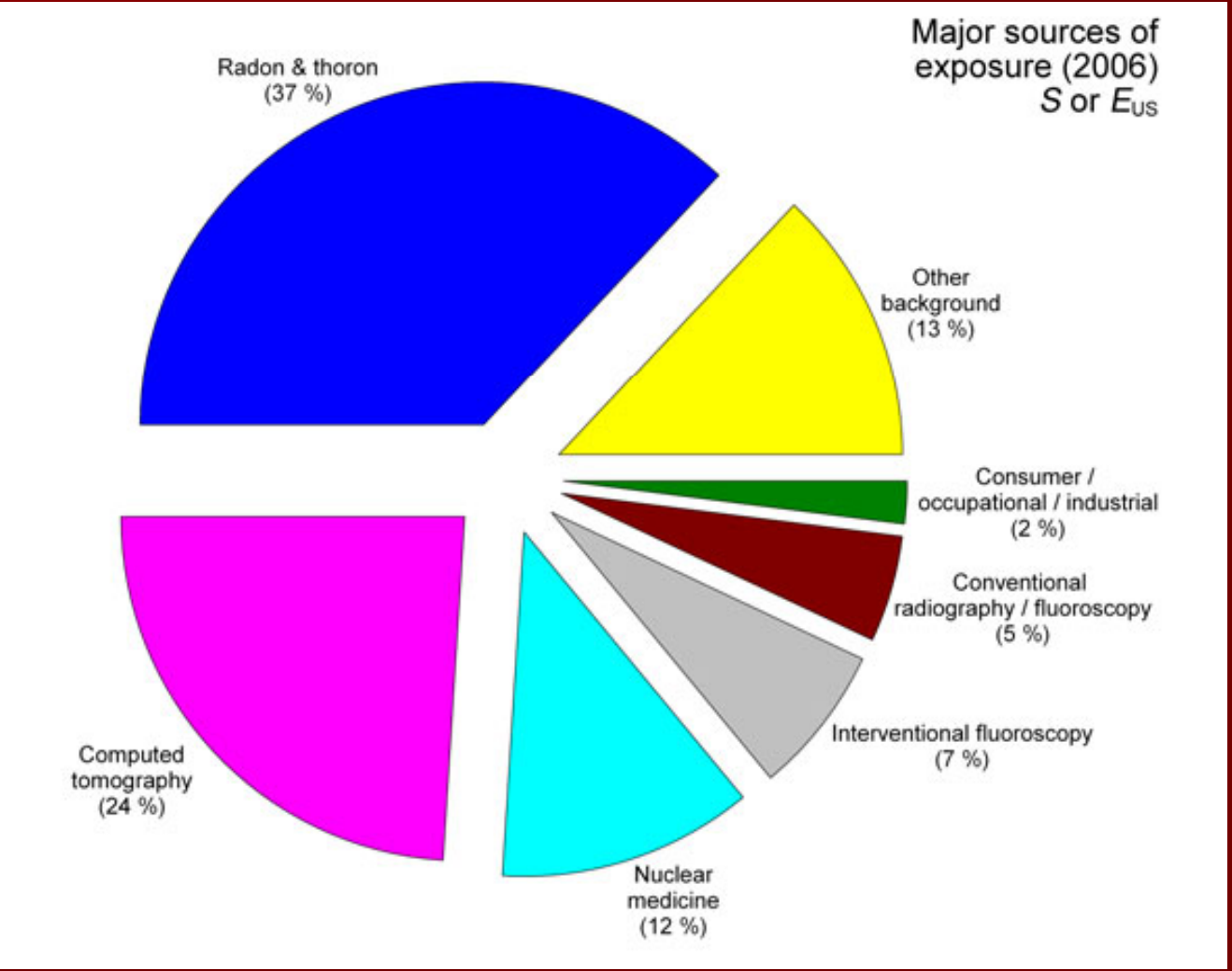
Objectives

- To review the most common uses of radiation in medicine.
- To discuss new uses for radiation in medicine.
- To review pertinent regulatory issues.

Introduction

- Medical exposure to an average American is about *3 mSv/yr (300 mrem/yr),* or about 48% of the total average exposure of 620 mrem.
- Medical exposure to radiation is the largest contributor to our annual average exposure from man-made sources.

NCRP Report 160



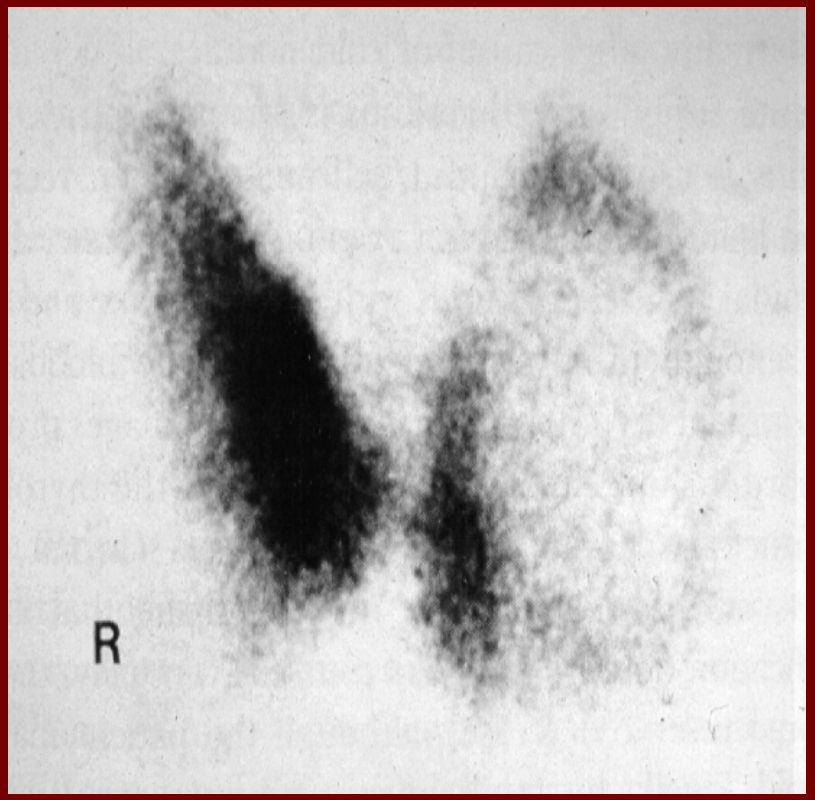
Introduction

People are *intentionally* and *purposefully irradiated* during medical radiological procedures, which is something that is usually avoided in all other applications using radiation.

Introduction

The goal in medicine is to *minimize risk* (keep doses low), without compromising the *benefit* of the procedure (diagnosis or treatment).

Introduction



- Radiation dose to patients is *not regulated*.
- Radiation *doses per procedure* are decreasing (with a few exceptions), but *more procedures* are being performed.

Introduction

There are traditionally three branches of medicine that use ionizing radiation.

- Diagnostic Imaging
- Nuclear medicine
- Radiation therapy

Diagnostic Imaging

- Diagnostic X-Ray
- Fluoroscopy
- Mammography
- Bone Densitometry
- Computed Tomography
- Special Procedures
- Cardiac Cath Lab

Diagnostic Imaging

MRI and ultrasound procedures do *not* use ionizing radiation, so will not be discussed.

Diagnostic Imaging

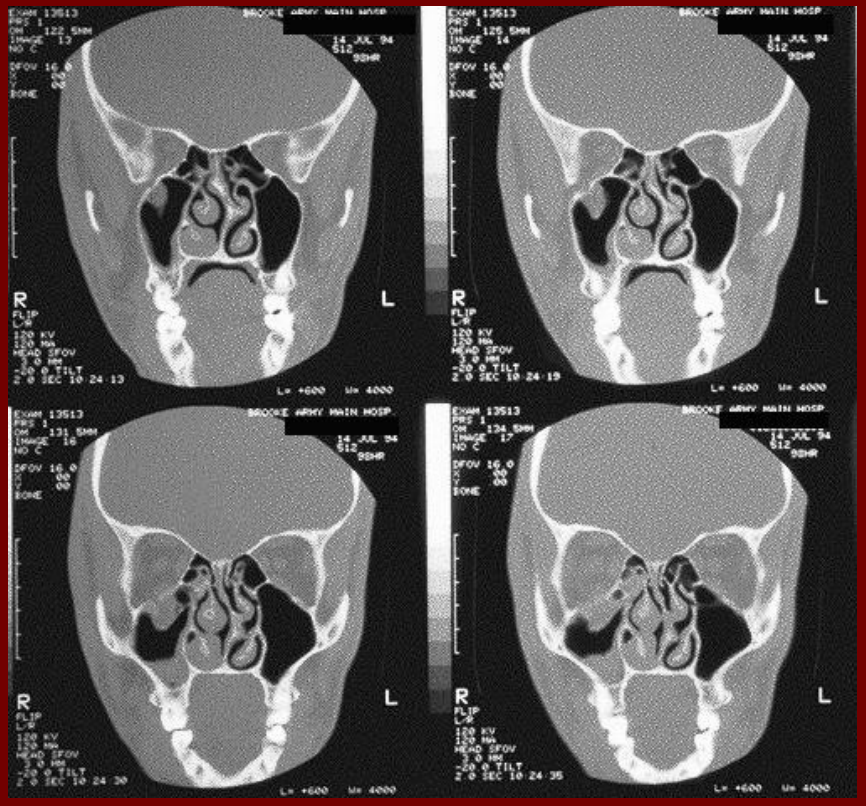
People who have had x-ray procedures or CT scans have been *exposed* to ionizing radiation, but are *not radioactive.*

Diagnostic Imaging

The *states* regulate the users of x-ray equipment, the *FDA* regulates the manufacture of x-ray equipment.

