Brachytherapy Overview

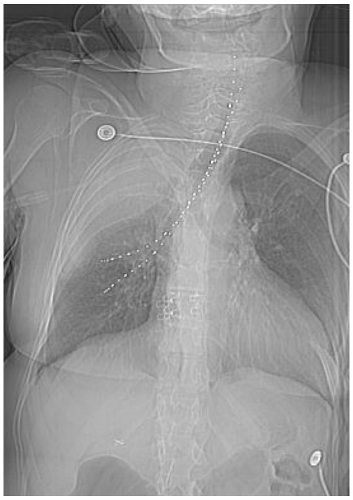
THOMPSON CANCER SURVIVAL CENTER

THE UNIVERSITY of TENNESSEE UT

Overview of Brachytherapy

What is Brachytherapy?

- Brachytherapy is a special procedure in therapeutic radiology that utilizes the irradiation of a target with radioactive sources placed at short distances from the target
- The sources can be implanted in the target tissue directly (*interstitial brachytherapy*) or are placed at distances of the order of a few millimeters from the target tissue (*intracavitary brachytherapy*), or externally on structures (*surface plaques or molds*)

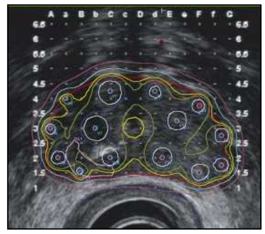


THOMPSON CANCER SURVIVAL CENTER

THE UNIVERSITY of TENNESSEE UT

Overview of Brachytherapy

- Brachytherapy generates highly conformal dose distributions because radioactive seeds are implanted directly within or in the vicinity of the target tissue
- For example, in a typical interstitial brachytherapy implant, 50 to 100 radioactive seeds, each about the size of a rice grain
- The sources are implanted in the tumor using image-guided implantation techniques
  - Ultrasound
  - CT
  - MRI
  - Fluoroscopy



Overview of Brachytherapy

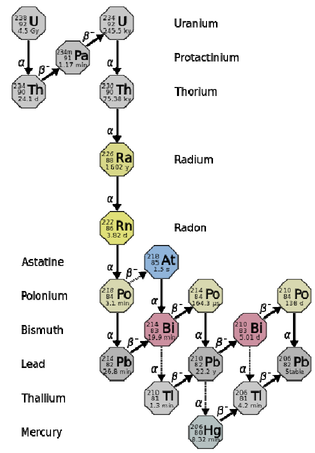
- Most brachytherapy procedures uses gamma-emitting radionuclides
- Radionuclides such as ^{137}Cs and ^{192}Ir emit high-energy gammas
  - Penetrate deeply and also require heavy shielding for radiation protection of the personnel and the patient's family
- Brachytherapy with low-energy gamma emitters, like ^{125}I and ^{103}Pd, requires minimal shielding for radiation protection
- Beta-emitting sources are commonly used as unsealed sources for systemic therapy

Isotope	Average[a] photon energy (MeV)	Half-life	HVL in lead (mm)
Co-60	1.25	5.26 a	11
Cs-137	0.66	30 a	6.5
Au-198	0.41	2.7 d	2.5
Ir-192	0.38	73.8 d	3
I-125	0.028	60 d	0.02
Pd-103	0.021	17 d	0.01

Overview of Brachytherapy Physics

Brachytherapy History

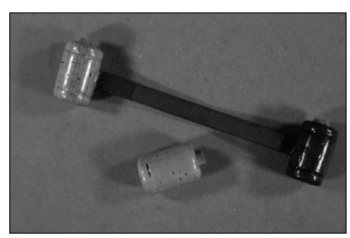
- The brachytherapy procedures were performed with radium
- In 1901, Danlos and Bloc irradiated lupus at the St. Louis Hospital in Paris
- In 1905 Abbe, performed radium implants in the US
- In 1906 Danne, Dominici, Degrais and Wickham created the Radium Biological Laboratory in Paris
- In 1909 Finze started treating patients with radium in England
- In 1909, the first radium therapy book was published by Wickham and Degrais



Overview of Brachytherapy Physics

Brachytherapy History

- After the first world war several different schools of brachytherapy were created
  - Radium Hemmet in Stockholm
  - Memorial Hospital in New York
  - the Radium Institute in Paris
- The Stockholm and Paris methods for intracavitary radiation were described in 1914 and 1919
- During the 1930s the rules of the Manchester System for interstitial radium therapy were published by Patterson and Parker



Colpostat and a cork to be loaded radium tubes for an intracavitary brachytherapy

A radium needle implant for a lower lip carcinoma.

Overview of Brachytherapy Physics

Brachytherapy History

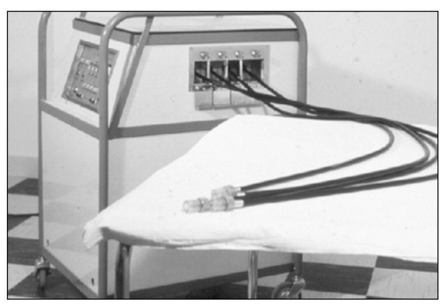
- During the 1950s and 1960's the first developments in afterloading were made and other new radioactive sources were developed, such as iodine and cesium
- New rules of implantation and dose calculation for interstitial brachytherapy of iridium wire sources were established in Paris by Pierquin, Chassagne and Dutreix
- This Paris System of dosimetry became widely used and the clinical results of brachytherapy improved
- These wire sources introduced new possibilities for implantations as a result of their flexibility and adaptability

The creators of the Paris System (Bernard Pierquin, Andrée Dutreix, Daniel Chassagne, Alain Gerbaulet)

Overview of Brachytherapy Physics

Brachytherapy History

- During the last two decades, the development of remote afterloading machines has allowed complete radiation protection
- In addition, the ability to vary source positions and the time that a source is in that position (*dwell time*) has also improved the quality of treatment
- Modern imaging facilities allow more accurate definition of target volume and the localization of adjacent normal tissue

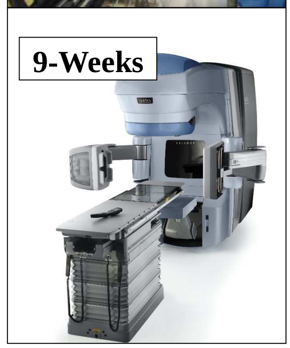


One of the first remote afterloading machines for gynecological tumors : Curietron prototype (1965)

Overview of Brachytherapy Physics

Brachytherapy History

- Most brachytherapy procedures today are performed in one-day surgery suites without the need for hospitalization.
- These factors and the depth dose characteristics make brachytherapy a very cost effective and patient friendly procedure compared to 3-D conformal radiotherapy (*3DCRT*) or intensity-modulated radiation therapy (*IMRT*)
- A key advantage of 3DCRT or IMRT over brachytherapy is that they are noninvasive



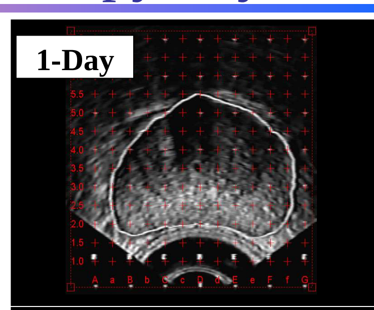
THOMPSON CANCER SURVIVAL CENTER

THE UNIVERSITY of TENNESSEE UT

Overview of Brachytherapy Physics

Brachytherapy History

- Both 3DCRT and IMRT are very sensitive to patient localization and setup errors because of high dose gradients
- Therefore, the target must be placed at the right position with a precision of about a millimeter relative to the linear accelerator (*linac*) daily over a course of many weeks
- Brachytherapy is far more forgiving of localization and target motion errors because the implanted sources of radiation in an interstitial implant move with the target

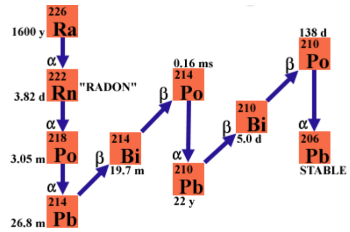


THOMPSON CANCER SURVIVAL CENTER

THE UNIVERSITY of TENNESSEE UT

Photon-Emitting Radionuclides: ^{226}Ra

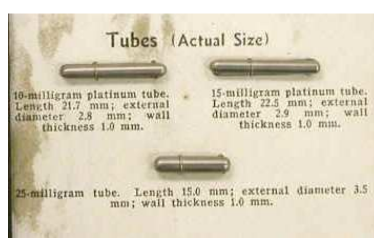
- Radium decays into radon, with a half-life of about 1622 years; radon is a heavy, inert gas that in turn disintegrates into its daughter products
- As a result of the decaying processes from ^{226}Ra to ^{206}Pb, at least 49 photons are emitted, with energies ranging from 0.184 to 2.45 MeV
- The average energy of the gamma rays from radium in equilibrium with its daughter products and filtered by 0.5 mm of platinum is 0.83 MeV
- There are also some high-energy beta particles and alpha particles emitted by this radionuclide that are absorbed by the encapsulation material



Radium's appearance is almost pure white, but it readily oxidizes on exposure to air, turning black

Photon-Emitting Radionuclides: ^{226}Ra

- ^{226}Ra and ^{222}Rn are virtually unused today, primarily because of the hazards of chemical and radioactive toxicity of radium and its by-products
- In addition, the high energy of the photons makes it difficult to shield
- The radioactive material was supplied mostly in the chemical form of radium sulfate or radium chloride loaded into cells about 1 cm long and 1 mm in diameter
- A typical radium source might contain 1 to 3 cells, depending on the source length
- Radium sources were manufactured as needles or tubes in a variety of lengths and activities



Photon-Emitting Radionuclides: ^{137}Cs

- ^{137}Cs is a by-product of nuclear fission and is generated in nuclear reactors
- It has a half-life of about 30 years and decays through beta emission (*93.5%*) to the metastable state of ^{137}Ba (*half-life 2.5 minutes*) and then through gamma-ray emissions
- The gamma rays emitted have a photon energy of 662 keV and the HVL for ^{137}Cs sources are less hazardous and require less shielding compared to that required for ^{226}Ra sources
- Although the half-life of ^{137}Cs is much less than that of ^{226}Ra, some of the cesium sources may have to be replaced after about 7 years

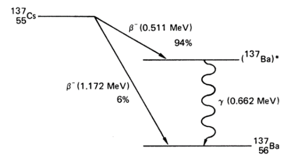


TABLE 3-3 Reactors with Significant Isotope Production Capability

Country	Location	Reactor	Power (MW)	Isotopes Currently Produced
United States	Hanford, Washington	FFTF	400	None; reactor in standby mode
	Idaho	ATR	250	^{60}Co, ^{63}Ni, ^{192}Ir, ^{153}Gd
	Oak Ridge National Laboratory	HFIR	100	^{252}Cf and other transuranics, ^{85}Kr, ^{64}Cu, ^{67}Cu, ^{117m}Sn, ^{195m}Pt, others
	Brookhaven National Laboratory	HFBR	60	^{47}Sc, ^{55}Fe, $^{64/67}$Cu, ^{119}Sn, ^{153}Sm, ^{186}Re $^{198/199}$Au, others
	University of Missouri	MURR	10	^{32}P, ^{192}Ir, ^{35}S, ^{198}Au, ^{186}Re, ^{51}Cr, ^{103}Pd, many others
	Los Alamos National Laboratory	OWR	8	None; possible production of ^{99}Mo
	Georgia Tech	GTTR	5	^{90}Y, ^{24}Na, ^{18}F, ^{140}La
	Massachusetts Institute of Technology	MITR-II	5	^{165}Dy, ^{166}Ho, ^{198}Au
	New Mexico	Sandia	2	None; possible production of ^{99}Mo
	Oregon State	OSTR	1	Variety
Belgium	Mol	BR-2	100	^{99}Mo, ^{133}Xe, ^{131}I, ^{192}Ir, others
Sweden	Nykoping	Studsvik	50	^{32}P, ^{60}Co, ^{192}Ir, ^{89}Sr, ^{90}Y, others; principal supplier for Amersham
The Netherlands	Petten	HFR	45	^{99}Mo, ^{133}Xe, ^{131}I, ^{192}Ir, others
Canada	Chalk River	NRU	40	^{99}Mo, ^{60}Co, ^{14}C, ^{32}P, ^{89}Sr, ^{90}Y, ^{125}I, ^{131}I, ^{137}CS, ^{133}Xe, ^{192}Ir
France	Saclay	OSIRIS	70	^{99}Mo, ^{133}Xe, ^{131}I, ^{192}Ir, others
	Grenoble	SILOE	35	^{99}Mo, ^{133}Xe, ^{131}I, ^{192}Ir, others
Poland	Warsaw	Maria	30	Possible fission products

Photon-Emitting Radionuclides: ^{137}Cs

- For ^{137}Cs sources, the radioactive material is supplied in the form of insoluble powders or ceramic microspheres labeled with cesium and doubly encapsulated in stainless steel for both needles and tubes
- The beta particles and low-energy characteristic x-rays are totally absorbed by the stainless steel encapsulation, making the clinical source a pure gamma emitter
- The active length of the tube sources typically used is 10 to 50 mm and diameters are approximately 1.5 to 2.0 mm

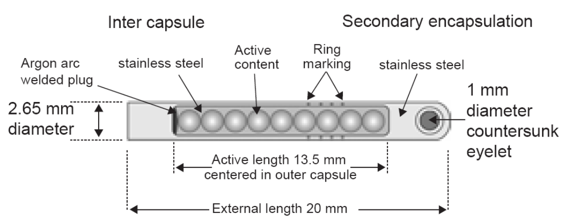
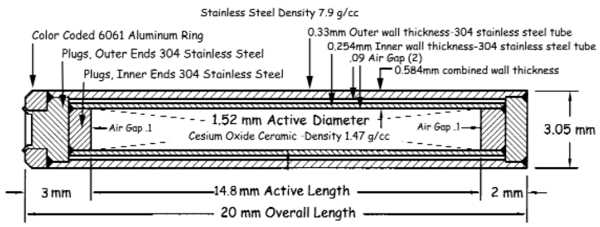


Fig. 1.1 Diagrammatic representation of a caesium-137 tube similar to an Amersham 'J-Type' tube.

