Shielding techniques
Summer School 2007

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Variables

- Primary
- Scatter
- Leakage
- Distance
- Occupancy
- Usage factor for barrier
- Workload

Single projection

- Scatter will not be isotropic
- But scatter is always predictable as a function of energy, angle and area

Techniques

- First principles- back of the envelope
- NCRP 147

Cardiac cath example
From NCRP 147

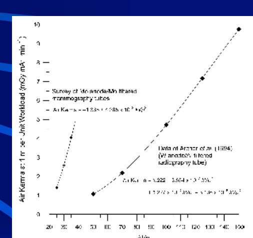
- 160 mAmin/patient
- Area of II=730 cm^2 (30.5 cm diameter)
- Distance of II = 0.9 m
- Stray radiation @ 1m =3.8 mGy/patient
- Scatter angle =135 degrees
- 25 patients/week
- Barrier @ 4m

Primary

NCRP 147

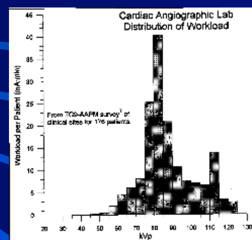
- **Primary -rule of thumb**
- 100 kVp 10 mR/mAs @ 1m
- mR at distance d

=10*mAs*((100/kVp)^2)*(1/d)^2



NCRP 147 assumption

- **Envelope**
- **Primary**
  - Use 82 kVp - to get appropriate scatter



Cardiac cath example From NCRP 147 More assumptions

- 82 kVp
- Patient at 46 cms from tube

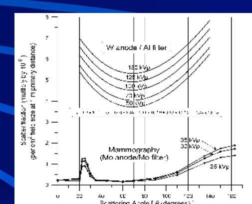
Results Patient dose

Envelope	NCRP 147
286 R	237 R
2.49 Gy (air kerma)	2.06 Gy (air kerma)

Results Patient Scatter @ 1m

- Envelope
- Rule of thumb
- Patient dose /1000

NCRP 147



Results Patient Scatter @ 1m

Envelope	NCRP 147
1/1000 of patient dose	135 degrees scatter
286 mR	422 mR
2.49 mGy	3.7 mGy

Scatter

- The NCRP 147 approach uses a conservative backscatter assumption

Results
Patient Scatter @ 1m

- Envelope
- 1/1000
- 286 mR
- 2.49 mGy

- NCRP 147
- 90 degrees
- 293 mR
- 2.55 mGy

Attenuation options

- Both approaches reduce the radiation by the same factor (1/16) for distance (4m)

Scatter at 4m for 25 patients/week

- Envelope
- 3.88 mGy /week
- 447 mR/week

- NCRP 147
- 5.74 mGy/week
- 660 mR/week

Required attenuation
to get 0.02 mGy beyond barrier

- Envelope
- 5.15e-3

- NCRP 147

3.49e-3 for 135 degree scatter
or
5.2e-3 for 90 degree scatter

Attenuation options

- Envelope
- HVL's
- TVL's
- Attenuation curves (NCRP 49 NCRP 147)

- NCRP 147

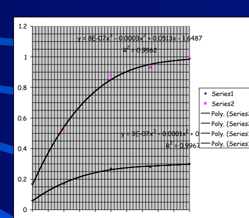
Curve Fig c2
Archer equation

HVL and TVL s

At 82 kVp from NCRP 49

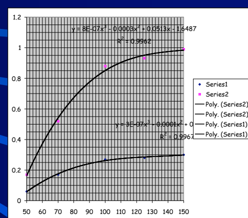
HVL for lead = 0.23 mms

- TVL for lead = 0.7 mms



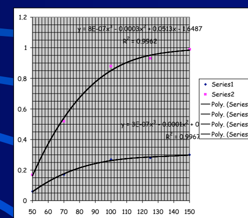
HVL and TVL s

- HVL
- attenuation (B) =(1/2)^n
- n=3.32* log(1/B)
- TVL
- attenuation =(0.1)^n
- n=log (1/B)
- B= 5.15^-3



HVL and TVL s

- # of HVLs=7.6* 0.23
- =1.75mm of lead
- # of TVLs =2.3*.7
- = 1.61 mm of lead



NCRP 147

Transmission through lead

- Using Simpkin curve

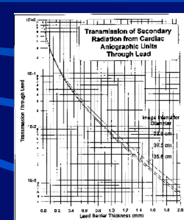


Figure 4. Transmission through lead of secondary radiation from cardiac angiography units for the indicated image intensifier input phosphor sizes.

