Fluoroscopic Radiation Safety

Patient and Occupational Safety

Michael J. Bohan, YNHH Radiation Safety Officer
(203) 688-2950 or mike.bohan@yale.edu

ACCREDITATION & DISCLOSURE

The Yale School of Medicine designates this Enduring Material for a maximum of 1 *AMA PRA Category 1 Credit*™. Physicians should claim only the credit commensurate with the extent of their participation in the activity.

Acknowledgement is made on behalf of the Department that:

There is no commercial support for this activity.

Confirmation is also made that disclosure has been peer reviewed and there are no conflicts of interest.

Basic Radiation Safety Techniques

Time - As exposure time increases, dose accumulates

-- Keep fluoro times as short as possible.
A bell or buzzer will go off after 5 minutes of beam time, keep track of fluoro time, report fluoro times in excess of 60 minutes to the Radiation Safety Office (203) 688-2950

Distance - As distance from the radiation source increases, the radiation intensity decreases rapidly by the inverse square law.

-- Keep patient anatomy and staff as far away from the x-ray tube port as possible

Shielding - Diagnostic x-rays are easily shielded with thin sheets of lead.

-- Wear lead aprons, thyroid shields, leaded glasses and use overhead leaded shields and table skirts whenever possible

Keep fluoro times as short as possible

Time

Dose Rate = 10 rad/min

Accumulated Dose (rad)

minutes

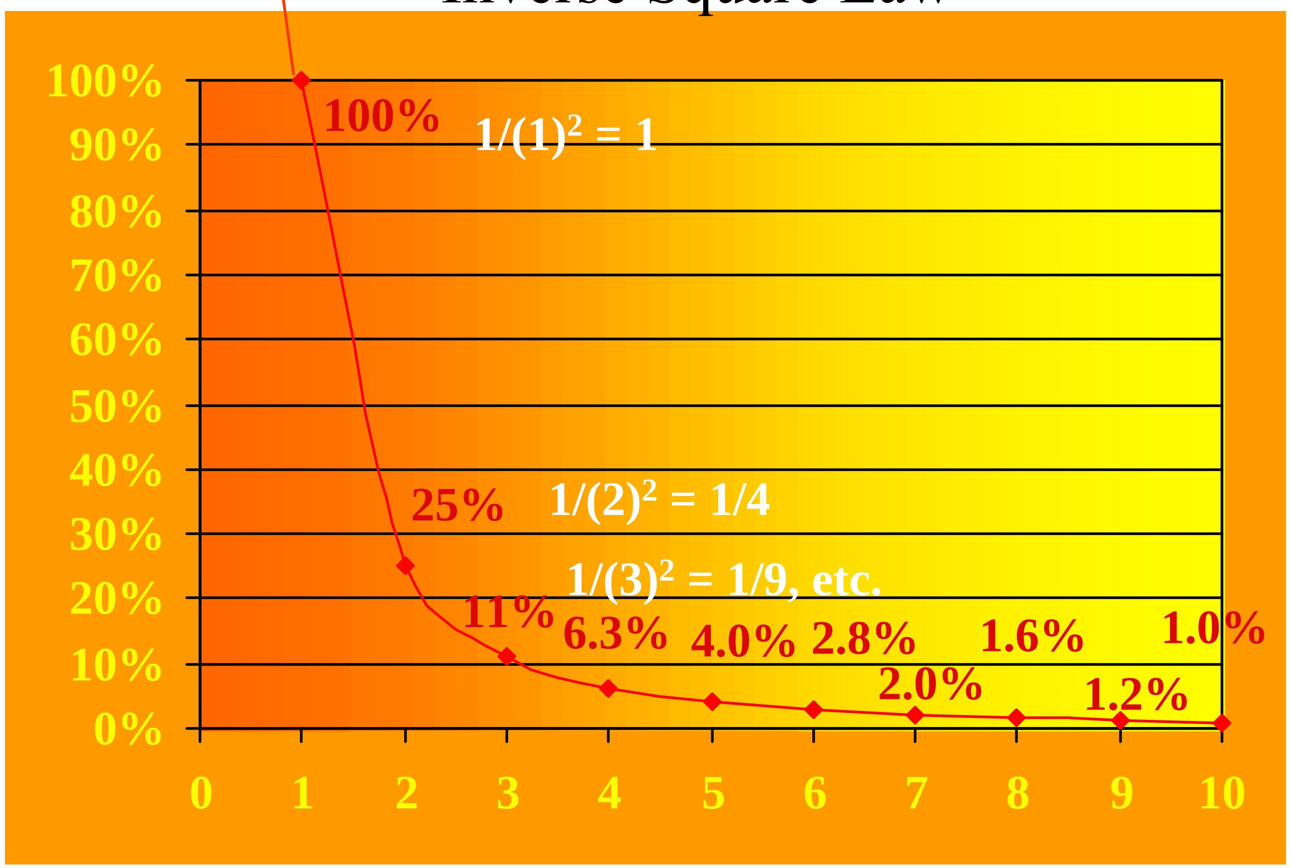
Stay as far away from the x-ray tube port as possible

Distance

$1/(0.5\ \text{ft})^2$ = 4 times dose rate @ 1 foot!

