Development of internal-dosimetry code based on ICRP 2007 Recommendations

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Japanese regulatory standards against internal exposures

- Three kinds of concentration limits (Bq/m$^3$) for:
  - Ambient air in facilities (Occupational)
  - Exhaust from facilities (Public)
  - Drainage from facilities

- Current standards are determined by using committed effective dose per unit intake, $e(\tau)$ (Sv/Bq), based upon ICRP 1990 Recommendations (mainly referred to ICRP Publ.68 and ICRP Publ.72).

ICRP started to release new $e(\tau)$ based upon 2007 Recommendations

- The Nuclear Regulation Authority of Japan (NRA) considers to introduce ICRP 2007 Recommendations into the regulatory system.
Revision of the Japanese Regulatory Standards

- It should be checked whether new $e(\tau)$ are correctly derived on the basis of ICRP dosimetry model or not by ourselves.
  - ICRP dosimetry model consists of various functions: biokinetic model, nuclear decay data, SAF data and so on.

- It is important to recognize which function makes the coefficient change.
  - Change in Tissue weighting factors ($w_T$)? Biokinetic models? Human models? Specific absorbed fractions (SAF)?

- It is necessary to comprehend the influence of Japanese specific conditions or parameters on doses.
  - Japanese specific biokinetics (e.g. uptake ratio of iodine to the thyroid).
  - Difference in physique between Japanese and Caucasian (i.e. SAFs).

JAEA has proposed a project to develop an internal dosimetry code to NRA, and the 4-year project (2017-2020 FY) is ongoing now.
Development of Internal Dosimetry Code

Purposes of the code

(a) Confirmation of new $e(\tau)$ for revision of the existing regulatory standards
(b) Estimation of internal doses considering various conditions for managing internal doses of workers, for evaluating retrospective doses in case of an accident based upon ICRP 2007 Recommendations.

Main functions of the code

(1) To calculate $e(\tau)$ using basic dosimetric models/data
   • Main function of this code for the purpose (a).
   Main part of this talk
(2) To estimate intakes of radionuclides and resulted doses from monitoring data
   • Application of the function (1) for the purpose (b).
**Language**

NRA considers to distribute the code for free in Japan.
→ Ease of use is also important.

- **Java** for making source code
  - Java application runs on multi-platforms: Windows, macOS, Linux.
- **XML** (eXtensible Markup Language) for some data files
  - Easy to edit data and understand the meanings

**New e(τ) including biokinetic models are being discussed in ICRP now.**

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<td><strong>Comp1</strong> <strong>Comp2</strong> 1.50E+01</td>
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**Example**

Biokinetic model

\[ \lambda^* = 15 \text{ d}^{-1} \]

\[
\begin{array}{c}
\text{Comp.1} \\
\text{Comp.2}
\end{array}
\]

*transfer coefficient
Methodology for $e(\tau)$ Calculation (ICRP Publ. 130)

Radiation weighted $S$ value, $S_w(T\leftarrow r_S)$:

$$S_w(T \leftarrow r_S) = \sum_R w_R \sum_j E_{R,j} Y_{R,j} \phi(T \leftarrow r_S, E_{R,j})$$

$\phi$ for specific energy is obtained by interpolating discrete SAF data.

$S_w(T \leftarrow r_S)_i$ (Sv): Radiation weighted $S$ value of chain member $i$ from source region $r_S$ to $T$.

$w_R$: Radiation weighting factor.


$\phi(T \leftarrow r_S, E_{R,j})$ (kg$^{-1}$): SAF from $r_S$ to $T$ at energy $E_{R,j}$.

Equivalent dose coefficient, $h_T(\tau)$ (Sv/Bq):

$$h_T(\tau) = \sum_i \sum_{r_S} \tilde{a}_i(r_S, \tau) S_w(T \leftarrow r_S)_i$$

$\tilde{a}_i(r_S, \tau)$: Number of disintegrations of chain member $i$ in source region ($r_S$) during $\tau$.

Evaluated by integrating simultaneous ordinary differential equations (ODEs) describing time dependent activities based on biokinetic models.

Effective dose coefficients, $e(\tau)$ (Sv/Bq):

$$e(\tau) = \sum_T w_T \left[ \frac{h_T^M(\tau) + h_T^F(\tau)}{2} \right]$$

$w_T$: Tissue weighting factor.

$h_T^{MorF}(\tau)$ (Sv/Bq): Committed equivalent dose per unit intake of tissue $T$ for male or female.
Flowchart of the Function to Calculate Dose Coefficients

1. **Biokinetic models [ICRP130, 134]**
2. **Nuclear decay data [ICRP107]**
3. **SAF data [ICRP133]**
4. **$w_R$ [ICRP130]**

Calculate $S_w$ for male and female

Construct ODEs describing time dependent activities and equivalent dose rates

Calculate $h_T^M(\tau)$ and $h_T^F(\tau)$ by integrating the ODEs

Calculate sex averaged $h_T(\tau)$

Calculate $e(\tau)$

ODE: Ordinary Differential Equation

According to the methodology in ICRP Publ. 130.
Used Calculation Techniques

Integration of ODEs

**J-LSODE**: Package of ODE solver written in Java

- Based on LSODE (Livermore Solver for Ordinary Differential Equations) written in FORTRAN77.
- Made from scratch to harmonize the language of the solver with that of the main code.

Interpolation of SAF data

**J-PCHIP**: Piecewise Cubic Hermite Interpolation Package written in Java

- We confirmed that PCHIP (lin.-lin.) is used in ICRP task group.
- Based on SLATEC*/PCHIP written in FORTRAN77.

*SLATEC: Sandia, Los Alamos, Air Force Weapons Laboratory Technical Exchange Committee
Quality Assurance of the Function to Calculate $e(\tau)$

Reference data

- $e(\tau)$ in OIR Data Viewer ver. 2.17 and ver 3.01 (except Rn)
  - for 454 cases of 101 radionuclides of 14 elements (ver. 2.17, Publ. 134)
  - for 885 cases of 183 radionuclides of 13 elements (ver. 3.01, Publ. 137)
  - with 2 digits of significant figures

Comparison of $e(\tau)$ between results by our function and OIR Data Viewer

- The values of $e(\tau)$ agreed with 2 digits for 426 cases in ver. 2.17 and 835 cases in ver. 3.01.
- For 28 cases in ver 2.17 and 50 cases in ver 3.01, the differences were only $\pm 1$ in the 2nd digit (due to round off).

Quality of the function has been assured for 27 elements in ICRP Publ.134 and Publ. 137
Various Output of Calculation Results

In addition to \( e(\tau) \) and \( h_{\tau}(\tau) \):

- Changes over time in activity and excretion rate
- Cumulative doses

\[ { }^{60}\text{Co}, \text{Inhalation Type F} \]

\[ { }^{90}\text{Sr}, \text{Inhalation Type F} \]

- Necessary for estimation of intakes
- Good reproduction of OIR Data Viewer
- Useful for detail analysis, public understanding, ...

We have progressed development of the function to estimate intakes of radionuclides and doses.

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Summary

● A project is ongoing to develop an internal dosimetry code based upon the ICRP 2007 Recommendations in Japan.
● The function to calculate $e(\tau)$ has been constructed. Quality of the function has been assured for 27 elements in ICRP Publ.134 and Publ. 137
● We have also developed a function to estimate intakes of radionuclides and resulted doses.

Foundation
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