Monte Carlo Calculations of Dose Kernels for various Radioactive Sources

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Status of internal dosimetry

- MIRD: Inaccurate
  - uniform source distribution
  - Uniform dose deposition
  - idealized anatomy

- Other efforts: MIRDOSE, OLINDA, RADAR, Monte Carlo
  - Standard anatomy
  - research tools
  - typical isotopes in nuclear medicine

Goals

To develop RAPID

(Rapid Assessment Package for Internal Dosimetry)

- rapidly and accurately determine organ dose due to internal irradiation
- uses non-invasive imaging technology
- readily accessible by general public.

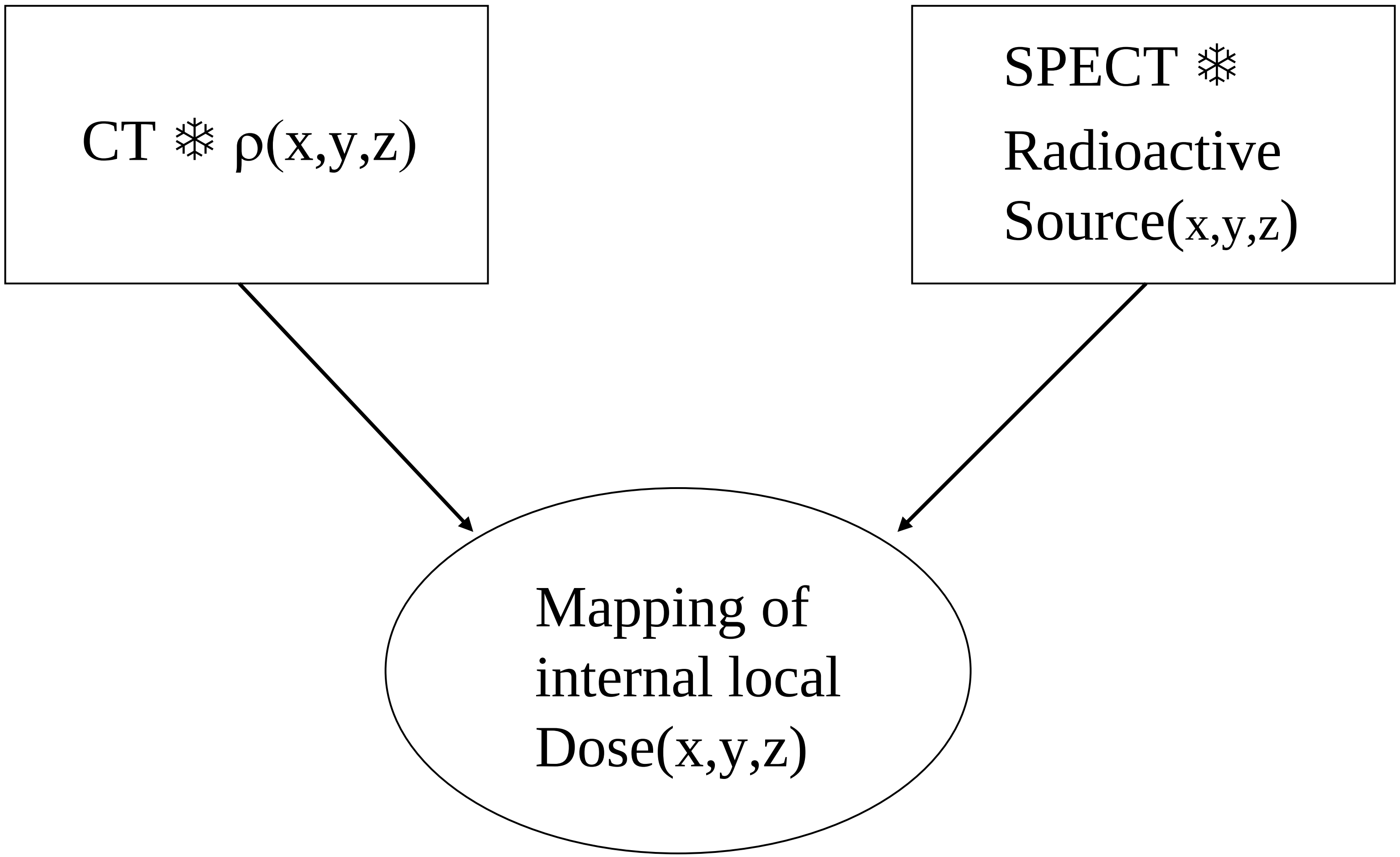
Computational and Analytical Tools of RAPID:

- “Rapid Assessment Package for Internal Dosimetry” (RAPID).