Inverse Square Law

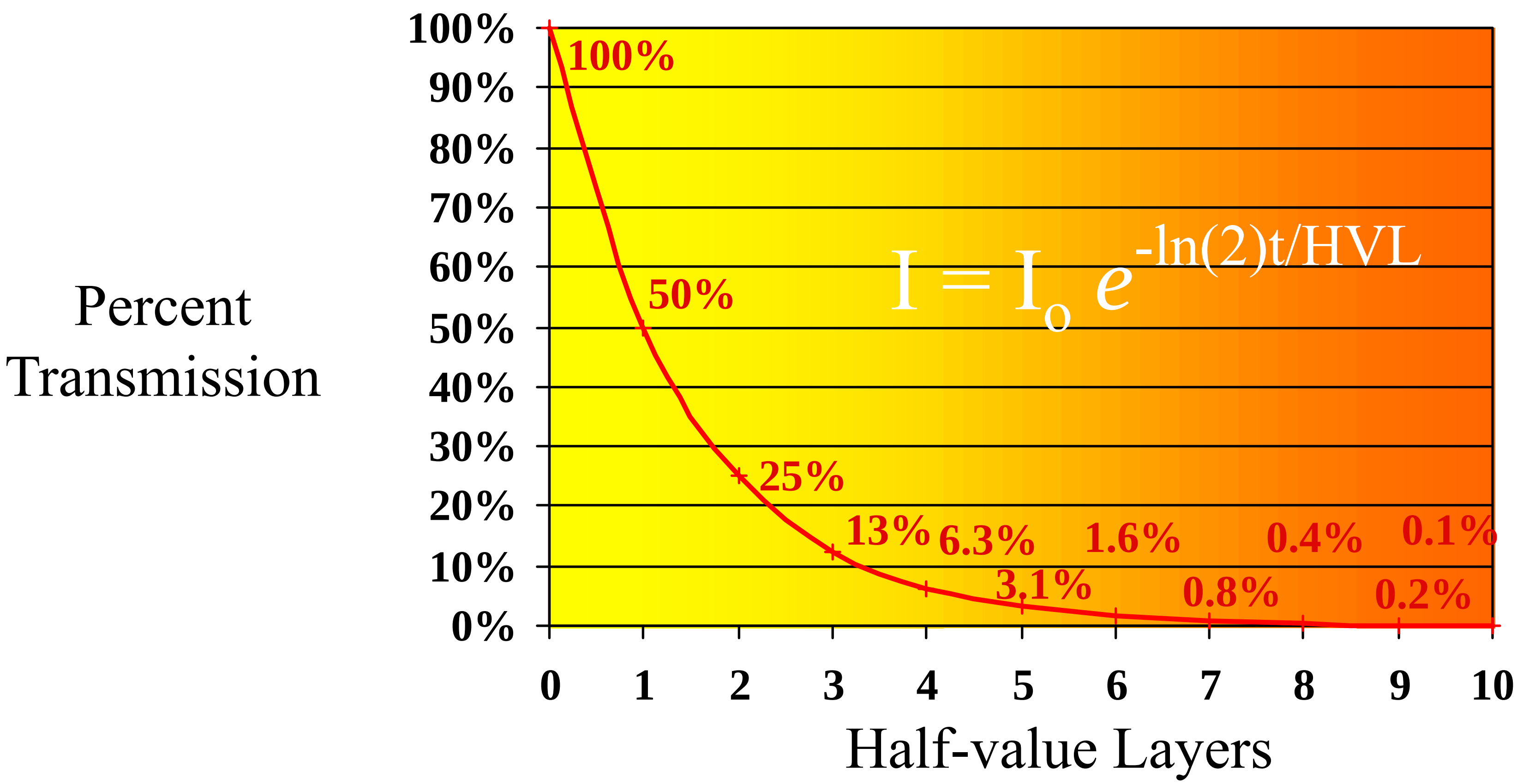
Percent of exposure rate at 1 foot



Feet from radiation source

Half-value Layer

Lead aprons are very effective at diagnostic x-ray energies and shield at least 95% of the radiation



Federal Regulatory Occupational Dose Limits

Total Effective Dose Limit (TEDE)	5,000 millirem/yr
Individual Organ Limit	50,000 millirem/yr
Len of the Eye (LDE)	15,000 millirem/yr
Skin, Hands & Single Organs	50,000 millirem/yr

TEDE - Summation of external and weighted internal doses

Federal Regulatory Internal Dose Weighting Factors

The organ weighting factors take into consideration the radiation sensitivity of the tissues.

Organ or tissue	Weighting Factor
Gonads	0.25
Breast	0.15
Red bone marrow	0.12
Lung	0.12
Thyroid	0.03
Bone surfaces	0.03
Remaining organs	0.30
Total body	1.00

Federal Regulatory General Public Dose Limits

Total dose (all sources)	500 millirem/yr
Individual source limit	100 millirem/yr
Declared pregnant worker	500 mrem/9 months (<50 mrem/month)

Occupational Exposures at Yale-New Haven Hospital

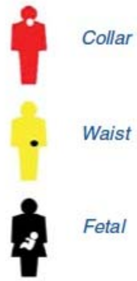
ALARA Radiation Dose Summary 2003

Dose	Series--------->				All Sources																							Cumul.	Dose
(mR/Yr)	AB	ACT	ADI	AER	ARN	ASP	AST	C	CCC	ENT	G	GK	I	K	M	MC	MD1	MD2	MD3	MDR	N	O	R	W	X	YPB	Totals	Percent	Percent	(mR/Yr)
5001 - 7500																											0	0.0%	100.0%	5001 - 7500
4001 - 5000																											0	0.0%	100.0%	4001 - 5000
3001 - 4000																		2									2	0.3%	100.0%	3001 - 4000
2001 - 3000	1																	2									3	0.4%	99.7%	2001 - 3000
1001 - 2000	2					1					1							4									8	1.1%	99.3%	1001 - 2000
501 - 1000	1					4					2							2		2							11	1.5%	98.2%	501 - 1000
401 - 500	1					1										1		1									4	0.5%	96.7%	401 - 500
301 - 400					1						1				1												3	0.4%	96.2%	301 - 400
201 - 300	1				1	1					2				1	2				3	1				1		13	1.8%	95.8%	201 - 300
101 - 200		1	1	2	2	4			1		6				6	4			4	2	1	1	1	2			38	5.2%	94.0%	101 - 200
51 - 100			2	2	7	2		1	1						12	4	1			1	5	4		3	1		46	6.3%	88.8%	51 - 100
11 - 50	1	8	4	6	8	6	1	3			3				14	3	1	2	3	1	12	8	1	3	1		89	12.2%	82.5%	11 - 50
1 - 10			1	5	8	4	2	9			3	6			7	3			1	2	7	4		1		2	65	8.9%	70.3%	1 - 10
Minimal	11	24	5	29	11	15	29	55	11	4	34	5	7	10	30	6	3	2	10	32	31	51	5	6	1	21	448	61.4%	61.4%	Minimal
Totals:	18	33	13	44	38	38	32	68	13	4	52	11	7	10	71	23	5	15	18	43	57	68	7	15	4	23	730	100.0%		

