The CPCC ^{131}Cs experience, Developing a Model for predicting Exposure rates around LDR prostate seed patients

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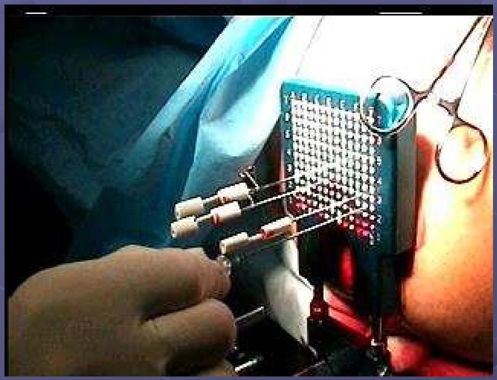
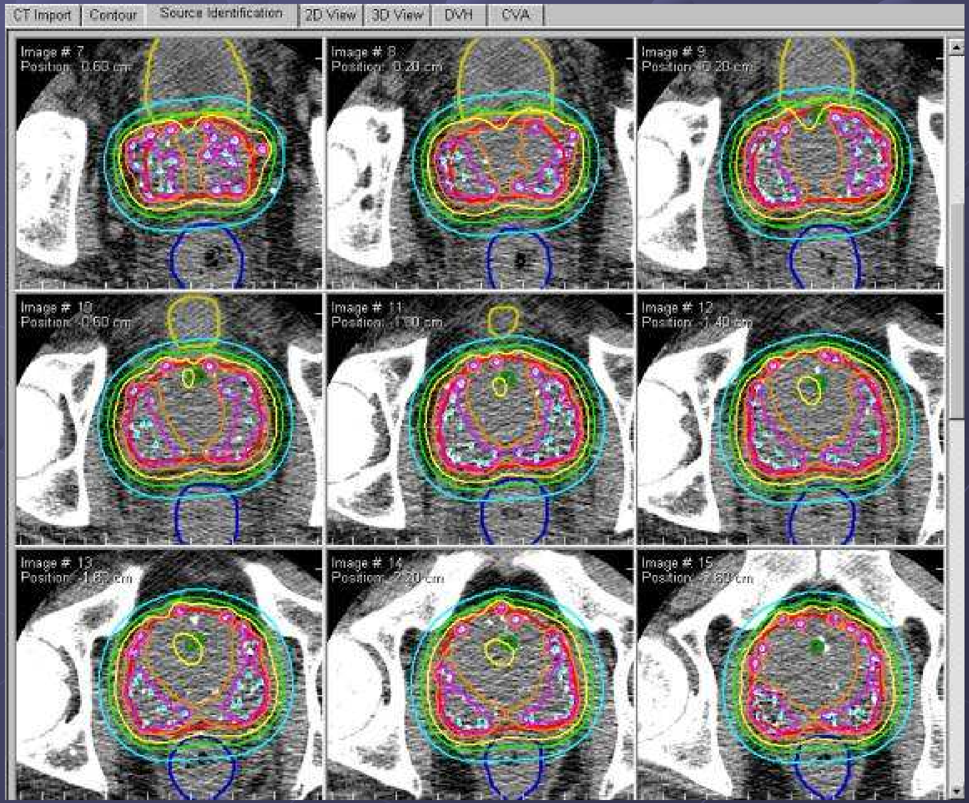
Prostate Seed Implants

- Intra-op procedure where LDR radioactive seeds are implanted into the prostate gland.

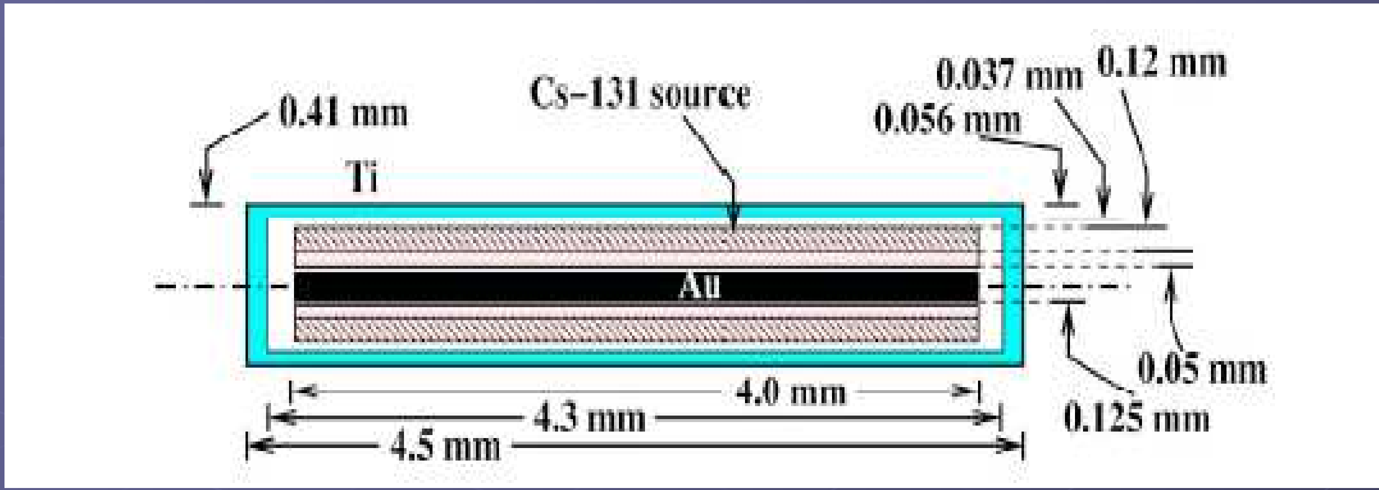




The only ^{131}Cs Brachytherapy seed

IsoRay™ MEDICAL

Seed Design Specifics (CS-1 Rev 2)



- 4.0mm active length, 4.5mm physical length
- Source on inorganic substrate surrounding central gold wire 0.25mm (serves as radio-opaque marker). The gold wire is surrounded by a glass and ceramic tube.
- Cesium is chemically attached and uniformly distributed to inorganic substrate
- Seed is encapsulated in titanium tube with argon filled space.

Wittman, R and. Fisher, D. Multiple estimate Monte Carlo calculation of the dose rate constant for a cesium-131 interstitial brachytherapy seed. Med Phys 34 (1) January 2007

How Cesium-131 Decays

- Cs-131 decays via electron capture to Xe-131.
- Cesium emits photons with energies:

4.11 keV
29.46 keV
29.78 keV
33.56 keV
33.62 keV
34.42 keV

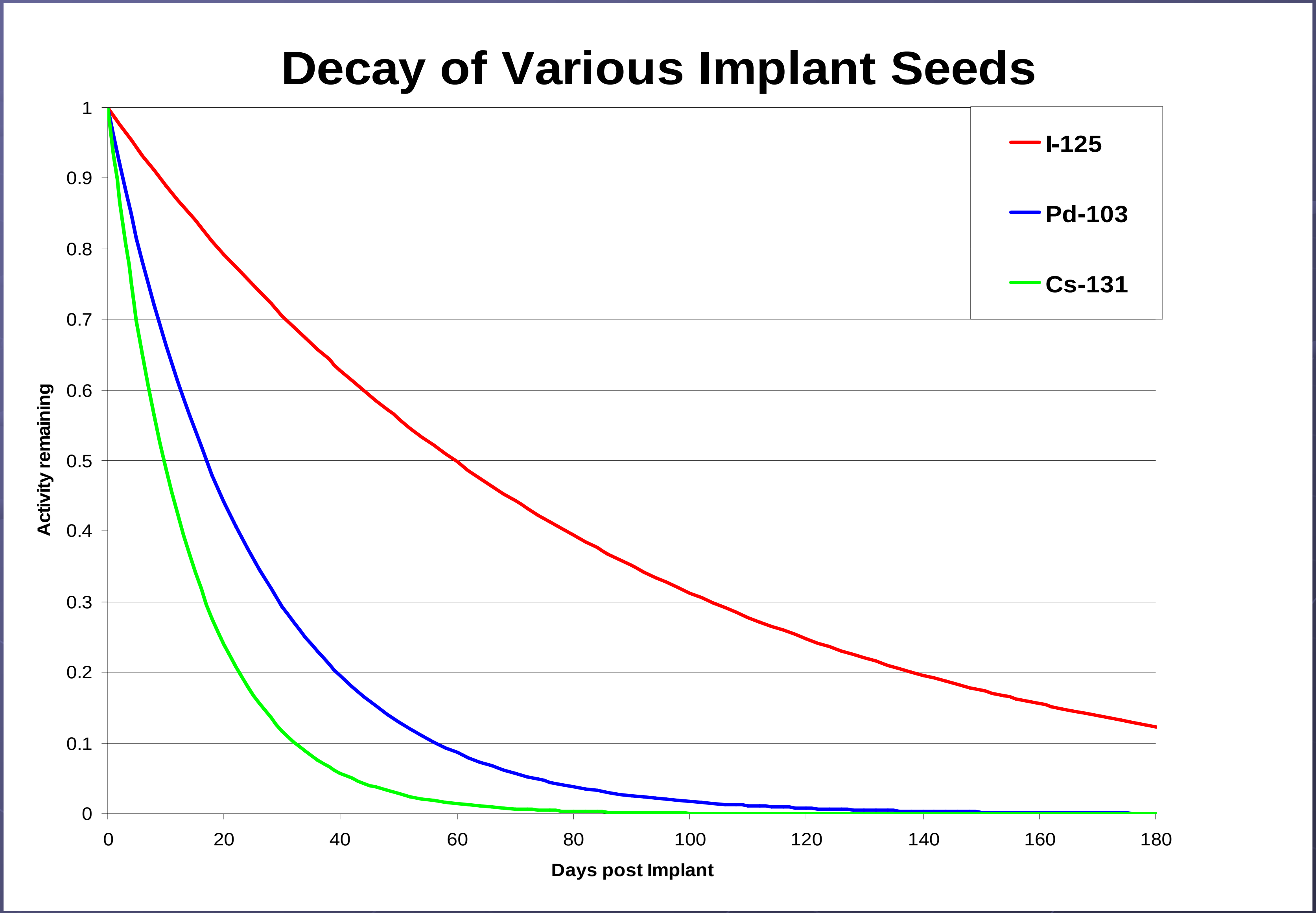
- 90% of the emitted photons have energies from 29.5 to 34.4 keV. Mean Photon Energy of 30.4 keV.
- The 4.11 keV photons are attenuated by the titanium capsule of the seed itself.