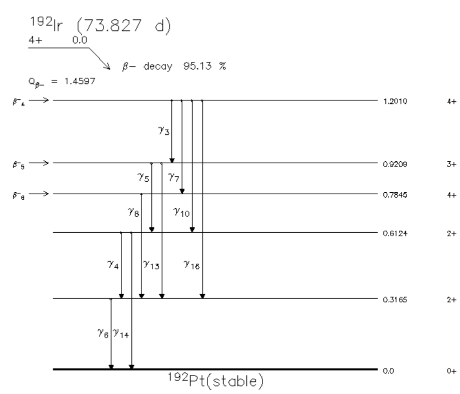
Photon-Emitting Radionuclides: ^{137}Cs

Item #	mg Ra-226 Equivalent (mg)	Color Code	Apparent Nominal Cesium-137 Activity (mCi)	Air Kerma Strength Nominal (µGy m²/h)	Air Kerma Manufacturing Range (µGy m²/h)	Air Kerma Manufacturing Tolerance (%)
067-6505	5	Purple	12.5 mCi	36.1	35.0 - 39.7	+10.0/-3.0
067-6510	10	Red	25.0 mCi	72.3	70.1- 79.5	+10.0/-3.0
067-6515	15	Black	37.5 mCi	108.4	105.1 - 119.2	+10.0/-3.0
067-6520	20	White	50.0 mCi	144.5	140.2 - 159.0	+10.0/-3.0
067-6525	25	Blue	62.5 mCi	180.7	176.2 - 197.9	+9.5/-2.5
067-6530	30	Orange	75.0 mCi	216.8	212.5 - 235.4	+8.6/-2.0
067-6535	35	Green	87.5 mCi	252.9	252.9 - 269.8	+6.7/-0.0
067-6540	40	Gray	100.0 mCi	289.1	289.1 - 308.2	+6.6/-0.0



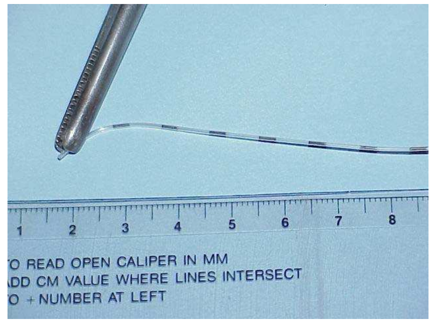
Photon-Emitting Radionuclides: ^{192}Ir

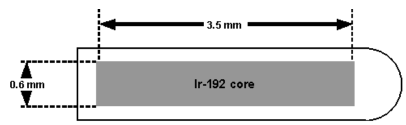
- ^{192}Ir is produced in a nuclear reactor via neutron capture by stable ^{191}Ir
- ^{192}Ir has a half-life of 73.83 days and has a very complicated gamma-ray spectrum with an average energy of about 0.38 MeV
- Because the gamma-ray energy is lower than ^{226}Ra or ^{137}Cs, ^{192}Ir sources require less shielding
- The HVL thickness for this radionuclide is about 2.5 mm



Photon-Emitting Radionuclides: ^{192}Ir

- ^{192}Ir sources are available in the form of small sources placed in nylon ribbons for safety purposes
- Typically, these sources are press-fitted, normally at 1-cm intervals, into nylon ribbons with an outer diameter of about 0.8 mm
- 3.5 mm long with a diameter of about 0.3 mm
  1. *Inner core alloy composed of 30% iridium and 70% platinum, encapsulated in stainless steel*
  2. *Inner core alloy composed of 10% iridium and 90% platinum surrounded by a 0.1-mm thick cladding of platinum*

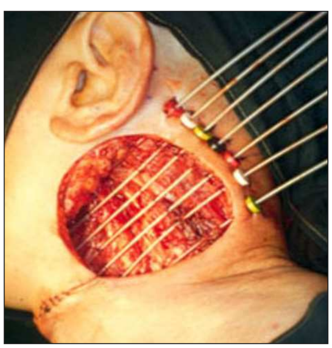


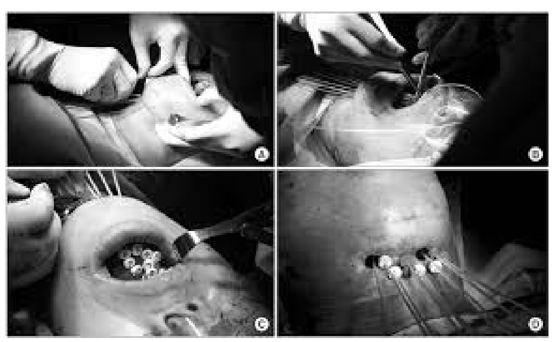


THOMPSON CANCER SURVIVAL CENTER

THE UNIVERSITY of TENNESSEE UT

Photon-Emitting Radionuclides: ^{192}Ir





Catheters are placed in the patient and the Ir-192 ribbons are loaded into each catheter

THOMPSON CANCER SURVIVAL CENTER

THE UNIVERSITY of TENNESSEE UT

Photon-Emitting Radionuclides: ^{192}Ir

- ^{192}Ir sources are available also available as high activity sources (*10 Ci*) for remote afterloading devices
- A single source is welded onto the end of a drive cable that remotely driven into and out of the patient
- The source is stepped into multiple dwell positions
- Varian and Elekta (Nucleatron) are the primary manufacturers in the United States

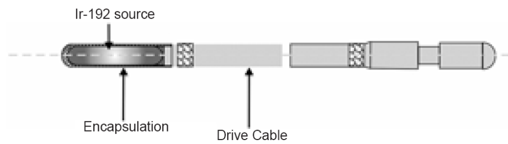
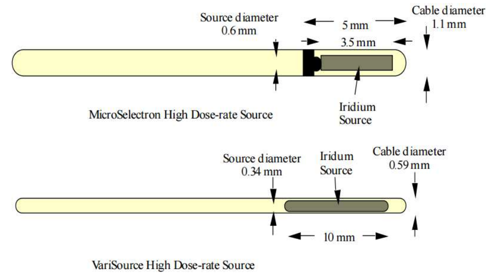
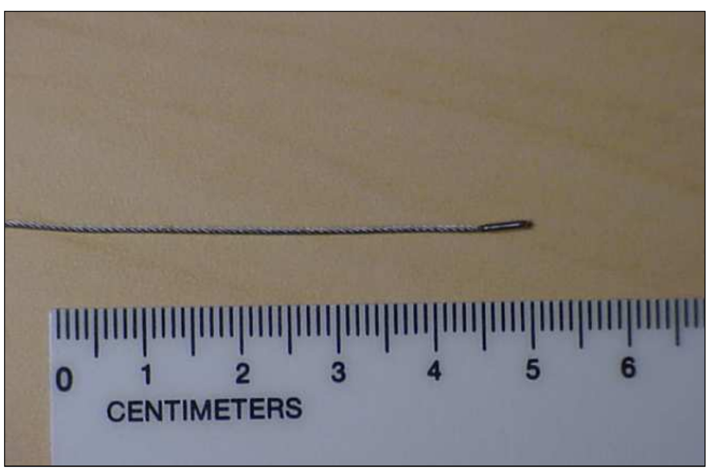


Fig. 1.4 Typical iridium-192 HDR afterloading source. Dimensions will depend on afterloader type.

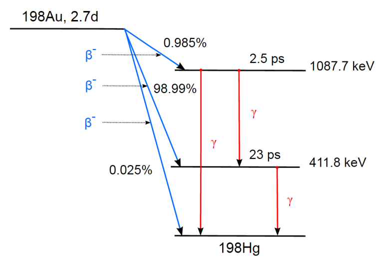


Photon-Emitting Radionuclides: ^{192}Ir



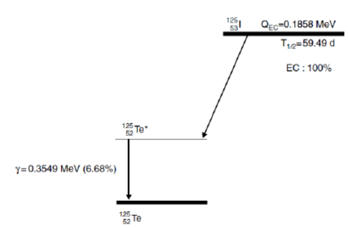
Photon-Emitting Radionuclides: ^{198}Au

- ^{198}Au is produced in a reactor by bombarding a gold target with neutrons
- ^{198}Au has a half-life of 2.7 days and 99% of its gamma rays are emitted with an energy of 0.412 MeV
- A typical gold seed, also known as a gold "grain," is encapsulated in 0.1 mm of platinum, which is sufficient to absorb the beta rays emitted by ^{198}Au
- The outside dimensions of a ^{198}Au source are 2.5 mm long and 0.8 mm in diameter.
- Because of their short half-life, ^{198}Au seeds are used in permanent implants



Photon-Emitting Radionuclides: ^{125}I

- 125-I has a half-life of 59.6 days decaying exclusively by electron capture process to an excited state of 125-Te
- This is followed by spontaneous decay to the ground state with the emission of 35.5 keV gamma rays
- Characteristic x-rays in the range of 27 to 32 keV are also emitted as a consequence of the electron capture and internal conversion processes
- The HVL thickness for the photons emitted by encapsulated sources containing this radionuclide is about 0.025 mm of lead



Photon-Emitting Radionuclides: ^{125}I

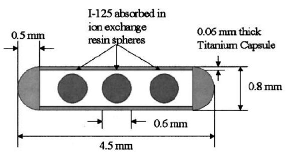


Figure 1a. 6701, 6702 sources. Model 6702 is shown. In the 6701, the central resin sphere is replaced with a radiopaque marker. [Reprinted from Heintz, B. H., R. E. Wallace, and J. M. Hevezi, "Comparison of I-125 sources used for permanent interstitial implants," *Med Phys* 28:671–682.

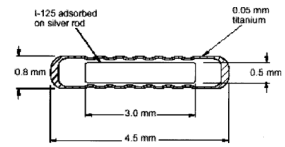


Figure 1c. Model 6733. [Reprinted from Meigooni, A. S., S. A. Dini, K. Sowards, J. L. Hayes, and A. Al-Otoom, "Experimental determination of the TG-43 dosimetric characteristics of EchoSeed™ model 6733 ^{125}I brachytherapy source," *Med Phys* 29:939–942.

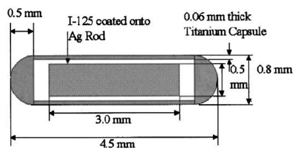


Figure 1b. Model 6711. [Reprinted from Heintz, B. H., R. E. Wallace, and J. M. Hevezi, "Comparison of I-1 sources used for permanent interstitial implants," *Med Phys* 28:671–682.