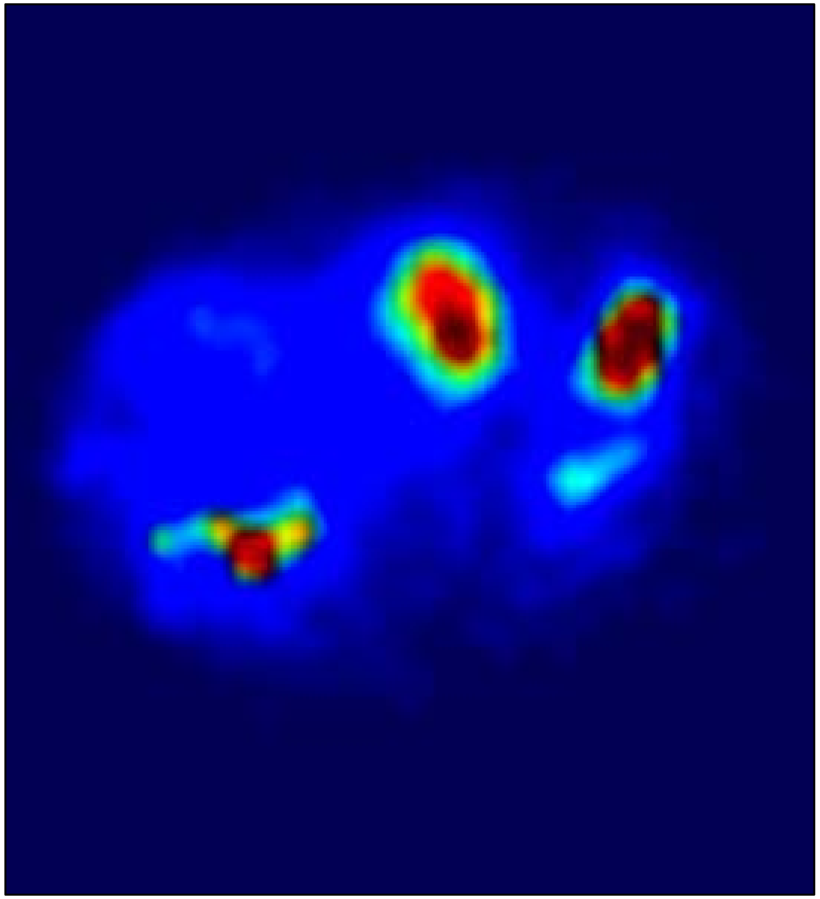
- A code to apply a compact data base consisting of Dose Kernels to determine the Doses per source from the radioistopes considered for patients.

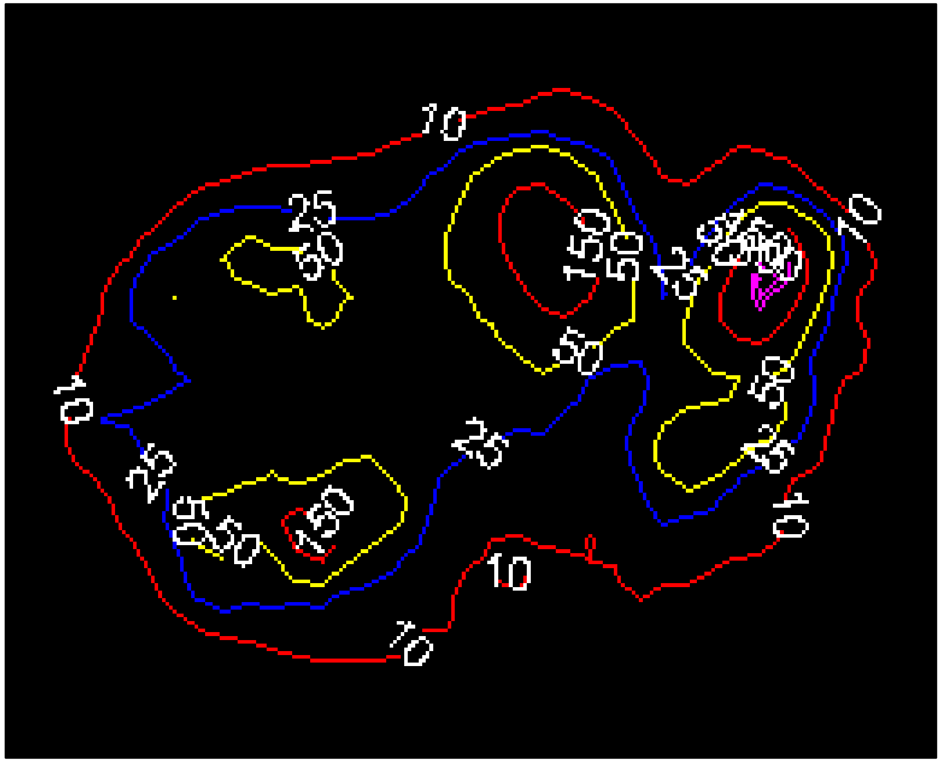
- RAPID shall determine the Dose and distribution of Dose imparted to the patient. - To do this, this code integrates and interprets data from SPECT profiles and from CT images (*per patient*).