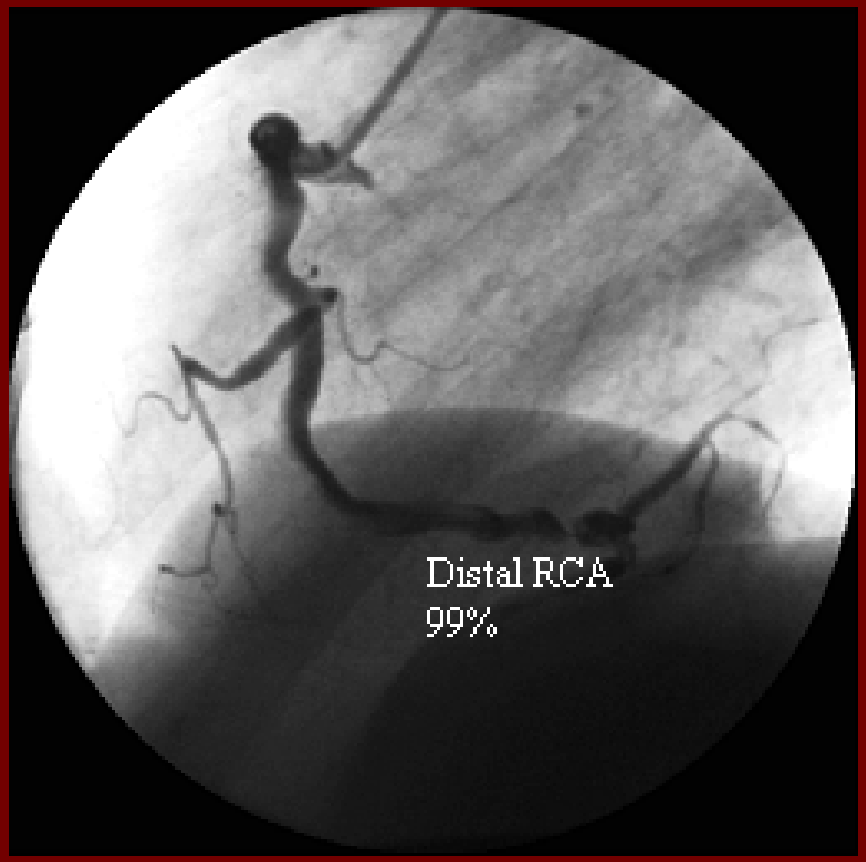
Diagnostic Imaging

Diagnostic Imaging



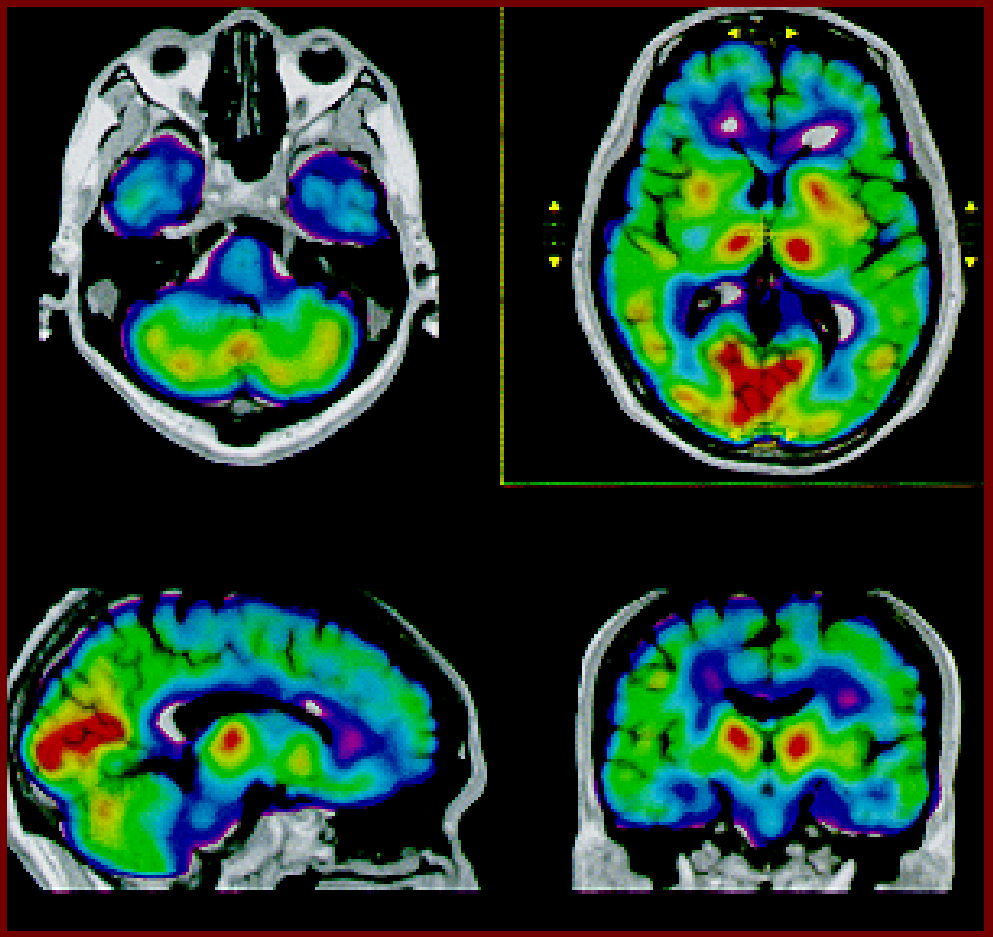
Diagnostic Imaging

Diagnostic Imaging

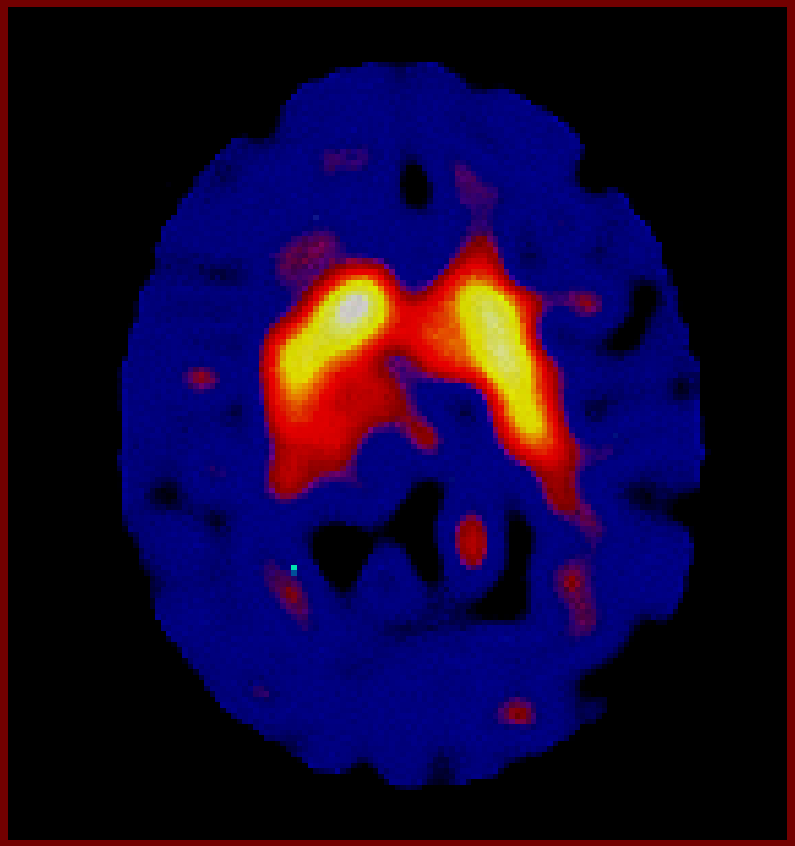


Nuclear Medicine

The patient is purposefully administered *radioactive material*, and *becomes the source* of radiation.



Nuclear Medicine



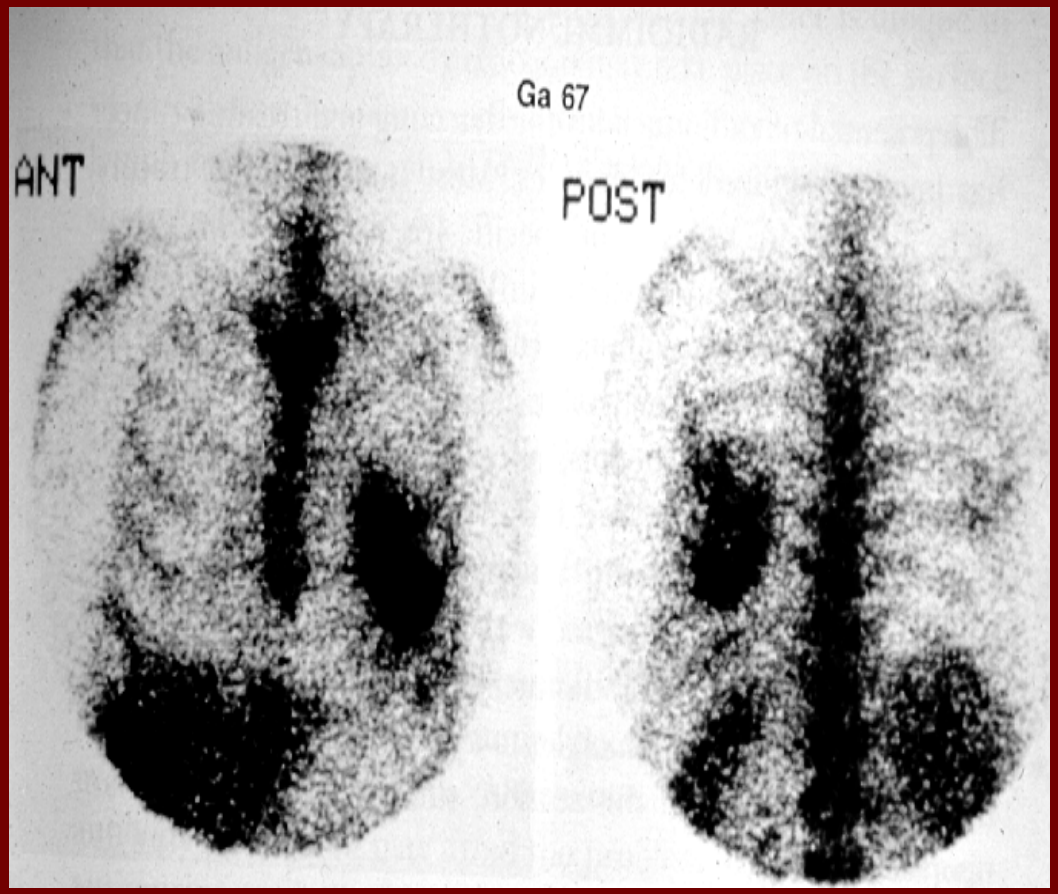
The radioactive material is tagged to a drug, called a *radio-pharmaceutical*.

Nuclear Medicine

- The radiopharmaceutical is a *drug,* and nuclear medicine procedures require a *prescription* from a physician.
- In addition, the NRC requires a *written directive* for therapeutic quantities of radiopharmaceuticals.

Nuclear Medicine

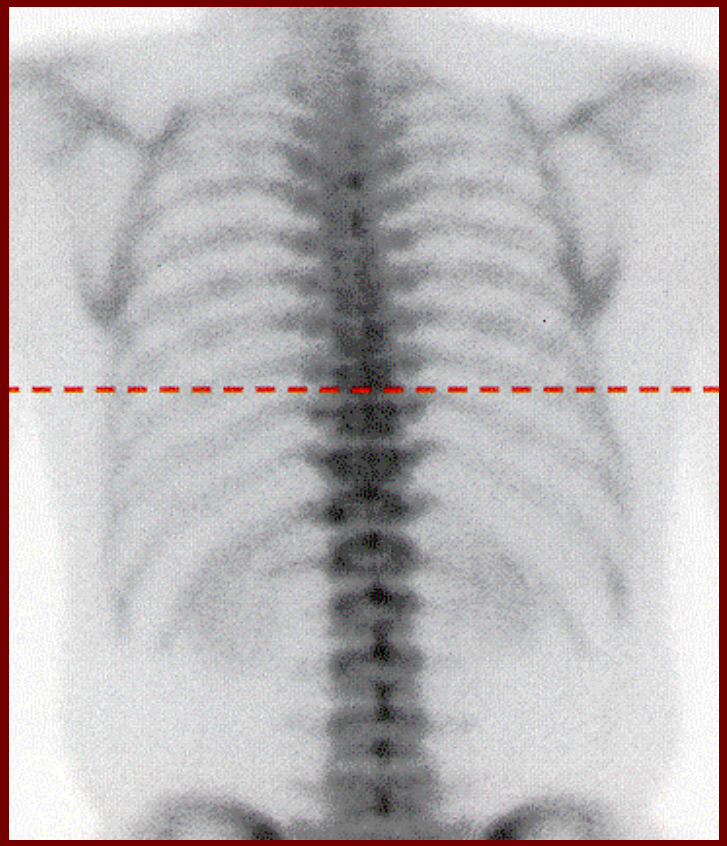
Then the radio-pharmaceutical is *injected, inhaled, or ingested* by patients.



Nuclear Medicine

- Diagnostic procedures
- Radionuclide therapy

Nuclear Medicine



Common diagnostic nuclear medicine procedures are:

- Bone scans
- Thyroid scans
- Heart scans
- Brain scans
- Lung scans
- Kidney scans

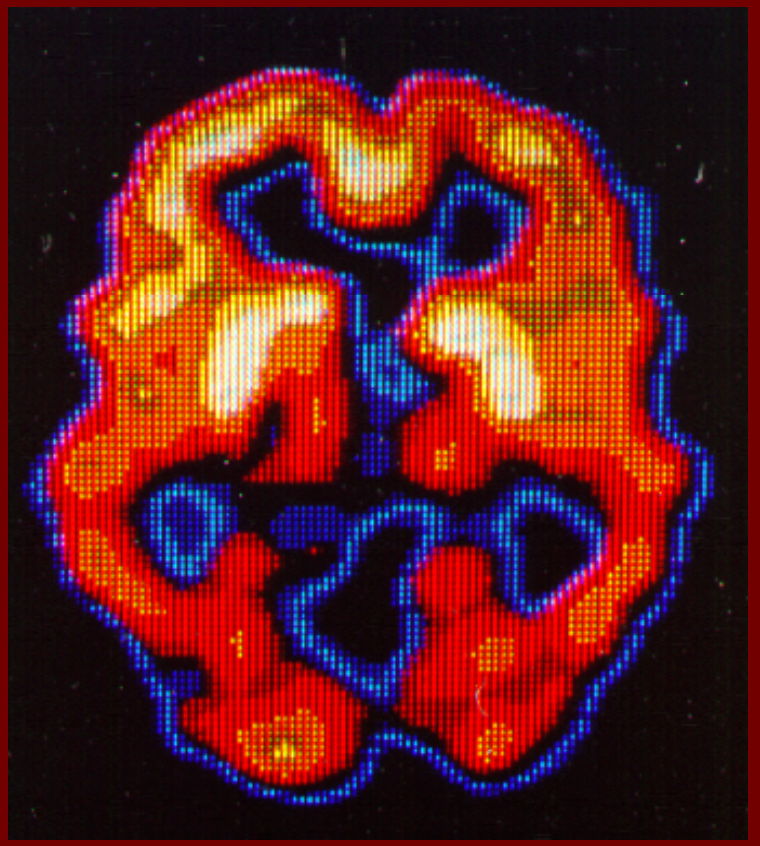
Common Nuclear Medicine Procedures		
Scan	Radionuclide	Activity MBq
Bone	Tc-99m	740
Thyroid	Tc-99m (I-123, I-131)	185 (15, 4)
Heart	Tc-99m, Tl-201	1,850 (110)
Brain	Tc-99m	185
Lung	Tc-99m, Xe-133	740 (370)
Kidney	Tc-99m, I-131	370 (15)

From NCRP 124, pg. 7.

Nuclear Medicine

Tc-99m is commonly used in diagnostic nuclear medicine procedures because of:

- Good *radiological* properties (6 hr half life, 140 keV gamma).
- Good *chemical* properties (easily binds to many compounds).