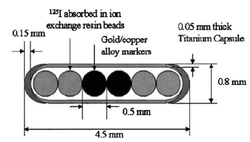
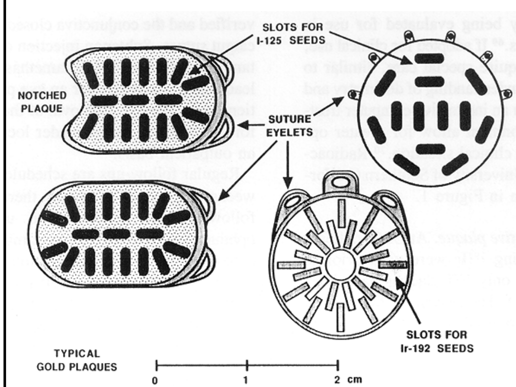


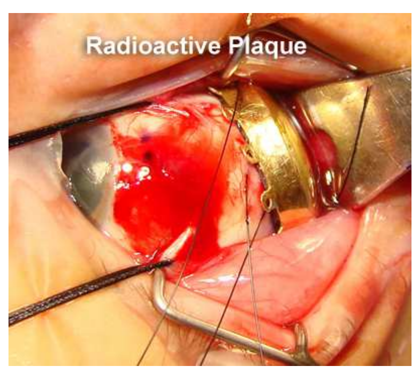
Figure 4. NAS Model 3631-A/M ^{125}I and Model 3633 ^{103}Pd sources. [Reprinted from Heintz, B. H., R. E. Wallace, and J. M. Hevezi, "Comparison of I-125 sources used for permanent interstitial implants," *Med Phys* 28:671–682. © 2001,

THOMPSON CANCER SURVIVAL CENTER

THE UNIVERSITY of TENNESSEE

Photon-Emitting Radionuclides: ^{125}I



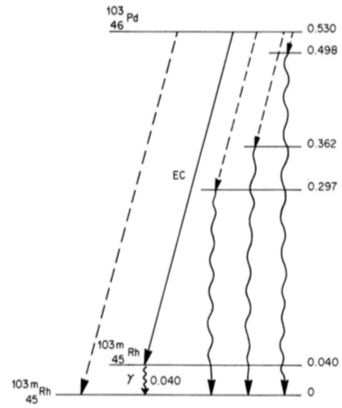


THOMPSON CANCER SURVIVAL CENTER

THE UNIVERSITY of TENNESSEE

Photon-Emitting Radionuclides: ^{103}Pd

- 103-Pd can be produced in a nuclear reactor when stable 102-Pd captures a thermal neutron
- It can also be produced in a cyclotron by bombarding protons into a rhodium target
- With a half-life of 17 days, it decays via electron capture process with the emission of characteristic x-rays in the energy range of 20 to 23 keV
- The weighted mean photon energy is 20.7 keV, and the HVL of photons emitted from encapsulated sources of 103-Pd is about 0.004 mm of lead



Photon-Emitting Radionuclides: ^{103}Pd

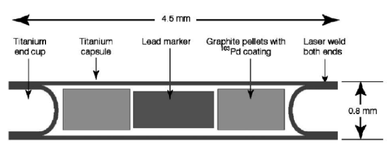


Figure 2. Model 200. [Reprinted from Rivard, M. J., B. M. Coursey, L. A. DeWerd, W. F. Hanson, M. S. Huq, G. S. Ibbott, M. G. Mitch, R. Nath, and J. F. Williamson, "Update of AAPM Task Group No. 43 Report: A revised AAPM protocol for brachytherapy dose calculations," *Med Phys* 31:633–674.

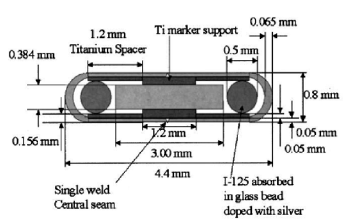
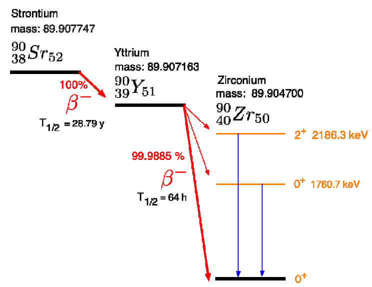


Figure 5. Draximage model LS-1 ^{125}I source. [Reprinted from Heintz, B. H., R. E. Wallace, and J. M. Hevezi, "Comparison of I-125 sources used for permanent interstitial implants," *Med Phys* 28:671–682.

Beta-Emitting Radionuclides: ^{90}Sr

- 90-Sr decays with a half-life of 28.9 years to 90-Y and yields only beta rays with a maximum energy of 0.5 MeV
- The daughter isotope 90-Y is a nearly pure beta emitter (*99.99% of decay events*) with a 64-hour half-life and emits betas with a maximum energy of 2.27 MeV
- This radionuclide is a beta-ray emitter suitable for treatment of superficial lesions
- The most common application for 90-Sr is in a ophthalmic applicator that used for treatment of lesions in the eye where the depth of penetration needed is a few millimeters



Beta-Emitting Radionuclides: ^{90}Sr

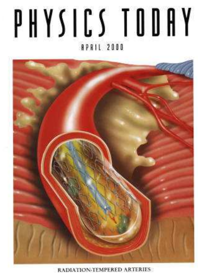
- METASTRON is a solution of strontium-89 chloride for intravenous administration for the relief of bone pain in patients with painful bone metastases
- METASTRON is an pain reliever that is a cost-efficient alternative to opioids
- Following intravenous injection, METASTRON is absorbed by the bones at the site of metastatic cancer lesions
- In patients with extensive skeletal metastases, over half the injected dose is retained in the bone lesions
- Systemic radiotherapy with METASTRON irradiates the cancer cells and relieves the pain caused by these bone lesions

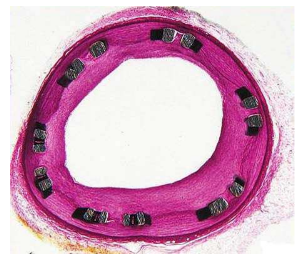
THOMPSON CANCER SURVIVAL CENTER

THE UNIVERSITY of TENNESSEE UT

Beta-Emitting Radionuclides: ^{90}Sr & ^{32}P

- The second most common application for ^{90}Sr was IVB for prevention of restenosis in coronary or peripheral arteries
- Angioplasty is the mechanical widening of a narrowed or totally-obstructed blood vessel
- Angioplasty can use balloon catheters to compresses the plaque and stretches the artery wall
- Restenosis is the re-narrowing of a coronary artery after it has been treated with angioplasty or stenting





Beta-Emitting Radionuclides: ^{90}Sr & ^{32}P

- The BetaCath IVB systems consisted of a string (*"train"*) of ^{90}Sr seeds that were encapsulated in stainless steel, and the activity is contained in a ceramic matrix
  - *The seeds are stored in a hand-held delivery device and are advanced by a closed loop hydraulic system, which uses sterile saline to advance (and then retract) the seeds into and out of a non-centered catheter*
- The Galileo IVB device utilized a linear wire source of 32P imbedded at the end of a steel cable
  - *A specially designed catheter was employed to center the source within the lumen*

Beta-Emitting Radionuclides: ^{90}Sr & ^{32}P

- The use of IVB ended very abruptly with the FDA approval of drug-eluting stents
- Unlike traditional (*bare metal*) stents, drug-eluting stents slowly releases a drug
- Restenosis is prevented by the suppression of tissue growth at the stent site and local modulation of the body's inflammatory and immune responses
- Three drugs (*sirolimus*, *everolimus and paclitaxel*) have been demonstrated safety and efficacy in this application in controlled clinical trials by stent device manufacturers
- However, in 2006 three broad European trials seem to indicate that drug-eluting stents may be susceptible to an event known as "late stent thrombosis", where the blood-clotting inside the stent can occur one or more years post-stent
- While this event is rare, it is extremely dangerous and is fatal in about one-third of cases when the thrombosis occurs

Neutron-Emitting Radionuclides: ^{252}Cf

- The only neutron emitter that has been used clinically is Californium-252, which has a 2.645 year half-life and decays by alpha emission (97%) and nuclear fission (3%)
- The fission decay path emits neutrons (*one microgram spontaneously emits 170 million neutrons per minute*) with a spectrum of energies similar to that of a fission reactor and with an average energy of 2.15 MeV
- A significant number of gamma rays with an average energy of 0.7 to 0.9 MeV are also emitted from the fission events and from the decay of fission products

Neutron-Emitting Radionuclides: ^{252}Cf

- The seed is about 6 mm long and 0.8 mm in diameter, and is intended for use in temporary implants
- One of the clinical 252Cf sources has a central core consisting of a ceramic metal mixture of 252Cf oxide and palladium
- The advantage of neutron emitters is that their interactions with tissues produce heavy charged particles that have much higher linear energy transfer (*LET*)
- Neutrons are theoretically more effective against hypoxic tumors
- Neutrons are rarely used except in a few major medical research centers

Types of Brachytherapy

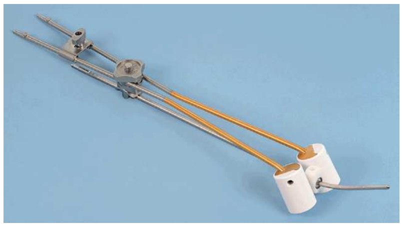
Intraluminal Application

- Intraluminal Brachytherapy is a subclass of intracavitary brachytherapy
- Radioactive sources are inserted in the lumen of a vessel such as the blood vessel, bronchus, esophagus, or bile duct

Types of Brachytherapy

Intracavitary

- Intracavitary techniques involve placing radioactive sources into custom-designed applicators, which are placed in body cavities
- This is commonly used for the treatment of gynecological tumors where the radioactive material can be placed in the uterine cavity and vagina
- This is also the most common brachytherapy procedure done worldwide



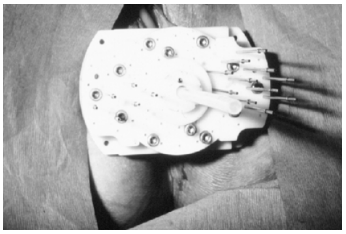
THOMPSON CANCER SURVIVAL CENTER

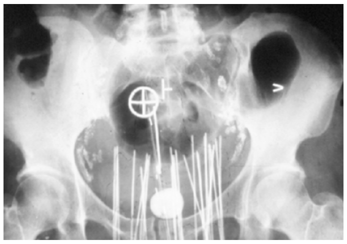
THE UNIVERSITY of TENNESSEE UT

Types of Brachytherapy

Interstitial Application

- Interstitial brachytherapy involves placing the sealed radioactive sources within tissues
- This is the most common brachytherapy procedure performed in the United States
- The most common application is permanent implantation for treatment of prostate cancer
- Less common are interstitial implants such as the Syed implants for gynecological tumors





THOMPSON CANCER SURVIVAL CENTER

THE UNIVERSITY of TENNESSEE UT

Types of Brachytherapy

Surface Application

- In this technique, the radioactive sources are placed in custom-designed molds or plaques
- The molds or plaques are then placed on the surface of the target tissue rather than being placed inside the target tissue
- These techniques are not very commonly used

THOMPSON CANCER SURVIVAL CENTER

THE UNIVERSITY of TENNESSEE UT

Brachytherapy Treatment Planning

Tables and Nomograms Techniques

- Before the use of computerized treatment planning systems became popular, clinicians relied on generalized systems of rules for pre-implant or intraoperative planning (*i.e., the Paterson-Parker System, the Quimby system, the Memorial system, the Paris system, the Manchester system, etc.*)
- All of these early systems depended on tables and nomograms to select number, location, and activities of radioactive sources in an implant to achieve desired dose coverage based on the culmination of years of clinical experience
- However, the actual delivered dose distribution and the underlying anatomy is at best approximate and qualitative with these traditional systems

