Bioassay Interpretation

Intake assessment methods

Intake Retention Fractions

Dose assessment

Learning Objectives

- Define the intake retention fraction and identify compilations of values for it
- Describe the methods for estimating intakes from bioassay data
- Interpret intake values in terms of regulatory limits

Methods for Quantitative Assessment of Intakes

- **Whole Body or Lung Counting:**
  - **Feasible for x- or gamma-ray emitters**
  - **Also for energetic beta particles - can be detected by their *bremsstrahlung***
- **Excreta analysis:**
  - **24-hour urine collections - most widely used**
  - **24-hour fecal collections**
  - **Material excised from wounds**

Flow Chart

- **Analytical results**
  - **in vivo or in vitro**
- **Calculation of intake via intake retention fraction**
- **Calculation of CODE from dose coefficients**
- **Calculation of CEDE from effective dose coefficient**
- **Recording and reporting**

Intake Estimation

- **Must know date/time of intake; if not, assume it was halfway since last clean sample/count**
- **Use NUREG/CR-4884 to determine intake based on bioassay results**
- **Multiply intake by dose coefficient or**
- **Compare intake to ALI to get dose**
- **In U.S. must check if ALI is based on deterministic or stochastic limit**

NUREG/CR-4884
Interpretation of Bioassay Measurements

- **Tables of distribution and excretion (as fraction of initial intake) for both inhalation and ingestion of radionuclides, based on ICRP 30 models**
- **Values are referred to as Intake Retention Fractions (IRF'S), ICRP uses symbol m(t)**
- **Brief summary of models**
- **Element Data Sheets**
- **Examples**

NUREG/CR-4884
BNL-NUREG-52063

Interpretation of Bioassay Measurements

Manuscript Completed: June 1987
Date Published: July 1987

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Prepared for
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Washington, DC 20555
NRC FIN A-3289