Flowchart for making Dose Map via RAPID



^{90}Yttrium Therapy
3D-dose Calcuation





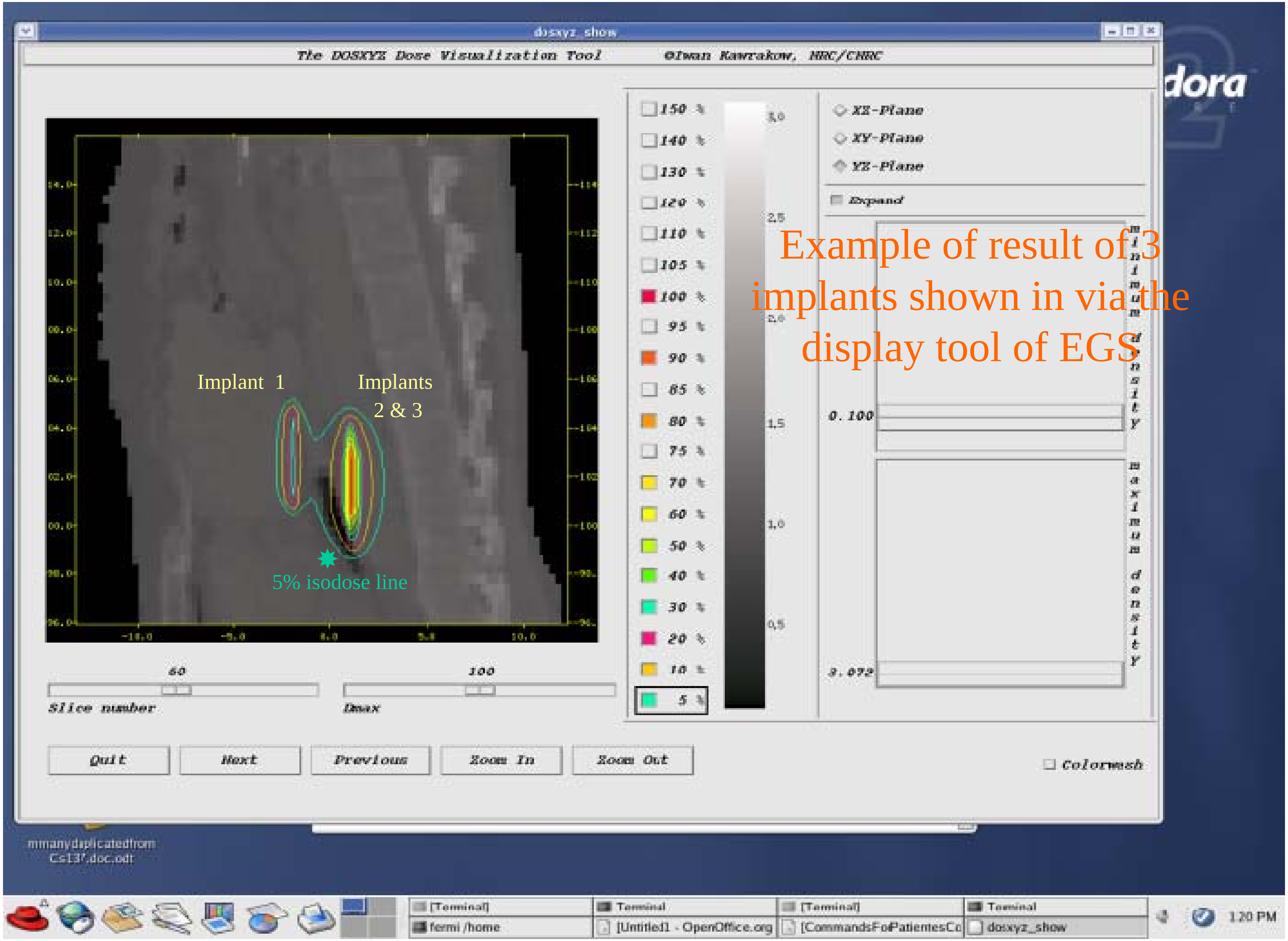
- The Dose Kernels are the superimposed sum of electron dose kernels and photon dose kernels.
- The Dose Kernels have been modeled using the code EGSNRC. EGSNRC simulates the rad. transport of e’s, X-rays, and γ-rays via the Monte Carlo method.
- $\exists$ other codes such as MCNP and Peregrine, but they are not as popular and adapted for many radiation oncologists.

Have Dose Kernel so that we don't have repeat MC simulations for each patient.

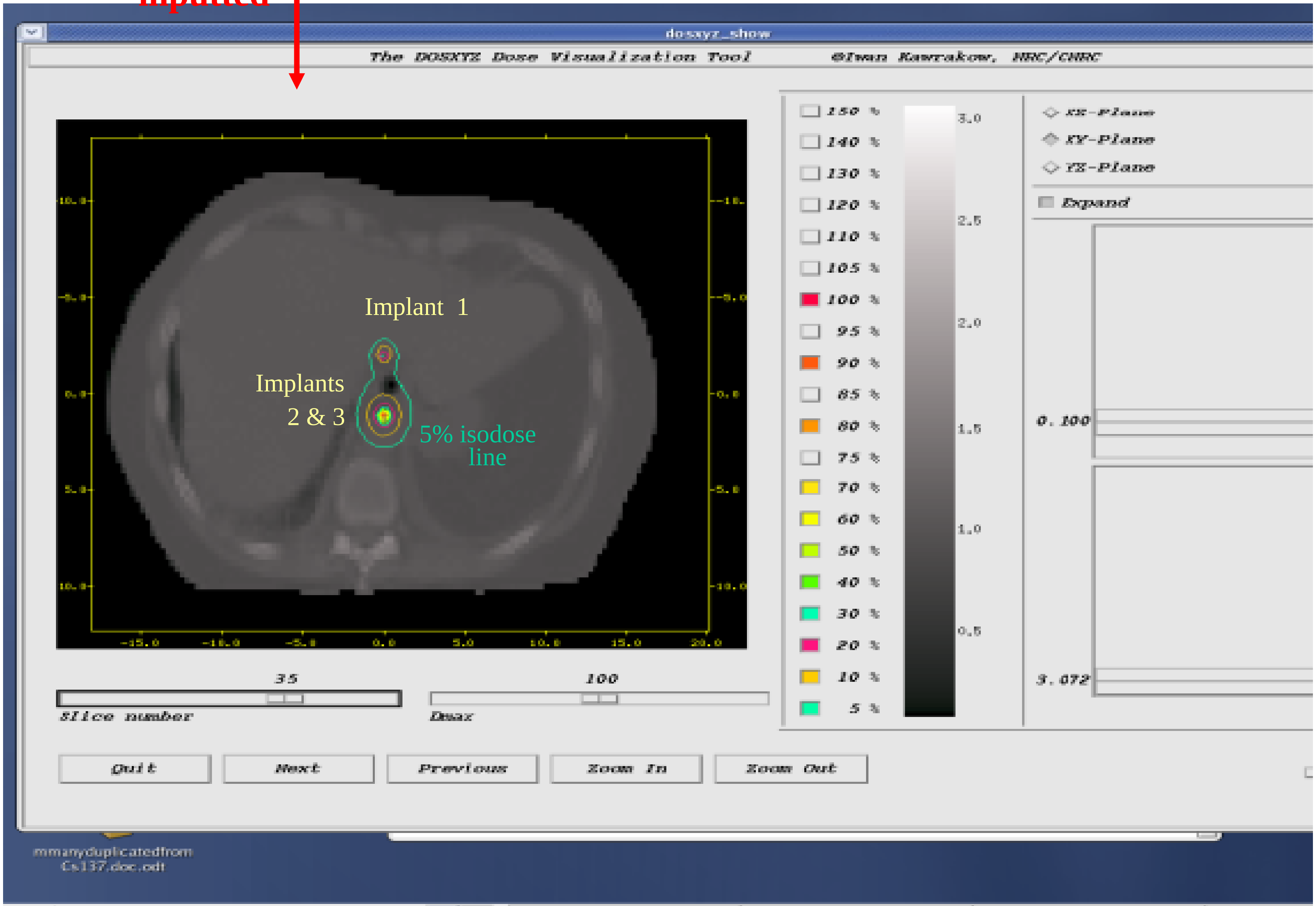
- The 'static' Dose Kernel is a Map of the spatial distribution of Dose per disintegration due to a point source of a standard magnitude of a given isotope on to a given material. (Have 9 isotopes on list currently).