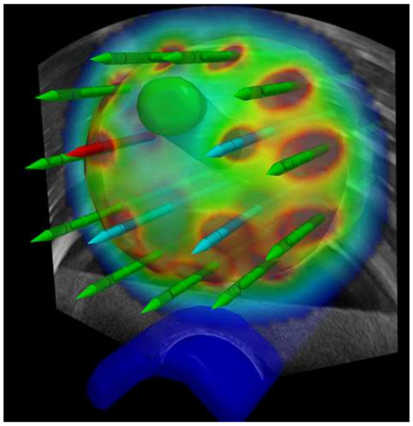
THOMPSON CANCER SURVIVAL CENTER

THE UNIVERSITY of TENNESSEE UT

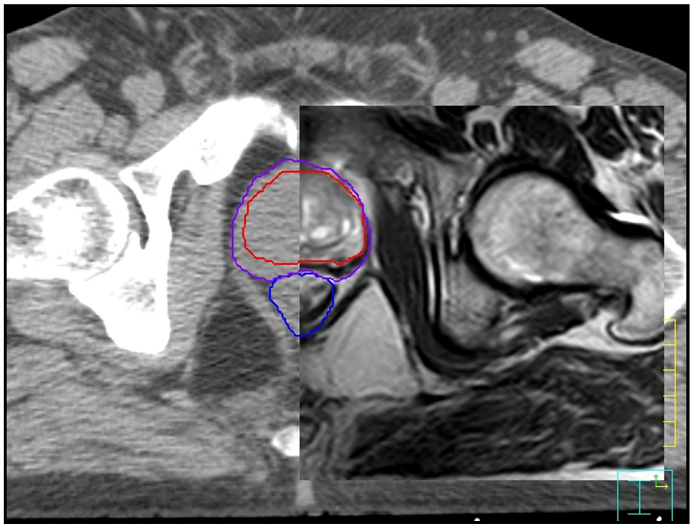
Brachytherapy Treatment Planning

Image-Guided Techniques

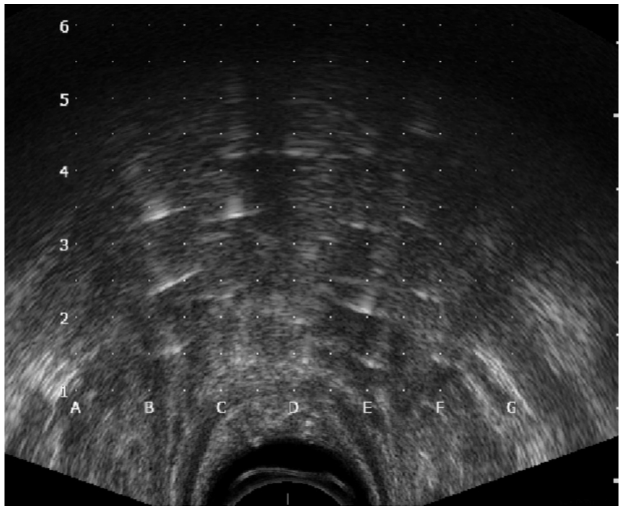
- In the last decade, two major advances have been made in brachytherapy treatment planning.
  1. Image based treatment planning and dose evaluation and
  2. Development of computer-assisted dose optimization algorithms for brachytherapy
- Developments in 3D image-based source localization techniques have made it possible to calculate and display dose distributions directly on top of the images of involved anatomy



Brachytherapy Treatment Planning



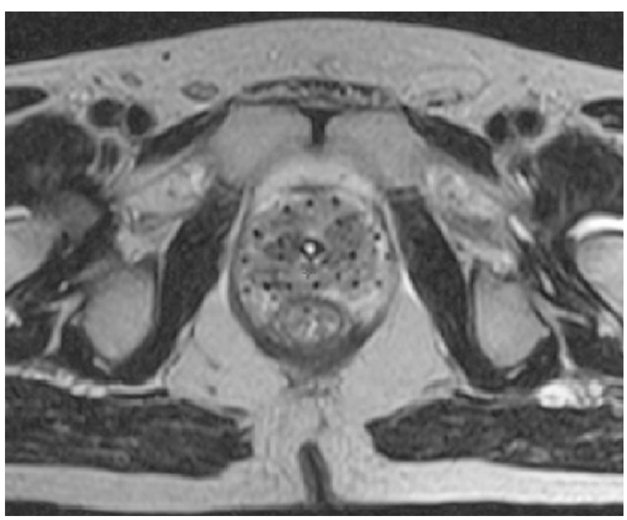
Brachytherapy Treatment Planning



THOMPSON CANCER SURVIVAL CENTER

THE UNIVERSITY of TENNESSEE

Brachytherapy Treatment Planning



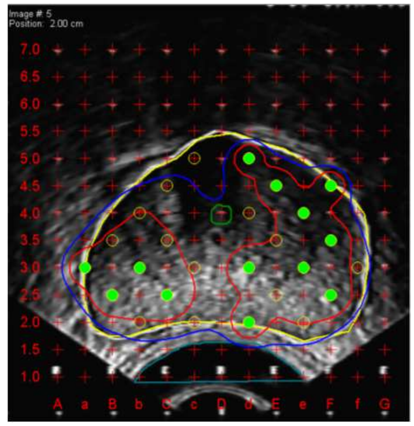
THOMPSON CANCER SURVIVAL CENTER

THE UNIVERSITY of TENNESSEE

Brachytherapy Treatment Planning

Image-Guided Techniques

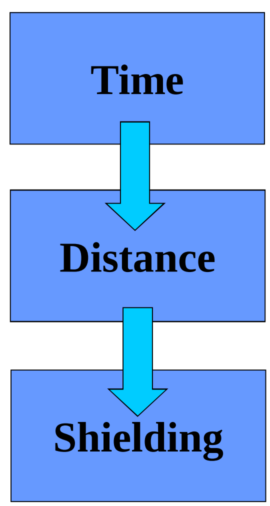
- This enables clinical decisions to be made based on the visualization of dose distributions with respect to patient anatomy instead of dose tables
- It has become routine that the target volume and normal organs be localized from CT, magnetic resonance imaging (*MRI*), or ultrasound (*US*) images
- Pre-implant planning can now be carried out by inspecting the instantaneous dose distribution changes resulting from different source placements



Brachytherapy Loading Systems

Manual Hot Loading

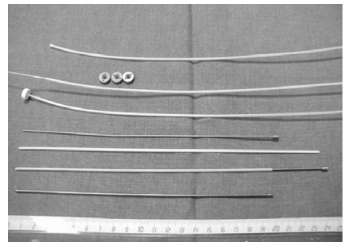
- When brachytherapy was first introduced over a century ago, the radiotherapy sources were manually introduced into the tumor, hence subjecting the physicians and other operating room personnel to unwanted radiation exposure and the subsequent adverse effects of radiation
- Direct “hot” loading is almost never used today because of its associated radiation hazards that can now be reduced by the adoption of alternative techniques



Brachytherapy Loading Systems

Manual Afterloading Techniques

- Since 1950s, most brachytherapy procedures have been performed using afterloading techniques where hollow needles, catheters, or applicators are first inserted into the target
- The applicators are usually inserted in the operating room
- Once the position of the applicators is confirmed, the radioactive material is introduced manually into the applicator
- This procedure is usually performed in the patient's room rather than the operating room



Dose Rates Used in Brachytherapy

Low Dose Rate (LDR):

- 0.4 to 2.0 Gy per Hour is the traditional dose rate for permanent and manually afterloaded brachytherapy
- These implants are generally manually afterloaded, although LDR remote afterloaders are also available, but not commonly used
- Most of the long-term clinical experience with brachytherapy is with LDR
- Many of the advantages of brachytherapy are attributed to the radiobiology of continuous LDR irradiation in LDR brachytherapy

Temporary implant LDR techniques result in typical treatment times of 3 to 5 days, which requires hospitalization of the patient

Dose Rates Used in Brachytherapy

Medium Dose Rate (MDR):

- 2 to 12 Gy per Hour are rarely used since it gives excessive exposure if such an implant is manually loaded, and this dose rate does not have the advantages of outpatient brachytherapy afforded by the HDR technique
- Pulsed dose rate (PDR) brachytherapy afterloaders were developed in this dose rate realm to replicate the LDR experience in terms of total treatment duration but with the source exposed in pulses for only 5 to 10 minutes per hour

Dose Rates Used in Brachytherapy

High Dose Rate (HDR):

- More than 12 Gy per Hour is considered High Dose Rate Brachytherapy
- HDR brachytherapy utilizes very high activity sources, typically a 10 Ci 192Ir source, which produces a very intense radiation field around the source.
- Since HDR brachytherapy is associated with high radiation exposure rates, it is only used in well-shielded bunkers (1-2 ft concrete).
- Depending on distance and usage factors, 1 to 2 feet of concrete shielding or its equivalent in other materials is required.

Dose Rates Used in Brachytherapy

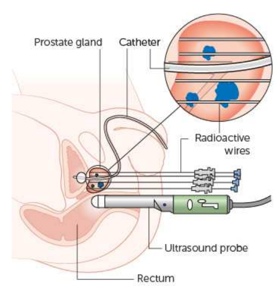
High Dose Rate (HDR):

- Treatment is delivered by remote-control techniques rather than manual loading.
- The usual dose rate in the commercially available HDR brachytherapy systems is about 100 to 300 Gy per hour, allowing the treatments to be given in only a few minutes on an outpatient basis.
- The introduction of HDR remote brachytherapy, with its advantages of thorough radiation protection and outpatient treatments, has led to a resurgence of interest in brachytherapy.

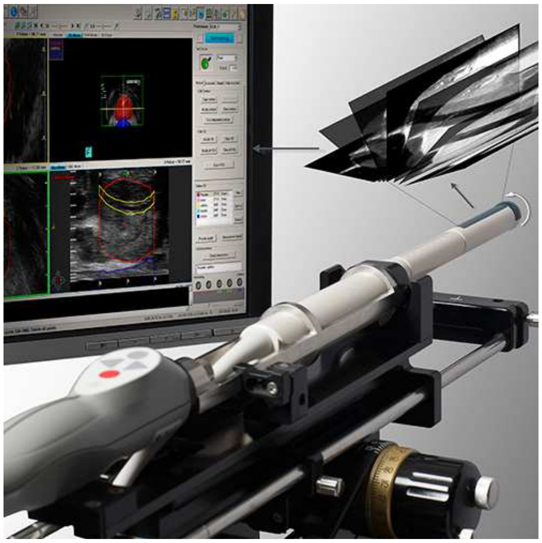
Durations of Brachytherapy

Permanent Implants

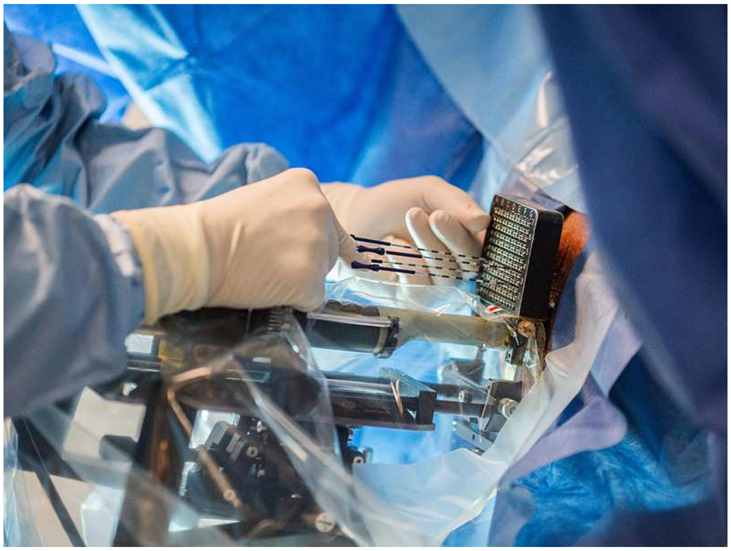
- Radioactive sources are permanently implanted into the tumor,
  - Patient is released from the hospital with radioactive material in him or her
  - Radioactivity is allowed to decay within the patient
- Permanent implants are performed with relatively short half-life radioisotopes like 125-I or 103-Pd
- Decays to a safe level within a few weeks or months
- Low energy does not present a radiation safety risk



