Chapter 11

- Internal Dosimetry
- Effective Half-Life
- Bioassay
- Air Sampling

Chapter 11

- **Internal Dosimetry**

Objectives

- Understand the Internal Dose pathways
- Describe the bioassay measurement frequencies
- Understand the regulatory requirements for establishing internal dose and describe the limitations of each method

Objectives

- Discuss methods for evaluating the amount of radioactive material deposited internally, and describe advantages and disadvantages of each
- Describe the difference between in vivo and in vitro bioassays and applications for each
- Describe the measurement frequencies used for bioassays

Objectives

- Describe the advantages and disadvantages of semiconductor and scintillation detection systems used in whole body counting
- Discuss the type of samples commonly collected for biological sampling

Internal Dosimetry Program

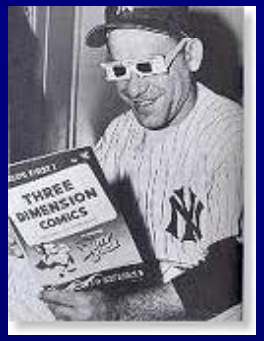
- An internal dosimetry program is part of an overall radiation protection program at a site
- Air sampling and bioassay programs are utilized to control internal dose to workers
- Effectiveness of engineering and administrative controls are evaluated by the program
- Dosimetrists must quantify the amount of radioactive material within the body
- Radionuclides distribute differently in the body (e.g. iodine seeks the thyroid, while strontium seeks the bone)

Internal Dosimetry

- Internal dosimetry is an art based on science

"In theory there is no difference between theory and practice. In practice there is."

Yogi Berra



"Baseball (and Internal Dosimetry) is ninety percent mental and the other half is physical."

Yogi Berra

Internal Dose Pathways

- Radioactivity may enter our body through:
  - Inhalation
  - Ingestion
  - Injection (wound or puncture)
  - Absorption, e.g., tritium
- Of these pathways, inhalation is the most prevalent

CEDE Calculations (Inhalation)

- Per Reg Guide 8.34, "Monitoring Criteria and Methods to Calculate Occupational Radiation Doses," there are at least five acceptable methods for calculating CEDE from inhaled radioactive materials:

1. Use of Federal Guidance Report No. 11
2. Use of stochastic inhalation ALIs from 10CFR20
3. Use of DACs from 10CFR20
4. Use of ICRP 30
5. Use of individual or material-specific information

CEDE Calculations (Ingestion)

- Per Reg Guide 8.34, four acceptable methods for calculating CEDE from ingested radioactive materials:

  1. Use of Federal Guidance Report No. 11
  2. Use of stochastic ingestion ALIs from 10CFR20
  3. Use of ICRP 30
  4. Use of individual or material-specific information

CDE Calculations

- Per Reg Guide 8.34, CDEs need be calculated only if the CEDE >1 rem or if an overexposure has occurred. Five acceptable methods for calculating CEDE from inhaled radioactive materials:

1. Use of Federal Guidance Report No. 11
2. Use of non-stochastic inhalation ALIs from Part 20
3. Use of DACs from Part 20
4. Use of ICRP 30
5. Use of individual or material-specific information

Internal Dosimetry Applications

- 10CFR20.1502 requires licensees to monitor the internal dose to adults likely to receive a dose in excess of 10% of the ALI.
- 10CFR20.1204(a) states that for assessing dose to ensure compliance with occupational dose limits, licensees may use either:
  - Concentrations of radioactive materials in air, or
  - Quantities of radionuclides in the body (*in vivo*), or
  - Quantities of radionuclides excreted from the body (*in vitro*), or
  - Combinations of these measurements.

Bioassay Limitations/Considerations

- Measurements of the activity in the body are compared to the ALI for the radionuclide. The fraction of the ALI corresponds to dose.
- The challenge is to determine the intake, not only the activity measured.
- Confounding factors include the inability of a detection system to distinguish activity that is on you, from activity that is in you.
- Must account for the presence of radionuclides from previous intakes.

Bioassay Requirement

- When respiratory protection equipment is used to limit intakes of airborne radioactive material, the licensee's respiratory protection program must include bioassay measurements to evaluate airborne intakes (20.1703).
- Acceptable methods are identified in Reg. Guide 8.9, ICRP-54, and NCRP-87.