Dose	NRC Byproduct Materials											Cumul.	Dose
(mR/Yr)	C	ENT	GK	I	K	M	MC	N	O	W	Totals	Percent	Percent	(mR/Yr)
5001 - 7500											0	0.0%	100.0%	5001 - 7500
4001 - 5000											0	0.0%	100.0%	4001 - 5000
3001 - 4000											0	0.0%	100.0%	3001 - 4000
2001 - 3000											0	0.0%	100.0%	2001 - 3000
1001 - 2000											0	0.0%	100.0%	1001 - 2000
501 - 1000											0	0.0%	100.0%	501 - 1000
401 - 500							1				1	0.3%	100.0%	401 - 500
301 - 400						1					1	0.3%	99.7%	301 - 400
201 - 300						1	2	1			4	1.2%	99.4%	201 - 300
101 - 200						6	4	1	1	2	14	4.2%	98.2%	101 - 200
51 - 100	1					12	4	5	4	3	29	8.7%	94.0%	51 - 100
11 - 50	3					14	3	12	8	3	43	12.9%	85.3%	11 - 50
1 - 10	9		6			7	3	7	4	1	37	11.1%	72.5%	1 - 10
Minimal	55	4	5	7	10	30	6	31	51	6	205	61.4%	61.4%	Minimal
Totals:	68	4	11	7	10	71	23	57	68	15	334	100.0%		

Series Codes

AB	Ped. Card.	M	Nuc. Med.
ACT	CAT Scan	MC	Nuc. Card.
ADI	Rad. Techs.	MD1	Dx Physicians
AER	E.R. Techs	MD2	Dx Physicians
ARN	Dx Nurses	MD3	Dx Physicians
ASP	Special Proc.	MDR	Dx Residents
AST	Dx Students	N	Rx Physics
C	Rx Techs.	O	9WP Nurses
CCC	CommCardCath MD's	R	Urology
ENT	EarNoseThroat MD's	W	Temp. Badges
G	Cardiology	X	Pulm. Med.
GK	Gamma Knife	YPB	YPB Dx Techs.
K	O.D. Surgery		



Occupational Exposures at Yale-New Haven Hospital

Ninety-seven percent of all monitored individuals at YNHH receive less than 10% of the annual exposure limit (500 mrem/yr).

The 3% who receive greater than 500 millirem/yr are the interventional radiologists and cardiologists.

Personnel who routinely receive greater than 10% of the limits are issued two film badges (collar & waist)

If you are issued only one badge, wear it at the collar outside of any protective aprons. Waist badges should be worn under protective aprons

Multiple Badge Fluoroscopic Dosimetry

Effective dose equivalent is calculated for multiple badge wearers using the ANSI formula as required by CT State DEP regulatory guidance.

Effective Dose Equivalent = (0.11 x collar badge) + (0.89 x waist badge)

HPS N13.41-1997

An American National Standard (ANSI)

Criteria for Performing Multiple Dosimetry

Multiple Badge Fluoroscopic Dosimetry

For example, if a fluoroscopist received 2,500 millirem to their collar badge and 250 millirem to their waist badge for the year, their effective dose equivalent (EDE) would be:

(0.11 * 2,500 mrem/yr) + (0.89 * 250 mrem/yr) = ANSI EDE

275 mrem/yr + 223 mrem/yr = 498 mrem/yr

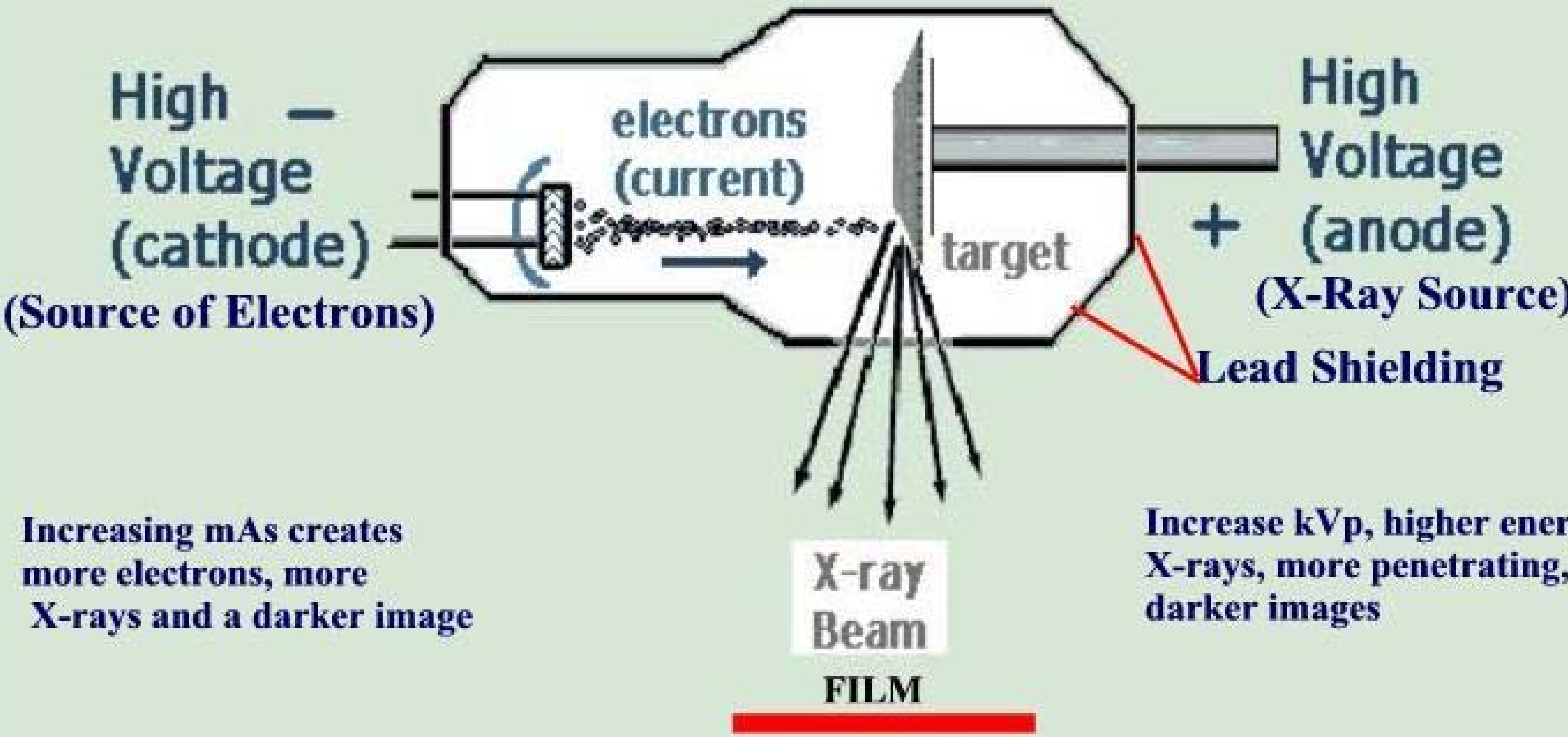
Patient Safety Issues

- Fluoroscopic techniques are being used by an increasing number of clinicians not adequately trained in radiation safety or radiobiology
- Patients are suffering radiation-induced skin injuries due to unnecessarily high radiation doses. Younger patients may face an increased risk of future cancer.
- Many fluoroscopic users are not aware of the potential for injury from procedures, their occurrence or the simple methods for decreasing their incidence utilizing dose control strategies.

Patient Safety Issues

- Many patients are not being adequately counseled about radiation risks before consent for difficult and challenging procedures, nor followed up for the onset of injury, when radiological procedures result in high doses.
- Untrained and inexperienced fluoroscopists have injured patients and exposed staff to high doses.
- Occupational doses can be reduced by limiting unnecessary patient dose, through the correct use and procurement of equipment (including the use of shielding devices).

X-RAY TUBE DIAGRAM



Increasing mAs creates more electrons, more X-rays and a darker image

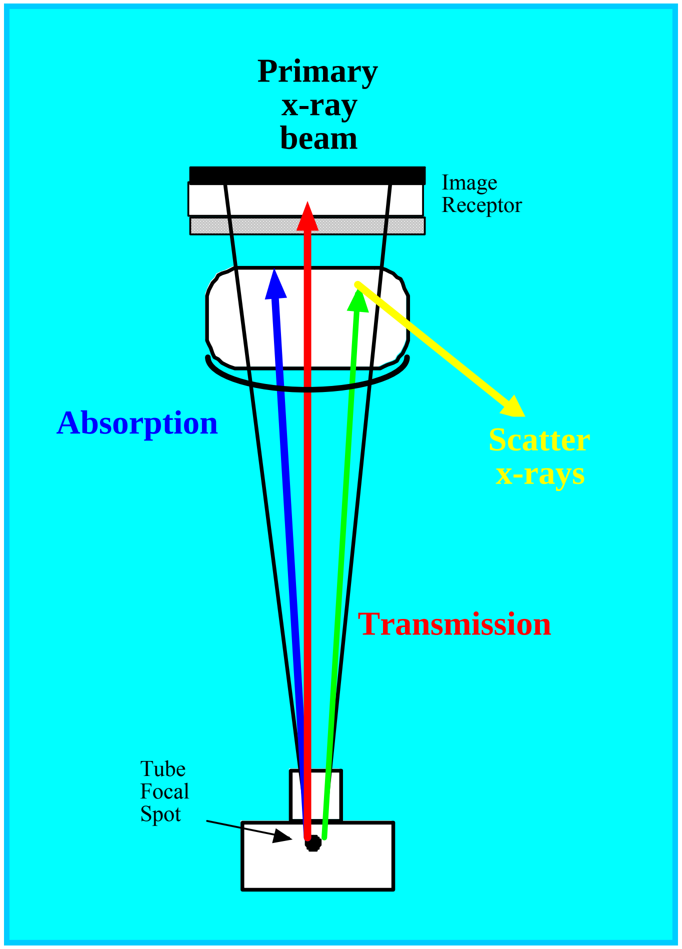
Increase kVp, higher energy X-rays, more penetrating, darker images

Increase film speed, more sensitive to X-rays & get darker image

The X-ray Imaging Process

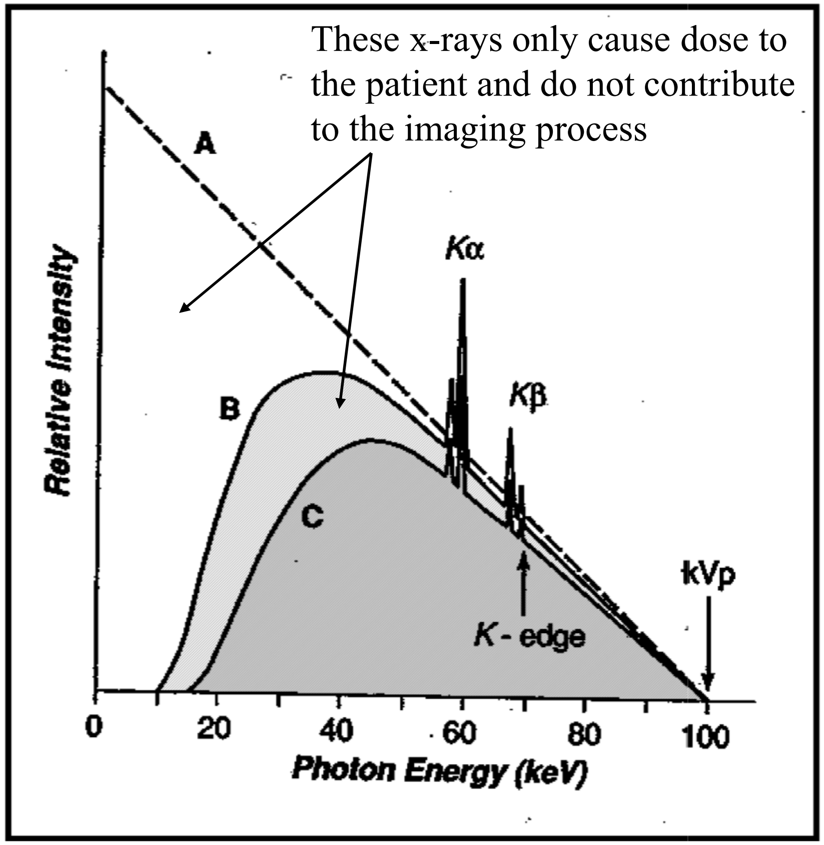
Absorption and transmission of x-rays contribute to the imaging process and patient dose.