CLASS W AMAD = 1 MICRON HALFLIFE= 1.92E+03 DAYS COBALT 60

TIME AFTER SINGLE INTAKE	FRACTION OF INITIAL INTAKE IN:				
DAYS	SYSTEMIC ORGANS	LUNGS	NASAL PASSAGES	GI TRACT	TOTAL BODY
1.00E-01	6.72E-02	2.76E-01	2.35E-01	5.68E-02	6.35E-01
2.00E-01	6.42E-02	2.65E-01	1.97E-01	1.04E-01	6.30E-01
3.00E-01	6.21E-02	2.56E-01	1.66E-01	1.42E-01	6.26E-01
4.00E-01	6.04E-02	2.47E-01	1.39E-01	1.73E-01	6.20E-01
5.00E-01	5.89E-02	2.40E-01	1.17E-01	1.99E-01	6.14E-01
6.00E-01	5.76E-02	2.33E-01	9.86E-02	2.18E-01	6.07E-01
7.00E-01	5.63E-02	2.26E-01	8.29E-02	2.33E-01	5.99E-01
8.00E-01	5.51E-02	2.21E-01	6.97E-02	2.43E-01	5.89E-01
9.00E-01	5.39E-02	2.16E-01	5.86E-02	2.50E-01	5.78E-01
1.00E+00	5.28E-02	2.11E-01	4.93E-02	2.53E-01	5.66E-01
2.00E+00	4.44E-02	1.77E-01	8.71E-03	1.93E-01	4.23E-01
3.00E+00	4.00E-02	1.60E-01	1.54E-03	1.07E-01	3.08E-01
4.00E+00	3.73E-02	1.50E-01	2.72E-04	5.40E-02	2.42E-01
5.00E+00	3.52E-02	1.44E-01	4.81E-05	2.68E-02	2.06E-01
6.00E+00	3.35E-02	1.41E-01	8.50E-06	1.38E-02	1.88E-01
7.00E+00	3.20E-02	1.38E-01	1.50E-06	7.68E-03	1.77E-01
8.00E+00	3.07E-02	1.35E-01	2.65E-07	4.76E-03	1.71E-01
9.00E+00	2.95E-02	1.33E-01	4.69E-08	3.35E-03	1.66E-01
1.00E+01	2.84E-02	1.32E-01	0.00E+00	2.66E-03	1.63E-01
2.00E+01	2.24E-02	1.15E-01	0.00E+00	1.77E-03	1.40E-01
3.00E+01	2.03E-02	1.01E-01	0.00E+00	1.53E-03	1.23E-01
4.00E+01	1.94E-02	8.88E-02	0.00E+00	1.33E-03	1.09E-01
5.00E+01	1.88E-02	7.78E-02	0.00E+00	1.15E-03	9.78E-02
6.00E+01	1.84E-02	6.83E-02	0.00E+00	1.00E-03	8.77E-02
7.00E+01	1.80E-02	5.98E-02	0.00E+00	8.68E-04	7.87E-02
8.00E+01	1.76E-02	5.25E-02	0.00E+00	7.53E-04	7.08E-02
9.00E+01	1.72E-02	4.60E-02	0.00E+00	6.53E-04	6.39E-02
1.00E+02	1.69E-02	4.03E-02	0.00E+00	5.67E-04	5.77E-02
2.00E+02	1.35E-02	1.07E-02	0.00E+00	1.37E-04	2.44E-02
3.00E+02	1.12E-02	2.83E-03	0.00E+00	3.29E-05	1.40E-02
4.00E+02	9.54E-03	7.41E-04	0.00E+00	7.95E-06	1.03E-02
5.00E+02	8.29E-03	1.93E-04	0.00E+00	1.92E-06	8.49E-03
6.00E+02	7.28E-03	4.99E-05	0.00E+00	4.62E-07	7.33E-03
7.00E+02	6.42E-03	1.28E-05	0.00E+00	1.11E-07	6.44E-03
8.00E+02	5.68E-03	3.29E-06	0.00E+00	2.69E-08	5.68E-03
9.00E+02	5.02E-03	8.42E-07	0.00E+00	0.00E+00	5.02E-03
1.00E+03	4.44E-03	2.15E-07	0.00E+00	0.00E+00	4.44E-03
2.00E+03	1.30E-03	0.00E+00	0.00E+00	0.00E+00	1.30E-03
4.00E+03	1.12E-04	0.00E+00	0.00E+00	0.00E+00	1.12E-04
5.00E+03	3.28E-05	0.00E+00	0.00E+00	0.00E+00	3.28E-05
7.00E+03	2.83E-06	0.00E+00	0.00E+00	0.00E+00	2.83E-06
8.00E+03	8.29E-07	0.00E+00	0.00E+00	0.00E+00	8.29E-07
9.00E+03	2.43E-07	0.00E+00	0.00E+00	0.00E+00	2.43E-07
1.00E+04	7.13E-08	0.00E+00	0.00E+00	0.00E+00	7.13E-08