Transmission through concrete

- Using Simpkin curve

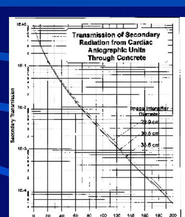


Figure 5. Transmission through concrete of secondary radiation from cardiac angiography units for the indicated image intensifier input phosphor sizes.

Transmission curve factors

Table 4
Fitting Parameters for Secondary Transmission Curves for Cardiac Angiographic Units

	Image Intensifier Diameter (cm)								
	22.9			30.5			35.6		
Material	α (mm^{-1})	β (mm^{-1})	γ	α (mm^{-1})	β (mm^{-1})	γ	α (mm^{-1})	β (mm^{-1})	γ
Lead	2.394	15.69	0.8027	2.397	15.48	0.7925	2.405	15.33	0.7087
Concrete	0.03749	0.1092	0.6063	0.03749	0.1097	0.5851	0.03749	0.1098	0.5502

Note.— In using these parameters with Equation (6), enter the thickness (x) in millimeters. See Figures 4 and 5 for graphs of these transmission curves.

NCRP 147 results

Curve Fig c2 = 1.35 mms

Archer equation = 1.35 mms

Attenuation options

- Envelope
- HVL=1.75 mm
- TVL= 1.61 mm
- NCRP 49 (100 kVp) attenuation=0.8 mm
- NCRP 147 (cardiac)=1.2 mm

- NCRP 147

Curve Fig c2 = 1.35 mms

Archer equation = 1.35 mms

Result

- Apart from the HVL and TVL estimates rounding up to commercially available thicknesses gives 1/16 inch of lead for the shield thickness

NCRP 147

- Fast and easy

The NCRP 147 quick way(1)

- Assumption

Stray radiation is 3.8 mGy /exam @ 1m

The NCRP 147 quick way(1)

- Scatter at barrier at 4m =3.8mGy/patient*25patients per week/4^2

The NCRP 147 quick way(1)

- Scatter at barrier at 4m =3.8mGy/patient*25patients per week/4^2
- =5.9 mGy/week at the barrier
- (compared to 5.74 mGy we got before)

The NCRP 147 quick way(1)

- Scatter at barrier at 4m =3.8mGy/patient*25patients per week/4^2
- =5.9 mGy/week at the barrier
- Attenuation required=0.02/5.9=3.4e-3
- (3.5e-3 before)

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- From curve 1.3 mm Pb
- From Archer 1.3 mm Pb

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- =5.9 mGy/week at the barrier
- Attenuation required=0.02/5.9=3.4e-3
- From curve 1.3 mm
- From Archer 1.3 mm
- Gives 1/16 inch of lead--again

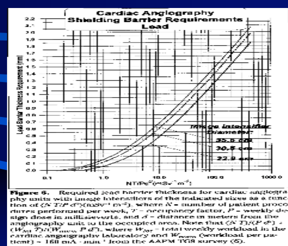
The NCRP 147 quick way(2)

- **NT/Pd^2**

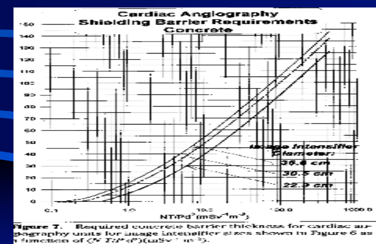
The NCRP 147 quick way(2)

- NT/Pd^2
- N=25   T=1   P =.02 mGy   d=4 m
- NT/Pd^2 = 78.1

Transmission through lead



Transmission through concrete



The NCRP 147 quick way(2)

- NT/Pd^2
- N=25 T=1 P =.02 mGy d=4 m
- NT/Pd^2 = 78.1
- From curve thickness of lead =1.3 mm
- Or rounding up 1/16 inch lead

How effective is 1/16 inch of lead?