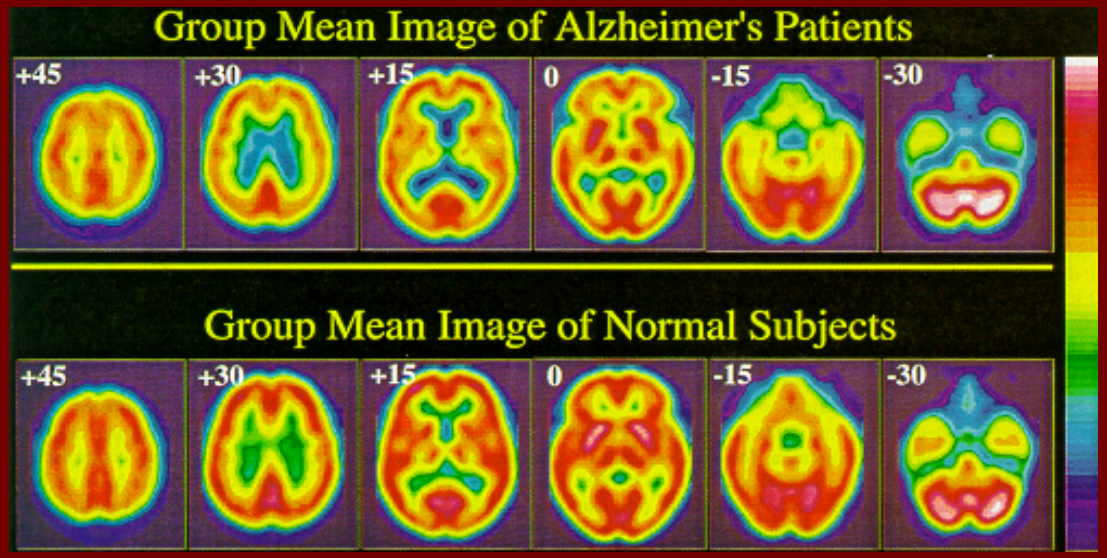


Nuclear Medicine

- A hospital usually orders patient-specific doses of the radiopharmaceuticals (unit doses) from a central *radiopharmacy.*
- The radiopharmacy makes shipments of these unit doses several times a day.

Nuclear Medicine

Each dose is *labeled* with the patient's name, radiopharmaceutical, and activity at a given time.



Nuclear Medicine

- Only the largest hospitals will order a *Tc-99m generator,* and prepare the radiopharmaceuticals on site.

- If a Tc-99m generator is used, the licensee *must measure* the activity of the radiopharmaceutical before it is administered to the patient.

Nuclear Medicine

An instrument called a *dose calibrator* (ionization chamber) is most commonly used for this purpose.

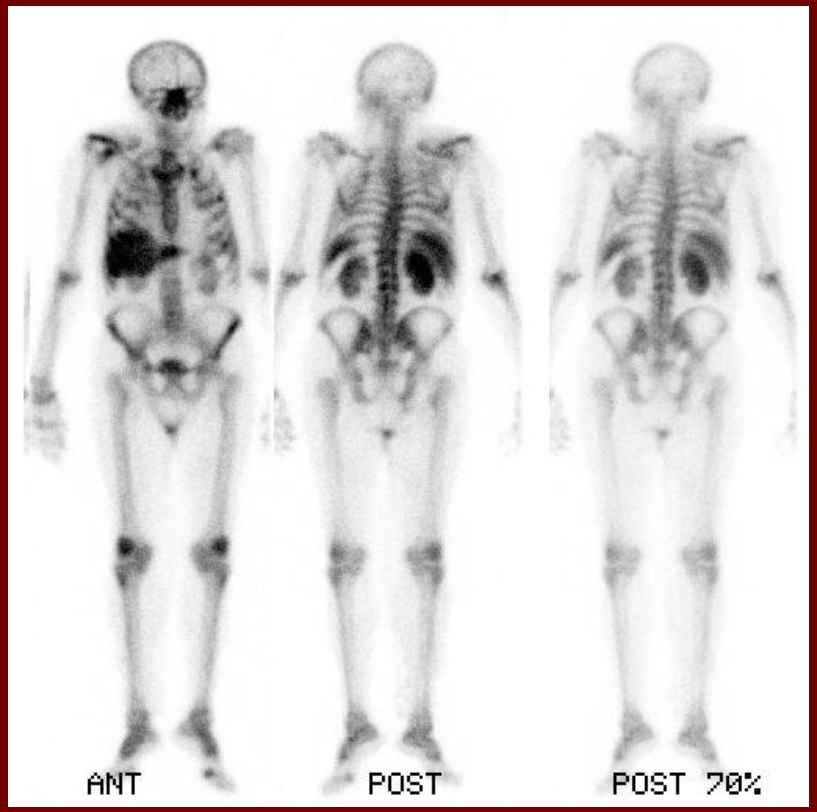
Nuclear Medicine

If the licensee uses prepared unit doses from a radiopharmacy, they may use the *stated activity* on the unit dose label.

Nuclear Medicine

- Nuclear medicine technologists are occupationally exposed workers.
- They *administer* the radiopharmaceuticals to patients, and *position* them to obtain the necessary images.

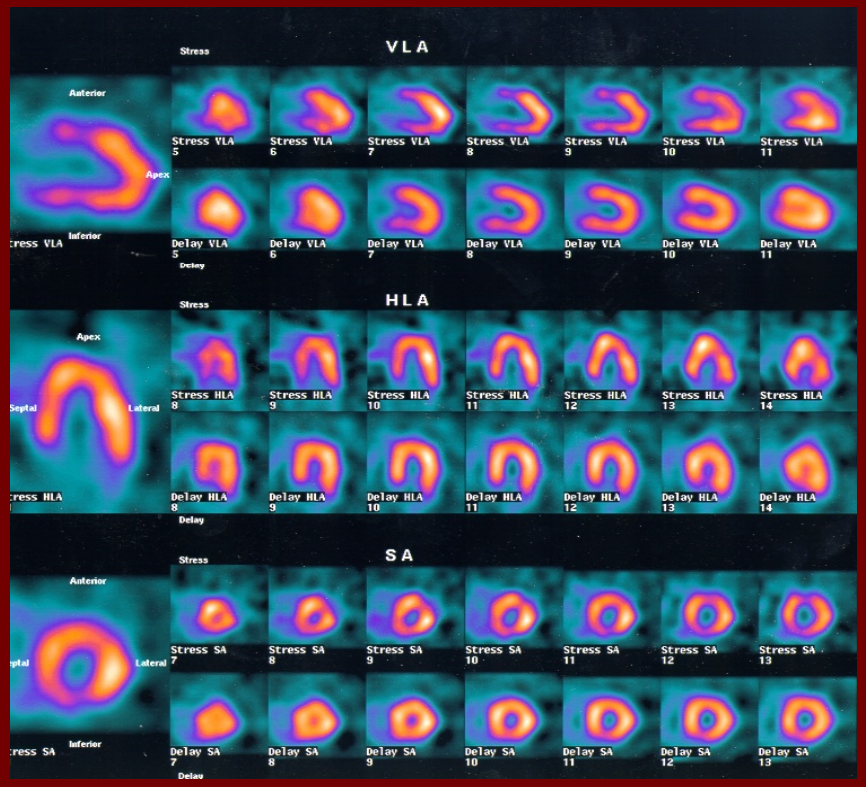
Nuclear Medicine



- The greatest source of radiation exposure to the technologists comes from *scatter from the radioactive patients.*
- They are also exposed during preparation and injection of radiopharmaceuticals.

Nuclear Medicine

The *dose rate at 1 meter* from a typical *diagnostic* patient is about *0.01 mSv/hr (1 mrem/hr)* (NCRP 124, pg. 17).

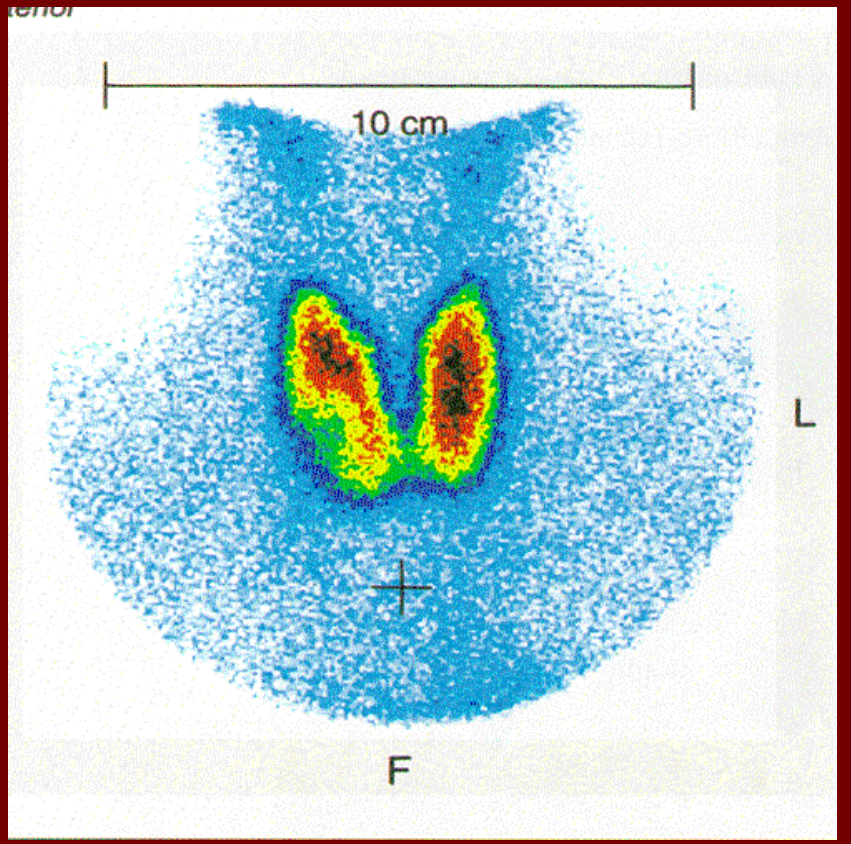


Nuclear Medicine

- Another branch of nuclear medicine is *radionuclide therapy,* or therapy using *unsealed* radiation sources.
- Just as in the diagnostic procedures, the patient is administered a radiopharmaceutical, and the *patient is radioactive.*

Nuclear Medicine

The *therapeutic procedures* use *a lot more radioactivity!*



Nuclear Medicine

- The most *common* radionuclide therapies are treatment of:
  - *Hyperthyroidism* (overactive thyroid).
  - *Thyroid cancer.*
- Both are treated with *large* doses of *I-131.*

Common Radionuclide Therapies		
Condition	Radio-nuclide	Activity MBq
Hyperthyroidism	I-131	100-1000
Thyroid Cancer	I-131	4000-8000+

From NCRP 124, pg. 39.

Nuclear Medicine

- Patients are *hospitalized* when they are treated for *thyroid cancer,* and released after the I-131 has decayed to a certain level or been biologically eliminated.

- Patients are *not hospitalized* for treatment of *hyperthyroidism.*

Nuclear Medicine

- Normally the dose limit to members of the *general public is 100 mrem/yr.*
- However, the dose limit to *family members* (general public) of patients treated with I-131 is *500 mrem/yr.*

Dose Rates mGy hr^{-1} after 3,700 MBq of I-131 for Thyroid Cancer					
Distance from patient	Time post administration (hr)				
	0	24	36	48	72
10 cm	9	5	3.5	3	0.7
30.5 cm	2	1	0.7	0.6	0.2
1 m	0.2	0.1	0.08	0.07	0.02

From NCRP 124, pg. 38.

Nuclear Medicine

- Two other radionuclide therapy procedures are:
  - Treatment of abdominal effusions with *P-32.*
  - Treatment of metastatic bone pain with *Sr-89.*
- Both of these radionuclides are *beta-emitters,* and do not present the same radiation safety problems as I-131.

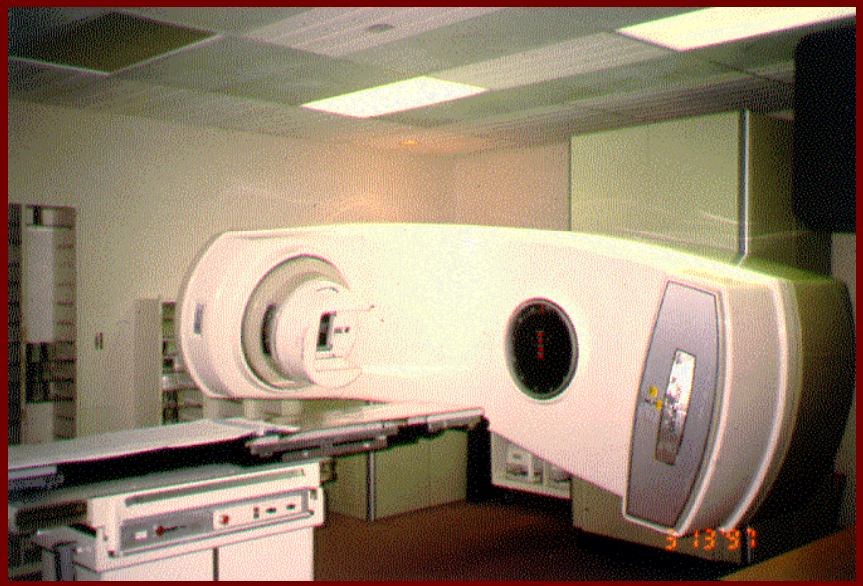
Radiation Therapy

- *Radiation Therapy* includes:
  - External beam therapy and teletherapy.
  - Brachytherapy with *sealed* sources.
- Radionuclide therapy is traditionally considered part of Nuclear Medicine (as discussed previously).