CLASS W AMAD = 1 MICRON HALFLIFE= 1.92E+03 DAYS COBALT 60

TIME AFTER SINGLE INTAKE	FRACTION OF INITIAL INTAKE IN:			
DAYS	24-HOUR URINE	ACCUMULATED URINE	24-HOUR FECES	ACCUMULATED FECES
1.00E-01		3.35E-03		8.47E-04
2.00E-01		7.09E-03		1.83E-03
3.00E-01		1.01E-03		3.06E-03
4.00E-01		1.29E-02		4.82E-03
5.00E-01		1.57E-02		7.33E-03
6.00E-01		1.81E-02		1.07E-02
7.00E-01		2.02E-02		1.51E-02
8.00E-01		2.23E-02		2.05E-02
9.00E-01		2.42E-02		2.67E-02
1.00E+00	2.59E-02	2.59E-02	3.36E-02	3.36E-02
2.00E+00	1.10E-02	3.69E-02	8.87E-02	1.22E-01
3.00E+00	5.13E-03	4.21E-02	7.33E-02	1.95E-01
4.00E+00	3.05E-03	4.50E-02	4.26E-02	2.38E-01
5.00E+00	2.26E-03	4.73E-02	2.20E-02	2.60E-01
6.00E+00	1.90E-03	4.91E-02	1.12E-02	2.71E-01
7.00E+00	1.67E-03	5.09E-02	5.93E-03	2.77E-01
8.00E+00	1.51E-03	5.23E-02	3.42E-03	2.81E-01
9.00E+00	1.38E-03	5.37E-02	2.21E-03	2.83E-01
1.00E+01	1.27E-03	5.50E-02	1.62E-03	2.84E-01
2.00E+01	6.62E-04	6.35E-02	8.47E-04	2.93E-01
3.00E+01	4.48E-04	6.86E-02	7.07E-04	2.99E-01
4.00E+01	3.59E-04	7.22E-02	6.03E-04	3.05E-01
5.00E+01	3.11E-04	7.53E-02	5.23E-04	3.09E-01
6.00E+01	2.78E-04	7.79E-02	4.55E-04	3.13E-01
7.00E+01	2.50E-04	8.02E-02	3.97E-04	3.16E-01
8.00E+01	2.26E-04	8.24E-02	3.47E-04	3.19E-01
9.00E+01	2.05E-04	8.42E-02	3.03E-04	3.21E-01
1.00E+02	1.85E-04	8.58E-02	2.65E-04	3.23E-01
2.00E+02	6.86E-05	9.43E-02	7.00E-05	3.25E-01
3.00E+02	2.70E-05	9.52E-02	1.95E-05	3.17E-01
4.00E+02	1.27E-05	9.37E-02	6.24E-06	3.07E-01
5.00E+02	7.65E-06	9.13E-02	2.65E-06	2.97E-01
6.00E+02	5.63E-06	8.87E-02	1.59E-06	2.87E-01
7.00E+02	4.63E-06	8.61E-02	1.20E-06	2.77E-01
8.00E+02	3.99E-06	8.34E-02	1.01E-06	2.67E-01
9.00E+02	3.50E-06	8.09E-02	8.73E-07	2.57E-01
1.00E+03	3.09E-06	7.83E-02	7.73E-07	2.49E-01
2.00E+03	9.03E-07	5.61E-02	2.25E-07	1.74E-01
3.00E+03	2.65E-07	3.95E-02	6.62E-08	1.21E-01
4.00E+03	7.76E-08	2.77E-02	1.94E-08	8.47E-02
5.00E+03	2.27E-08	2.24E-02	0.00E+00	5.90E-02

Use of IRF’s

- **Point estimates: each bioassay result divided by the appropriate IRF value gives a single estimate of intake; multiple values may be averaged**
- **Multiple values may give a single estimate of intake via unweighted least squares**
- **Multiple values may give a single estimate of intake via weighted least squares**

Bioassay Example

A worker spends some time in an area where Co-60 oxides are present. At the end of the quarter (70 days later), activity is detected in his routine urine sample. Follow-up samples reveal the following excretion pattern:

Days after suspected exposure	24-hour urine activity (Bq)
70	60
100	50
130	45

A lung count on day 70 revealed 0.25 MBq of Co-60. What is your best estimate of this individual's intake and dose?

Determine m(t) values

We first look up the values supplied in NUREG/CR-4884 (Lessard et. al.) for class Y Co-60 (oxide). The IRF values are:

Days after intake	Fraction of initial intake in: 24-hour urine	Fraction of initial intake in: Lung
70	2.97×10^{-5}	0.136
100	2.60×10^{-5}	0.130
200	1.99×10^{-5}	0.113
130 (interpolated)	2.40×10^{-5}	

(Note - these numbers include radioactive decay)

Point Estimates of Intake

- Intake = V/m(t) where:

  V = value of bioassay result (Bq, Bq d^{-1})

  m(t) = IRF for bioassay measurement at time t after intake

- Treat each data point as a separate trial
- Average separate estimates if consistent
- If not consistent, look at biokinetic model

Point estimates of intake

Day 70: 60 Bq/2.97 x 10^{-5} = 2.02 MBq

Day 100: 50 Bq/2.60 x 10^{-5} = 1.92 MBq

Day 130: 45 Bq/2.40 x 10^{-5} = 1.88 MBq

Day 70: 0.25 MBq/0.136 = 1.84 MBq

The average is 1.92 MBq. The most reliable estimate might be 1.84 MBq, if lung counter was well calibrated. The "best" answer is 2 MBq, given the accuracy of the models.