- Very

Diagnostic x-ray rooms

- This evaluation was first carried out in 1994 when the exposure limits to the general were lowered from 500 to 100 mR/year
- At that time only TLD were readily available for long-term monitoring with a lower detectable limit of 10 mR

Shielding Investigation

- OSL dosimeters give an order of magnitude increase in sensitivity over TLD
- Dosimeters were exposed in groups of two for eight weeks to minimize spurious results

Optically Stimulated Luminescent Dosimeters

- Range from 1 mR - 1,000 R
- Good long term stability
- Convenient for environmental monitoring

Technique factors

- Technique factors were evaluated by a random sampling over several days
- Room and protective cubicle shielding was confirmed by doing Tc- 99m transmission studies and comparing with known thicknesses of lead sheet.

Rooms

Room1	Dedicated chest	5 days/week
Room 6	General purpose Radiographic room	7 days/week
Room 7	General purpose Radiographic room	7 days/week
Room 5	General purpose R&F room	5 days/week

Dedicated chest room

Location	mR inside	mR outside	% Transmission
Behind chest stand	63-103	0	<1%
Protective cubicle glass	75-103	0	<1%

General purpose Rad room

Location	mR inside	mR outside	% Transmission
Behind chest stand	69-112	0	<1%
Protective cubicle glass	297-414	0	<.3%
Wall inside	319-322	0	<0.3%

General purpose Rad room

Location	mR inside	mR outside	% Transmission
Behind chest stand	43-22	0	<3 %
Protective cubicle glass	97-117	0	<.9%
Wall inside	209-205	0	<0.5%

General purpose R / F room

Location	mR inside	mR outside	% Transmission
Behind chest stand	43-22	0	<3 %
Protective cubicle glass	323-308	0	<.3%
Wall inside	197-192	0	<0.5%
Corridor wall	39-41	0	<2.5%

Conclusion

- All the rooms examined were designed according to NCRP 49 to 10 mR/week with corridor occupancy factor of 0.25 and full occupancy behind protective cubicle

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- The corridor should expect about 320 mR over 8 weeks

Conclusion

- All the rooms examined were designed according to NCRP 49 to 10 mR/week with corridor occupancy factor of 0.25 and full occupancy behind protective cubicle
- Each room actually had 1/16 inch of lead everywhere-except behind the chest stand (1/8 inch)
- The corridor should expect about 320 mR over 8 weeks
- We see less than 1 mR therefore these rooms are overshielded by at least 2 to 3 orders of magnitude

"It started out with lactose, but now he's intolerant of everything."

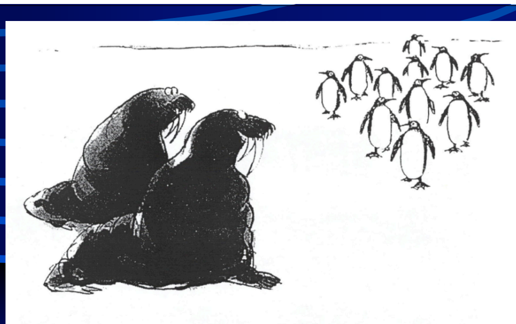
Mammography

Mammography

- Good news!

Mammography

- Good news!
- If you're in Michigan it's all been done for you



"Here come the suits."

Michigan requirements

Required shielding (for pre 9/30/99 machines)		Required shielding (for post 9/30/99 machines)	
Lead	0.19 mm	Lead	0.139 mm
Concrete	23.1 mm	Concrete	16.6 mm
Gypsum	60.3 mm	Gypsum	45.8 mm
Steel	1.03 mm	Steel	0.731 mm
Plate glass	24.5 mm	Plate glass	17.4 mm
Wood	389 mms	Wood	238 mms

Assumptions

Michigan		NCRP 147	
# of patients/week	150	# of patients/week	80-160
mAmin/patient	8	mAmin/patient	6.8
mAmin/week	1200	mAmin/week	550-1075
kVp	23-35	kVp	23-35
Occupancy factor	1	Occupancy factor	1-1/40
Primary use factor	0.25	Primary use factor	0
Secondary use factor	1	Secondary use factor	1

Assumptions

- Michigan
  - Leakage 100mR/hr
  - Primary distance(m) 1.5
  - Secondary distance(m) 1.5
  - Leakage distance(m) 1.5
  - SID (m) 0.65
  - Beam size) 24x30
  - Scatter angle 135
- NCRP 147
  - Leakage 0 mR/hr
  - Primary distance(m) ?
  - Secondary distance(m) ?
  - Leakage distance(m) ?
  - SID (m) 0.6
  - Beam size) 24x30
  - Scatter angle 135