Z. Chen, P. Bongiorni, and R. Nath. **Dose rate constant of a Cesium-131 interstitial brachytherapy seed measured by thermoluminescent dosimetry and gamma-ray spectrometry. Med Phys 32 (11) November 2005.**

Prostate Brachytherapy Isotopes

	Half Life (days)	Ave Energy (keV)	S(k) (U) cGy cm^2/hr	Total Dose Gy (Full / Boost)
^{131}Cs	**9.7**	**(29 – 34) Ave = 30.4**	**2.0**	**115 / ?**
^{103}Pd	**17.0**	**(20.1 , 23.0) Ave = 21**	**~2.4**	**125 / 90**
^{125}I	**59.6**	**(27.4 - 35.5) Ave = 28.5**	**~0.47**	**144 / 108**

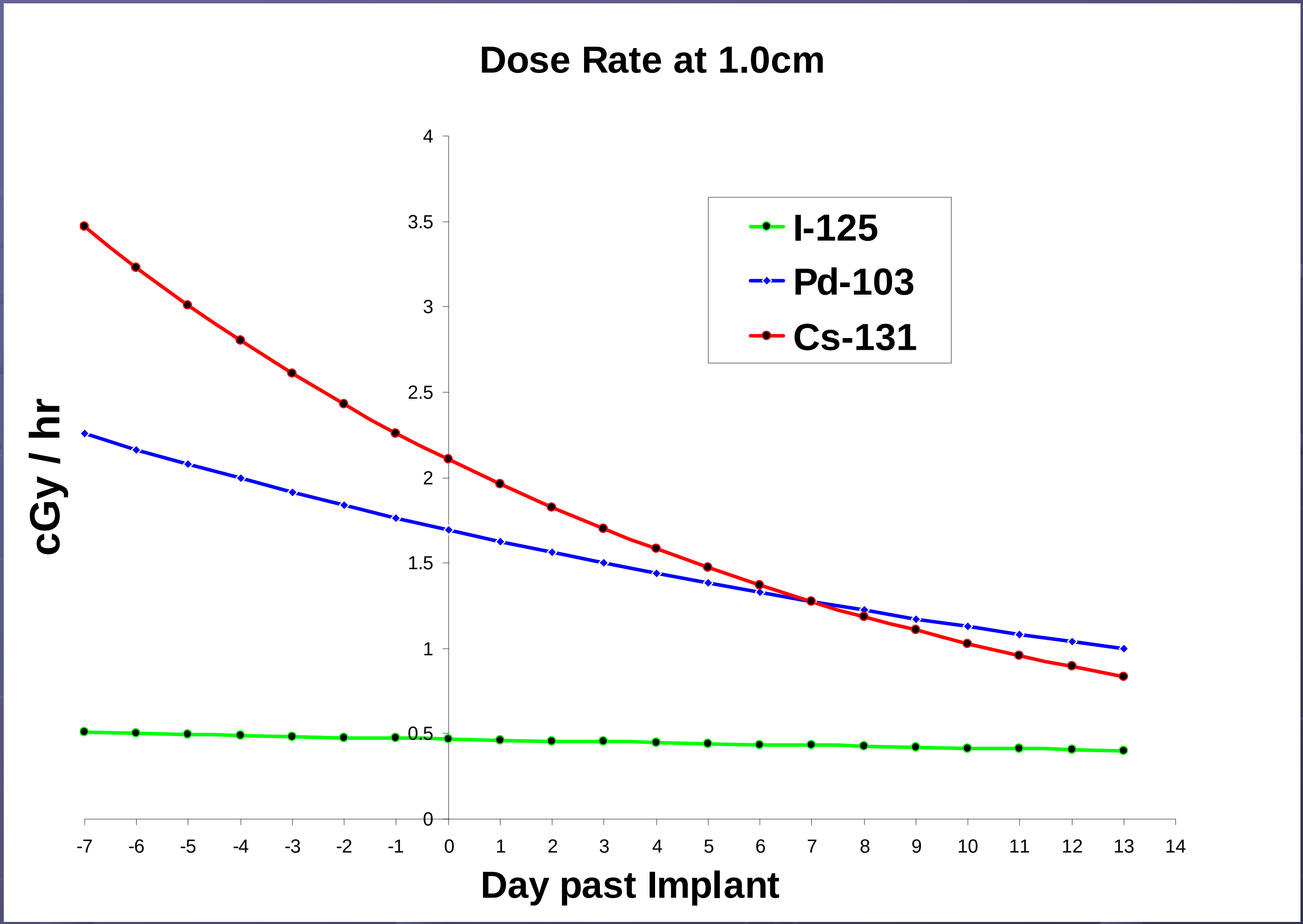
Different Half-life



Different Half-life = Different results

- Short Half life
  - Need more activity
  - More effective killing cells with shorter doubling time
  - More susceptible to edema effect

Dose Rates at 1.0cm



BED and Half-life

I. J. Radiation Oncology ● Biology ● Physics Volume 55, Number 2, 2003

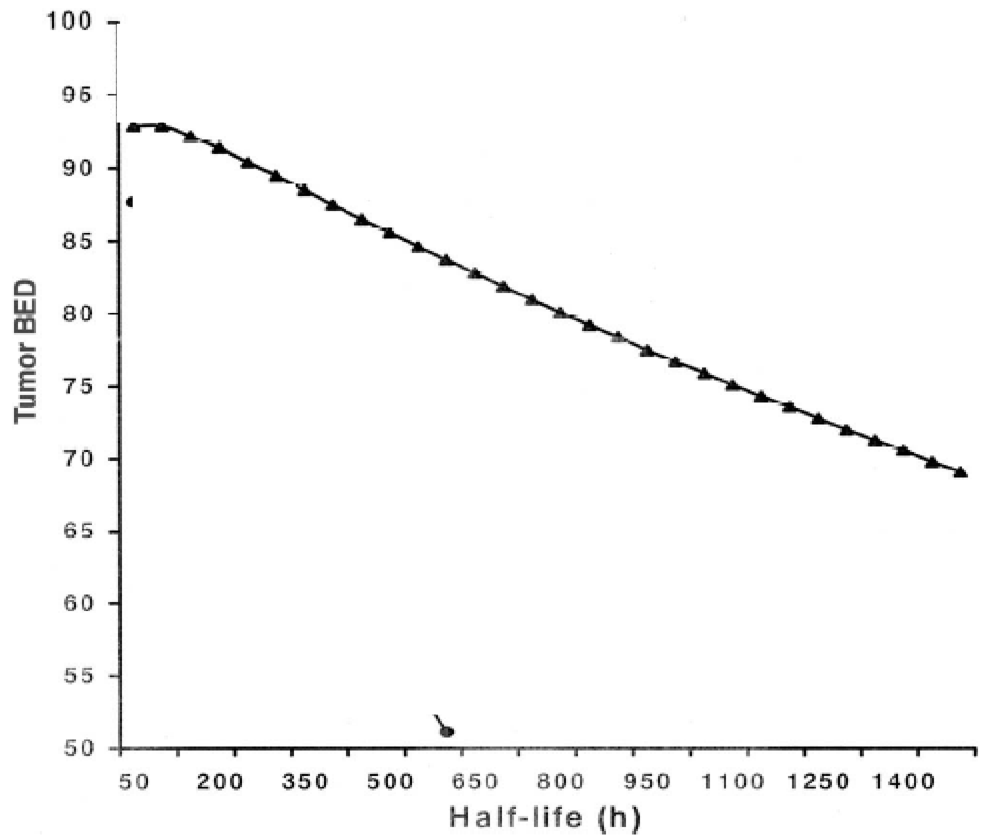
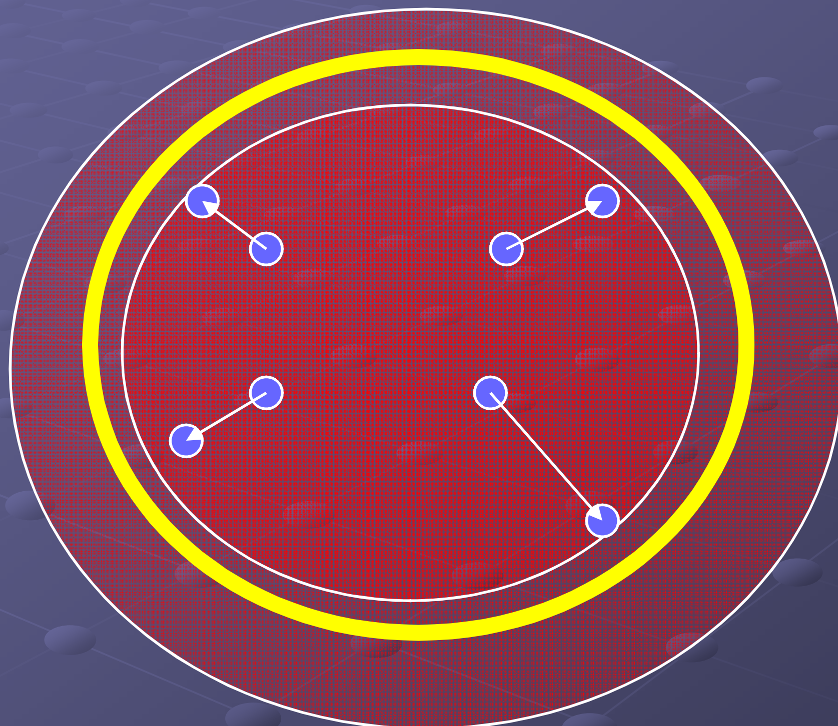