Radiation Therapy

Most radiation therapy treatments today are made with an *external beam* of high energy photons from *linear accelerators*.

Radiation Therapy



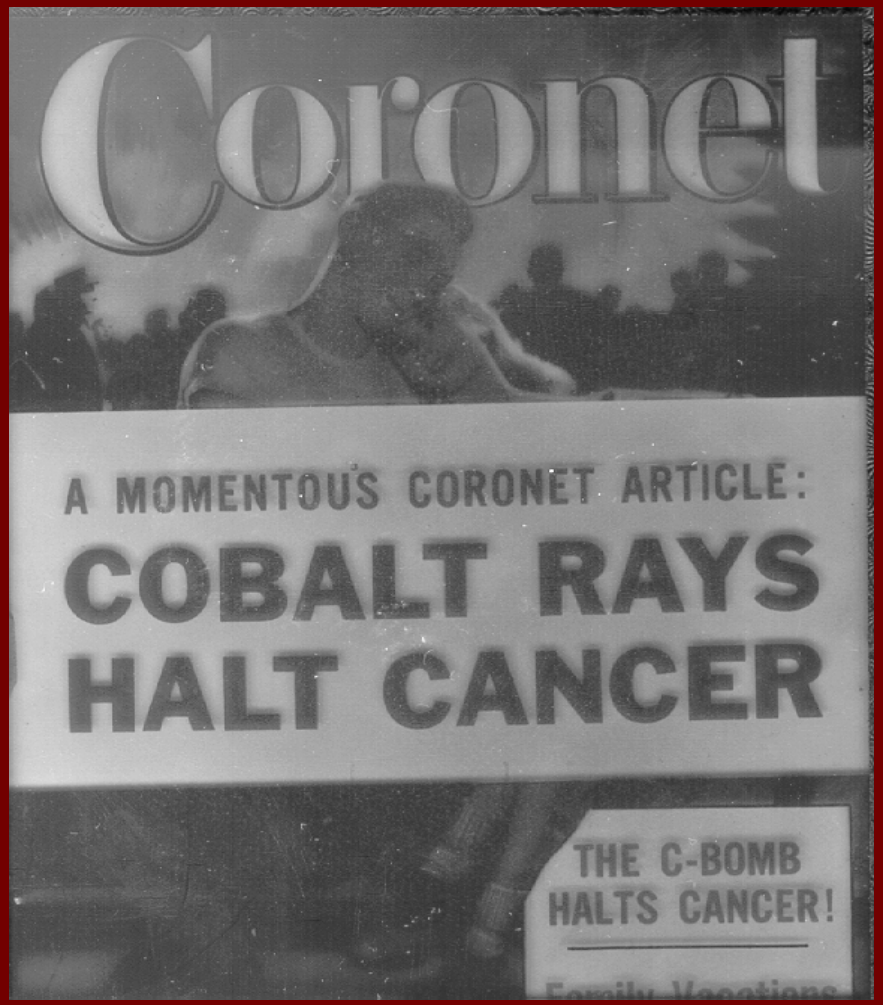
- People who have had external beam radiation therapy have been *exposed* to ionizing radiation, but are *not radioactive.*
- The States regulate linear accelerators, not NRC.

Radiation Therapy

- NRC does regulate teletherapy units, which contain a large quantity of Co-60.
- Radiation therapy with *Co-60* is an *outmoded* means of therapy (on humans) in this country today.

Radiation Therapy

Hospitals are *donating* Co-60 therapy machines to veterinary hospitals or to *developing countries.*



Radiation Therapy

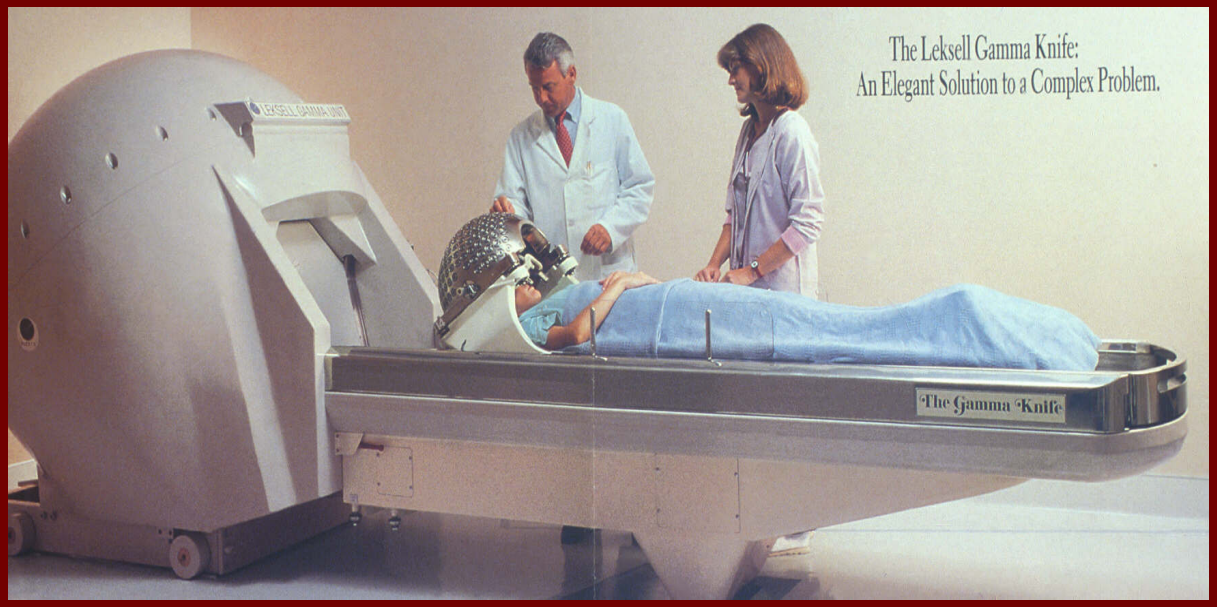
- This practice has resulted in a number of accidents in other countries where a Co-60 machine in storage was dismantled for *scrap metal.*
- The Co-60 source pellets were *not recognized* as radioactive material, and were *melted* in foreign foundries.

Radiation Therapy

One of those accidents resulted in the manufacture of radioactive table legs from contaminated scrap metal from a Mexican foundry.

Radiation Therapy

Co-60 sources are used in the Stereotactic Radiosurgery (SRS), using a Gamma Knife.

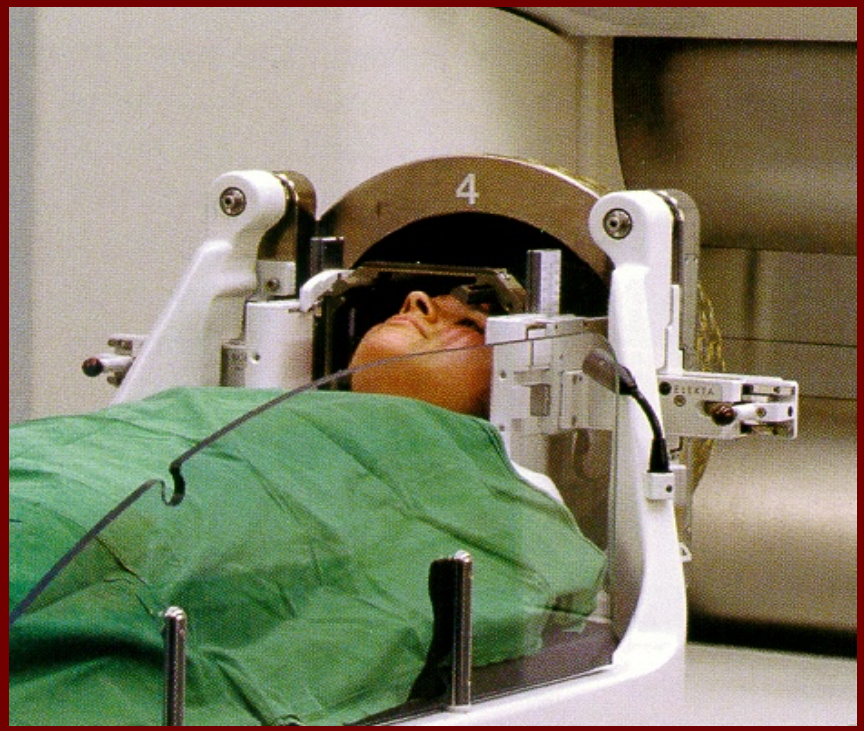


Radiation Therapy

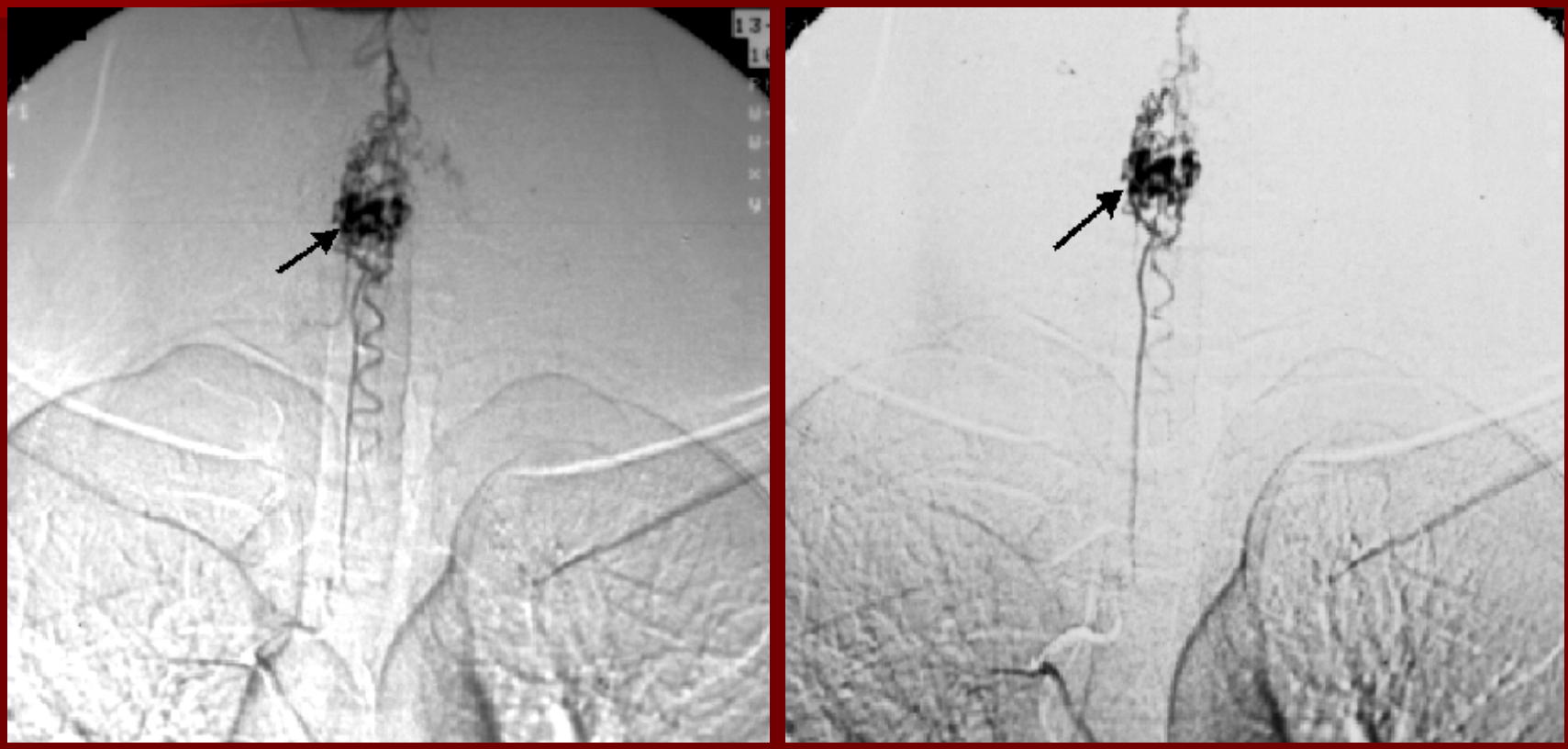
This procedure uses many pinpoint beams of Co-60 that are focused at a small volume (mm^3).