NCRP 147

- NCRP 147 calculation for Michigan example
- Only assumption for calculation is that scatter at 1m
  =3.6e-2 mGy /patient

NCRP 147

- NCRP 147 calculation
- Only assumption for calculation is that scatter at 1m
- =3.6e-2 mGy /patient
- =3.6e-2 *150 mGy/week

NCRP 147

- NCRP 147 calculation
- Only assumption for calculation is that scatter at 1m
- =3.6e-2 mGy /patient
- =3.6e-2 *150 mGy/week
- =3.6e-2*150/(1.5)^2 mGy for barrier at 1.5 m

NCRP 147

- NCRP 147 calculation
- Only assumption for calculation is that scatter at 1m
- =3.6e-2 mGy /patient
- =3.6e-2 *150 mGy/week
- =3.6e-2*150/(1.5)^2 mGy for barrier at 1.5 m
- =1.6 mGy/week

NCRP 147

- NCRP 147 calculation
- Only assumption for calculation is that scatter at 1m
- =3.6e-2 mGy /patient
- =3.6e-2 *150 mGy/week
- =3.6e-2*150/(1.5)^2 mGy for barrier at 1.5 m
- =1.6 mGy/week
- Attenuation= 0.02/1.6

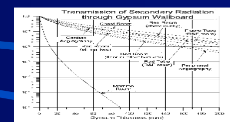
NCRP 147

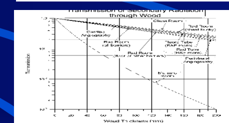
- NCRP 147 calculation

- Only assumption for calculation is that scatter at 1m
- =3.6e-2 mGy /patient
- =3.6e-2 *150 mGy/week
- =3.6e-2*150/(1.5)^2 mGy for barrier at 1.5 m
- =1.6 mGy/week
- Attenuation= 0.02/1.6
- =1.25e-2

Transmission through wood and sheetrock

- Required transmission is 1.25e-2





Required shielding

- NCRP 147

- Attenuation factor =1.25e-2

- From transmission curve

- Sheetrock = 10 mm
- Wood   = 110 mm

NT/Pd^2 method

- NCRP 147

- Or   using NT/Pd^2

- = (150*1)/(0.02*1.5^2)

NT/Pd^2

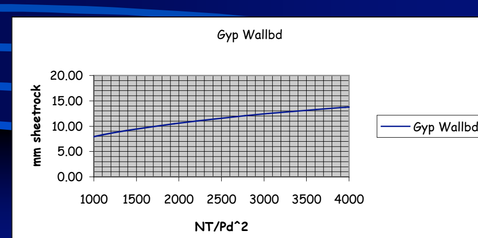
- NCRP 147

- Or   using NT/Pd^2

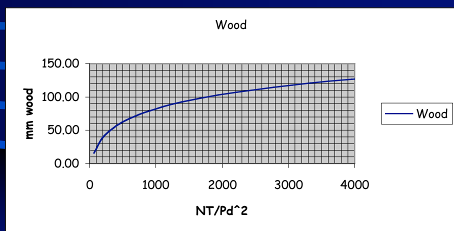
- = (150*1)/(0.02*1.5^2)

- =3333 mGy^-1 m^-2

Sheetrock



Wood

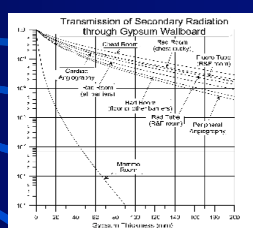


NT/Pd^2

- NCRP 147
- Or using NT/Pd^2
- = (150*1)/(0.02*1.5^2)
- =3333 mGy^-1 m^-2
- =12.9 mms sheetrock
- =120.8 mm wood

Using Michigan requirements

- Transmission for suggested sheetrock
- thicknesses
- 45.8 mms ~ 8e-5
- 60.3 mms ~2e-5
- Compared to 1.25e-2