- Tissue densities of different patients are accommodated for; RAPID inputs the CT image files of the given patient.

- -- much faster than running MC simulations on the CT files of each single patient.


The DOSXYZ Dose Visualization Tool
©Iwan Kawrakow, NRC/CNRC
Implant 1
Implants 2 & 3
5% isodose line
Example of result of 3 implants shown in via the display tool of EGS
XZ-Plane
XY-Plane
YZ-Plane
Expand
Slice number
Dmax
Quit
Next
Previous
Zoom In
Zoom Out
Colorwash

CT file of patient inputted



9 different isotopes have been considered for point sources in of radiation internally located.

Non-typical radiotopes for Imaging:

- Cs-137 (to H_20, lung, & bone)
- Ir-192 (to H_20, lung, & bone)
- I-125 (to H_2O, lung, & bone)

Typical radioisotopes for Medical Imaging:

- I-123 (to H_20 , flesh, lung, & bone)
- I-131 (to flesh, lung, & bone)
- In-111 (to fles, lung, & bone)
- Tc-99m (to fles, lung, & bone)
- Tl-201 (to fles, lung, & bone)
- Xe-133 (to fles, lung, & bone)

Bare sources.

- Note that My radioisotopes were all modelled as bare sources.

- EGSNRC often provides spectrum files of radioisotopic sources immersed in capsules or containers.

- No such assumption here for RAPID.

Materials Subjected to Dose

- The four materials which have been simulated for distribution of Dose due to presence of implanted radioisotopic point source are: flesh equiv. tissue or H_2O, lung, and bone.

Quickly

List of most energetic photons emitted from Isotopes considered for RAPID

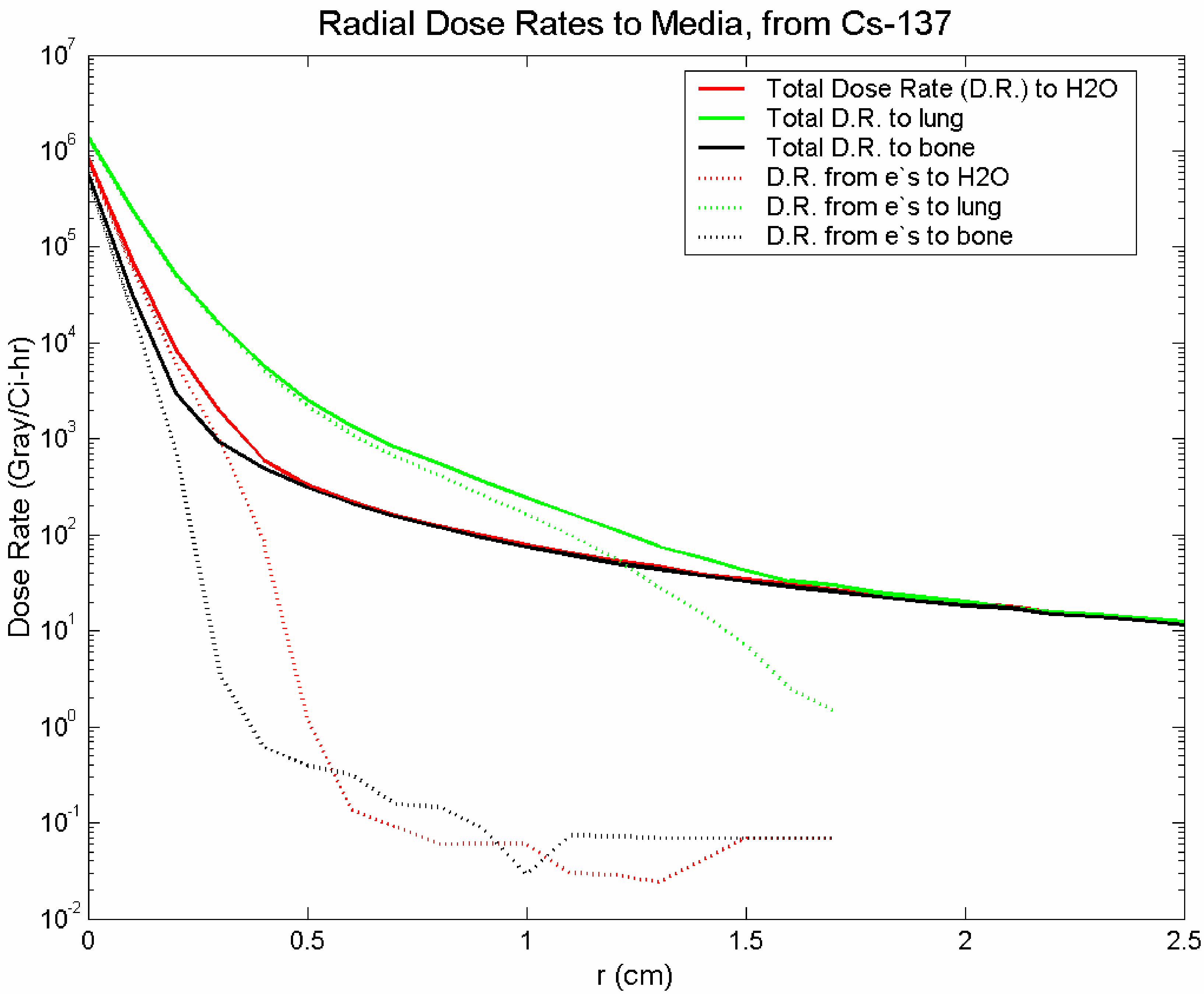
Isotope	Energy of predominant photon (MeV)	Energy of 2nd hardest or 2nd commonest γ (MeV)
Cs-137	.661, 94.6 per 100 dis's.	-negligible- .05
Ir-192	.615, 13.5 per 100 dis's	.470, 48 per 100 disi's
I-125	.031 /weakest but safe for detector/	Familiar in nuc med
I-131	.3645, 81.7 per 100 disi's	0.6370, 7.17 per 100 disi's
I-123	.1590, 83% o.t.	0.5290, 1.39% o.t.
In-111	.2454, 94% o.t.	.171, 91% o.t.
Tc-99m	.1405	
Tl-201	.1674, 10% o.t.	.071, 46% o.t.
Xe-133	.0809	