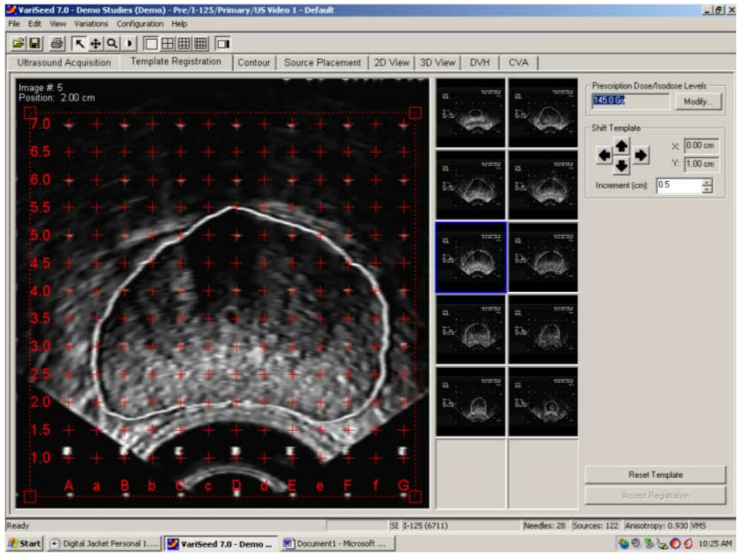
Prostate Seeds: Ultrasound Guidance



Prostate Seeds: Needle Placement



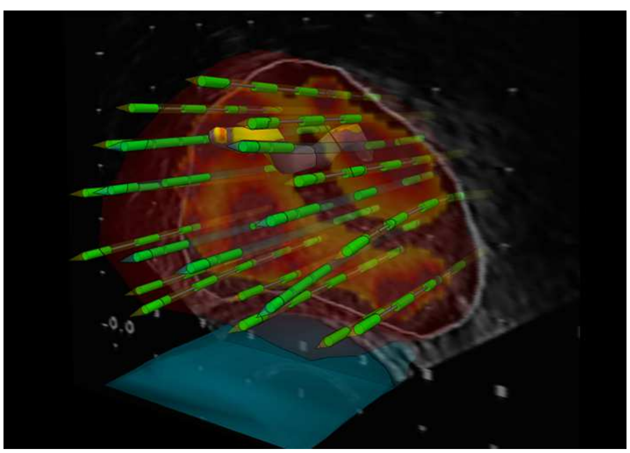
Prostate Seeds: Needle Placement

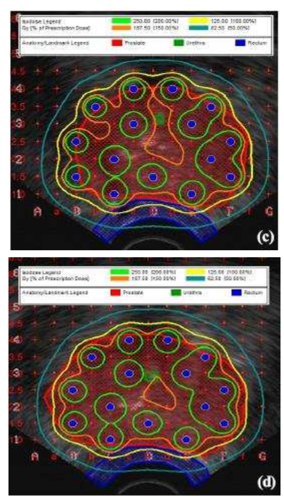


Prostate Seeds: Mick Applicator

Prostate Seeds: Pre-Loaded Needles

Prostate Seeds: Treatment Planning

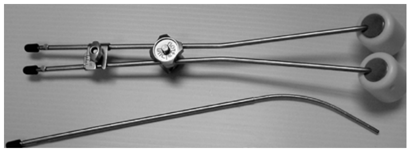




Temporary Low Dose Rate Implants

Temporary Implants

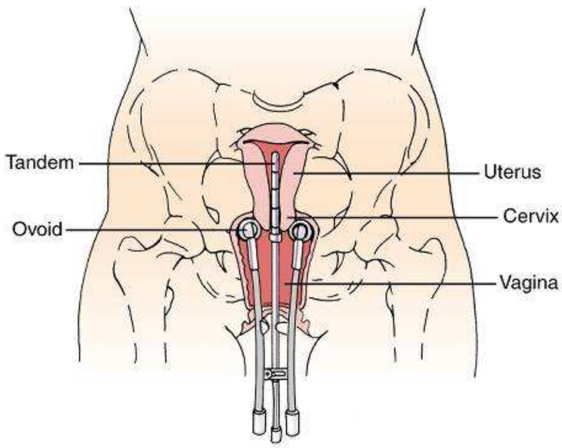
- Radioactive material is temporarily implanted close to the tumor and is removed once the radiation dose has been delivered
- Lower precision and accuracy can be tolerated in Low Dose Rate (*LDR*) temporary implants
- Dwell locations and times may be adjusted to correct for poor needle placement



THOMPSON CANCER SURVIVAL CENTER

THE UNIVERSITY of TENNESSEE UT

Temporary Low Dose Rate Implants

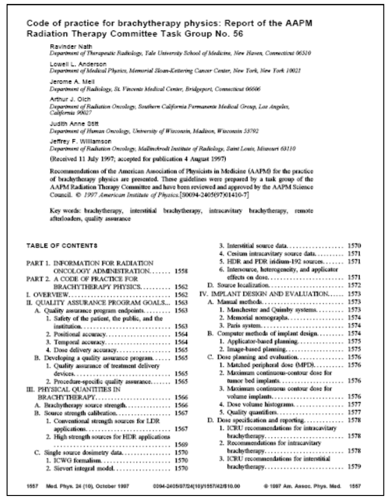


THOMPSON CANCER SURVIVAL CENTER

THE UNIVERSITY of TENNESSEE UT

LDR Source Acceptance Testing

- The local physicist has the responsibility of assuring the accuracy of the calibration of the sources used for brachytherapy
- TG-56 states "*Every institution practicing brachytherapy shall have a system for measuring source strength with secondary traceability for all source types used in its practice*"



Code of practice for brachytherapy physics: Report of the AAPM Radiation Therapy Committee Task Group No. 56

Ravinder Nath
Department of Therapeutic Radiology, Yale University School of Medicine, New Haven, Connecticut 06510

Lowell L. Anderson
Department of Medical Physics, Memorial Sloan-Kettering Cancer Center, New York, New York 10021

Jerome A. Meli
Department of Radiology, St. Vincents Medical Center, Bridgeport, Connecticut 06606

Arthur J. Olch
Department of Radiation Oncology, Southern California Permanente Medical Group, Los Angeles, California 90027

Judith Anne Stitt
Department of Human Oncology, University of Wisconsin, Madison, Wisconsin 53792

Jeffrey F. Williamson
Department of Radiation Oncology, Mallinckrodt Institute of Radiology, Saint Louis, Missouri 63110

(Received 11 July 1997; accepted for publication 4 August 1997)

Recommendations of the American Association of Physicists in Medicine (AAPM) for the practice of brachytherapy physics are presented. These guidelines were prepared by a task group of the AAPM Radiation Therapy Committee and have been reviewed and approved by the AAPM Science Council. © *1997 American Institute of Physics.*[S0094-2405(97)01410-7]

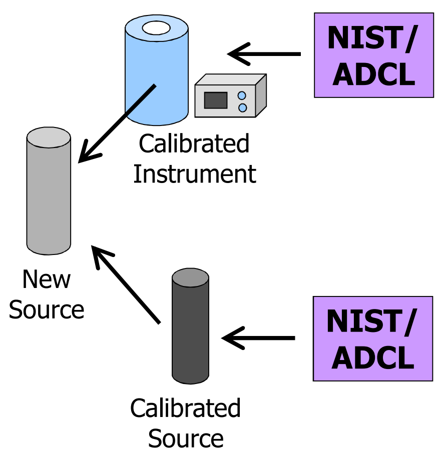
Key words: brachytherapy, interstitial brachytherapy, intracavitary brachytherapy, remote afterloaders, quality assurance

TABLE OF CONTENTS

1557 Med. Phys. 24 (10), October 1997 0094-2405/97/24(10)/1557/42/$10.00 © 1997 Am. Assoc. Phys. Med. 1557

LDR Source Acceptance Testing

- Secondary traceability means that the source strength is:
  1. *Measured with an instrument that has been itself calibrated for that source at NIST or an ADCL*
  2. *Measure by comparison to a source of the same type that has been calibrated at NIST or an ADCL*
- In practice, such measurements are best done with a well-type chamber



LDR Source Acceptance Testing

- The first step in the process is to obtain a chamber-electrometer system and arrange with an ADCL to calibrate either that system or an appropriate source
- Well-type ionization chambers are hollow cylindrical instruments that are used for brachytherapy calibrations
- The source(s) are placed in holders that are positioned inside the ionization chamber

THOMPSON CANCER SURVIVAL CENTER

THE UNIVERSITY of TENNESSEE UT

LDR Source Acceptance Testing

- The source holder are designed so that the source is positioned at a reproducible position inside the chamber
- There are source holders for each different type of brachytherapy source
- One well counter is typically used for a variety of sources using different holders
- However, the instrument must have separate calibrations for each type of source

Cesium Tube Holder

THOMPSON CANCER SURVIVAL CENTER

THE UNIVERSITY of TENNESSEE UT

LDR Source Acceptance Testing

- The single LDR seed source holder has a 1.2 mm inner diameter tube that positions an individual iodine, palladium, iridium or gold seed at the most sensitive area of the well chamber
- The seed batch assay tool is designed to provide multiple seed measurements for up to 500 of the iodine or palladium seeds

Single Seed Holder　　Batch Seed Holder

Long-Lived LDR Source Acceptance

- For long-lived sources such as 137Cs tubes, TG-56 recommends the following steps:
  1. *Document the physical/chemical form and encapsulation based on the manufacturer's specification in order to support dosimetry calculations*
  2. *Document the initial leak test based on the manufacturer's certification, and, optionally, repeat with local equipment (see below)*
  3. *Verify the uniformity of the activity distribution within each source (most likely with an autoradiograph; no tolerance limit is given)*

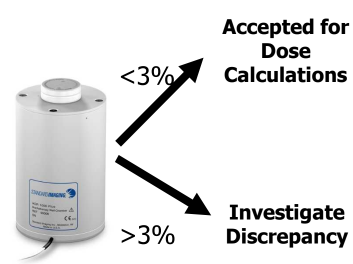
THOMPSON CANCER SURVIVAL CENTER
THE UNIVERSITY of TENNESSEE

Long-Lived LDR Source Acceptance

- For long-lived sources such as 137Cs tubes, TG-56 recommends the following steps:
  4. *Verify the location of the activity distribution within each source relative to the exterior dimensions to a tolerance of 1 mm (most likely by combining an autoradiograph with a transmission radiograph)*
  5. *Verify the identification of each source (serial numbers, color coding, etc.)*
  6. *Calibrate each source*

Long-Lived LDR Source Acceptance

- If the measured source strength agrees with the manufacturer's specification to within 3%, then either may be used for dose calculations
- When sources are batched for dosimetry purposes, then the 3% tolerance applies to the mean of the batch, and the range of source strengths within the batch should not exceed 5%
- Differences larger than 3% should be investigated, and differences larger than 5% should be reported to the manufacturer



Long-Lived LDR Source Acceptance

- Long-lived sources need to be leak tested at intervals specified by the radioactive materials license, typically 6 months or 3 years
- Such sources should have certified leak tests before being shipped, and that documentation can show initial compliance
- Users of sources such as 137Cs tubes may decide to repeat the leak test locally during acceptance; certainly that should be done if there is any suggestion of damage

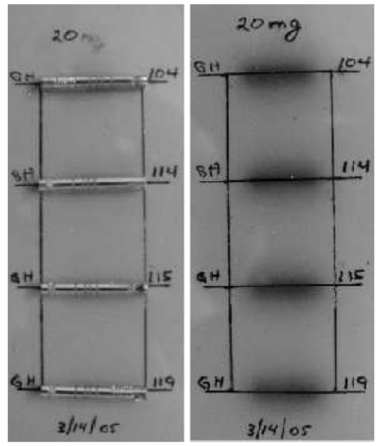
Long-Lived LDR Source Acceptance

- Properly leak testing sealed sources requires sensitive instrumentation
  1. *NaI well counter are frequently used for measuring wipe tests*
  2. *The system must have a means of determining the counting efficiency for the energies being analyzed*
  3. *In the United States, the minimum detectable activity (MDA) must be less than 0.005 μCi*

Long-Lived LDR Source Acceptance

- The activity distribution within the source can be evaluated using Gafchromic film

1. *The position of each source is drawn on the film surface with lines showing the axis and endpoints of each tube assembly*
2. *The sources are then placed in the film for approximately 10 minutes*
3. *The self-developed autoradiograph shows the location of the distribution relative to the physical source*



THOMPSON CANCER SURVIVAL CENTER

THE UNIVERSITY of TENNESSEE

Short-Lived LDR Source Acceptance

- For short-lived sources such as 125I seeds, TG-56 recommends the following steps:
  1. *Document the physical/chemical form and encapsulation based on the manufacturer's specification in order to support dosimetry calculations*
  2. *Verify the uniformity of the activity distribution within each source, where applicable, or the distribution of seeds along an extended ribbon.*
  3. *Calibrate the sources, either individually or as a batch.*