Michigan requrements

- These differ by ~ 2 and 3 orders of magnitude respectively

Michigan requrements

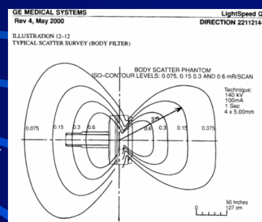
- These differ by ~ 2 and 3 orders of magnitude respectively
- Which would be even more if real room dimensions were used for the NCRP 147 calculations

CT shielding

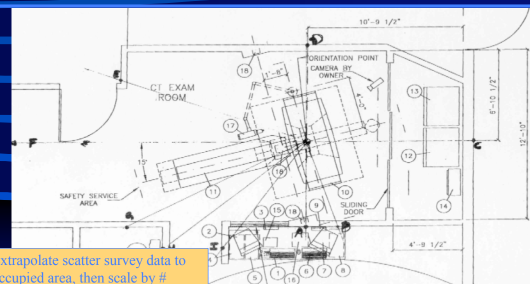
Overview

CT Scanners: Estimate Unshielded Kerma

- Estimate ambient kerma around scanner
  - Manufacturer's isoexposure curves
    - extrapolate using $1/r^2$ from isocenter
    - scale by mAs used clinically vs. for isoexposure curve
    - varies with phantom!



Estimate unshielded kerma around room



Extrapolate scatter survey data to occupied area, then scale by # patients, # slices or length of patient imaged, and technique.

CT Shielding

- Due to multiple projection scanning scatter will be generated isotropically
- Modified by the gantry
- So scatter at a distance will be determined by
- The dose to the patient
- The length (area or volume) scanned
- Modified by pitch

CT

- Dose to the patient is related to CTDI (in some form)
- Scatter will depend on the phantom chosen
- So FDA dosimetry phantoms are chosen as standard scattering objects
- And the axis 1 cm from the periphery chosen as the CTDI measurement location

CT

- $CTDI_{vol} = (1/3\ CTDI_{100,center} + 2/3\ CTDI_{100,periphery})/p$
- Where p is pitch
- $DLP = CTDI_{vol} *$ length scanned
- So scatter is a direct function of DLP

CT

- $CTDI_{vol} = (1/3\ CTDI_{100,center} + 2/3\ CTDI_{100,periphery})/p$
- For the FDA Body phantom where the central dose is about half of the peripheral dose
- $CTDI_{vol} = (1/6\ CTDI_{100,center} + 4/6\ CTDI_{100,periphery})/p$
- $= 5/6\ CTDI_{100,periphery})/p$
- $CTDI_{100,periphery})/p = 6/5 * CTDI_{vol}$
- $CTDI_{100,periphery} = 1.2 * CTDI_{vol} * p$

CT

- Scatter = constant * DLP for the standard measurements
- Head scatter = constant* DLP
- Body scatter = (some other constant) *DLP

CT

- Head scatter = constant* DLP

Constant = 9*e-5 per cm NCRP 147

- =1.1 e-4 per cm Larson (2007)

- Body scatter = other constant *DLP
- Constant =3.0 e-4 per cm NCRP 147
- =5.2e-4 per cm Larson (2007)

CT

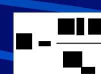
- Head scatter = constant* DLP

= Head constant *DLP

Body scatter = other constant *DLP

- Constant = 1.2 *Body constant *DLP
- if we use $CTDI_{vol}$ to determine DLP

CT Scanner Shielding: Overview

- Estimate unshielded weekly kerma in occupied area near scanner, K_{un}
- Presume *P/T*
- Barrier requires transmission 
- Get barrier thickness
  - Data in NCRP Rept 147 from Simpkin *Health Phys* **58**, 363-7: 1990 (refit)

CT Scanners: Estimate Unshielded Kerma

- Estimate Workload
  - Ben Archer (c.1993) guessed that there were ~40 (10 mm thick) slices/patient
  - Helical/multislice scanners: probably more like
    - 20 cm total thickness imaged for head patients
    - 40-60 cm total thickness imaged for body patients
    - ×2 for patients scanned with & without contrast
- 100 - 200 patient/wk typically

Unshielded Kerma from CTDI

- Estimate, for either head or body scans, the ambient kerma per patient around scanner for a slice t (mm) thick generated by N_R rotations each at technique $mAs_{Clinical}$