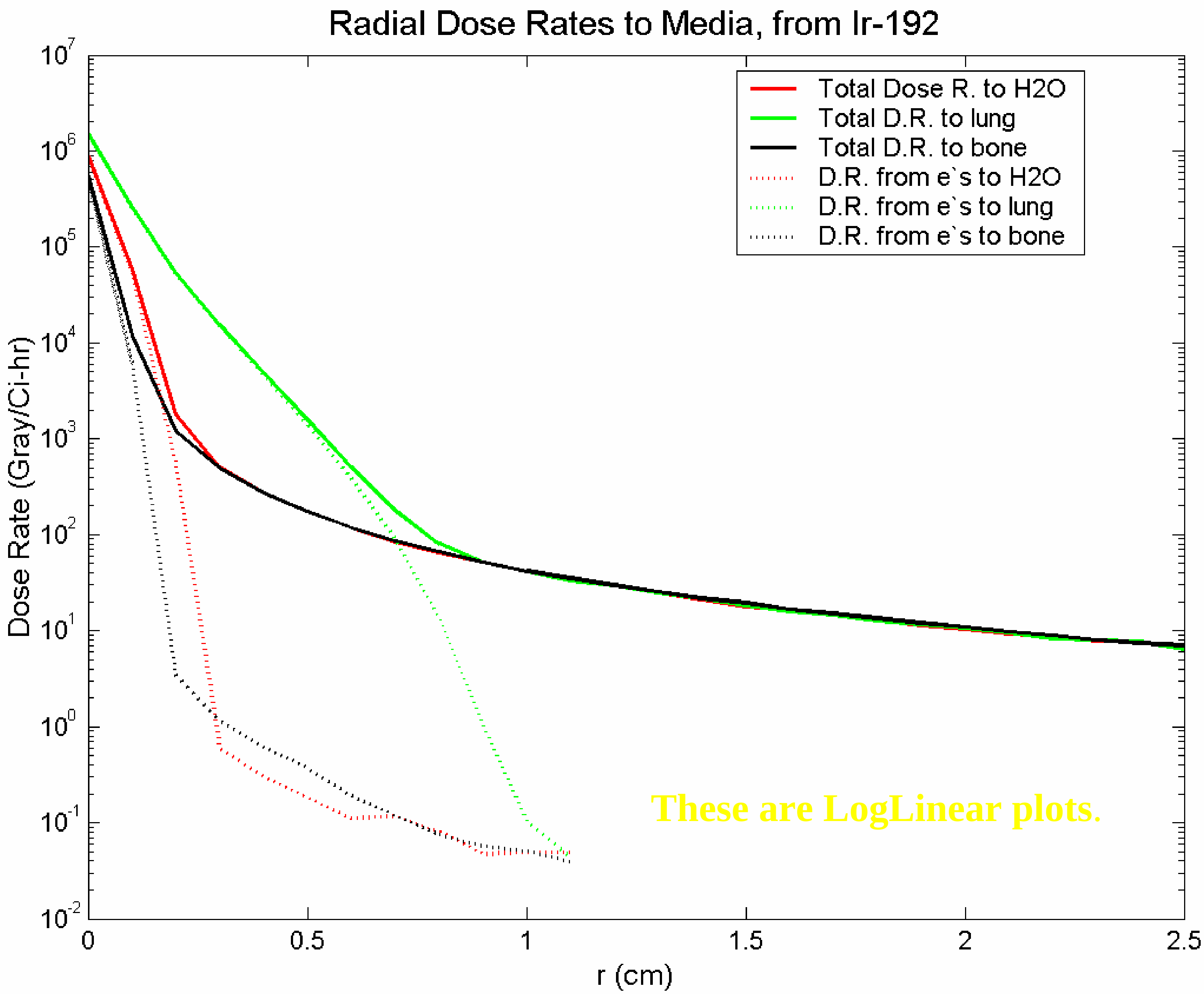
Ranking of Iso's by E_γ :