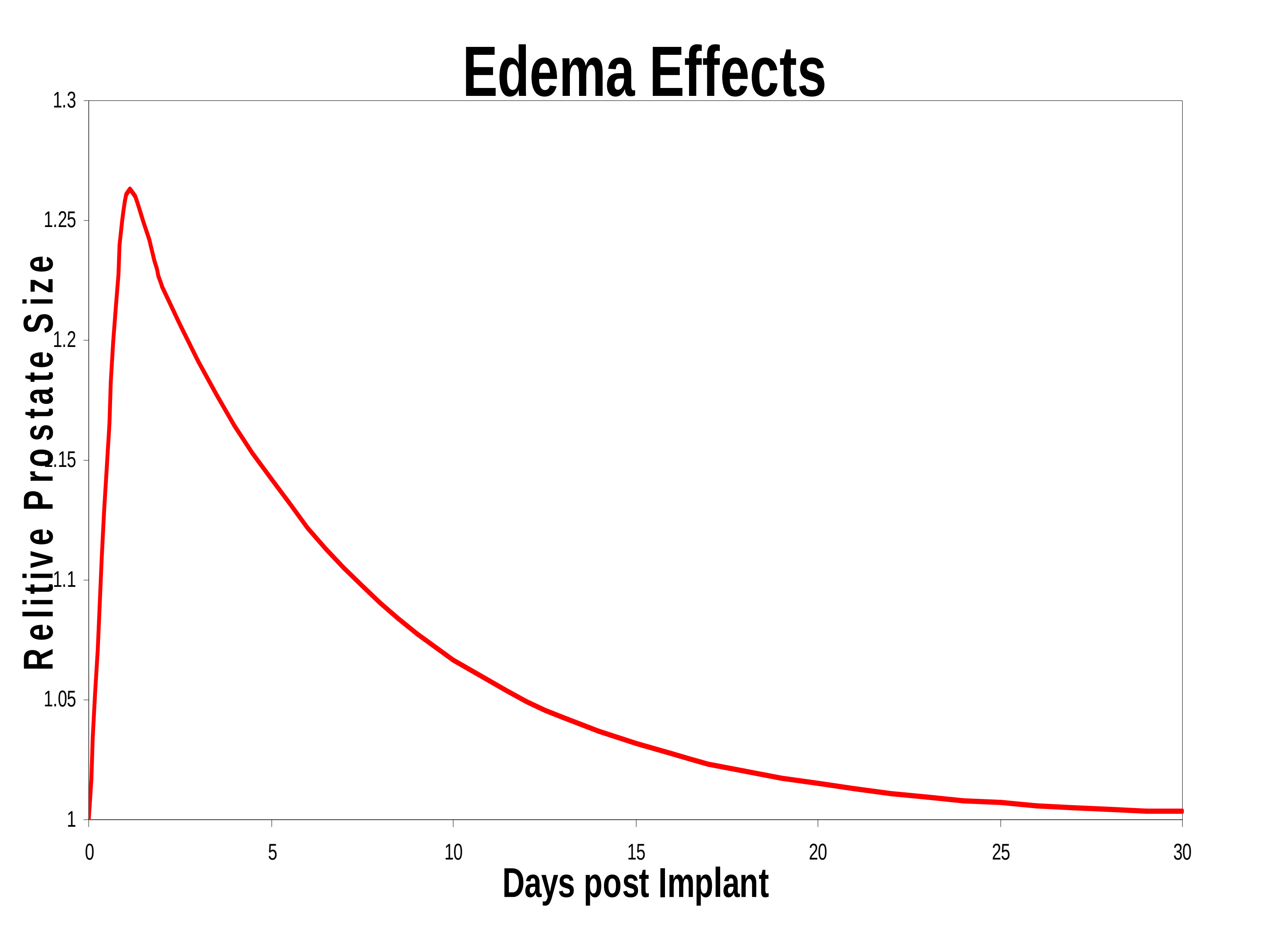
Fig. 1. Example of variation of tumor BED with radionuclide half-life ($T_{1/2}$). In this example, results have been obtained by assuming $(\alpha/\beta)_{nt} = 3$ Gy, $(\alpha/\beta)_{tum} = 3.5$ Gy, $RBE_{max} = 1$, $K = 0.1$ Gyday^{-1}, $\mu_{tum} = \mu_{nt} = 0.5$ h, and $BED_{nt} = 100$ Gy. The half-life of iodine-125 is ~1440 h, placing this nuclide at a point on the far right of the scale.

Additional data was omitted from this chart for simplicity sake

Edema



Model Edema Resolution



Effects of Edema for Cs-131

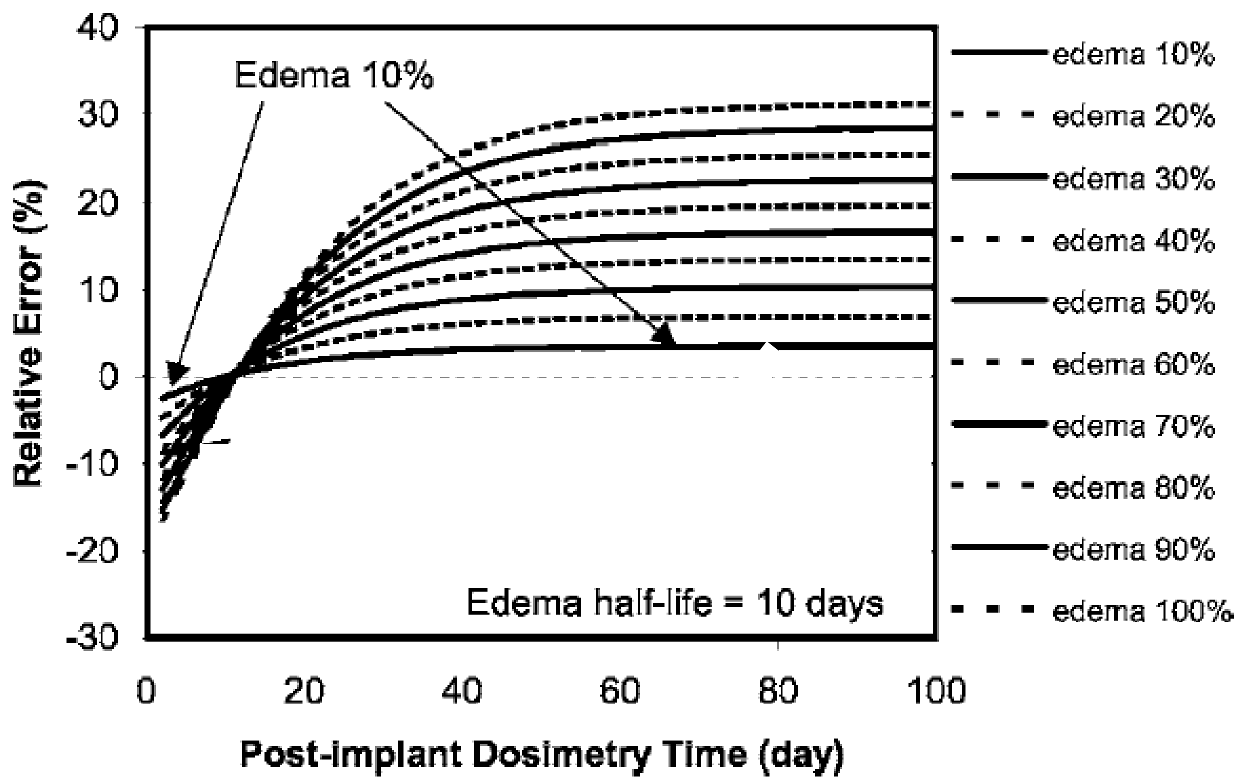


FIG. 3. Relative dosimetry error that resulted from conventional post-implant dosimetry as a function of the post-implant dosimetry time and edema magnitude for a ^{131}Cs implant with an edema half-life of 10 days.