THOMPSON CANCER SURVIVAL CENTER

THE UNIVERSITY of TENNESSEE

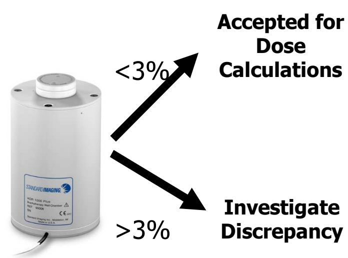
Short-Lived LDR Source Acceptance

- For large batches of loose seeds, TG-56 allows for “secondary traceability by statistical inference” in which a “suitable random sample” is calibrated with secondary traceability
- TG-40 calls for that sample to comprise at least 10% of the total batch
- A disadvantage of batch measurements is that one or more significant outlier sources may be lost in the background

Batch Seed Holder

Short-Lived LDR Source Acceptance

- As with long-lived sources, the expectation is that the local calibration should agree with that provided by the manufacturer within 3%
- The range of source strengths should not exceed 5%, but TG-56 acknowledges that verifying this for a large batch of seeds may not be practical
- For sources purchased in a sterile assembly, TG-40 recommends, “purchasing and calibrating a single (non-sterile) seed for each designated-strength grouping”



Short-Lived LDR Source Acceptance

There are several ways to deal with the problem of sterile seeds

1. *Purchase and calibrate some loose seeds of the same type and activity*
2. *Purchase additional assemblies, which are then calibrated and discarded*
3. *Break sterility on some assemblies, then calibrate and sterilize*
4. *Calibrate some of the assemblies in the OR under sterile conditions*
5. *In the OR, remove some of the seeds from the assemblies under sterile conditions, and then go to a non-sterile area to calibrate and subsequently discard them*
6. *Purchase the seeds from the manufacturer and have them sent to a third party that can provide an independent calibration and sterilize the assemblies*

THOMPSON CANCER SURVIVAL CENTER

THE UNIVERSITY of TENNESSEE UT

LDR Source Periodic Testing

For sources that are maintained in inventory, the quality management program should include some periodic activities:

1. A formal inventory check needs to be completed quarterly; this is a Nuclear Regulatory Commission (*NRC*) requirement that applies to federal and state licensees (*Note that this could apply to 125I seeds if an inventory is maintained*)
2. The calibration of each source should be checked annually
   - *Deviations from the apparent half-life may indicate contamination with a different isotope*
   - *Should any such deviation be found and confirmed, the dose distribution around the source may differ from standard tables*
   - *Assessing that dose distribution is beyond the capabilities of most clinics, so any such sources would typically be returned to the manufacturer*

THOMPSON CANCER SURVIVAL CENTER

THE UNIVERSITY of TENNESSEE UT

LDR Source Periodic Testing

For sources that are maintained in inventory, the quality management program should include some periodic activities:

3. Leak testing should be performed at the intervals required by the radioactive materials license (*Note that this could also apply to 125I seeds kept in service for longer than 6 months*)
4. Rechecking the uniformity of the activity within the source, while not specifically recommended by the AAPM, is another possible element of the QM program

THOMPSON CANCER SURVIVAL CENTER

THE UNIVERSITY of TENNESSEE UT

Per-Patient Testing

- For long-lived sources maintained in an inventory, such as 137Cs tubes, each time the sources are used there should be a mechanism for checking the proper selection and arrangement of the sources
- Typically, this is accomplished by using a color-coding system
- Where staff resources permit, one can have one person build the source assembly and another check it

Item #	mg Ra-226 Equivalent (mg)	Color Code
067-6505	5	Purple
067-6510	10	Red
067-6515	15	Black
067-6520	20	White
067-6525	25	Blue
067-6530	30	Orange
067-6535	35	Green
067-6540	40	Gray

THOMPSON CANCER SURVIVAL CENTER

THE UNIVERSITY of TENNESSEE UT

High Dose Rate Brachytherapy

- High dose rate (HDR) brachytherapy devices have become common with the advent of methods to deliver the dose at a much higher dose rates, up to 700 cGy/min at 1 cm from the source
- All HDR treatments are temporary and treatments are administered using discrete fractions
- Treatment is delivered by a remote afterloader (RAL), which is a computer-driven system that transports the radioactive source from a shielded safe into the applicator placed in the patient

Low Dose Rate
0.4 to 2.0 Gy per Hour

Medium Dose Rate
2 to 12 Gy per Hour

High Dose Rate
>12 Gy per Hour

THOMPSON CANCER SURVIVAL CENTER

THE UNIVERSITY of TENNESSEE UT

High Dose Rate Brachytherapy

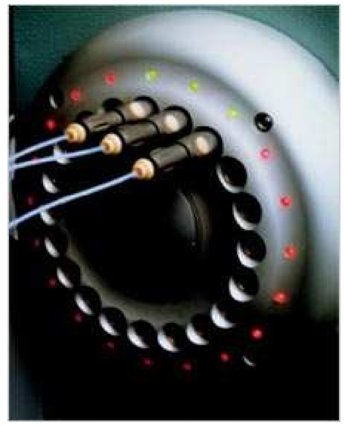
- The device may move the source by one of several methods, most commonly pneumatic pressure or cable drives
- The currently available HDR RALs use stepping-source technology
- This design consists of a single source at the end of a cable that moves the source through applicators placed in the treated volume
- The treatment unit can treat implants consisting of many needles or catheters

THOMPSON CANCER SURVIVAL CENTER

THE UNIVERSITY of TENNESSEE UT

High Dose Rate Brachytherapy

- Each catheter or part of an applicator is connected to the RAL through a channel
- The computer drives the cable so that the source moves from the safe through a given channel to the programmed position in the applicator (dwell position) for a specific amount of time (dwell time)
- After treating all the positions in a given catheter (channel), the source is retracted to its safe and then driven to the next channel



High Dose Rate Brachytherapy

Currently, there are three HDR RALs available in the market:

1. *The GammaMed marketed by Varian Associates*
2. *The VariSource™ marketed by Varian Associates*
3. *The microSelectron marketed by Nucletron*

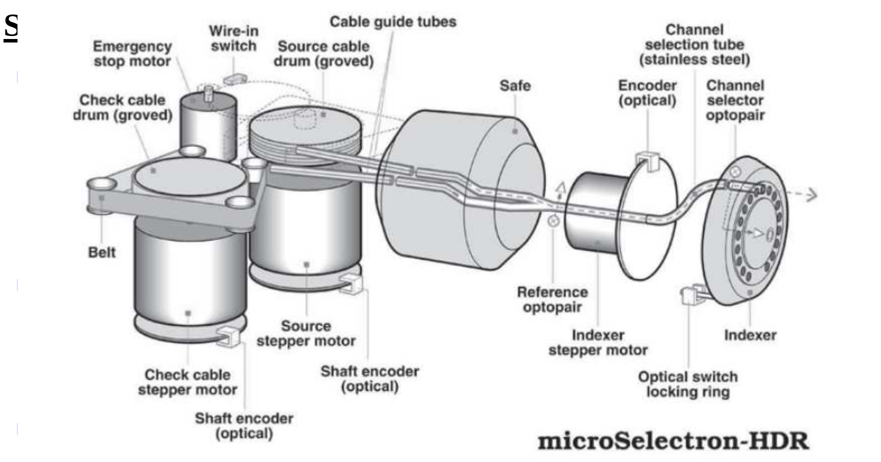
High Dose Rate Brachytherapy

Table 1. Specific Features of Three HDR RALs

	MicroSelectron V2	GammaMed+	VariSource 200/200t
Vendor	Nucletron	Varian	Varian
Sources	10 Ci of ^{192}Ir	10 Ci of ^{192}Ir	10 Ci of ^{192}Ir
Source Dimension	3.5 mm L, 1.1 mm OD	4.52 mm L, 0.9 mm OD	5 mm L, 0.59 mm OD
Source Cycle	25,000 transfer	5000 transfer	5000 transfer
Channels	18	2, 3, or 24	20
Source Extension	1500 mm	1300 mm	1500 mm
Channel Length	Variable	Fixed	Variable
Source Movement	Stepping forward	Stepping backward	Stepping backward
Step sizes	2.5, 5, or 10 mm	1–10 mm, 1 mm steps	2–99 mm, 1 mm steps
Dwells/channel	48	60	20

Components of a HDR Afterloader

S

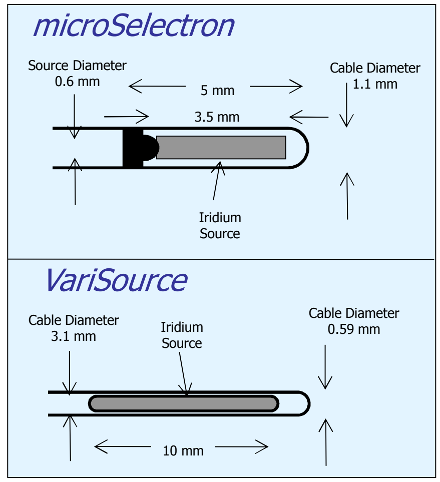


is driven back to the shielded safe

Components of a HDR Afterloader

Radioactive Source

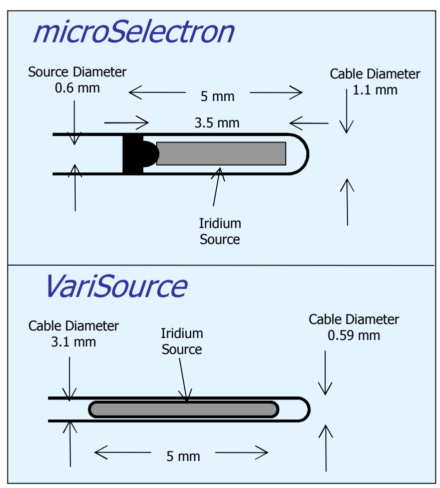
- The radionuclide used for all HDR RALs now marketed is 192Ir, although early versions of HDR RAL used 60Co
- ^{192}Ir has a high specific activity of 450 Ci/g and a γ energy of 0.38 MeV
- 10 Ci sources made of Ir can be smaller and easier to shield compared to ^{60}Co or ^{137}Cs
- The radioactive source in an HDR RAL is usually 3 to 10 mm in length and less than 1 mm in diameter, fixed at the end of a steel cable



Components of a HDR Afterloader

Radioactive Source

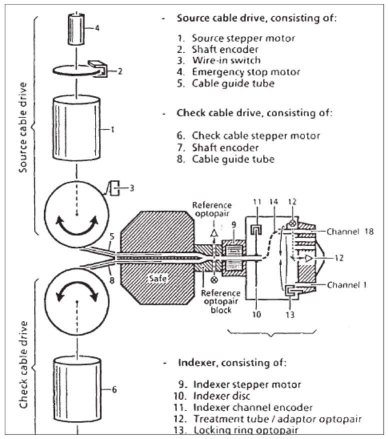
- The Nucletron source is placed in a stainless steel capsule and welded to the cable
- The Varian source is placed in a hole drilled into the cable and closed by welding
- ^{192}Ir has a half-life of only 74 days and the source needs to be changed every 3 months
- The physicists need to calibrate the source after each installation using a well-type chamber and an electrometer



Components of a HDR Afterloader

Source Drive Mechanism

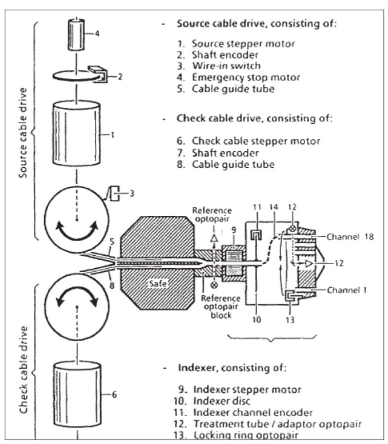
- The check cable is an exact duplicate of the source along with its cable
- A stepper motor drives the check cable to the programmed length to verify the integrity of the system.
- This checks the proper attachment of the transfer tube to the indexer ring and the attachment of the transfer tube to the applicator used for the treatment
- A successful run of the check cable initiates the source cable stepper motor connected to the source reel



Components of a HDR Afterloader

Source Drive Mechanism

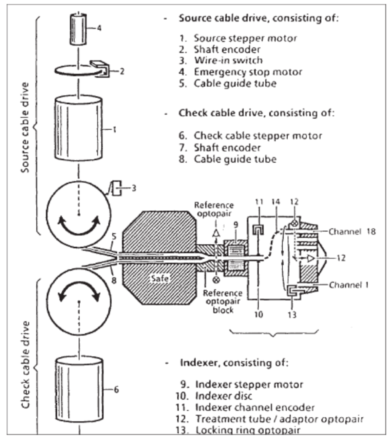
- The source cable then advances from the shielded safe along a path constrained by transfer tubes to the first treated dwell position in the applicator attached to the first channel
- Some units step as the source drives out (*microSelectron*), stopping first at the dwell position most proximal to the afterloader, while in the others (*VariSource and GammaMed*) the source travels first to the most distal dwell (*towards the tip of the applicator*)