Cs-137,Ir-192,I-131,In-111,I-123,Tl-201

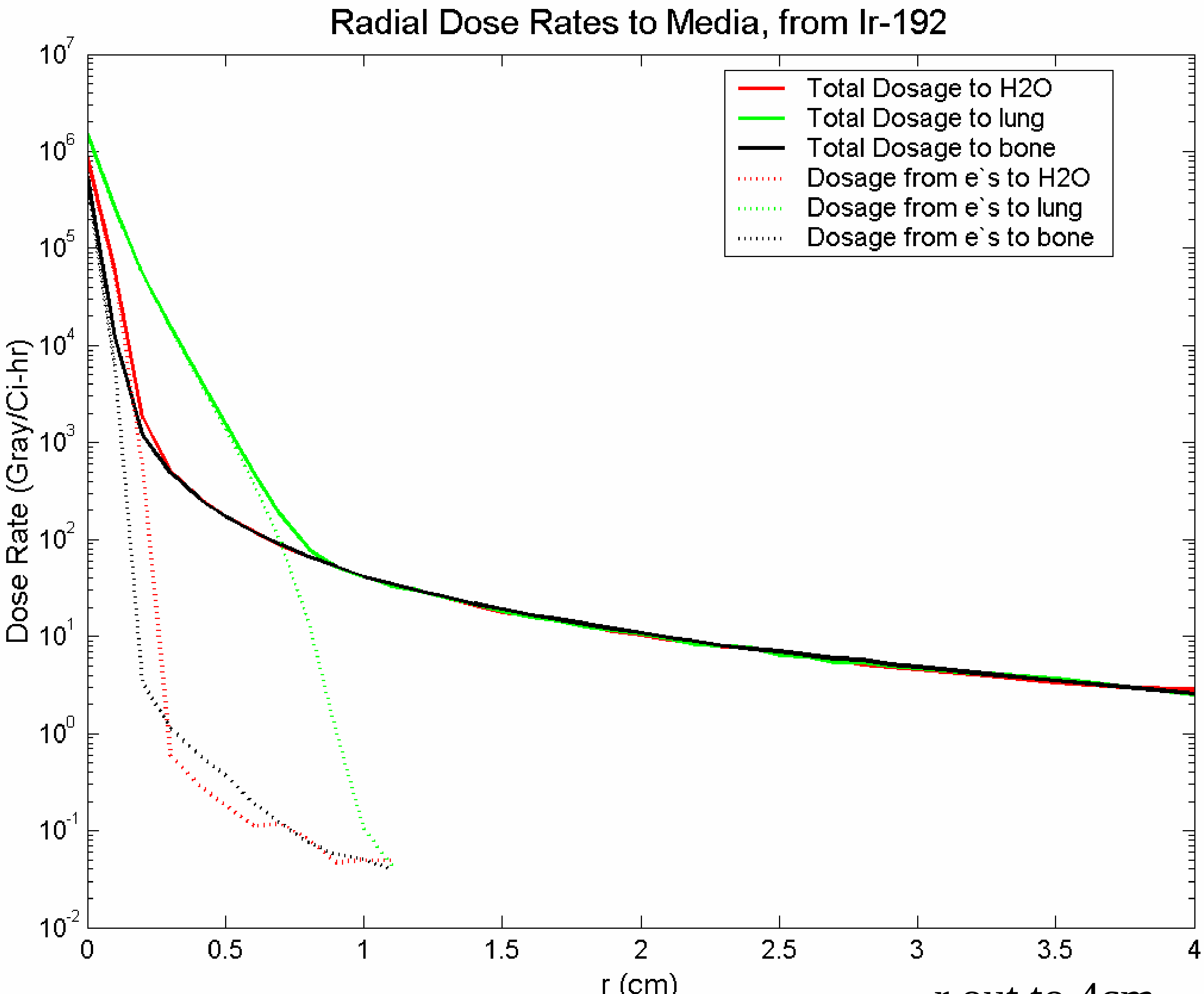
notation: "% o.t." means % of the time per disintegration (dis.).

- Now let us look at some of the profiles of the dose kernels generated by static point sources of our 9 main candidates of radioisotopes:


Radial Dose Rates to Media, from Cs-137
Total Dose Rate (D.R.) to H2O
Total D.R. to lung
Total D.R. to bone
D.R. from e`s to H2O
D.R. from e`s to lung
D.R. from e`s to bone
Dose Rate (Gray/Ci-hr)
r (cm)



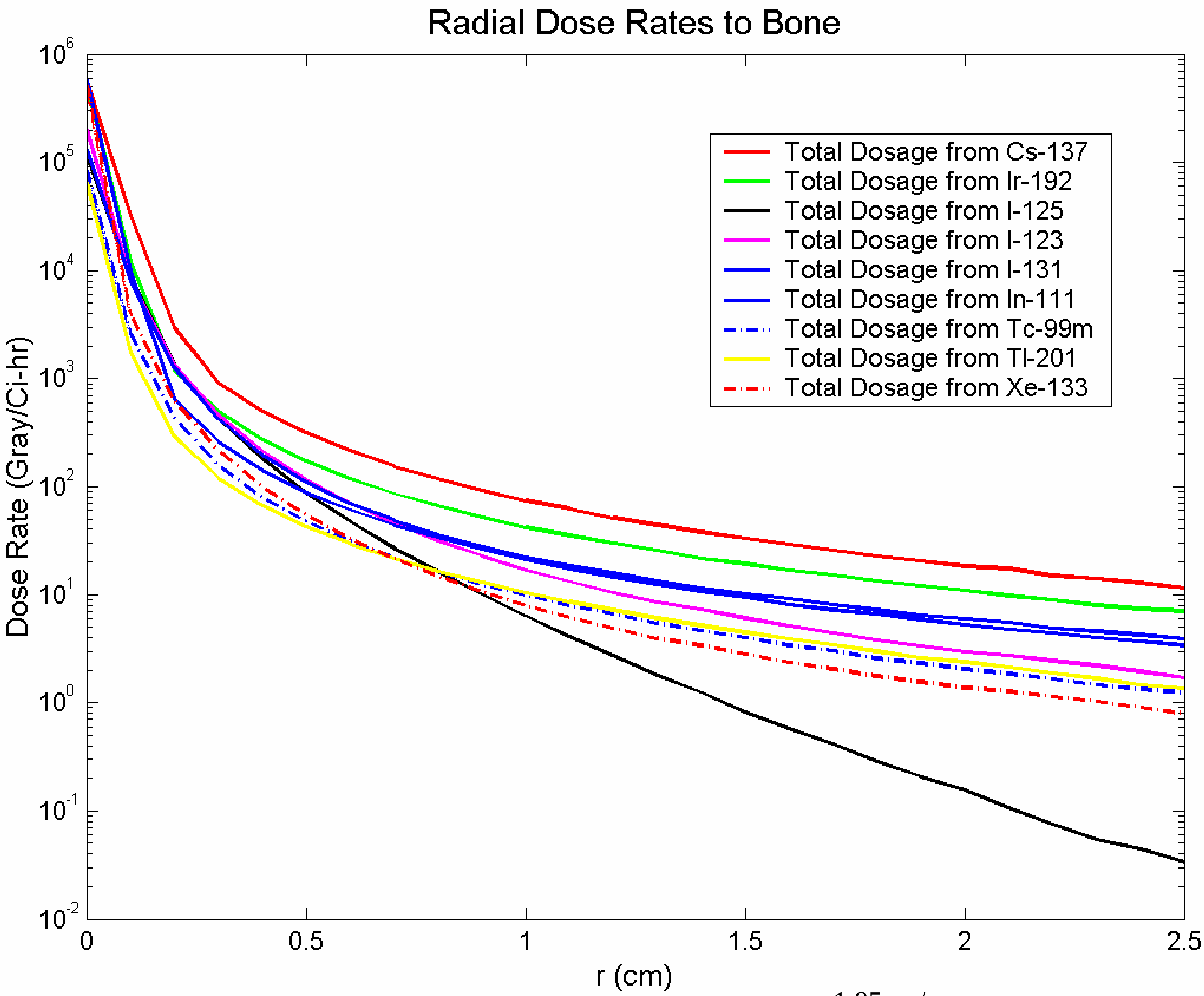
Radial Dose Rates to Media, from Ir-192
Dose Rate (Gray/Ci-hr)
r (cm)
Total Dose R. to H2O
Total D.R. to lung
Total D.R. to bone
D.R. from e`s to H2O
D.R. from e`s to lung
D.R. from e`s to bone
These are LogLinear plots.