Comments on Edema

- When does it start and end
- Unpredictable
- Larger effect on short half-life isotopes
- Smaller effect with higher energy
- Try to minimize the risks
  - Skilled surgeon
  - Fewest needles possible
  - At CPCC we CT immediately after procedure

Different Energy = Different results

- Energy effects
  - Radial Dose Function (g(r))
  - Anisotropy
  - How dose this effect plans?
  - How dose this effect radiation safety?

Dose, **D(r),** as a function of distance

(TG43 point-source approximation)

$$\dot{D}(r,\theta) = S_K \cdot \Lambda \cdot \frac{G_L(r,\theta)}{G_L(r_0,\theta_0)} \cdot g_L(r) \cdot F(r,\theta),$$

where **S_k = air kerma strength [cGy cm^2 h^{-1}]**

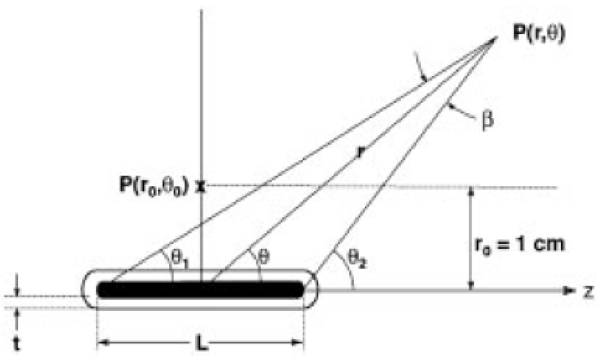
Λ = dose rate constant [cGy h^{-1} U^{-1}]