Methodology

- ICRP-30, "Limits for Intakes of Radionuclides by Workers" provides the schema (biokinetic models, etc.) for calculating Annual Limit on Intake (ALI) and Derived Air Concentration (DAC) values that appear in 10CFR20.
- Modeling in ICRP-30 serves as the basis for NUREG-4884, "Interpretation of Bioassay Measurements."
  - time-dependent values for retention and excretion of ingested or inhaled radioactive material
  - The metabolism of radionuclides presents uncertainty

Action Levels

- Individual physiological characteristics and biochemical processes are unique.
- Reg. Guide 8.9 contains acceptable methods for evaluating bioassay data.
  - Evaluation Level > 0.02 ALI: additional information, such as airborne samples or bioassay measurements should be used to obtain the best estimate of the actual intake.
  - Investigational Level > 0.1 ALI: a thorough investigation of the exposure should be made; multiple bioassay measurements should be conducted. If practical, daily measurements should be made until patterns of bodily retention and excretion can be established. For potential intakes near or exceeding ALI's, bioassay data should consider physical and chemical characteristics of the individual's biokinetic processes.
- The use of intake retention and excretion fractions (IRF's) and adjustments for particle size will be presented in subsequent lectures in this course.

END OF INTERNAL DOSIMETRY

Chapter 11

- **Effective Half life**

Objectives

- Discuss the concept of effective half-life and derive it mathematically
- Discuss significance of effective half-life
- Calculate the effective half life, the radiological half life, or the biological half life given information about the other two quantities

Effective Decay Constant

For internal deposition of radioactive material, the two removal processes are radiological transformation "r" of the material and biological clearance "b" of the material from the body. The combination of the two processes yields an effective removal or clearance "e"

$$\lambda_e = \lambda_r + \lambda_b$$

$$= \frac{\ln 2}{T_r} + \frac{\ln 2}{T_b}$$

$$= \ln 2 \left[\frac{1}{T_r} + \frac{1}{T_b} \right]$$

Effective Half Life

$$\lambda_e = \frac{\ln 2}{T_e} \quad \text{so that} \quad \frac{\ln 2}{T_e} = \ln 2 \left[\frac{1}{T_r} + \frac{1}{T_b} \right]$$

$$\frac{1}{T_e} = \left[\frac{1}{T_r} + \frac{1}{T_b} \right]$$

$$\frac{1}{T_e} = \frac{1}{T_r} \frac{T_b}{T_b} + \frac{1}{T_b} \frac{T_r}{T_r}$$

$$\frac{1}{T_e} = \frac{T_b + T_r}{T_b T_r}$$

If we multiply each element on the right side of the equation by "1" we don't change anything

$$\frac{T_b}{T_b} = \frac{T_r}{T_r} = 1$$

Effective Half Life

Since there is a unique denominator on both sides of the equation, we can flip both sides to get:

$$T_e = \frac{T_b\, T_r}{T_b + T_r}$$

$$T_e = \frac{\text{Product}}{\text{Sum}}$$

Effective Half Life

If $T_r = T_b$:

$$T_e = \frac{T_b^2}{2T_b} = \frac{T_b}{2} = \frac{T_r}{2}$$

If $T_r >> T_b$: then $T_r + T_b \approx T_r$

$$T_e = \frac{T_b T_r}{T_r} = T_b$$

If $T_b >> T_r$: then $T_r + T_b \approx T_b$

$$T_e = \frac{T_b T_r}{T_b} = T_r$$

Thus, T_e must always be bounded by the smallest half life and ½ of the smallest half life.

Effective Half Life

$\frac{1}{2}T_b \leq T_e \leq T_b$

T_e will equal T_b if $T_r >> T_b$
and
T_e will equal $\frac{1}{2}T_b$ if $T_r = T_b$

$\frac{1}{2}T_r \leq T_e \leq T_r$

T_e will equal T_r if $T_b >> T_r$
and
T_e will equal $\frac{1}{2}T_r$ if $T_b = T_r$

Example

Given that the radiological half life is 1 year and the biological half life is also 1 year then $T_r = T_b$.