Scattered or partially absorbed x–rays contribute to occupational exposure, but are less than 1% of the primary beam intensity.



X-Ray Beam Spectrum - 100 kVp

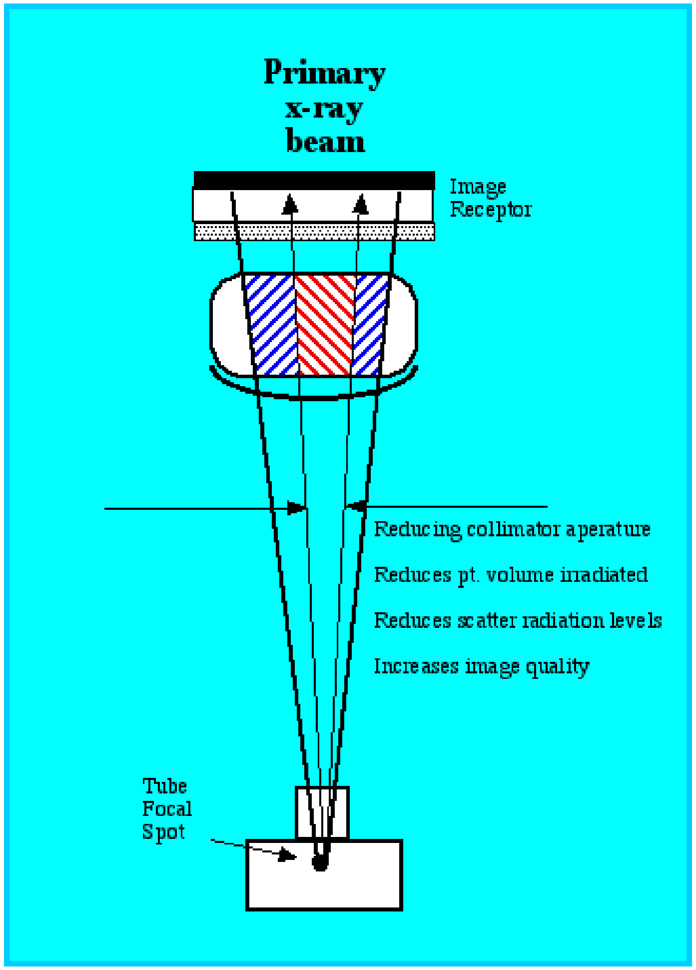
- A. - Hypothetical x-ray spectrum
- B. - Spectrum from tungsten target without filtration
- C. - Spectrum with filtration equivalent to 2.4 mm Al (inherent + added)
- The mean x-ray energy (keV) is approximately 1/3 the peak energy (kVp)
- Unfiltered x-ray beams cause excessive dose to skin because low energy photons cannot penetrate through the patient
- keV - kilovolt
- kVp - kiloVolt peak



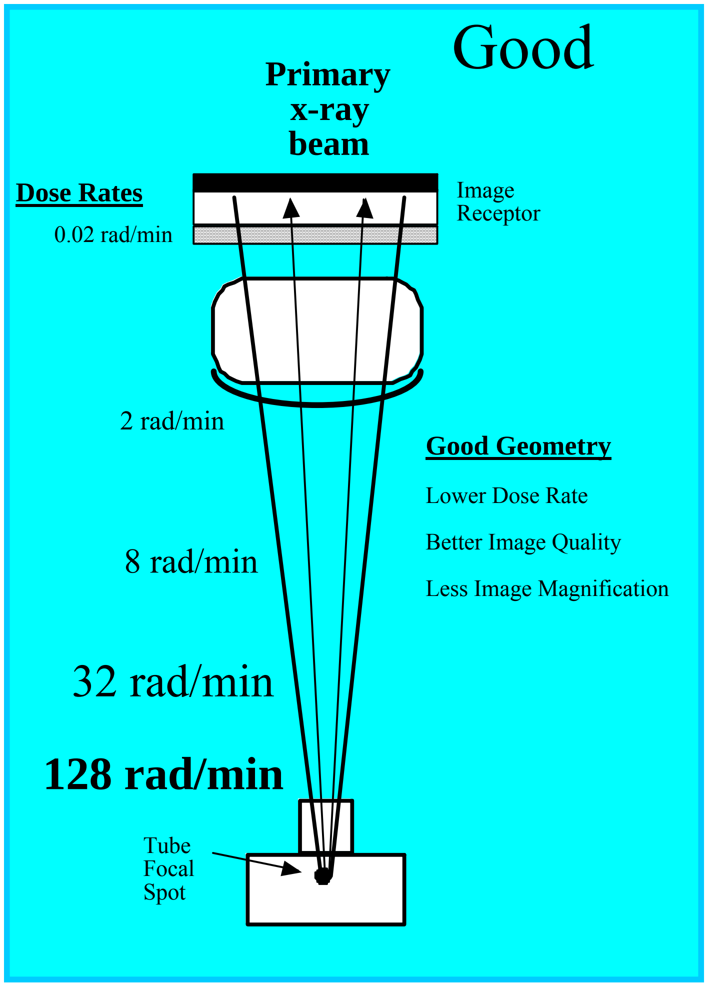
The X-ray Imaging Process

Collimation of the x-ray beam reduces dose to the patient, to the staff and improves image quality due to reduction in x-ray scatter.