G(r,θ) = Geometric factor

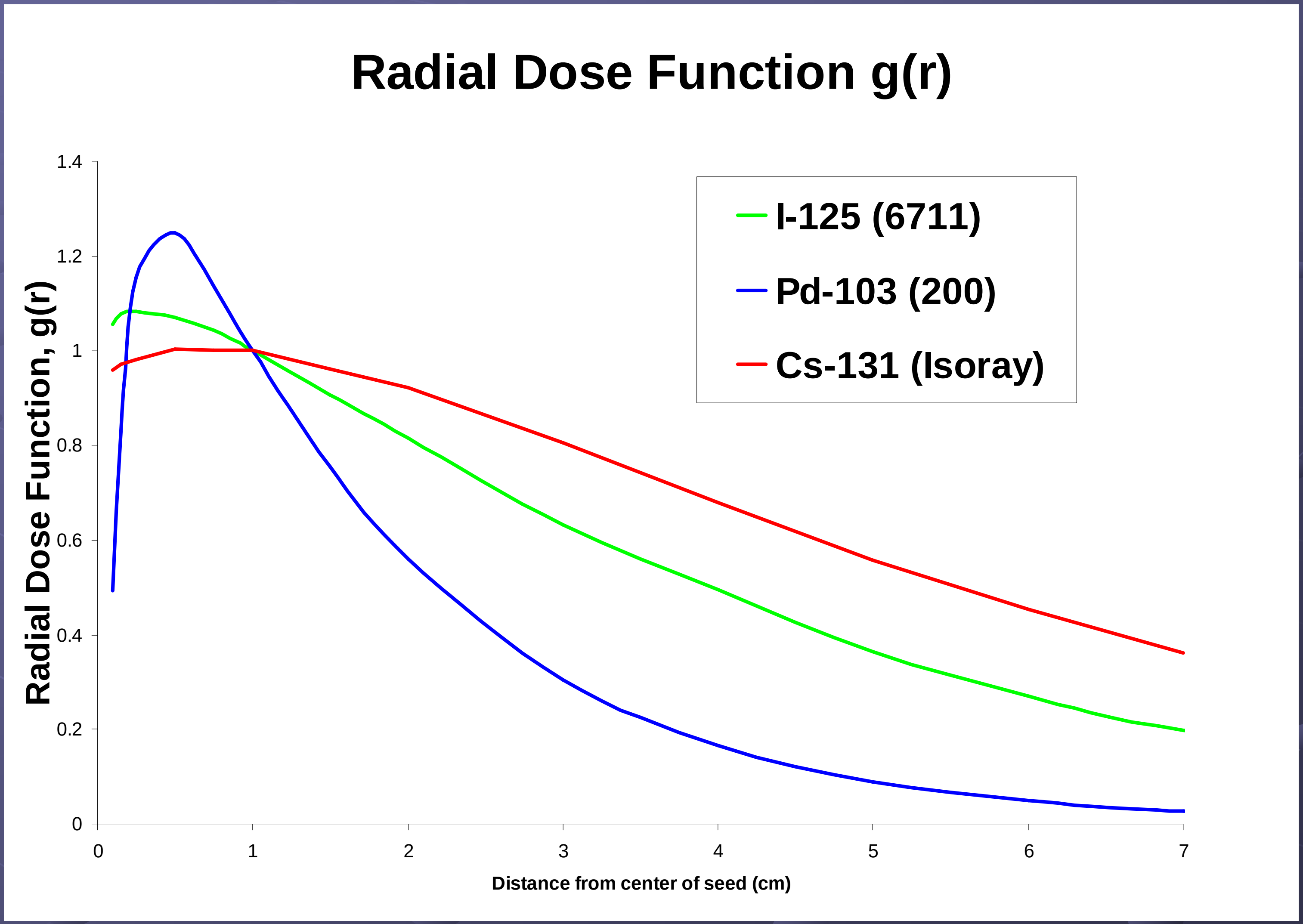
g(r) = radial dose function

F(r,θ) = Anisotropy factor

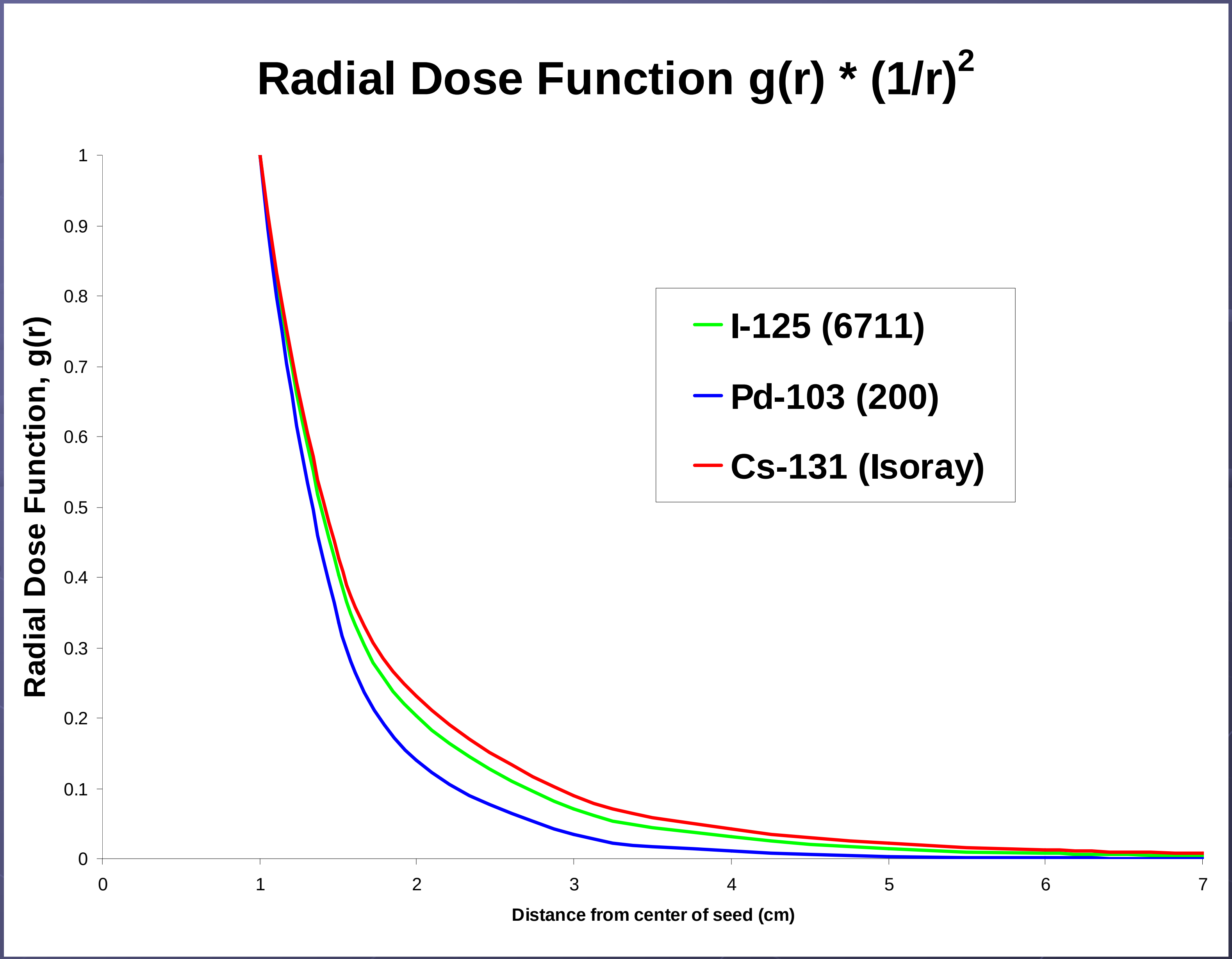
r = distance



Cs-131 Higher Energy

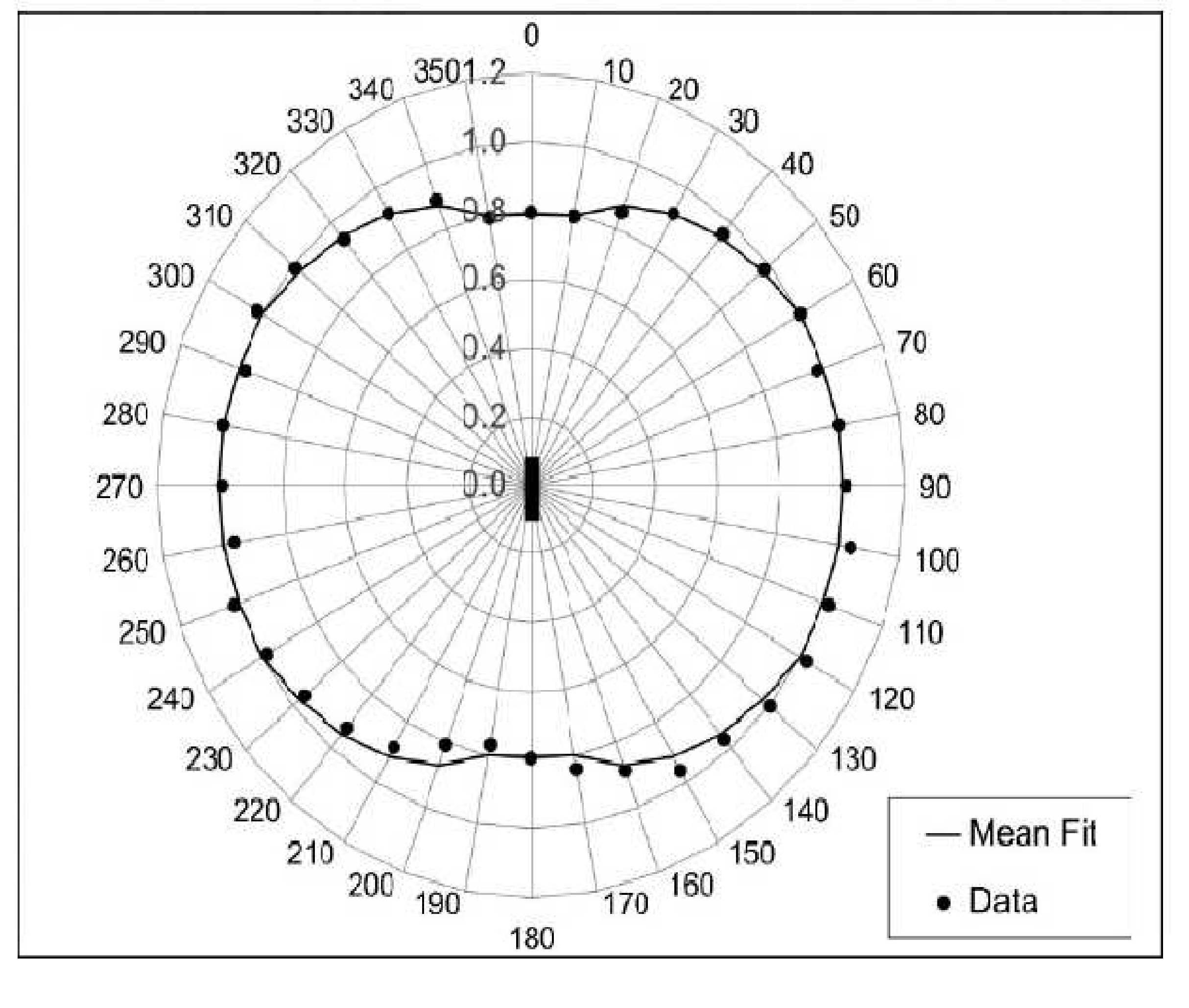


$g(r) * (1/r)^2$



Radial Dose Function g(r) * (1/r)2
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
Radial Dose Function, g(r)
0
1
2
3
4
5
6
7
Distance from center of seed (cm)
I-125 (6711)
Pd-103 (200)
Cs-131 (Isoray)

Cesium-131 Anistropy



- Measured in-phantom anisotropy results at 3cm.

Murphy M, Piper R, Greenwood L, et al. Evaluation of the new cesium-131 seed for use in low energy x-ray brachytherapy. Med Phys (31) 6 June 2004.

These seeds are different!

- New considerations for radiation safety?
  - Employee/physician exposure
  - Recommendations/education for patients
    - Newer rules from IEMA
    - Model expected exposure better to make safety recommendations that are more patient specific?

Radiation Safety, Seed Assay

- 10% of seeds are assayed
- Assay performed behind shield
- Vacuum seed loader shields hands and provides good distance protection
- Seeds sterilized in Pb pigs
- Surveys performed after assay completed

Radiation Safety, Seed Loaders

- Loading performed behind shields in sterile environment
- Most seeds are pre-stranded
- Loaders prepare before loading begins
- Careful survey performed after loading is completed
- Loaded needle boxes are wrapped and stored immediately after completion

Radiation Safety, Physicians

- Be aware that this is a Cs-131 case
- Time is the best ALARA factor
- Be prepared for the case

Employee Exposure

- Exposures (Seed loaders)
  - Emp1
    - Whole Body = 4mREM
    - Finger = 170mREM
  - Emp2
    - Whole Body = 28mREM
    - Finger = 700mREM

Exposure Rate Limits

- **Section 335.2110 Release of Individuals Containing Unsealed Radioactive Material or Implants Containing Radioactive Material**
  - effective April 28, 2006

Exposure Rate Limits

- **Section 335.2110(a) :**
  - A licensee may authorize the release from its control of any individual who has been administered unsealed radioactive material or implants containing radioactive material if the total effective dose equivalent to any other individual from exposure to the released individual is not likely to exceed 5 mSv (0.5 rem) following assessment of the patient's medical, living and working conditions.

Exposure Rate Limits

- **Section 335.2110(b) :**
  - If the total effective dose equivalent to any other individual is likely to exceed 1 mSv (0.1 rem), the licensee shall provide the released individual and, as determined appropriate by the authorized physician user, the individual's spouse, parent, guardian or other primary caregiver, with verbal and written instructions, on actions recommended to maintain doses to other individuals as low as is reasonably achievable. If the total effective dose equivalent to a minor, pregnant individual, or nursing infant or child could exceed 1 mSv (0.1 rem), assuming there were no interruptions of breast-feeding, the instructions shall also include:

    1) Guidance on the interruption or discontinuation of breast-feeding;

    2) Guidance on minimizing close and/or extended contact; and

    3) Information on the potential consequences, if any, of failure to follow the guidance.

Exposure Rate Limits

- **Section 335.2110(c) :**
  - **Release of the patient pursuant to this Section shall be approved by an authorized physician user who is approved for the applicable use of radioactive material (i.e., Subpart F or Subpart H of this Part). The authorized user physician shall state in writing that he or she is professionally satisfied that patient compliance with necessary instructions is likely and the patient is suitable for release.**

Exposure Rate Limits

- **Section 335.2110(d) :**

  - **A licensee shall retain a record for 5 years after the release of the individual for the following:**

    1) The basis for authorizing the release of an individual in accordance with subsections (a) and (b) of this Section to include the assessment and evaluation criteria for the patient's medical, living and working conditions, activities of radioactive material used (i.e., retained or administered activity), occupancy factors, biological or effective half-life of radioactive material, shielding by tissue, and means of estimating doses to any other individual and the physicians.

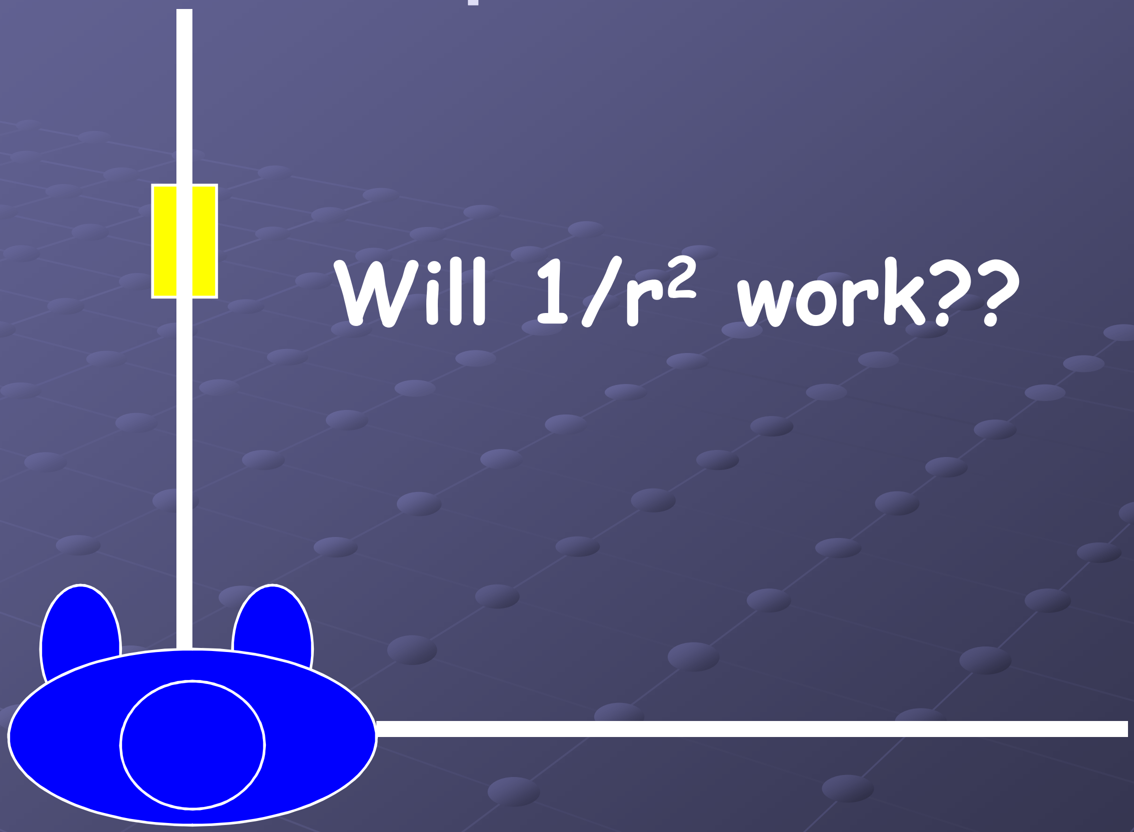
    2) The instructions for each patient required by subsection (b) of this Section.