Components of a HDR Afterloader

Source Drive Mechanism

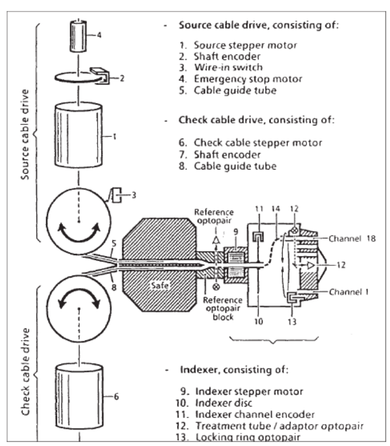
- Stepping on the outward (*microSelectron*) drive obviates any concern about the effect of slack in the drive mechanism affecting the accuracy of the source position
- The units that steps on the way back into the unit (*VariSource and GammaMed*) includes correction for slack in the calibration of the source location



Components of a HDR Afterloader

Source Drive Mechanism

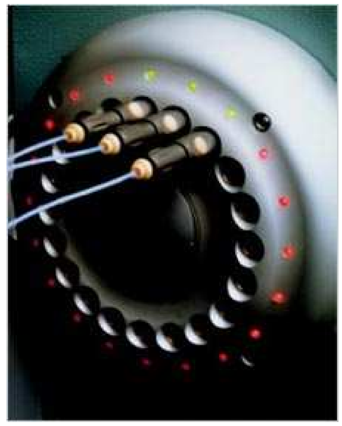
- The movement of the source is verified by means of an optical encoder that compares the angular rotation of the stepper motor or cable length ejected or retracted with the number of pulses sent to the drive motor
- This system is capable of detecting catheter obstruction or constriction as increased friction in the cable movement
- Under certain fault conditions, a high-torque, direct-current (*DC*) emergency motor will retract the source



Components of a HDR Afterloader

Indexer

- The indexer is the part of the RAL that directs the source cable from the exit of the safe to one of the exit ports from the unit (*channels*)
- This mechanism gives the option of connecting a number of catheters
- The various catheters or applicator parts connect to these channels, usually through connecting guides called "transfer tubes"
- Different units have between 2 and 24 channels available for connection



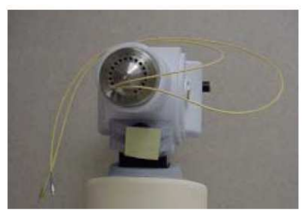
THOMPSON CANCER SURVIVAL CENTER

THE UNIVERSITY of TENNESSEE UT

Components of a HDR Afterloader

Transfer Tubes

- Transfer tubes are long tubes that act as a conduit to transfer the source from the RAL to the applicators or catheters for treatment
- One end of the transfer tube is attached to the indexer of the RAL, and the other end is attached to the applicators
- The applicator end of the transfer tube contains spring-loaded ball bearings that block the path through the tube if no applicator is attached



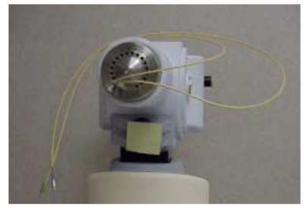
THOMPSON CANCER SURVIVAL CENTER

THE UNIVERSITY of TENNESSEE UT

Components of a HDR Afterloader

Transfer Tubes

- When an applicator is inserted, it pushes aside the ball bearings, opening the path for the source cable
- When the check cable makes its test run, if no applicator is attached to the transfer tube, the check cable hits the obstacle of the ball bearings, and prevents ejection of the source
- Each type of applicator has its own type of transfer tube



Components of a HDR Afterloader

Treatment Control

- The treatment control station transfers the data to the RAL
- A hard or soft START button initiates the execution of the treatment according to the program
- In addition, there is an INTERRUPT button, which when pressed retracts the source and stops the timer, allowing the user to enter the treatment room without receiving radiation exposure

Components of a HDR Afterloader

Treatment Control

- A RESUME or START button resumes the treatment from the time and the dwell position where it was interrupted
- A master EMERGENCY OFF button initiates the high-torque DC emergency motor to retract the source
- In the normal course of a successful termination of the treatment, the timer runs to zero and the machine automatically retracts the source

HDR Safety Features

Emergency Switches

- EMERGENCY OFF switches are located at convenient places and easily accessible
- One EMERGENCY OFF switch is located on the control panel, and another EMERGENCY OFF button is located on the top of the RAL treatment head
- Vendors usually install one or two emergency switches in the walls of the treatment room

HDR Safety Features

Emergency Crank

- RALs have emergency cranks to retract the source cable manually if the source fails to retract normally
- Using the crank requires the operator to enter the room with the source unshielded
  - *At 1-cm from the source, the operator would have 1.35 minutes until likely injury (10 Sv)*
  - *At 10-cm from the sources, the operator would have 6.8 minutes before exceeding the annual dose limit*

THOMPSON CANCER SURVIVAL CENTER

THE UNIVERSITY of TENNESSEE UT

HDR Safety Features

Door Interlock

- Interlock switches prevent initiation of a treatment with the door open
- The interlock also prohibits the use of two radiation sources simultaneously
- When a treatment is in progress, opening the door interrupts the treatment
- This safety feature protects the medical personnel from radiation exposure in the event somebody enters the treatment room without the knowledge of the operator

THOMPSON CANCER SURVIVAL CENTER

THE UNIVERSITY of TENNESSEE UT

HDR Safety Features

Door Interlock

- If a door is inadvertently opened during the treatment, the treatment is interrupted and the source returns to the safe
- The treatment can be resumed at the same point where it was interrupted by closing the door and pressing the START or the RESUME button at the control panel

HDR Safety Features

Audio/Visual System

- All HDR treatment rooms must be equipped with an audio/visual system
- Closed-circuit television system (CCTV) with two cameras is typically used for visual monitoring during treatment
- Shielded windows and/or mirrors can be used, but very few facilities use this approach
- A two-way audio system can also be used for audio communication with the patient during treatment

HDR Safety Features

<u>Radiation Monitor and TREATMENT ON Indicator</u>

- Three separate independent systems alert personnel when the source is not shielded
  - *Detector #1: is part of the treatment unit and indicates on the control panel when it detects radiation*
  - *Detector #2: is an independent unit, that is typically mounted on the treatment room wall*

HDR Safety Features

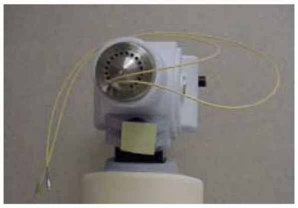
<u>Radiation Monitor and TREATMENT ON Indicator</u>

- *Detector #2: will have displays both inside and outside the room to alerts the operator and other personnel when the radioactive source is out of the safe*
- *Detector #3: is a TREATMENT ON indicator outside the room that is activated when the source passes the reference optical pair to indicates that a treatment is in progress*

HDR Safety Features

Emergency Service Instruments

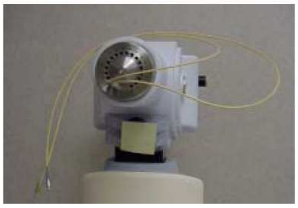
- In the event the radioactive source fails to retract after termination, interruption, pushing the EMERGENCY OFF switch or cranking the stepper motor manually, the immediate priority is to remove the source from the patient
- The preferred approach is to remove the applicator from the patient as quickly as possible and to place the applicator containing the source in a shielded container



HDR Safety Features

Emergency Service Instruments

- Removing the applicator attached to the transfer tube keeps the system closed
- If it is clear that the cable is caught in the transfer tube, it may be disconnected and the source pulled from the applicator
- The reason to avoid disconnecting the applicator from the transfer tube is that a source may stay in the applicator if the source capsule shatters



HDR Safety Features

Emergency Service Instruments

- A situation may arise when the source nee to be detached manually from the treatmer unit
- In this special situation, the source cable should be cut from the unit and the source placed in the shielded container always present in the room
- In cutting the source cable, it must be clear that the cut is not through the source capsule
- For units with the capsule welded on the cable, the cut must be through the braided cable as opposed to the smooth steel capsule

Exposure Rates from an Exposed 10 Ci 192Ir Source

Typical situation	Distance [m]	Time to receive: 10 Sv (Likely injury)	Time to receive: 0.05 Sv (Annual body limit)
In Patient	0.01	1.35 minutes	0.007 minutes 0.4 seconds 0.67 minutes
Handling with Kelly Clamps	0.1	2.3 hours	(6.8 minutes for hand limit)
Handling with Kelly Clamps	0.3	20 hours	0.10 hour 6 minutes
Standing near	1	9.5 days	1.1 hours
Standing far	2	37.5 days	4.5 hours

HDR Safety Features

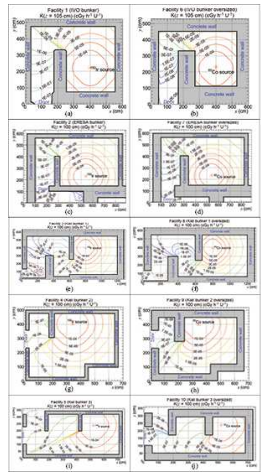
Backup Battery

- In case of a power failure during the treatment, the machine is equipped with a backup battery to provide retraction of the source to its safe
- The batteries should be tested with each source change

HDR Safety Features

Shielding

- The radioactive source in the HDR machine starts about 10 Ci with an exposure rate at a distance of 1 m from the source of about 46 mSv/h
- In order to drop the exposure rate 0.02 mSv/h, the HDR must be housed in an adequately shielded room
- To meet these requirements in an HDR suite, where the walls and the ceiling are at least 5 feet from the machine head, concrete walls of about 43 to 50 cm (or 4 to 5 cm of lead) are needed



HDR Quality Assurance

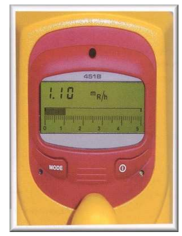
New Source QA

- When a new ^{192}Ir source arrives, is 1.) surveyed on the institution loading dock, 2.) wipe tested, 3.) moved to a secured location, and 4.) added to the institution's radioactive inventory
- Several days later field service engineer will arrive to swap out the ~3 month old (*i.e., 4 Ci*) ^{192}Ir source into a transport pig for return back to the manufacturer,
- The FSE will then perform planned maintenance and inspection of the RAL and control console

HDR Quality Assurance

New Source QA

- The new ^{192}Ir source (*i.e., 10 Ci*) will be transferred into the RAL, and the service engineer will ask the physicist to review the work performed, before leaving the institution
- It is then the physicist's responsibility to arrange for shipment of the weaker ^{192}Ir source back to the manufacturer for decay/disposal, and to oversee a radiation survey of the environment with the new device in place
- The physicist must next perform a set of QA tasks needed to characterize the output of the source and behavior of the RAL system and control console



Exposure Rates Near Treatment Unit (mR/h)
(orientation facing indexer, source retracted in safe)

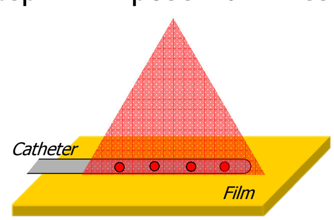
@ surface	@ 1 meter
Right ____________	Right ____________
Left ____________	Left ____________
Front ____________	Front ____________
Rear ____________	Rear ____________
Above ____________	Above ____________
Below ____________	Below ____________

HDR Quality Assurance

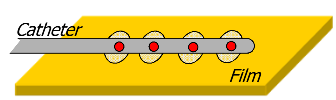
Autoradiograph

- An autoradiograph is an image produced on an x-ray film by the pattern of decay emissions from a distribution of a radioactive substance
- In HDR, the source position can be checked by double exposing a film
  1. *A dummy strand in placed in the HDR catheter/applicator*
  2. *A x-ray source is used to image the position of the dummy sources on the film*
  3. *The HDR sources is then driven out to prescribed positions*