Always collimate down once you get to the area of interest.



The X-ray Imaging Process

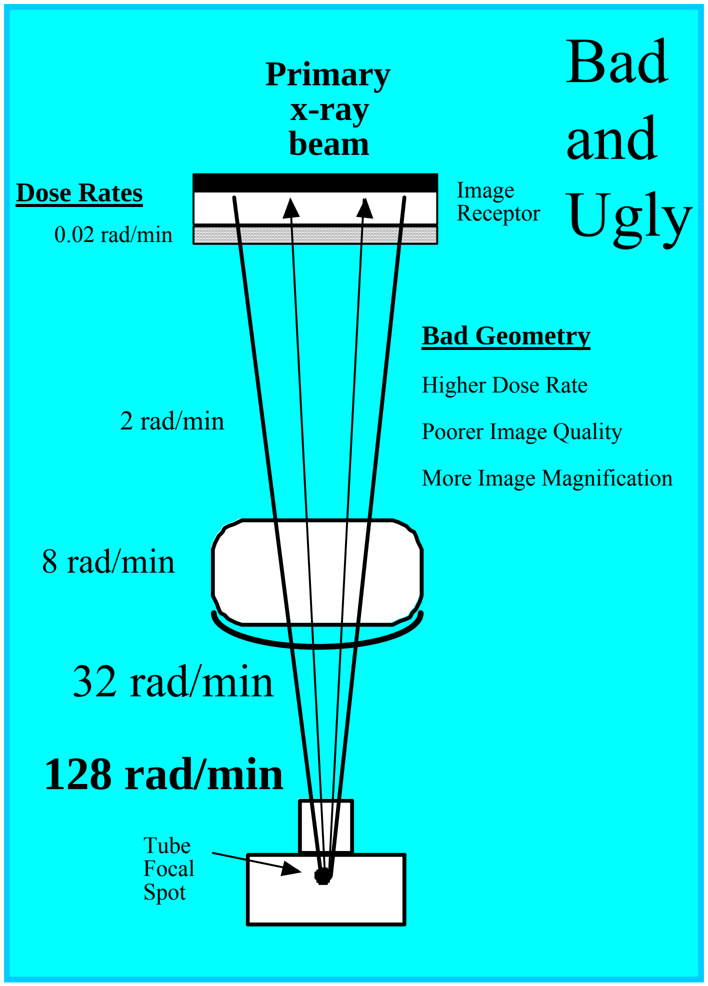


The Good,
The Bad,
and the
Ugly

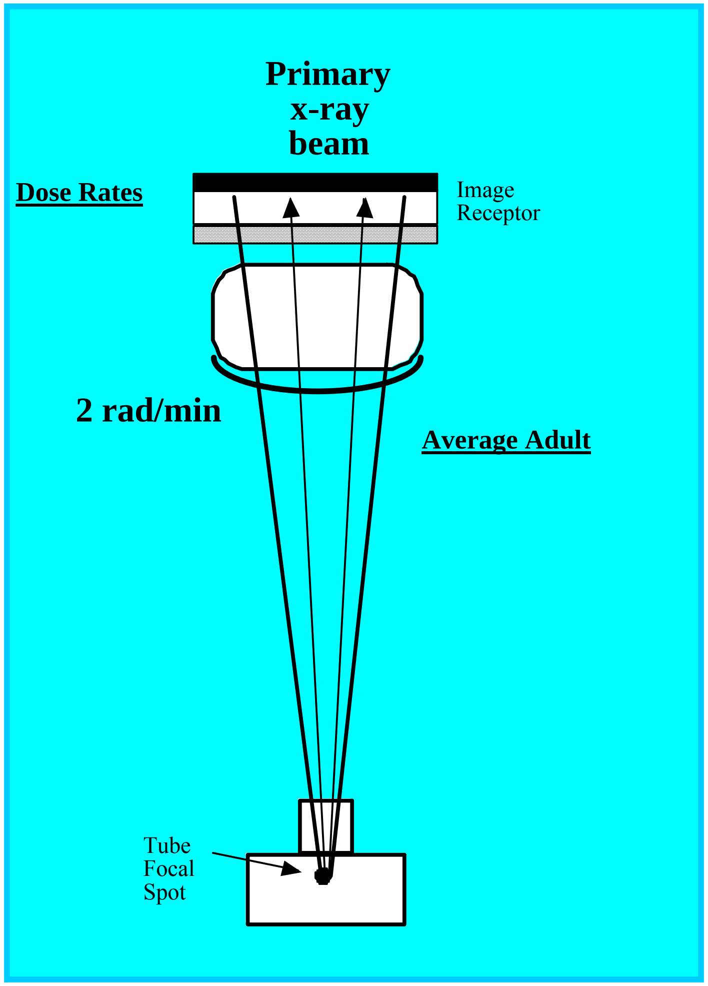
Entrance
Dose Rates

Good Geometry
2 rad/min

Bad Geometry
32 rad/min!