    3) The physician's certification for patient release required by subsection (c) of this Section.

Exposure Rate Limits

- **In Summery:**
  - Cannot expose others to > 5 mSv (>0.5 rem)
  - But if it's possible to reach 1/5 of that (> 0.1 mSv (>0.1 rem), need to educate the patient and family on appropriate radiation safety
  - There are no dose rate dependant restrictions

Consider this simple model



Will $1/r^2$ work??

Ep(AP,r) = E(ion chamber,AP, 1meter) * f(AP,r)

Ep(Lat,r) = E(ion chamber, AP,1meter) * f(Lat,r)

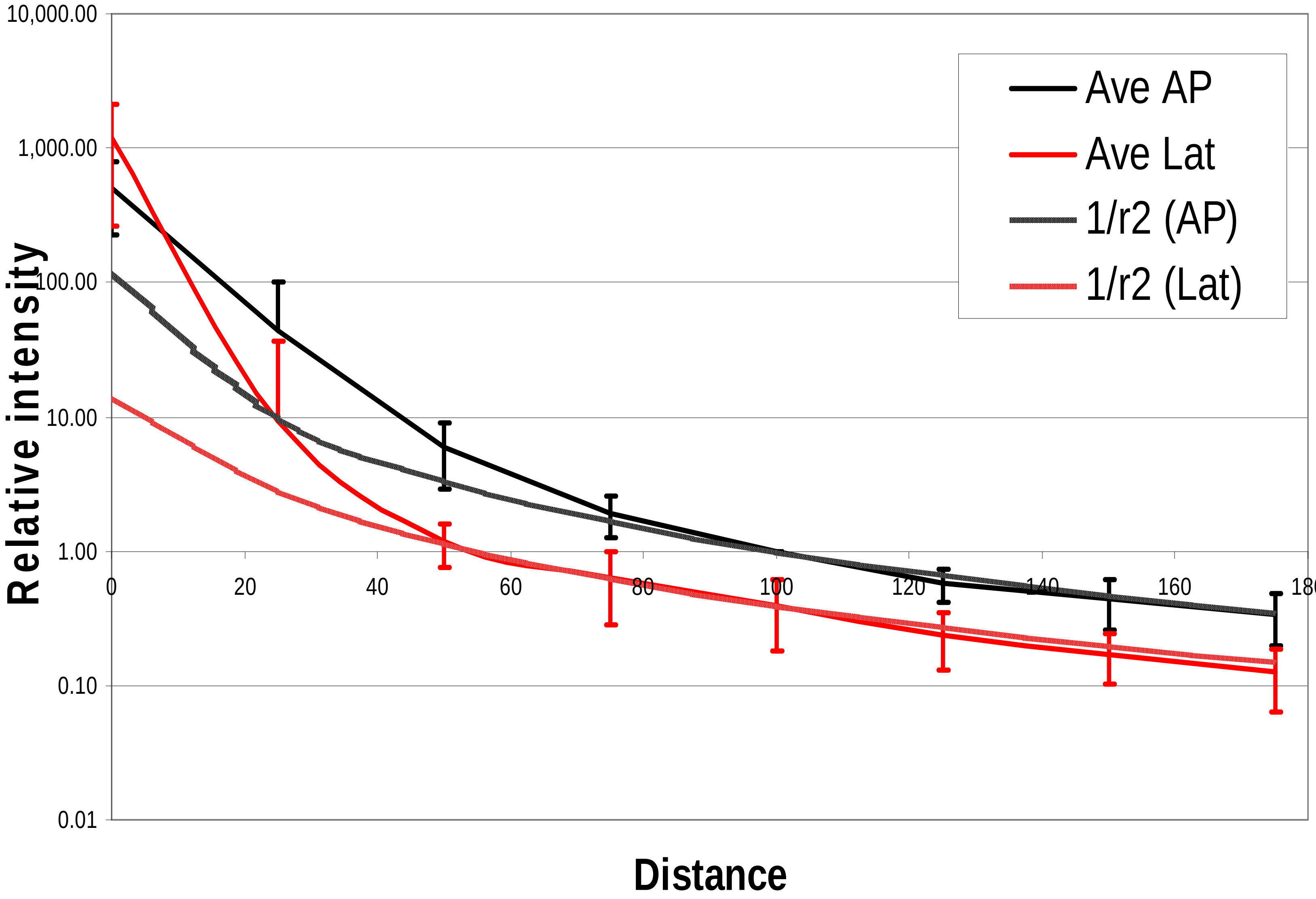
Gig was designed

- Positional accuracy / reproducibility is always a problem.
  - Notches for Ionization at 1 meter
    - Absolute reading
  - Notched of scintillation counter
    - Relative reading