Radiation Therapy

- The procedure is used to treat a condition called an Arterio-venous malformation.
- The malformation is localized and placed at the focal point of the Co-60 beams.



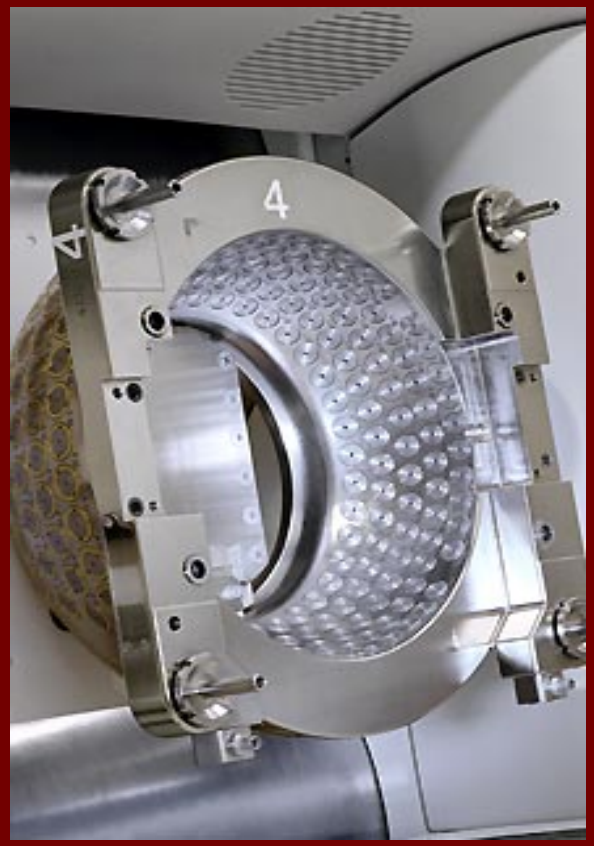
Arterio-venous malformation



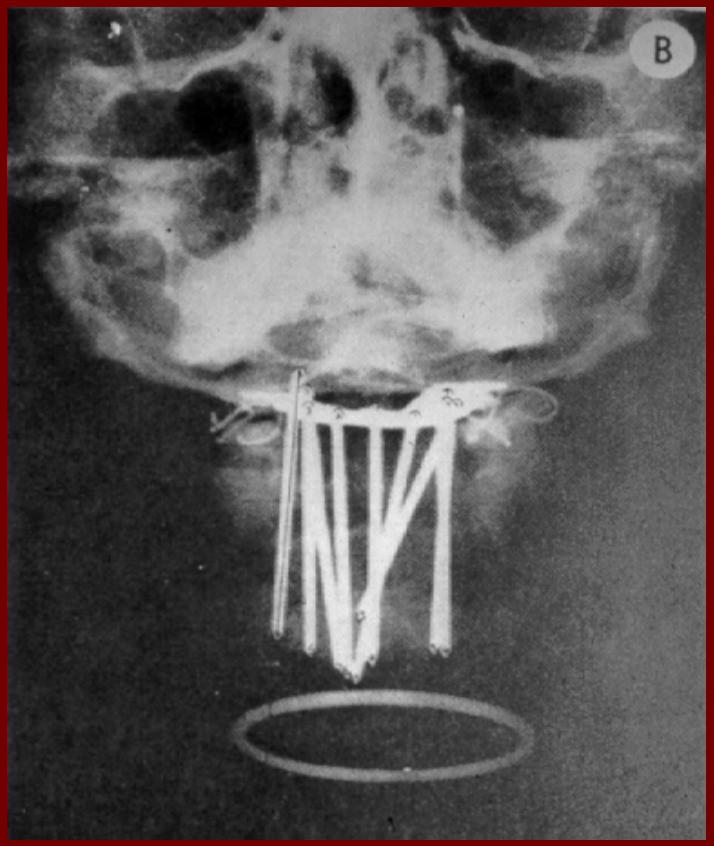
An abnormally dilated tortuous vessel pattern is visible during the arterial phase in the region of the central canal in the AP view of the cervical spine

Radiation Therapy

- NRC regulates the Co-60 Gamma Knife.
- There are also accelerator-based Stereotactic Radiosurgery devices, regulated by the states.



Radiation Therapy



Brachytherapy is the *implanting* of *sealed* radioactive material into the body.

Radiation Therapy

- The implants can be *temporary,* where the patient is *hospitalized during the time* the radioactive implants are in the body.
- Cervical cancer is often treated with temporary implants of Cs-137.

Radiation Therapy

- The traditional interstitial brachytherapy implants are now known as *Low Dose Rate (LDR)* brachytherapy.
- In the last 10 years or so, another brachytherapy technique has been in use called *High Dose Rate (HDR)* brachytherapy.

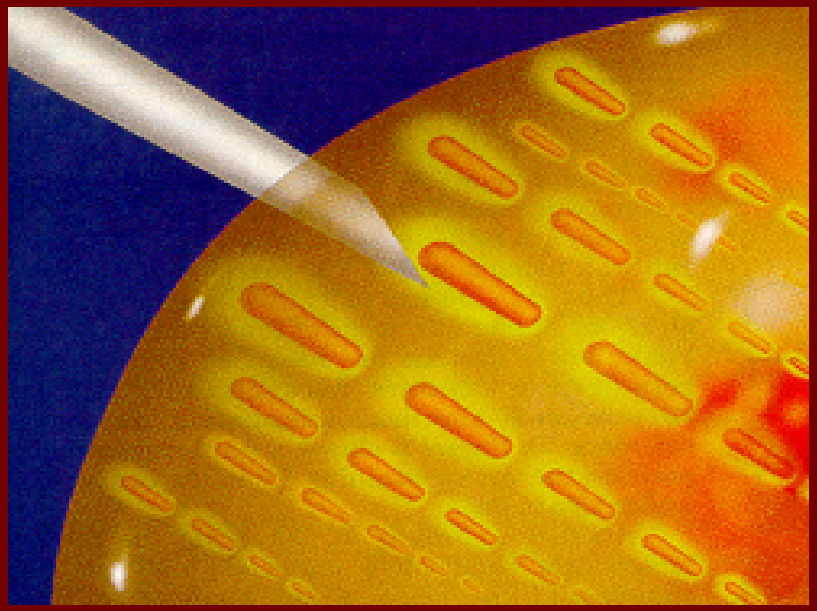
Radiation Therapy

One of the advantages is that the treatment can be performed on an outpatient basis.

Radiation Therapy

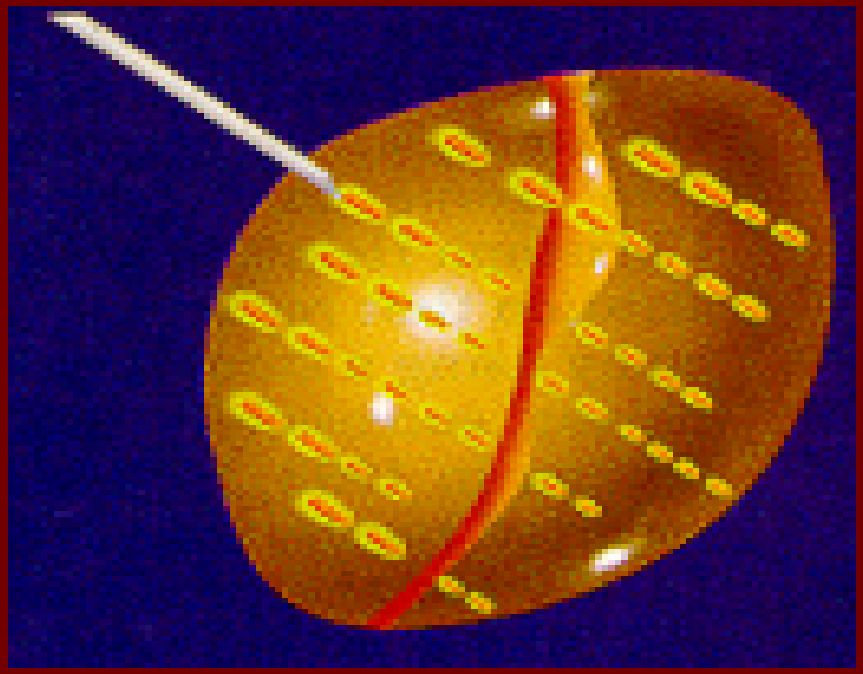
The HDR unit consists of several catheters (tubes) through which large activities of *Ir-192* are moved once they have been placed where the treatment is to be delivered.

Radiation Therapy



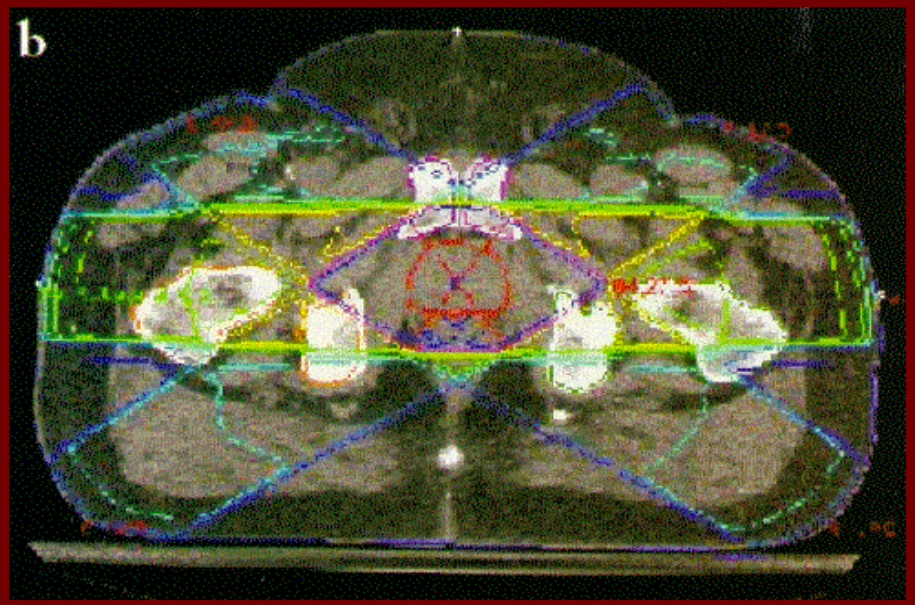
- Implants can also be *permanent,* where the patient leaves the hospital *with the implants inside* the body.
- *Permanent* implants are now commonly used to treat *prostate cancer.*

Radiation Therapy



- *I-125* or *Pd-103* *"seeds"* are implanted into the prostate and left there.
- They irradiate the prostate gland until the radioactive material decays.

Radiation Therapy



“New” Modalities

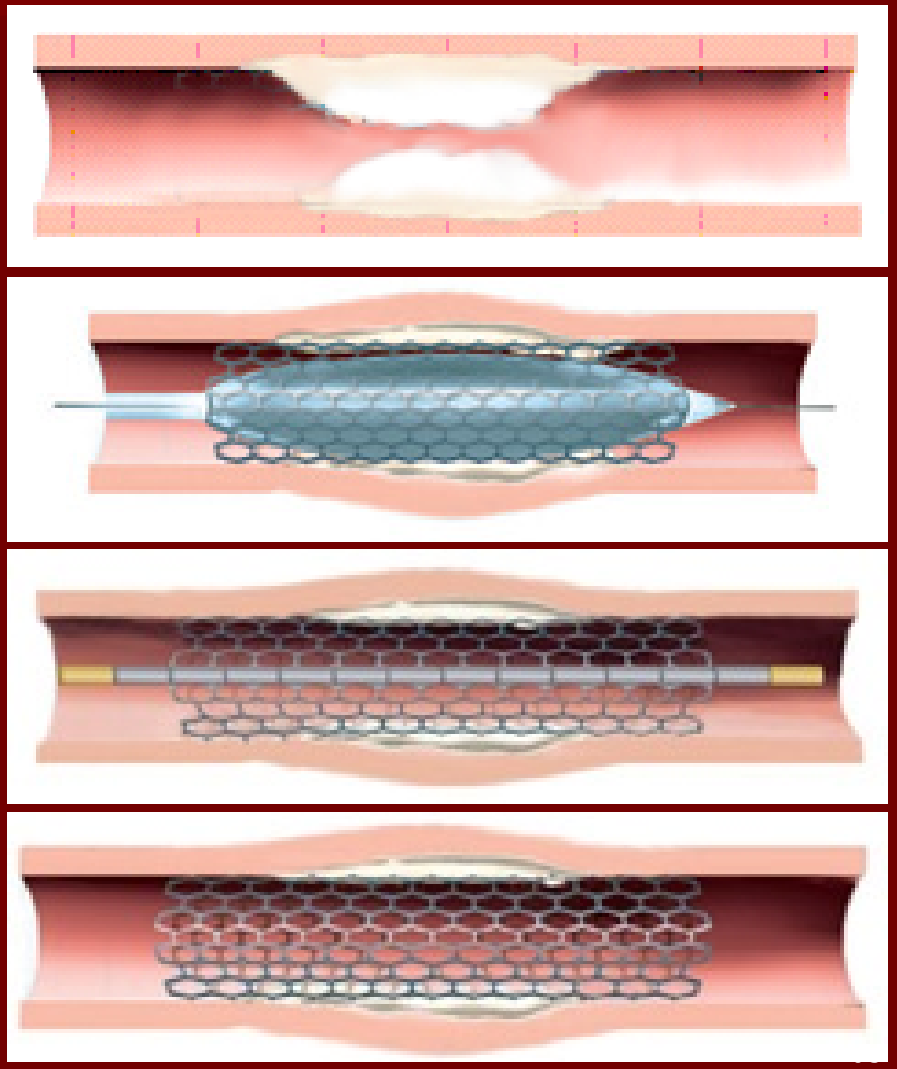
- Intravascular Brachytherapy
- Microspheres
- Gliasite

Intravascular Brachytherapy (IVB)

- IVB is used to combat restenosis at the location of the stent.
- It is the first therapy approved by the FDA for this purpose.
- Both IVB and angioplasty damage the endothelium of the vessels. Since these cells are necessary to prevent the accumulation of platelets and blood clotting, IVB and angioplasty must be accompanied by some type of drug treatment.