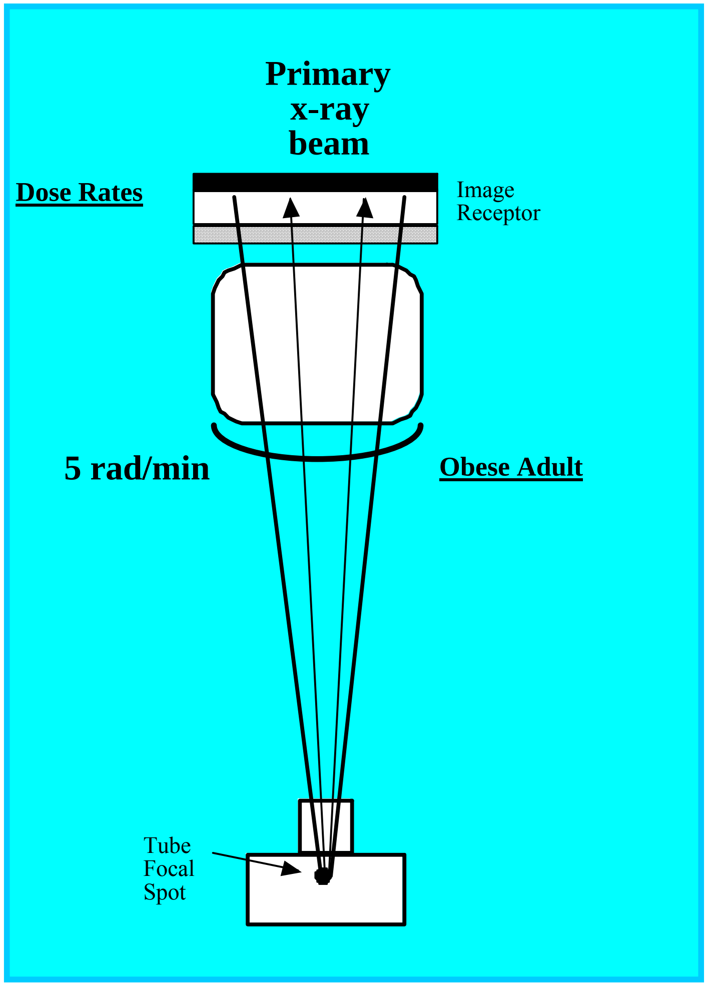


The X-ray Imaging Process

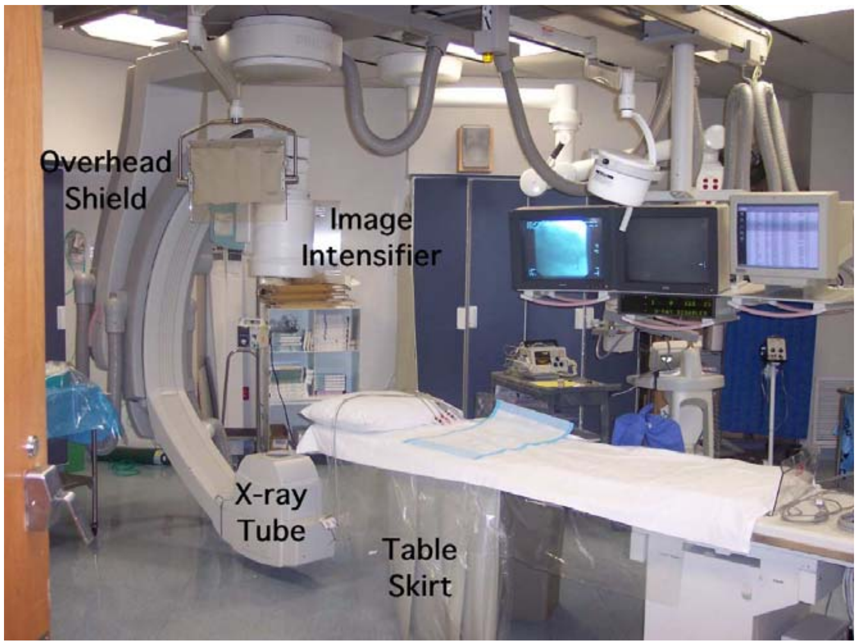


Fluoroscopes are routinely operated in automatic exposure mode.

As the patient becomes thicker x-ray output goes higher to maintain image quality



A Typical Fluoroscopic Lab



Overhead shields need to be positioned down next to the patient and adjacent to the image intensifier to seal scatter off from below.

Table skirts shield the highest backscatter levels from the x-ray tube.

Case Reports

- Patient skin doses in some interventional procedures approach those experienced in some cancer radiotherapy fractions
- Skin injuries are occurring in patients as a result of very high radiation doses during interventional procedures, as a result of the use of inappropriate equipment and more often poor operational technique.
- Injuries to physicians and staff performing interventional procedures have been observed recently, due to the use of inappropriate equipment, poor operational technique and less than optimal radiation safety practices.

Doses in interventional procedures

Effect	Threshold dose (rad)	Minutes fluoro at 2 rad/min	Minutes fluoro at 20 rad/min
Transient erythema	**200**	**100**	**10**
Permanent epilation	**700**	**350**	**35**
Dry desquamation	**1,400**	**700**	**70**
Dermal necrosis	**1,800**	**900**	**90**
Telangiectasia	**1,000**	**500**	**50**
Cataract	**>500**	**>250 to eye**	**>25 to eye**
Skin cancer	**Not known**	**Not known**	**Not known**

Case Study

- FIG.1
  - Radiation wound 22 months after angioplasty procedure.
  - Injury resulted in dermal necrosis
  - Dose > 1,800 rad
  - > 360 minutes fluoro time

During long procedures, move beam entry point to spread cumulative dose

Typical fluoro skin entrance dose rate ≈ 2 - 5 rad/min

Case Study

- FIG.2
  - Patient arm exposed to lateral c-arm radiation.
  - Elbow was located right next to x-ray tube port

1. Keep arm out of lateral fields

2. Keep x-ray tube port as far from the skin as possible

3. Patient should be closest to the image intensifier

Controlling Patient Dose

- Practical Actions: To control dose to the patient & staff
  - Keep beam-on time to an absolute minimum --- The Golden Rule
  - Reduce fluoroscopy pulses/sec to as low as possible/suitable (30/sec, 15/sec, <u>7/sec</u>, 3/sec)
  - Reduce cine frame rates (4, 2 or 1/sec)
  - Remember that dose rates will be greater and dose will accumulate faster in larger patients.

Controlling Patient Dose

- Keep the tube current as low as possible by keeping the kVp as high as possible to achieve the appropriate compromise between image quality and low patient dose.

- Keep the x-ray tube at maximal distance from the patient.

Controlling Patient Dose

– Keep the image intensifier as close to the patient as possible.

– Don’t “over use” geometric magnification.

- Smaller I.I. view increases dose rate

– Consider removing the grid during procedures on small patients (pediatric cases) or when the image intensifier cannot be placed close to the patient.