Unshielded Kerma from CTDI

- Can recast this in terms of the thickness of each patient imaged, $L = N_R \times t \times pitch$, with each rotation acquired at technique $mAs_{Clinical}$

[illegible]

- or, equivalently, the total imaging time T_{CT} (sec) per patient, with beam width t(mm) per rotation

[illegible]

Unshielded Kerma from DLP

- Since the product of the CTDI used for each patient and the thickness of the patient imaged is the Dose Length Product, *DLP*, can simplify:

[illegible]

[illegible]

  - (where the 1.2 comes from converting peripheral CTDI into DLP)
- The *DLP* values can be read off of the scanner, or from European Commission Guidelines:
  - *DLP* = 1,200 mGy cm for heads
  - *DLP* = 550 mGy cm for bodies

CT Scanner Example

- Wall (or floor, or ceiling) of CT scanner room: $P/T = 0.02$ mGy wk^{-1}, d=3 m
- 200 patients wk^{-1} (125 bodies + 75 heads)
- Assume (per NCRP Rept #147)
  - *DLP* = 1,200 mGy cm for each body patient
  - *DLP* = 550 mGy cm for each body patient
- Assume 40% of patients will have scans both pre- and post-contrast medium injection
- Assume 140 kVp operation

CT Scanner Example

The unshielded kerma per head patient at 1 m is:

[illegible]

The unshielded kerma per body patient at 1 m is:

[illegible]

So total unshielded weekly kerma at 1 m is

$$K^1_{un} = 75\ head\ pat \times 0.15 \frac{mGy}{head\ pat} + 125\ body\ pat \times 0.28 \frac{mGy}{body\ pat}$$
$$= 46.3\ mGy$$

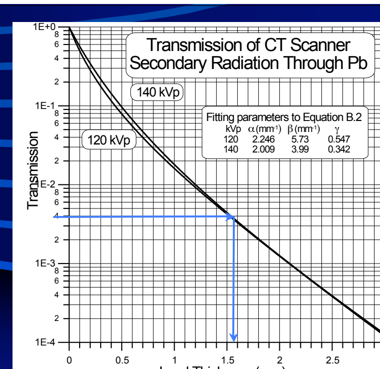
CT Scanner Example

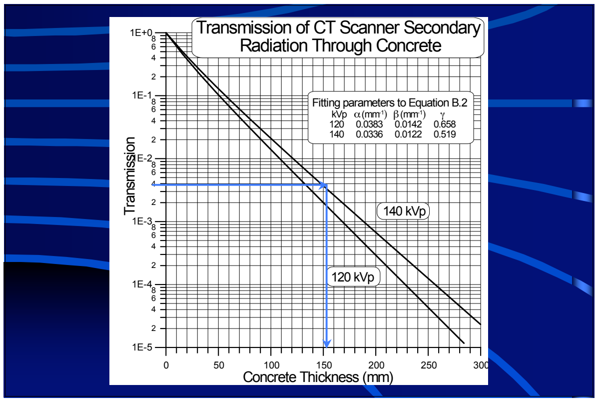
- The unshielded weekly kerma at 3 m is

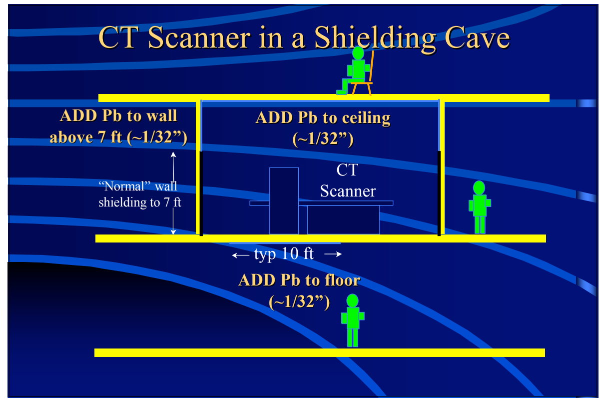
[illegible]

- The transmission required in this wall is therefore
- which, at 140 k [illegible]
  - 1.52 mm Pb, [illegible]
  - 150 mm = ***5.9 inches standard density concrete***

WATCH OUT ABOVE & BELOW!







Summary

- NCRP 147 calculations are simple and fast
- Only a few assumptions are required
- These can be modified for local circumstances or changes in technology