Radionuclide Dosimetry I: Introduction to Radionuclide Dosimetry and Measurement of Radioactivity by Planar Imaging

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Two Types of Internal Emitter Dose Estimation.

1. Type I refers to a MIRD-style (MIRDOS3) or other phantom which lives inside the computer system. Organs defined by mathematical functions. This is the older of the two formats. Other phantoms may be developed.

2. Type II refers to patient-specific geometric data probably from CT or MRI. This is the more recent of the formats and may become more common in the future due to clinical use of Radioimmunotherapy (RIT).

Internal Emitter Dose Algorithm.

• Determine activity (A) in tissues of interest at various times (t).
• Integrate A(t) over time to form \( \dot{A} \). Modeling.
• Convert \( \dot{A} \) to dose (D) via a matrix or convolution relationship; i.e., \( D = S \ast \dot{A} \). S may be phantom derived or be voxel-based. This will be described initially.

Use of Standard Geometry for S

• In type I calculation, the patient (pt) may have organ size dissimilar to phantom; e.g. in MIRDOS3. Thus, the \( \dot{A} \) value must be adjusted.

• In type II calculation, dissimilarities between pt and phantom masses require S adjustment.
Two Corrections to MIRDOSE3 Estimations of Absorbed Dose.

- Correct $\bar{\alpha}$ (pt) to Allow Substitution into Program. Type I Estimate.
- Correct $S$ (MIRD) to Allow Patient-Specific Estimation of Absorbed Dose. Type II Estimate.

Anatomic Imaging is Probably More Appropriate for Organ Mass (Volume) Determination.

1. Nuclear Images:
   - A. Diffuse; size is problematic.
   - B. Planar images inadequate: need SPECT.
   - C. Not used in Medical or Radiation Oncology.

2. Anatomic Images:
   - A. Increased signal intensity gives a very sharp edge.
   - B. Used in Medical and Radiation Oncology.

Conclusions Regarding Two Types of Dose Estimation

Type I refers to phantom-based (MIRD) doses. Type II refers to patient-specific doses. Both types require corrections to the data sets to make the computations self-consistent. In Type I, we need to make changes in the $\bar{\alpha}$ values. With Type II, the lowest-order correction concerns changing $S$ values because of the mass of the target tissues.

We recommend that the dose estimator use anatomic data to perform either of these two corrections. Use or non-use of correction factors should be cited in any dose report.

Correction to Patient Activity for use in a standard MIRDOSE3 Dose Calculation.

$$\bar{\alpha}(\text{MIRD}) = \bar{\alpha}(\text{pt}) \times \frac{m(\text{MIRD})}{M(\text{MIRD})} \times \frac{m(\text{pt})}{M(\text{pt})}$$

where $m$ is organ mass and $M$ total body mass. Pt refers to the patient. Here, we assume use of standard phantom $S$ values for use in a legal/scientific context such as FDA application.
Correction for Organ S values in MIRDose3 to Compute a Patient-Specific Absorbed Dose.

\[S_{np}(pt) = S_{np}(MIRD) \times \frac{m(MIRD)}{m(pt)}\]

Here, \(m\) refers to organ mass and \(np\) implies non-penetrating radiation such as beta or alpha rays.

The Historical Record of Type I Calculations.

Of the first 12 MIRD Reports, only two used an explicit correction for the mass of source organs and the whole body: Report 1 (\(^{75}\)Se-Methionine) and Report 2 (\(^{67}\)Ga Citrate). In both cases, autopsy data were available for analyses.

In the case of the other 10 Reports, it is unclear if any correction was made for organ mass/whole body (\(m/M\)) mass ratios. Thus, these results are probably not of Type I.

Determination of Activity (A) in a Patient’s Normal Tissues and Tumor.

- Direct Sampling as of blood or from surgery.
- Single Camera Projection of the tissue.
- Geometric Mean of Two Opposed Projections.
- CAMI Method.

- Quantitative SPECT. (Prof. Koral)
- PET (SUV) Results. (Prof. Koral)

Geometric Mean Method

If two opposing projections are obtained of the same object:

\[\Psi_N a N p = \varepsilon \Delta t A \exp\left(-\mu (a + b + L)/2\right) \sinh(\mu L/2)/\mu L/2\]

Thus, one may solve for \(A\), the unknown activity. The term \(a + b + L\) is the total thickness of the patient at that cross section.
Example of an Integrated System: Radionuclide Treatment and Dosimetry System (RTDS) for Human Dose Estimates.

1. System merges CT and Nuclear Planar Images.
2. True organ size is included in the estimates. (unlike MIRD method)
3. Uptake determined by GM or CAMI methods.
4. Modeling of the Biodistribution to allow data interpolation and extrapolation.
5. Decay constant is a free parameter to allow radionuclide shifts.
6. Dose-volume histograms are available.
Errors in Absorbed Dose Estimates.

- A value is uncertain to +/- 30% in GM. CAMI yields errors on the order of +/- 10%.
- $\lambda$ is uncertain to +/- 10% due to integration.
- $S$ is uncertain to factors of two or three due to variation in patient organ masses. This is, by far, the largest error in the $D = S \cdot \lambda$ formula.