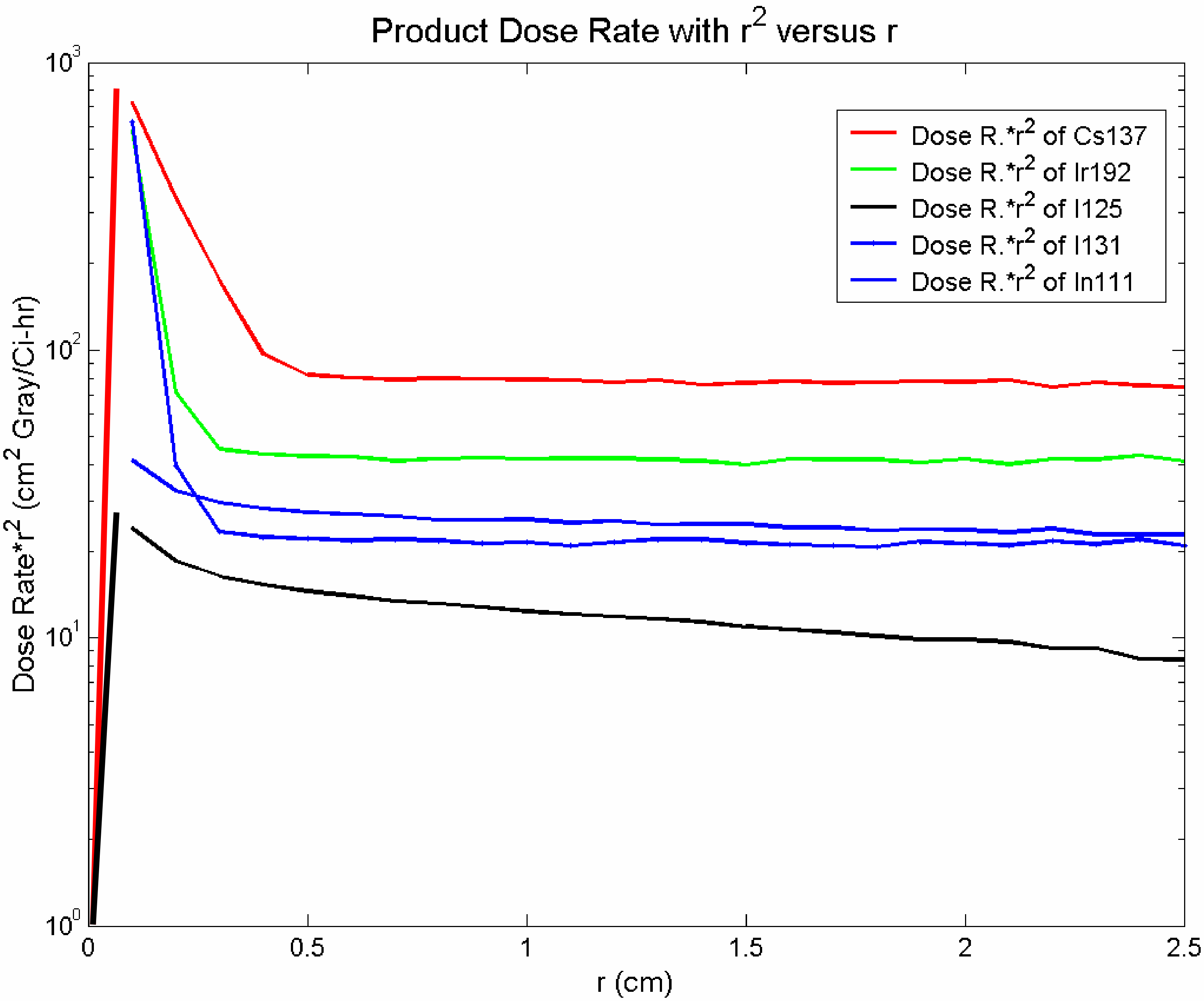
Radial Dose Rates to Media, from Ir-192
Total Dosage to H2O
Total Dosage to lung
Total Dosage to bone
Dosage from e`s to H2O
Dosage from e`s to lung
Dosage from e`s to bone
Dose Rate (Gray/Ci-hr)
r (cm)
10^7
10^6
10^5
10^4
10^3
10^2
10^1
10^0
10^-1
10^-2
0
0.5
1
1.5
2
2.5
3
3.5
4

r out to 4cm.