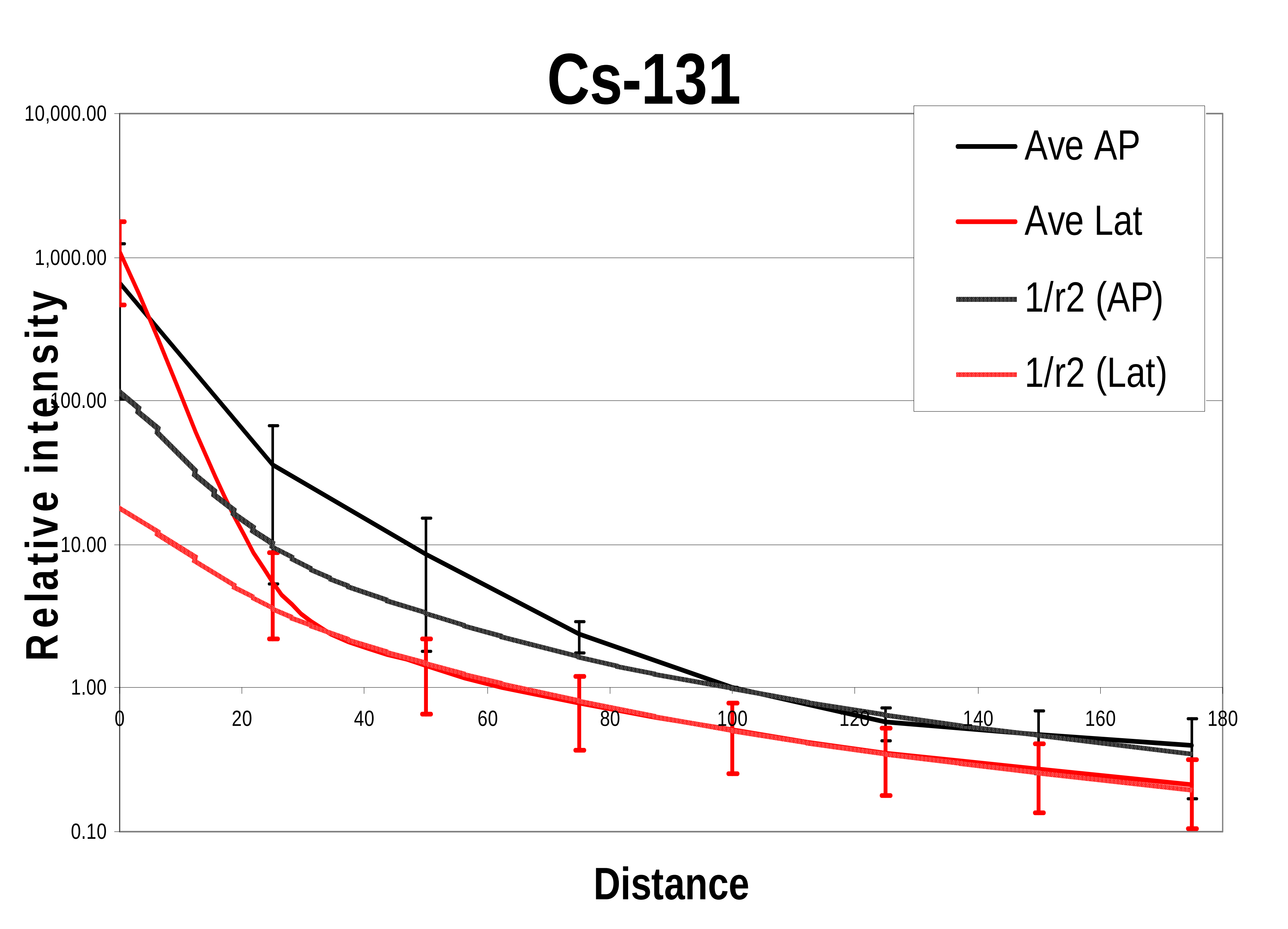
Absolute Exposure readings at 100cm

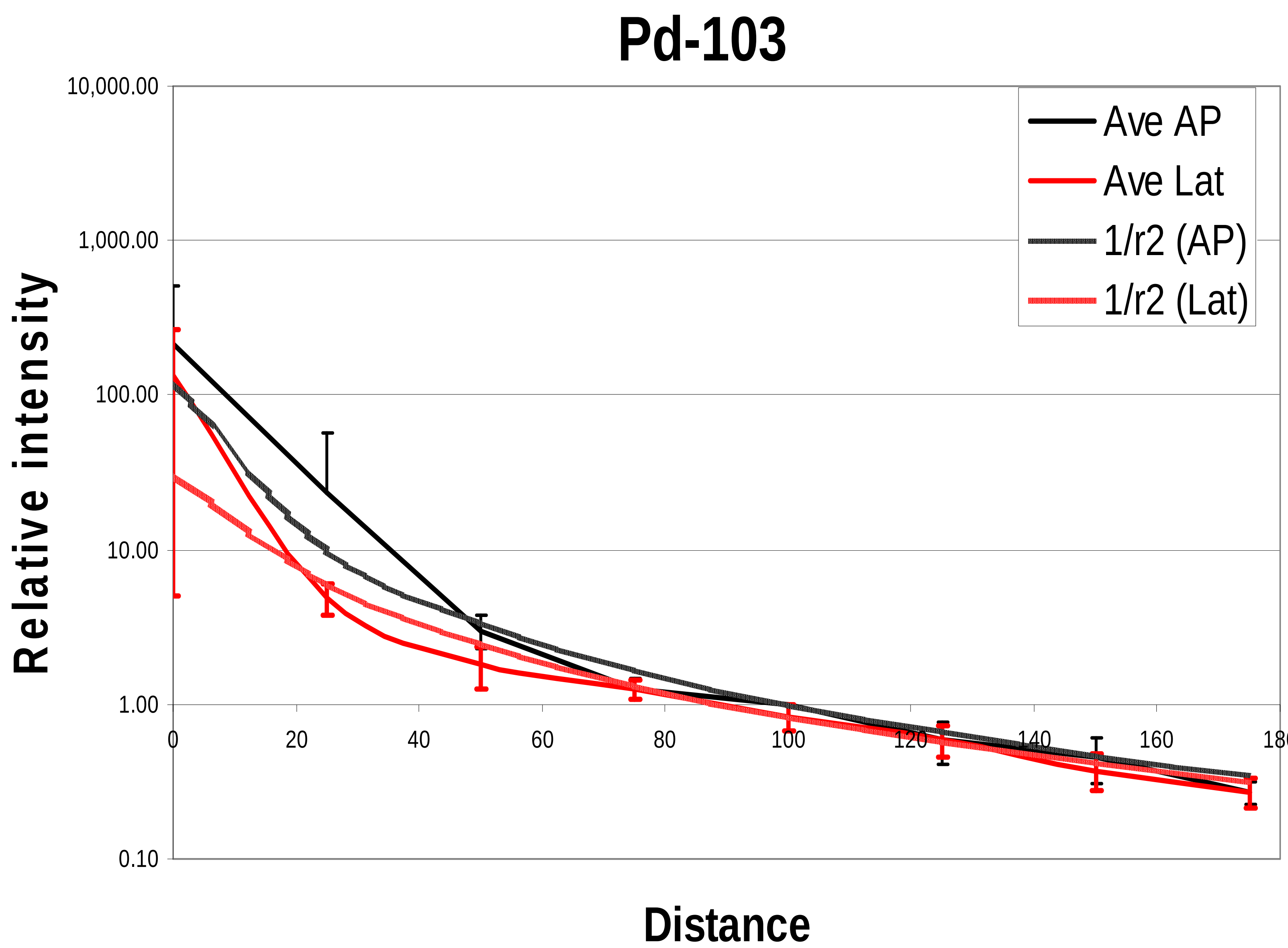
Relative Exposure reading

I-125

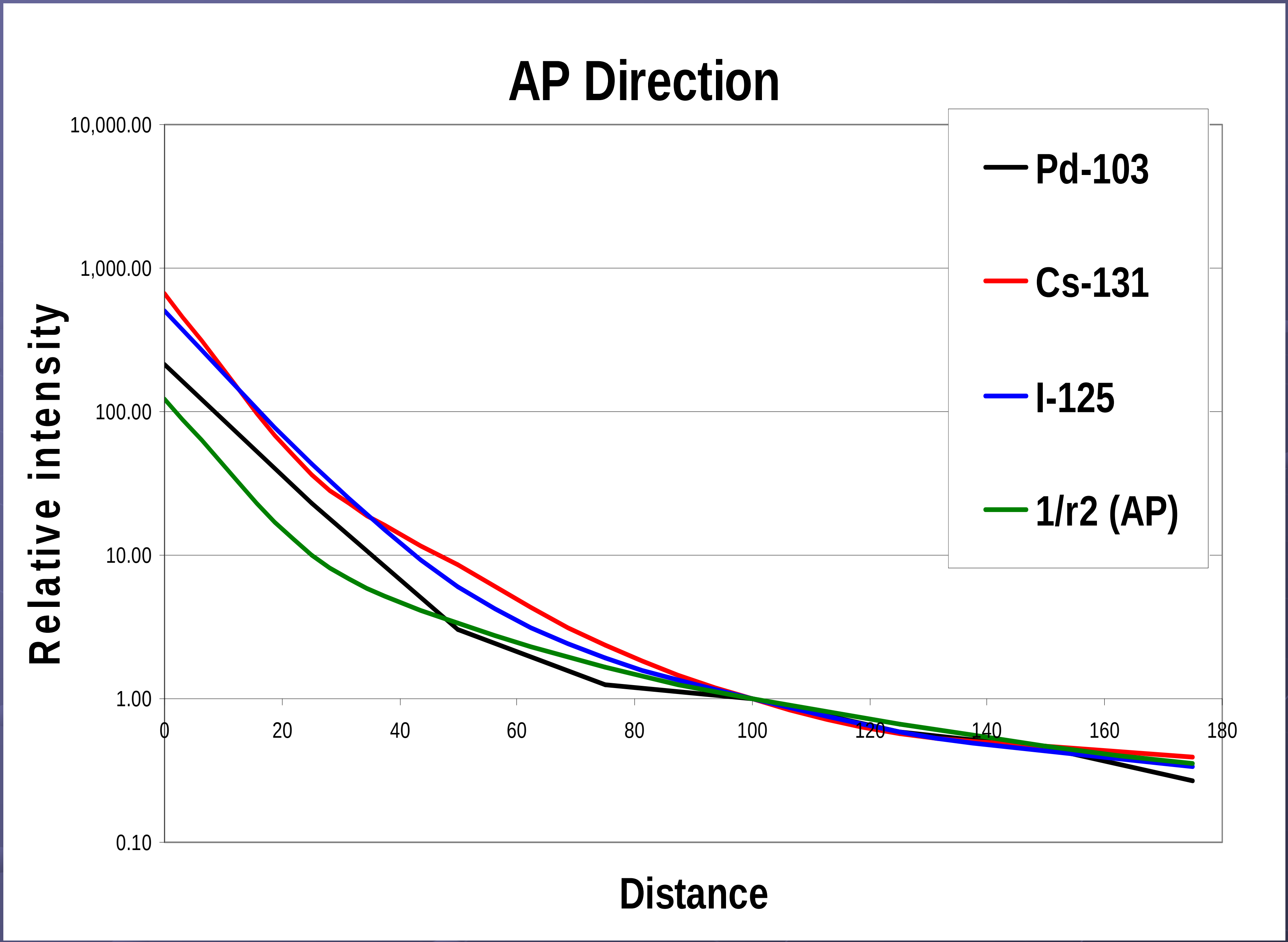


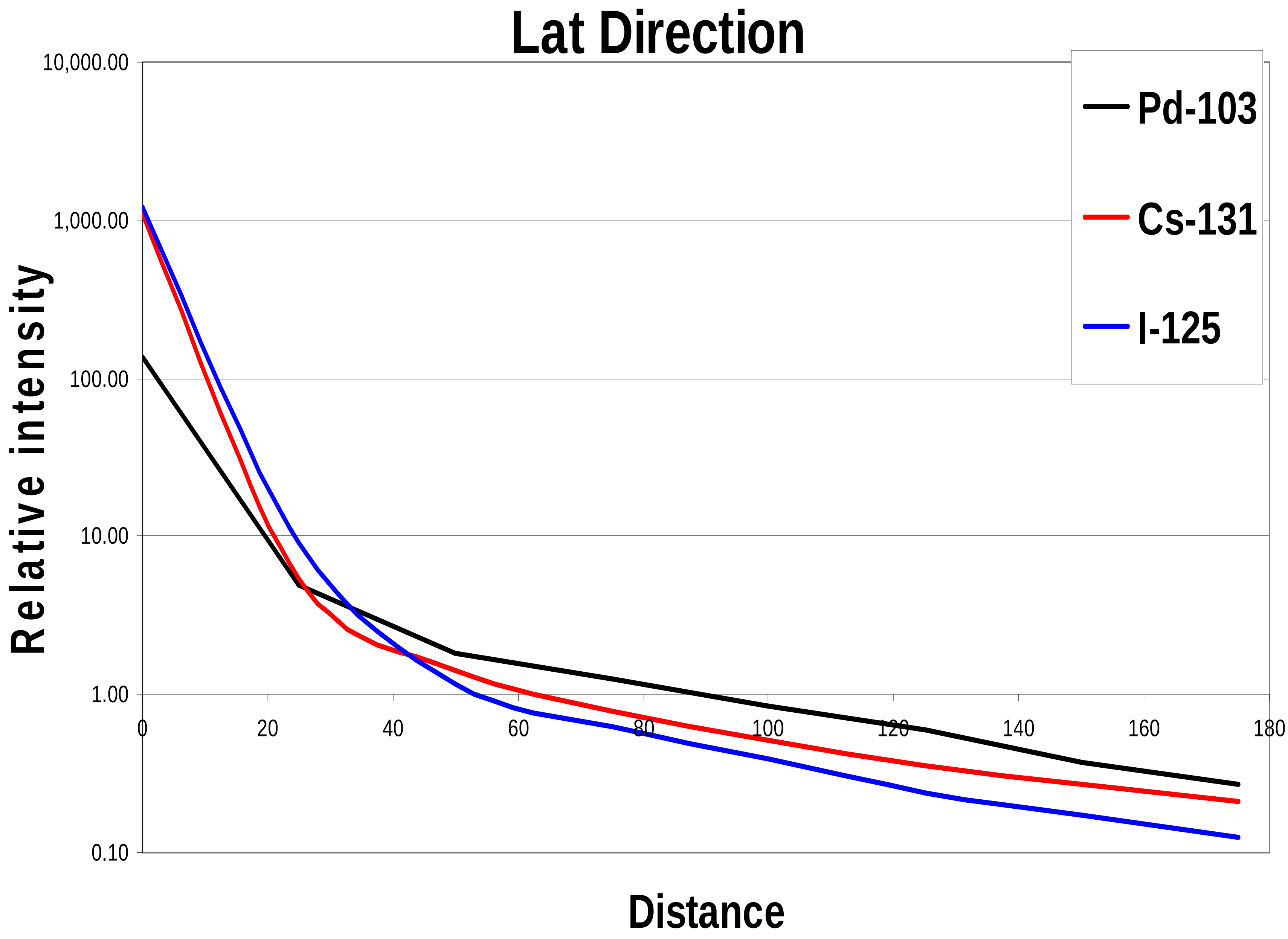
Ave AP
Ave Lat
1/r2 (AP)
1/r2 (Lat)
Relative intensity
10,000.00
1,000.00
100.00
10.00
1.00
0.10
0.01
0
20
40
60
80
100
120
140
160
180
Distance


Cs-131
Ave AP
Ave Lat
1/r2 (AP)
1/r2 (Lat)
Relative intensity
10,000.00
1,000.00
100.00
10.00
1.00
0.10
0
20
40
60
80
100
120
140
160
180
Distance



Pd-103
10,000.00
1,000.00
100.00
10.00
1.00
0.10
Relative intensity
0
20
40
60
80
100
120
140
160
180
Distance
Ave AP
Ave Lat
1/r2 (AP)
1/r2 (Lat)


AP Direction
Relative intensity
10,000.00
1,000.00
100.00
10.00
1.00
0.10
0
20
40
60
80
100
120
140
160
180
Distance
Pd-103
Cs-131
I-125
1/r2 (AP)



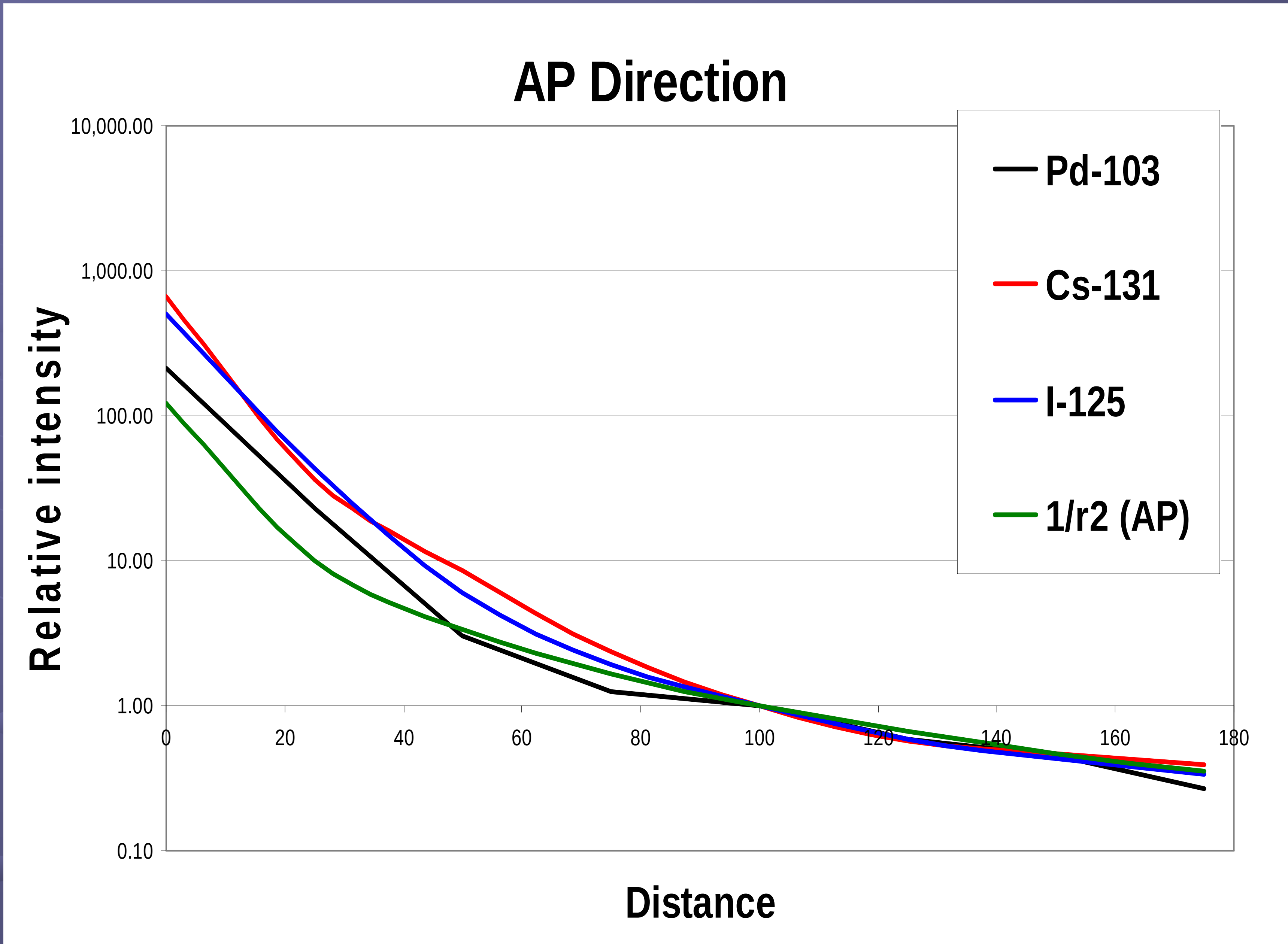
Lat Direction
10,000.00
1,000.00
100.00
10.00
1.00
0.10
Relative intensity
0
20
40
60
80
100
120
140
160
180
Distance
Pd-103
Cs-131
I-125

Absolute Exposure

	Average Exposure (mR/hr)	$T_{(1/2)}$ (days)	Average Life (hr)	Total AP 1 meter Exposure (mR)
I-125	0.026	59.6	2063.63	53.88
Pd-103	0.028	17.0	587.58	16.65
Cs-131	0.473	9.7	335.86	158.81

Maximum Possible Exposure

	Total AP 1 meter Exposure (mR)	Dist Fact for Surface	Max possible Exp (mR)
I-125	53.884	1000	53,884
Pd-103	16.648	1000	16,648
Cs-131	158.814	1000	158,814



AP Direction
Pd-103
Cs-131
I-125
1/r2 (AP)
10,000.00
1,000.00
100.00
10.00
1.00
0.10
0
20
40
60
80
100
120
140
160
180
Relative intensity
Distance

Patient Education

- With the ideas of such a model can we:
  - Take AP reading then approximate exposures well enough to design patient specific safety recommendations?
    - Possible contact:
      - Children
      - Pregnant women
      - Public
    - Discuss lifestyles and patient expectations
    - Can we trust the patient to respect recommendations? Too complicated? Is risk << benefits?

Additional work

- Gather more data for each isotope
- Try different detectors in obtain smaller deviations and eliminate possible energy dependences.
- Continue communications with IEMA to ensure compliance with the intent of the regulations

Thank You for your attention!

- Special Thanks to:
  - Louis Bravo
  - Kathy Banghart
  - Jane Hinkle
  - Robin Verbose