Step#1: Expose Dummies



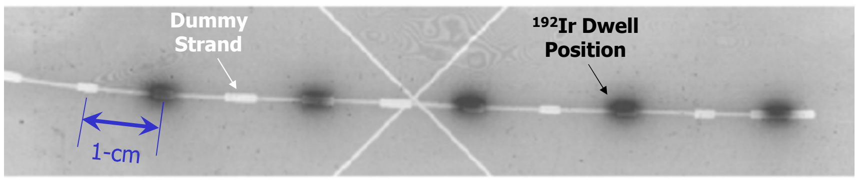
Step#2: Expose ^{192}Ir



HDR Quality Assurance

Autoradiograph

- The double exposed film will show the expected position of the sources from the dummy strand and the actual position of the source driven into position by the RAL
- The ^{192}Ir position should be within 1-mm of the expected position



Position1	1	3	5	9	11	13	15	17	19	23	25	27	29	31	33
1000 mm 6F Shift [mm]															

1 3 5 7 9 11 13 15 17 19 21 23 25 27 29 31 33 35 37 39 41 43 45

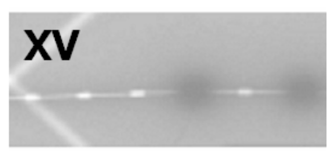
HDR Quality Assurance

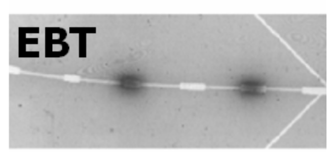
Autoradiograph

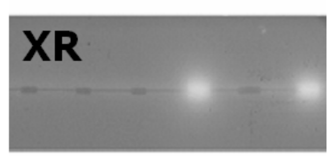
- The x-ray exposure and dwell times required to produce a usable image depends on the type and speed of the film

Parameters used to obtain co-registered images (source activity of about 370 GBq)

Film	Diagnostic Radiograph kVp	Diagnostic Radiograph mAs	Diagnostic Radiograph SSD (cm)	Autoradiograph Dwell time (sec)
XV-2 (radiographic)	85	500	100	0.3
EBT (radiochromic)	80	2500	45	0.3
XR-QA (radiochromic)	75	250	100	0.3



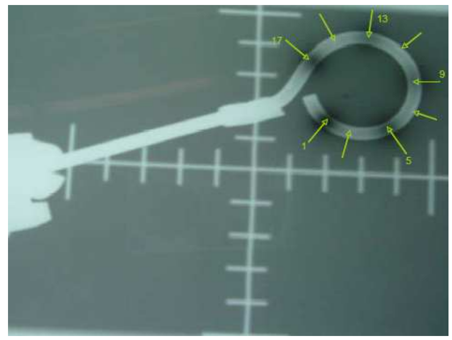




HDR Quality Assurance

Autoradiograph

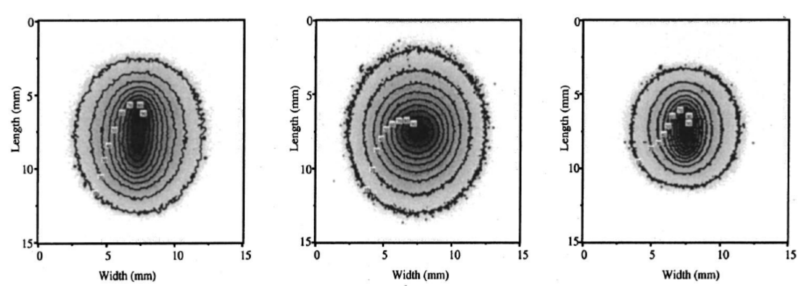
- AAPM TG-56 recommends that QA of device-related equipment (*catheters, applicators, tubes, dummy wires, etc.*) be performed once every 3 months



HDR Quality Assurance

Autoradiograph

- Films can also be used to check the dose distribution around the source



a — Redesigned VariSource

b — Redesigned MicroSelectron

c — "Classic" MicroSelectron

HDR Quality Assurance

Calibration

- A chamber-electrometer system with an ADCL calibrate is used to check the activity of the ^{192}Ir Source
- The air kerma strength reported by the manufacturer must agree to within 5% with the measured value
- If ratio is not within 5%, have another Physicist perform the calibration and and consider cross-calibration using another well chamber

THOMPSON CANCER SURVIVAL CENTER

THE UNIVERSITY of TENNESSEE

Daily HDR Quality Assurance

Prime Alert/Alarm

- Ensure operation of prime alert/alarm by visual inspection of power indicator and placing check source near detector
- Switch outside monitor to audible mode and listen for detector status while holding check source against the detector
- Disconnect power from detector to check battery operating status

THOMPSON CANCER SURVIVAL CENTER

THE UNIVERSITY of TENNESSEE

Daily HDR Quality Assurance

CCTV & Intercom

- Check operation of remote camera(s) and intercom
- Check zoom/focus functions on camera(s)

THOMPSON CANCER SURVIVAL CENTER

THE UNIVERSITY of TENNESSEE UT

Daily HDR Quality Assurance

Console & Peripherals Readiness /Function & Indicator Lights

- This is performed during startup of the TCS computer
- Also check overall operation of all peripherals (printer) associated with TCS computer and RAL device (power light indicator, etc.)
- The TCS Operator’s Manual should be located at the TCS console
- A copy of the RAM license should also be located at the TCS console

THOMPSON CANCER SURVIVAL CENTER

THE UNIVERSITY of TENNESSEE UT

Daily HDR Quality Assurance

RAL Vertical Head Movement

- Ensure the RAL device vertical head moves up and down smoothly
- It is ideal to check the full range of the elevator motor

Daily HDR Quality Assurance

Emergency OFF (all stations)

- This is done to ensure operation of the emergency OFF circuits
- This is performed prior to initiating any source movement
- Depress (*one at a time*) the emergency stop buttons on the RAL device (on treatment head), the remote stop location in the maze, and the emergency stop button on the TCS

Daily HDR Quality Assurance

RAL/CT Three (3) Way Selector

- The HDR should only work with the key in the HDR location.
- Nothing should work with the key in the neutral position, and the CT should only work with the key in the CT position
- Ensure proper operation of each key position
- If the key is not in the correct position for the equipment to be used, a door interlock or fault will be seen.

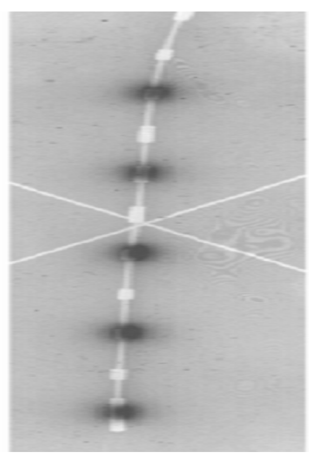
THOMPSON CANCER SURVIVAL CENTER

THE UNIVERSITY of TENNESSEE

Daily HDR Quality Assurance

Autoradiograph/Source Position

- Using the film jig, insert a verification film and tighten the four (4) knobs against the film
- The source position tolerance is +/- 1 mm and any discrepancies can be seen easily
- The source exposure (black dot) should line up with the tungsten line markers



THOMPSON CANCER SURVIVAL CENTER

THE UNIVERSITY of TENNESSEE

Daily HDR Quality Assurance

Interrupt Switch Test (w/source)

- Allow the source to reach its static position and then engage the interrupt button on the TCS
- Ensure the source retracted back into the safe and that the TCS system properly documented the interruption
- Also check the timer operation to ensure the system knows to restart the treatment at the same time/location it was interrupted

THOMPSON CANCER SURVIVAL CENTER

THE UNIVERSITY of TENNESSEE UT

Daily HDR Quality Assurance

Interrupt Switch Test (w/source)

- Allow the source to reach its static position and then engage the emergency stop button on the TCS control panel
- Ensure the system acknowledges the emergency stop being “active” and properly documents
- Also check the timer operation to ensure the system knows to restart the treatment at the same time/location it was interrupted

THOMPSON CANCER SURVIVAL CENTER

THE UNIVERSITY of TENNESSEE UT

Daily HDR Quality Assurance

Interrupt Switch Test (w/source)

- Allow the source to reach its static position and then open the treatment room door
- Ensure the source retracted and the TCS system properly documented a door interlock (door has been opened)
- Also check that the system will restart the treatment at the correct time/location

THOMPSON CANCER SURVIVAL CENTER

THE UNIVERSITY of TENNESSEE UT

Daily HDR Quality Assurance

Battery Backup (UPS)

- Ensure the UPS backup power is on and functioning
- A very dim indicator light can be seen on the front switch
- Do not turn this off (it will shut the system down)

THOMPSON CANCER SURVIVAL CENTER

THE UNIVERSITY of TENNESSEE UT

Daily HDR Quality Assurance

Activity Check

- Write in the initial activity, today's activity from the TCS (*print preview of treatment*) and the elapsed days since the source was installed
- Write down the planning system's reported activity
- Read manual decay data from decay table in QA binder
- These three (3) values should be very close together
  - *Note that RTP decays every 12 hours and the TCS performs a continuous decay*
  - *The decay has "master" control in terms of source activity*
  - *In other words, any plan information from planning system will be governed by the source strength as determined by TCS*

Daily HDR Quality Assurance

Emergency Equip. Staging/Readiness

- Ensure the emergency container ("pig"), tong(s), and lead apron(s) are functional and in a state of readiness
- The lead aprons are to be used as a "blanket" to immobilize the source cable should it fail to retract and become exposed
- The primary emergency equipment are the source container and the tongs, and should be located near the RAL device to facilitate an expeditious removal and storage movement if required

Daily HDR Quality Assurance

Timer(s) Operation (primary vs secondary)

- While performing the source autoradiograph and treatment QA portions, ensure that both the individual timer for dwell position, and the overall treatment (or total) timers are operational
- Timer accuracy is evaluated during the source exchange and is not the focus of this check
- This check is to ensure that all timers function

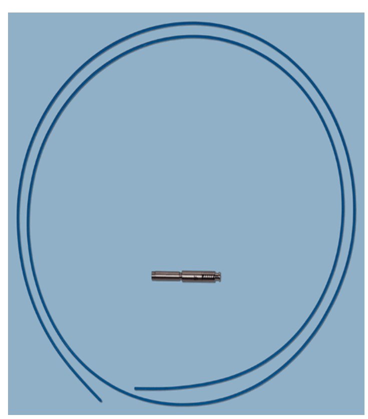
THOMPSON CANCER SURVIVAL CENTER

THE UNIVERSITY of TENNESSEE UT

Daily HDR Quality Assurance

Mechanical Integrity of Applicator(s) (visual inspection)

- Applicators are initially checked at acquisition for physical defects
- Any applicator with physical defects should not be used clinically and should be repaired/replaced
- Considerations include the application(s) (anatomic site), transfer tube(s), and connector(s) for clinical and quality assurance



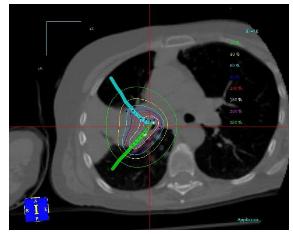
THOMPSON CANCER SURVIVAL CENTER

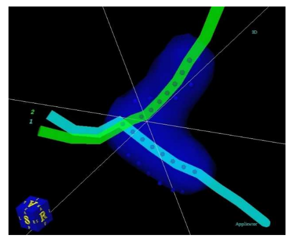
THE UNIVERSITY of TENNESSEE UT

Daily HDR Quality Assurance

Time & Date (RTP vs TCS)

- Ensure the time/date stamp on the TCS is accurate/correct as well as on the RTP system when performing the activity check
- Also ensure that the time/date stamps for each are close to each other
- This becomes a more important issue for daylight savings time adjustment
- The RTP system automatically adjusts for this, however the TCS does not and the time must be adjusted





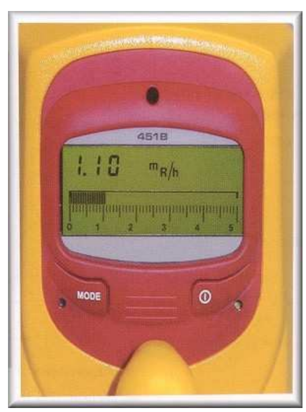
THOMPSON CANCER SURVIVAL CENTER

THE UNIVERSITY of TENNESSEE UT

Daily HDR Quality Assurance

Survey Meter Check

- Ensure the survey meter to be used for HDR treatments is operational and functioning
- Use a Cs-137 check source to ensure detection ability, and ensure the meter has an “active” calibration
- Do not use an uncalibrated, or “out of date” survey meter.



THOMPSON CANCER SURVIVAL CENTER

THE UNIVERSITY of TENNESSEE UT