Least Squares Fits

- **Unweighted LSF:**

  Intake = $\{\Sigma_i[V_i m(t_i)]\}/\{\Sigma_i[m(t_i)]^2\}$

- **Weighted LSF:**

  Intake = $\{\Sigma_i V_i\}/\{\Sigma_i m(t_i)\}$

LSF calculations

Days post intake	V*m(t)	$m(t)^2$	V	m(t)
70	0.00178	8.82×10^{-10}	60	2.97×10^{-5}
100	0.00130	6.76×10^{-10}	50	2.60×10^{-5}
130	0.00108	5.76×10^{-10}	45	2.40×10^{-5}
Sums:	0.00416	2.13×10^{-9}	155	7.97×10^{-5}

Best estimate of initial intake:

unweighted: $0.00416/2.13 \times 10^{-9} = 1.95 \times 10^{6}$ Bq

weighted: $155/7.97 \times 10^{-5} = 1.95 \times 10^{6}$ Bq

Committed dose $(2 \times 10^{6}\ \text{Bq}) \cdot (3.4 \times 10^{-7}\ \text{Sv/Bq}) = 0.68$ Sv

Things to remember

- **Not a good idea to combine WBC and excreta data if values differ by several orders of magnitude**
- **If the intake estimates via ULSF and WLSF differ quite a bit, the biokinetic model is probably wrong**
- **Can use m(t) values to distinguish between Class D, W, and Y (or Type F, M, and S) intakes if sequential bioassay data are available**

Interpretation - Chronic Uptakes

$$A = I\,(\lambda_e)^{-1}(1 - e^{-\lambda_e t})$$

where: A = activity in the body (Bq)

I = rate of intake of activity (Bq/day)

λ_e = effective removal constant (day $^{-1}$)

t = time since activity intake began (days)

$$\text{Daily excretion} = I\,\lambda_b(\lambda_e)^{-1}$$

where: λ_b = the biological removal constant

Quality Assurance
for dose calculations

- Primary determinant of dose quality is bioassay data quality
- Computer-based calculations must be periodically verified
- Results must be reviewed by an experienced dosimetrist
- Errors (where quantifiable) should be propagated through to final result

Remember Uncertainties

- Analytical results
- Daily variation in excretion
- Background variability
- Biokinetic model
- Particle size and solubility class
- Breathing rate
- Gastrointestinal uptake
- Etc., etc., etc.

Quality Control

- Maintain configuration control of software
- Double (if not triple) check data entry
- Remember to protect subject’s privacy
- Consistency is a good quality indicator (all monitoring and scenario-type data)
- Exercise the system occasionally
- Somebody must understand all aspects of the internal dosimetry operation

More Things to Remember

- Two significant figures is pushing it
- Nobody behaves exactly like the models
- Keep records of everything
- Ensure management is aware of accuracy of bioassay data and resulting doses
- Try not to allow yourself to be forced to draw a conclusion you're really not comfortable with

References

NCRP 87 - Use of Bioassay Procedures for Assessment of Internal Radionuclide Deposition

NRC Reg. Guide 8.11 - Applications of Bioassay for Uranium

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ANSI N13.14 - Internal Dosimetry Programs for Tritium Exposure - Minimum Requirement

AECL - 6478 - Annual Limits on Intake, Organ Burdens, and Excretion Rates for Occupational Exposure to Uranium

References

NUREG/CR-4884 - Interpretation of Bioassay Measurements

ICRP 54 - Individual Monitoring for Intakes of Radionuclides by Workers: Design and Interpretation

NRC Reg. Guide 8.9 - Acceptable Concepts, Models, Equations, and Assumptions for a Bioassay Program

HPS N13.30 - Performance Criteria for Radiobioassay

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