IVB

- Intravascular brachytherapy (IVB) involves positioning a radiation source (or sources) at the location of a stent.
- After the vessel walls have been irradiated for the appropriate period, the source is withdrawn.



Alternative Forms of IVB

- Radioactive liquid-filled balloons (Re-188)
  - Better placement
  - Risk of rupture
- P-32 labeled oligonucleotide loaded onto a polymer coated stent
- P-32 containing stent

Alternative Forms of IVB

- A miniature x-ray generator inserted into the artery that would expose the artery walls to 20 keV photons.
- Radioactive material (e.g., Tc-99m) injected directly into the wall of the artery.
- A P-32 coated angioplasty balloon (has been tested).
- An angioplasty balloon filled with a radioactive gas (e.g., Xe-133).

Alternative Forms of IVB

- An alternative is the use of a drug-eluting stent. Such a stent is coated with a drug (e.g., sirolimus) that prevents or slows a reblockage of the artery.
- Drug-eluting stents are becoming the method of choice to treat restenosis, but IVB is still performed.

IVB Commercial Systems

- Cordis CHECKMATE System (Ir-192)
- Guidant Galileo System (P-32)
- Novoste Beta-Cath System* (Sr-90/Y-90)

* Only the Novoste system is still on the market

Novoste Beta-Cath

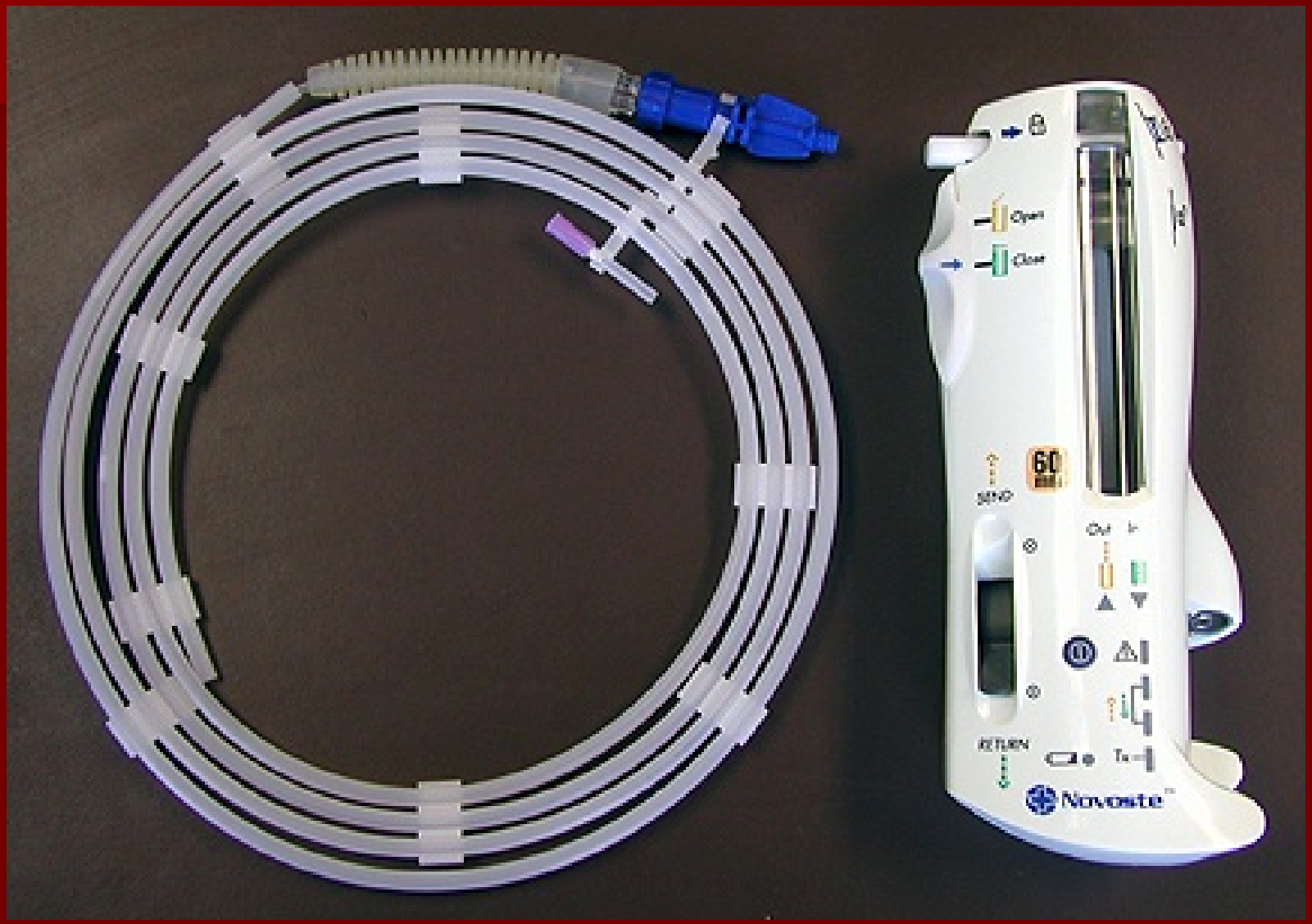
- The source train can hold 12, 16 or 24 sources.
- Each source contains up to 5 mCi (0.185 GBq) of Sr-90/Y-90.
- The maximum activity is therefore 120 mCi (4.44 GBq).

Novoste Beta-Cath

There are several advantages to using a pure beta emitter such as Sr-90/Y-90 rather than a gamma emitter (e.g., Ir-192):

- shorter treatment times
- lower dose to non-target tissue
- medical personnel can remain in the cath lab during the procedure
- gamma shielding not required

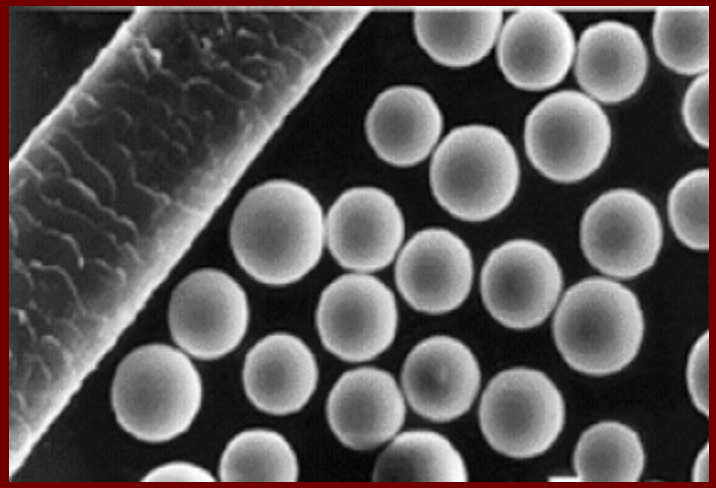
Novoste Beta-Cath



Novoste Beta-Cath

Microspheres

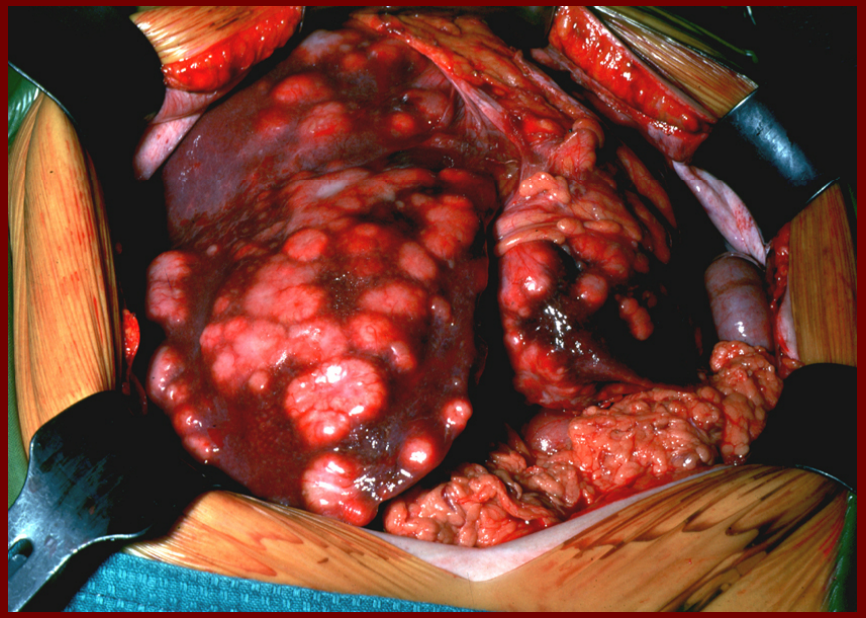
- Y-90 containing microspheres suspended in a solution are injected into the hepatic artery in order to shrink cancerous tumors.
- Brachytherapy using microscopic sources.



Microspheres

- The liver dose (assuming uniform distribution) can be 80 to 150 Gy.
- This is higher than that possible with external beam radiotherapy where doses as low as 30 to 35 Gy can result in hepatitis.
- Future possible applications of microspheres might be head and neck cancer, ovarian cancer, bone metastases.

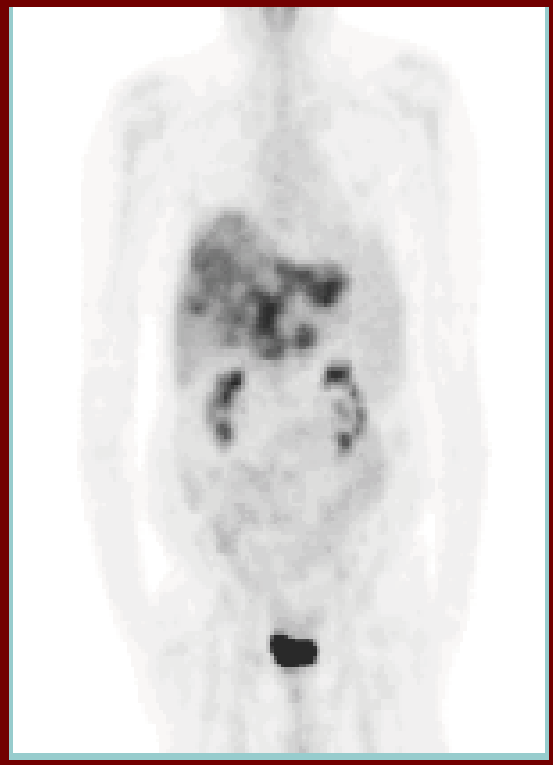
Photo courtesy of SIRTEX



Microspheres

Pre-therapy PET Image

Post-therapy PET Image



Note significant reduction in mass of cancerous tissue in liver (F-18) .

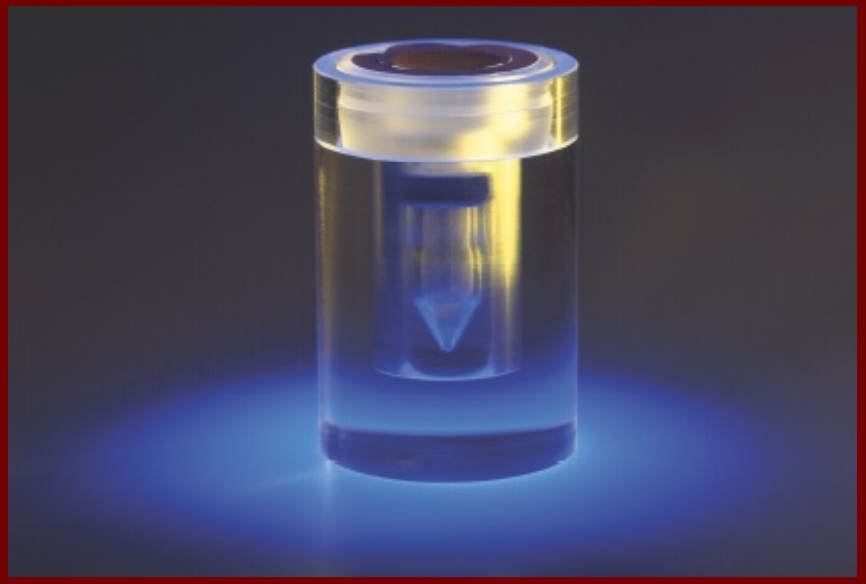
SIR-Spheres

- Selective Internal Radiation Therapy (SIRT)
- Shipped activities: 3 GBq (79 mCi) or 3.6 GBq (at time of calibration).
- There is a 24 hour expiration, i.e., should be used within one day of calibration date.