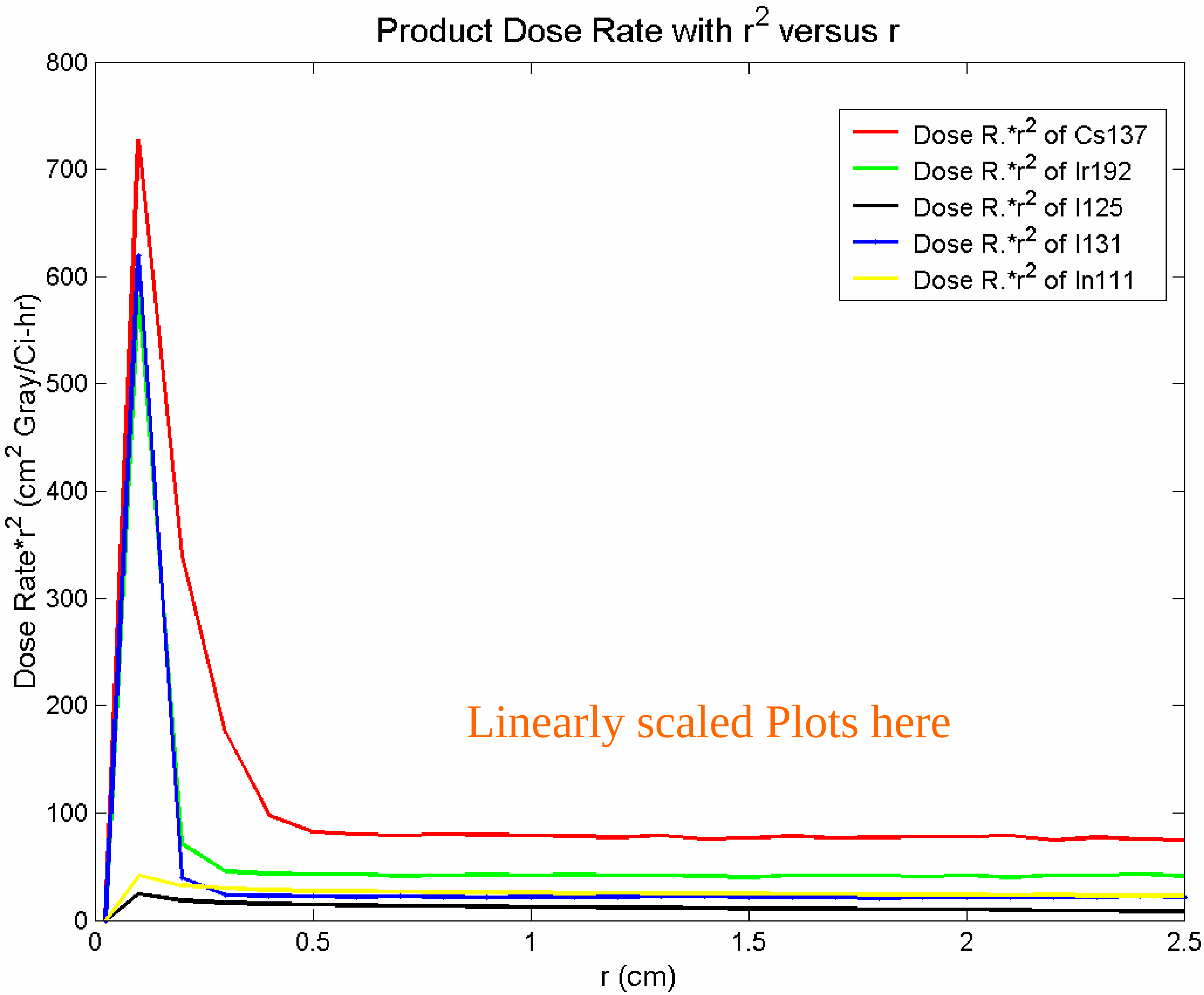
- Comparisons of Dose Rates to the same medium:



ρ_m= 1.85gm/cc ρ_{num}= 5.6E23 e's/cc



Product Dose Rate with r2 versus r
Dose R.*r2 of Cs137
Dose R.*r2 of Ir192
Dose R.*r2 of I125
Dose R.*r2 of I131
Dose R.*r2 of In111
Dose Rate*r2 (cm2 Gray/Ci-hr)
r (cm)
10^0
10^1
10^2
10^3
0
0.5
1
1.5
2
2.5


Product Dose Rate with r2 versus r
Dose Rate*r2 (cm2 Gray/Ci-hr)
r (cm)
0
100
200
300
400
500
600
700
800
0
0.5
1
1.5
2
2.5
Dose R.*r2 of Cs137
Dose R.*r2 of Ir192
Dose R.*r2 of I125
Dose R.*r2 of I131
Dose R.*r2 of In111
Linearly scaled Plots here

Preliminary Conclusions

- For Distances greater than the range of the beta particles and other emitted e's, Doses do follow a pattern close to the $1/r^2$ pattern.

  Our main exception is is I-125, which goes like $e(-kr)/r^2$.

- (The greater the range of the β particles and other e's are) and (the greater their probabilities are), then the lower is the typical Dose curve is in the photonic range, even though the Dose curves are mostly // out in photonic range.