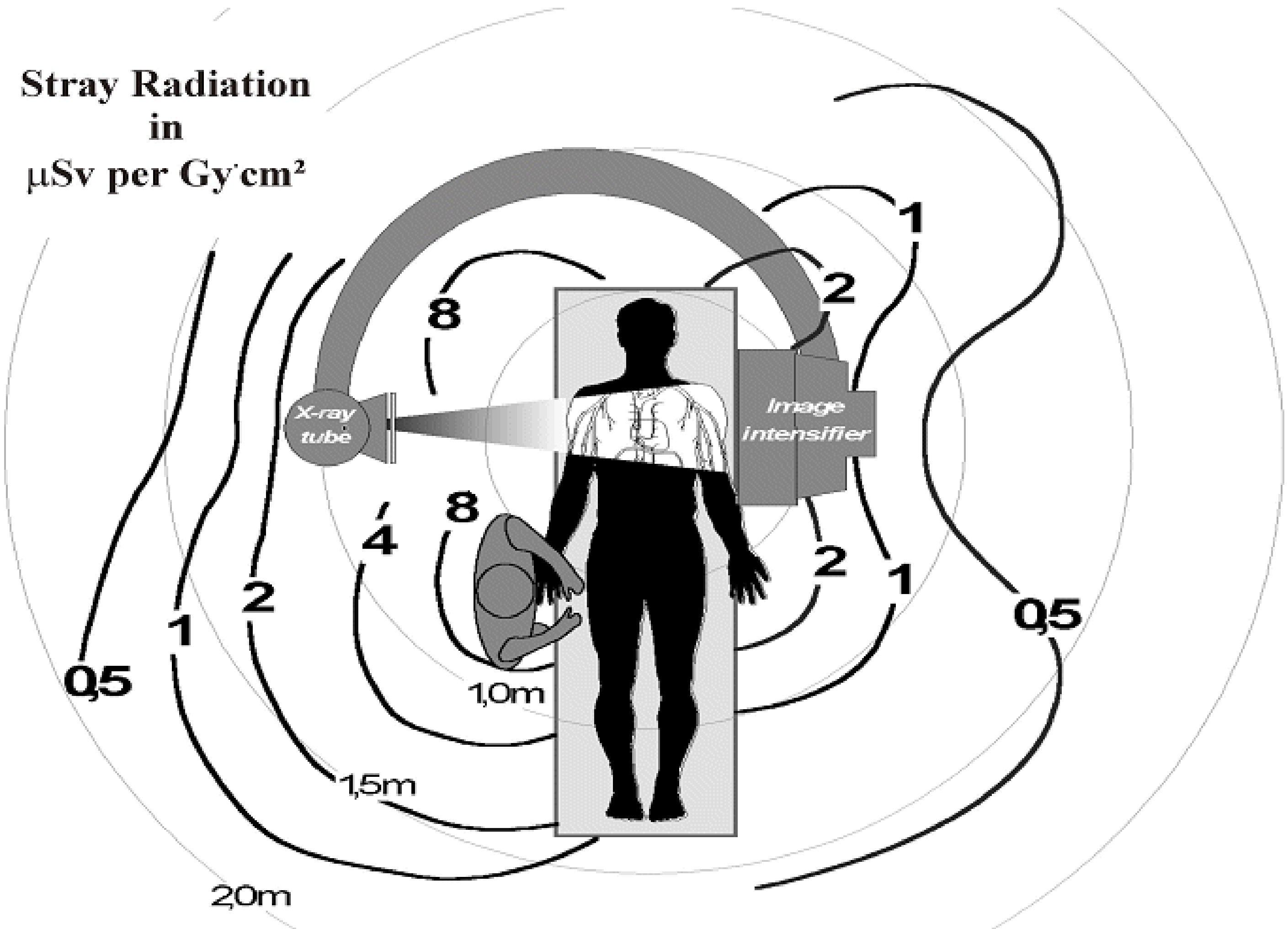
Controlling Patient Dose

- Always collimate closely to the area of interest.
- Use the last image hold feature whenever possible, don’t use live fluoro to confirm static information
- When the procedure is unexpectedly prolonged, consider options for positioning the patient or altering the field so that the same area of skin is not continuously in the direct x-ray field.

Controlling Staff Dose

- To control dose to the staff:
  - Personnel must wear protective aprons, use shielding, monitor their doses, and know how to position themselves and the machines for minimum dose.
    - Overhead glass & table apron shields
  - If the beam is horizontal, or near horizontal, the operator should stand on the image intensifier side [to reduce dose].

Plan view of an interventional operating x-ray unit with isodose curves



Dose rates are 4 times higher on the x-ray tube side

Controlling Staff Dose

– If the beam is vertical, or near vertical, keep the tube under the patient. Use table "skirt" shields whenever available.

– The one exception to this rule is for mini C-arms. When used for extremities, the dose rates are low enough that for practical reasons it is better to have the x-ray tube above the stage.

– Wear your film badge monitors properly and return them promptly.
  - Collar Badges - Outside protective aprons
  - Waist Badges - Under protective aprons

Mini C-arms

- Mini C-arms emit about 1/10th the dose rate as compared to a regular
- C-arm.

- However, good radiation safety practices must still be followed to keep staff and patient exposure As Low as Reasonably Achievable (ALARA).

- Leaded aprons should be worn by all personnel located within 6 feet
- (2 meters) of the Mini C-arm during operation.

- Mini C-arms should be limited to extremity use only. They are not designed to examine thick structures.

- Since Mini C-arms are commonly used for pediatric purposes, limiting exposure time is still important in minimizing long term radiation risk to this population.

Additional Resources and References

For additional training contact the YNHH Radiation Safety Office at

(203) 688-2950 or mike.bohan@yale.edu

Online References:

http://www.e-radiography.net/radsafety/rad_physics.htm

http://www.fda.gov/Radiation-EmittingProducts/RadiationEmittingProductsandProcedures/MedicalImaging/MedicalX-Rays/ucm116672.htm

http://www.icrp.org/downloadDoc.asp?document=docs/ICRP_85_Interventional_s.pps