Photo courtesy of SIRTEX

Theraspheres

- Glass microspheres
- The Y-90 is an integral component of the matrix.
- Available in six dose sizes:
  - 3 GBq (81 mCi)
  - 5 GBq (135 mCi)
  - 7 GBq (189 mCi)
  - 10 GBq (270 mCi)
  - 15 GBq (405 mCi)
  - 20 GBq (540 mCi).



Courtesy of Nordion

Microspheres

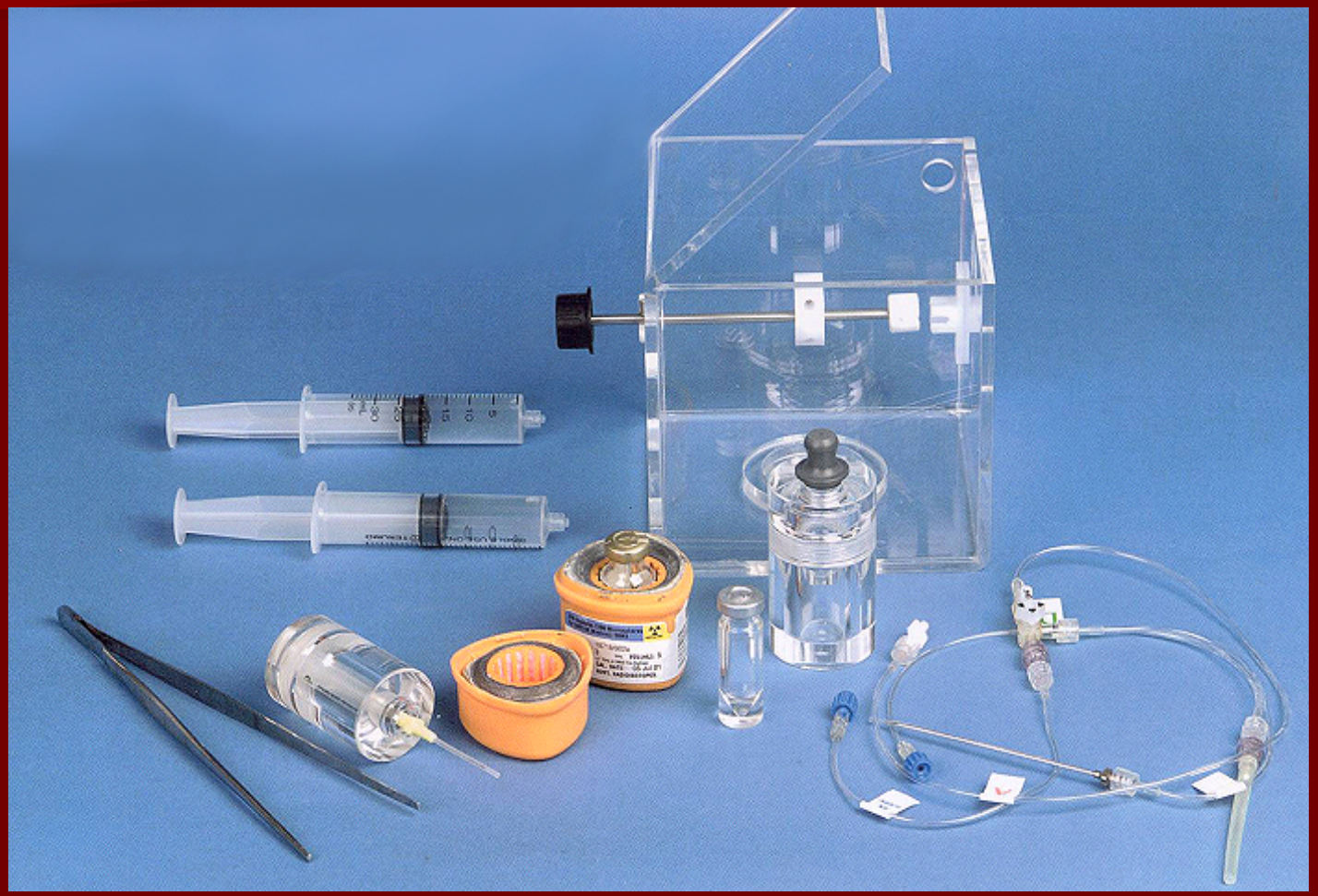
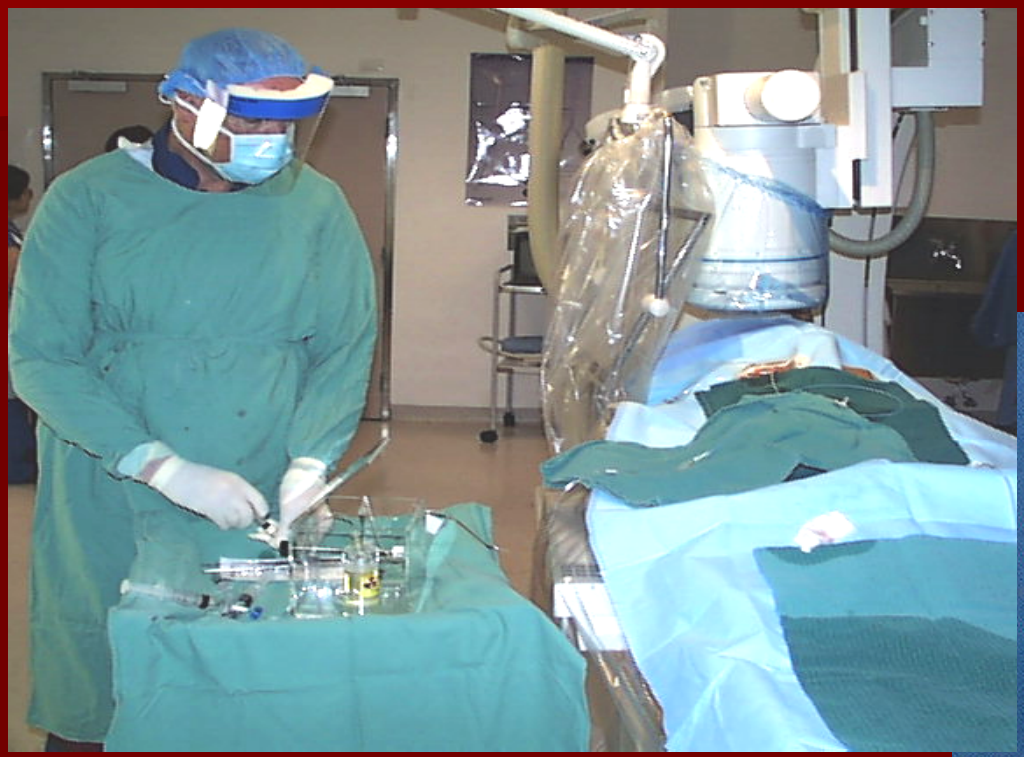
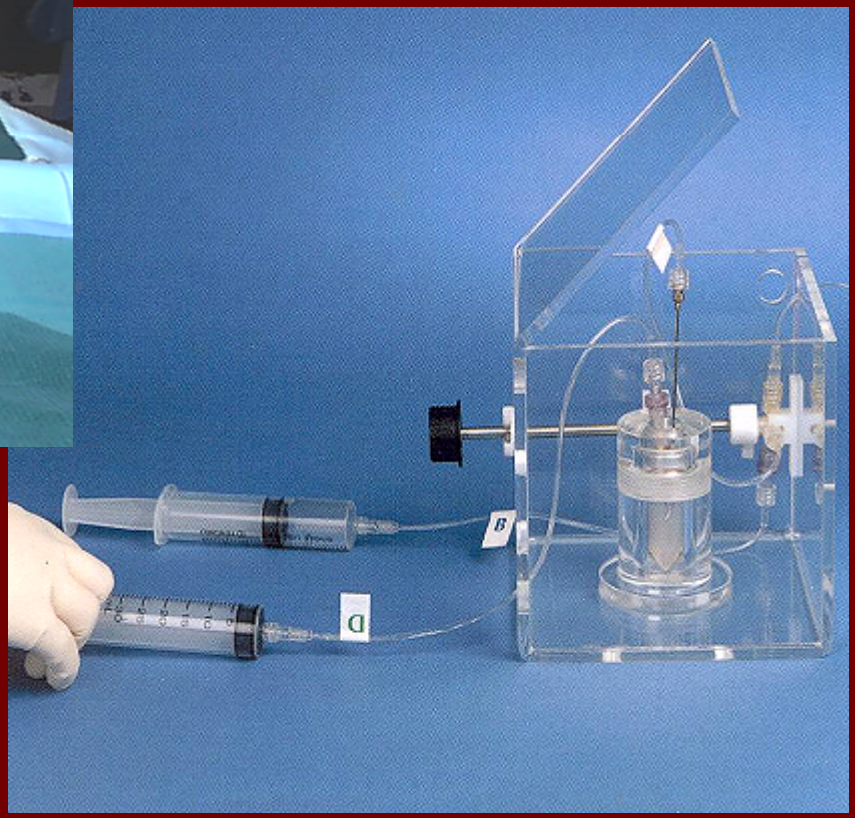


Photo courtesy of SIRTEX

Microspheres





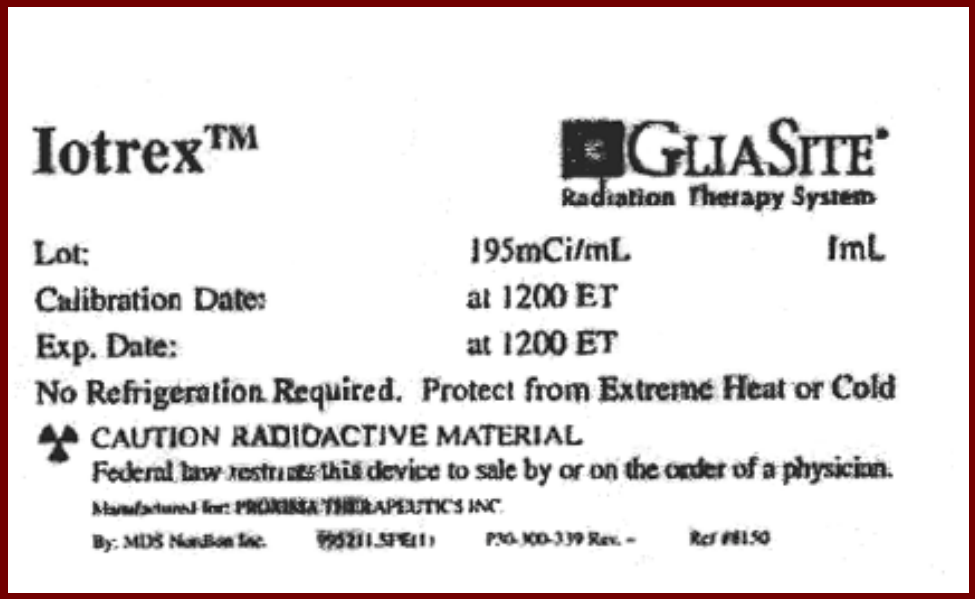
Photos courtesy of SIRTEX

Gliasite

- Employs Iotrex, an organically bound I-125 containing solution.
- Available in vial or preloaded syringe.
- Minimum of 150 mCi/dose
- Maximum activity 1320 mCi
- Average afterloaded activity of 330 mCi

Gliasite

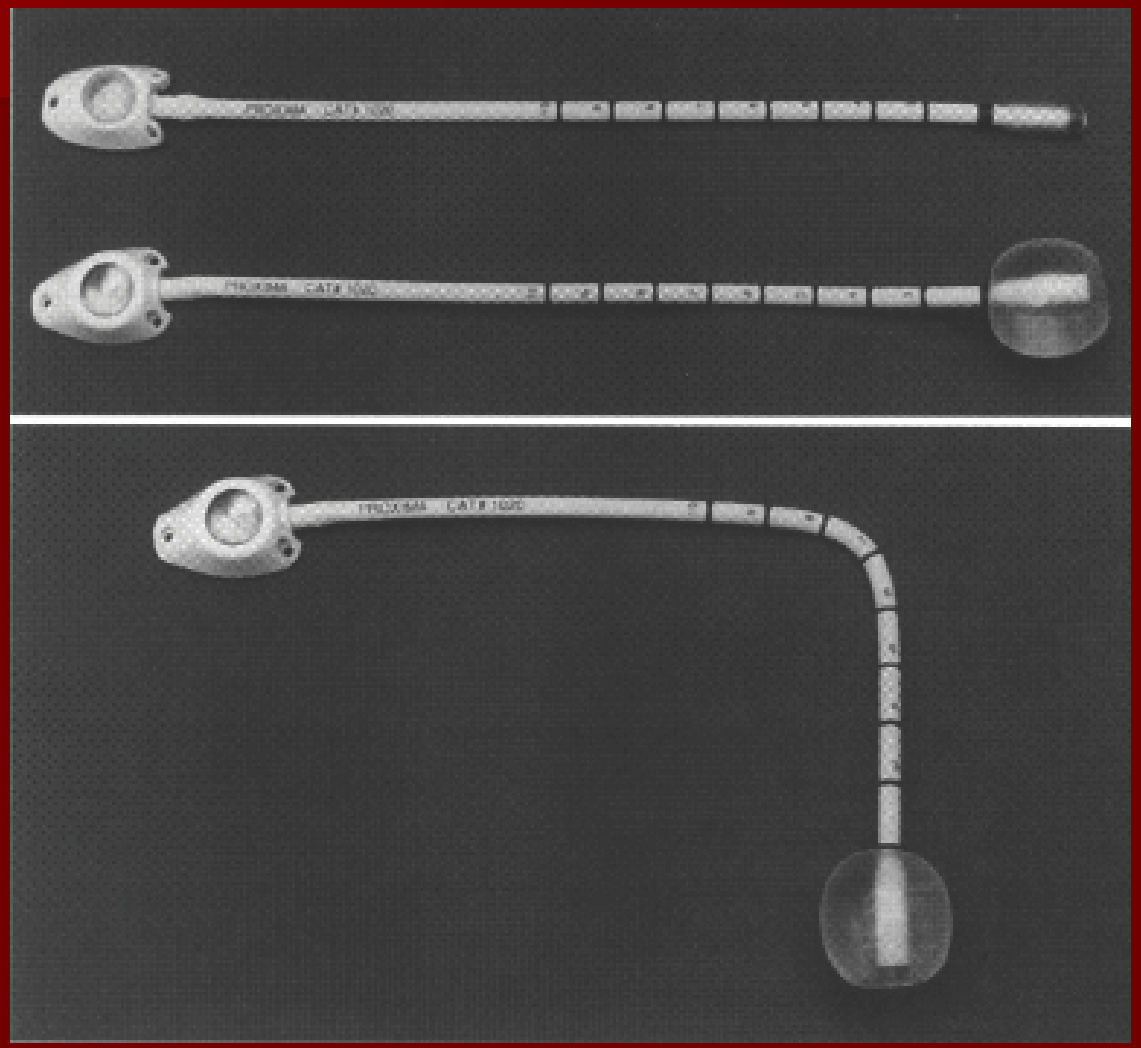
- I-125 decays by electron capture. It does not emit charged particles.
- I-125 emits low energy photons in the 28 to 35 keV range
- I-125 has a 59.4 day half-life
- The Iotrex solution has a 27 day shelf-life.



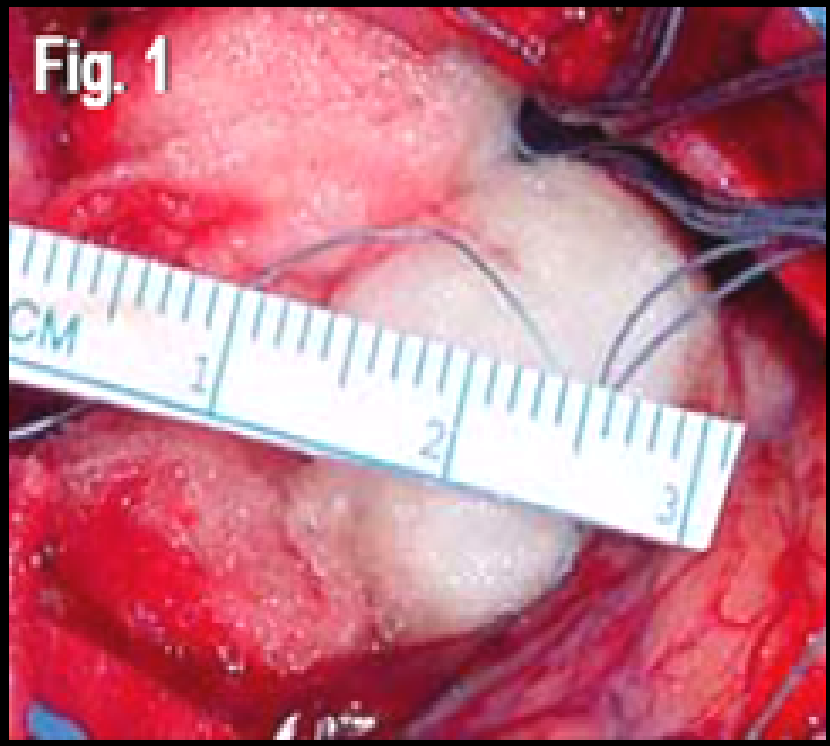
Gliasite

- In the OR, the neurosurgeon places the inflatable balloon into the space left by the resected tumor.
- The injection port is fixed on top of the skull, but hidden under the skin.
- The patient is discharged.

Gliasite



Gliasite



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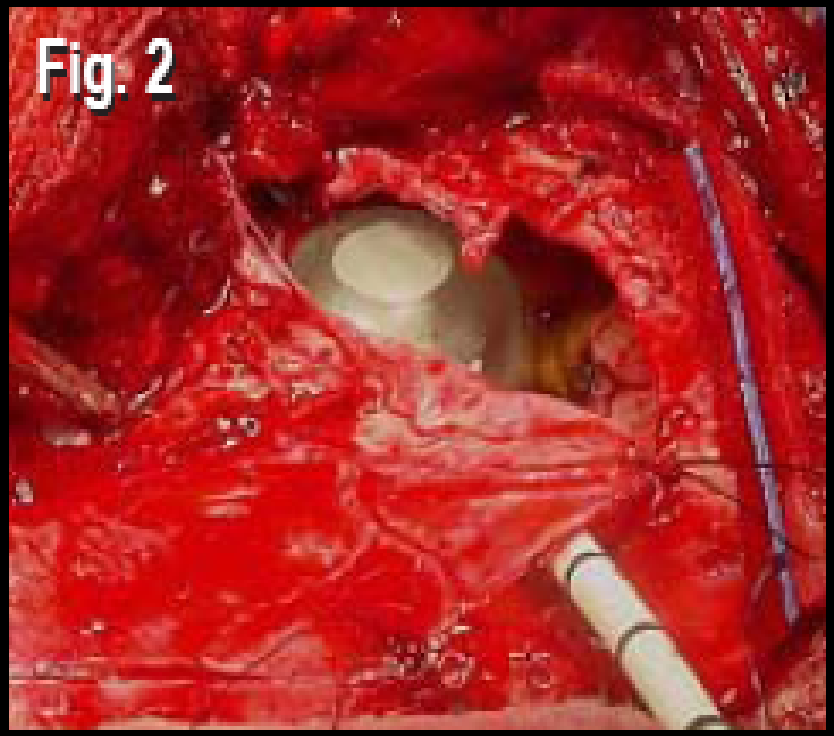
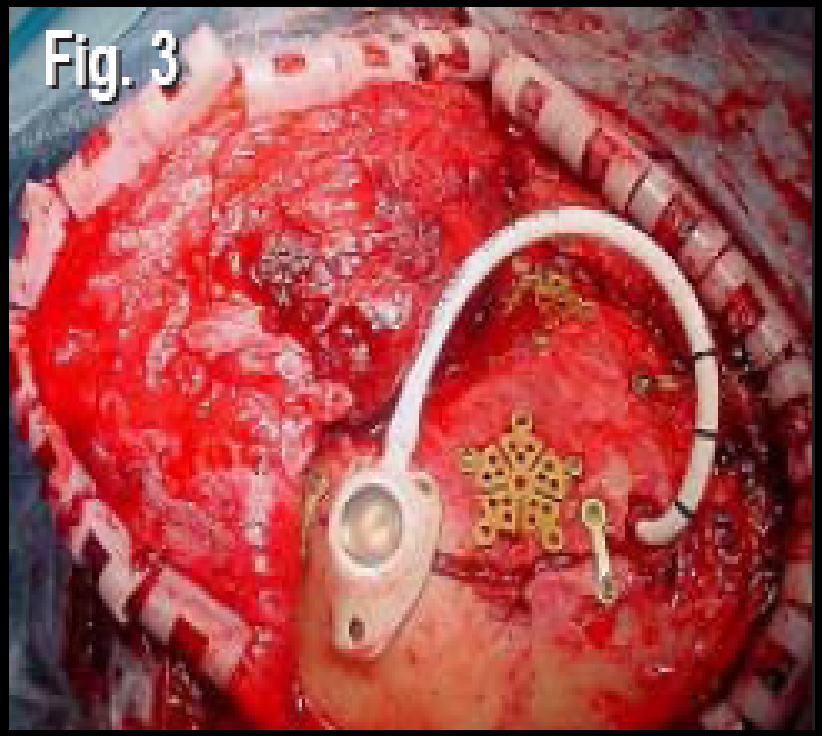
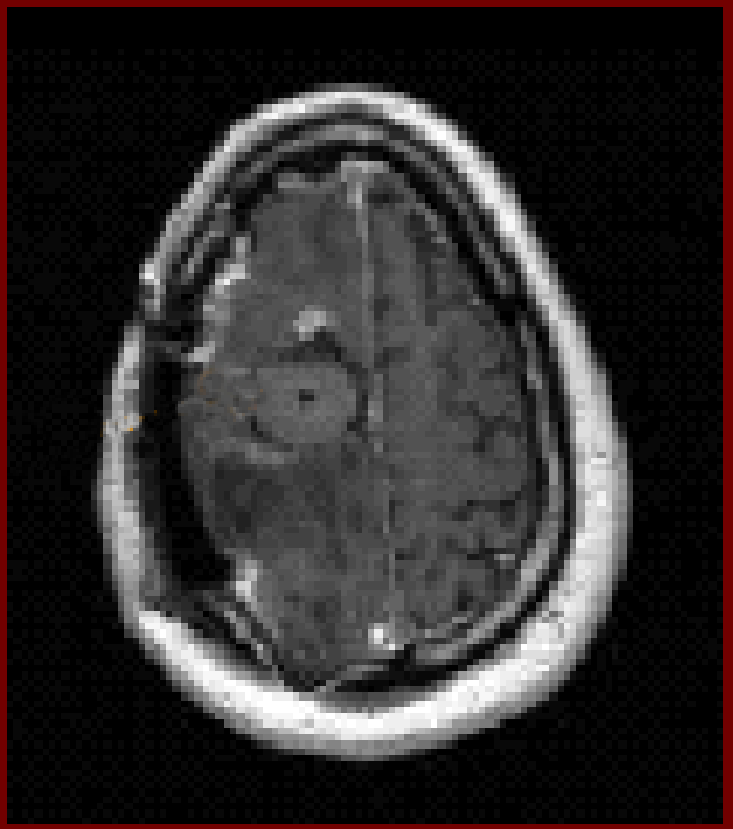




Gliasite

- After the patient recovers from surgery, the balloon is inflated with saline and 10-50% iodinated contrast media for size and placement verification.
- A few days later, an Iotrex-saline mixture is injected into the catheter and balloon. This can be done in patient's room.
- Treatment is typically 3 to 7 days.



Gliasite

- The Iotrex is removed.
- The catheter is then flushed two or three times with 4 to 5 mls of sterile saline.
- This is often done in the patient's room.

Regulatory Issues

- NRC regulates the intentional internal or external administration of *byproduct material,* or the *radiation from byproduct material* to patients or human research subjects for medical use.
- The purpose of NRC regulations is to protect patients, workers, and the public from unnecessary exposure to radiation.

Regulatory Issues

- NRC issues three types of licenses:
  - In vitro license.
  - Specific license of limited scope.
  - Specific license of broad scope.

Regulatory Issues

In vitro procedures are clinical *laboratory tests* using *small quantities* of radioactive material, but *not* involving administration of radioactive materials to humans.

Regulatory Issues

- A specific license of *limited scope* (e.g. private practice or mobile nuclear medicine practice) will have a list of authorized users.
- A specific license of *broad scope* authorizes *multiple quantities* and types of material for *unspecified uses* (e.g. large university medical center).

Regulatory Issues

A medical licensee's radiation protection program should include descriptions of:

- The audit program.
- Occupational dose.
- Public dose.
- Contamination Control.
- Operating and Emergency procedures.

Regulatory Issues

- Material receipt and accountability.
  - Ordering and receiving.
  - Opening packages.
  - Sealed source inventory.
  - Use records.
- Leak tests.
- Area surveys.
- Procedures for administrations requiring a written directive.

Regulatory Issues

- Safe use of unsealed licensed material.
- Spill procedures.
- Emergency response for sealed sources or devices containing sealed sources.
- Safety procedures for therapy treatments.
- Transportation.
- Waste management.

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