So $T_e = \frac{1}{2}T_r$ or $\frac{1}{2}T_b = 0.5$ years. $T_e = \frac{T_b T_r}{T_b + T_r} = \frac{1 \times 1}{1 + 1} = \frac{1}{2}$

Given that the radiological half life is 1 year (365 days) and the biological half life is 1 day then $T_r >> T_b$.

So $T_e = T_b = 1$ day. $T_e = \frac{T_b T_r}{T_b + T_r} = \frac{1 \times 365}{1 + 365} = \frac{365}{366} = 1$

Example

Given that the radiological half life is 10 days and the biological half life is 6 days then $T_r > T_b$.

So T_e is somewhere between T_b (6 days) and $\frac{1}{2}T_b$ (3 days)

$\frac{1}{2}T_b \leq T_e \leq T_b$ or $3 \leq T_e \leq 6$

$$T_e = \frac{T_b T_r}{T_b + T_r} = \frac{10 \times 6}{10 + 6} = \frac{60}{16} = 3.8$$

Problem

If ^{131}I has a radiological half life of 8 days and a biological half life of 3 days, then what would be the effective half life of the stable form of iodine?

Problem

An individual has an intake of ^{60}Co. Lung counting reveals an effective half life of 100 days. What is the biological clearance rate for this isotope?

T_e = 100 days T_r = 5.25 yr = 1916 days T_b = ?

Answer

HINT: Since T_e must be between ½ and 1x the smallest T, T_r can't be the smallest, otherwise T_e would be between 962 days and 1,916 days.

Thus, T_b must be the smallest. T_e = 100 d must fall between ½T_b and T_b (½$T_b \leq 100\ d \leq T_b$)

T_b cannot be less than 100 days. If it were, T_e would have to be less than 100 days which it isn't. T_b must also be less than 200d. If T_b were equal to 200 days then the only way that T_e could be equal to 100 days would be if T_r were also equal to 200 days which it isn't. So T_b must be greater than 100 days and less than 200 days.

Problem

The radiological half life of ^{32}P is 14 days and the biological half life is 1 day. The effective half life is approximately (DO NOT CALCULATE - USE RULES):

a. 7 days
b. 10 hours
c. 12 days
d. 22 hours

END OF EFFECTIVE HALF LIFE

Chapter 11

- **Bioassay**

Bioassay

- Bioassays are used to provide information on the intake which is used to assess one's dose
- *In Vivo,* "in life" (e.g. Whole Body Count) vs.

  In Vitro, "in glass" (e.g. urine, fecal or blood samples)

Bioassay Measurement Frequency

- Baseline measurements – new hires,
- Periodic measurements – annually as a minimum,
- Termination measurements – to ensure intakes are quantified,
- Special monitoring – high levels of facial and/or nasal contamination, entry into airborne areas w/o appropriate controls, operational events, known or suspected worker ingesting material, incidents resulting in contamination of wounds, damage or failure of respiratory protection equipment.

Radionuclides of Interest

Fission Products:

^{89}Sr, ^{90}Sr, ^{90}Y, ^{95}Zr, ^{95}Nb,
^{103}Ru, ^{106}Rh, ^{110m}Ag,
^{124}Sb, ^{125}Sb, ^{134}Cs, ^{137}Cs,
^{140}Ba, ^{140}La, ^{141}Ce, ^{144}Ce,
^{147}Pm

Activation Products:

^{51}Cr, ^{54}Mn, ^{55}Fe, ^{59}Fe,
^{58}Co, ^{60}Co, ^{63}Ni, ^{65}Zn,
^{94}Nb, ^{95}Zr, ^{95}Nb, ^{113}Sn,
^{124}Sb, ^{125}Sb

Obviously this list is skewed toward nuclear power plants…

Isotope Library

- Whole Body Counter (WBC) software uses a library to correlate a peak for a given channel (energy) to an isotope
- Avoid other “nearby” peaks, avoid peaks near 0.511 MeV (annihilation peak).
- Select peaks with greater abundance when possible.

Isotope Library

- Use “confirmatory” peaks if possible, e.g., 1.17 and 1.33 MeV for ^{60}Co
- Develop a “medical library” to identify unknowns
- Consider what isotopes are most likely

WBC Calibrations

Three calibrations are performed on WBC equipment:

- Energy
- Efficiency
- FWHM (Full Width Half Maximum) – Resolution

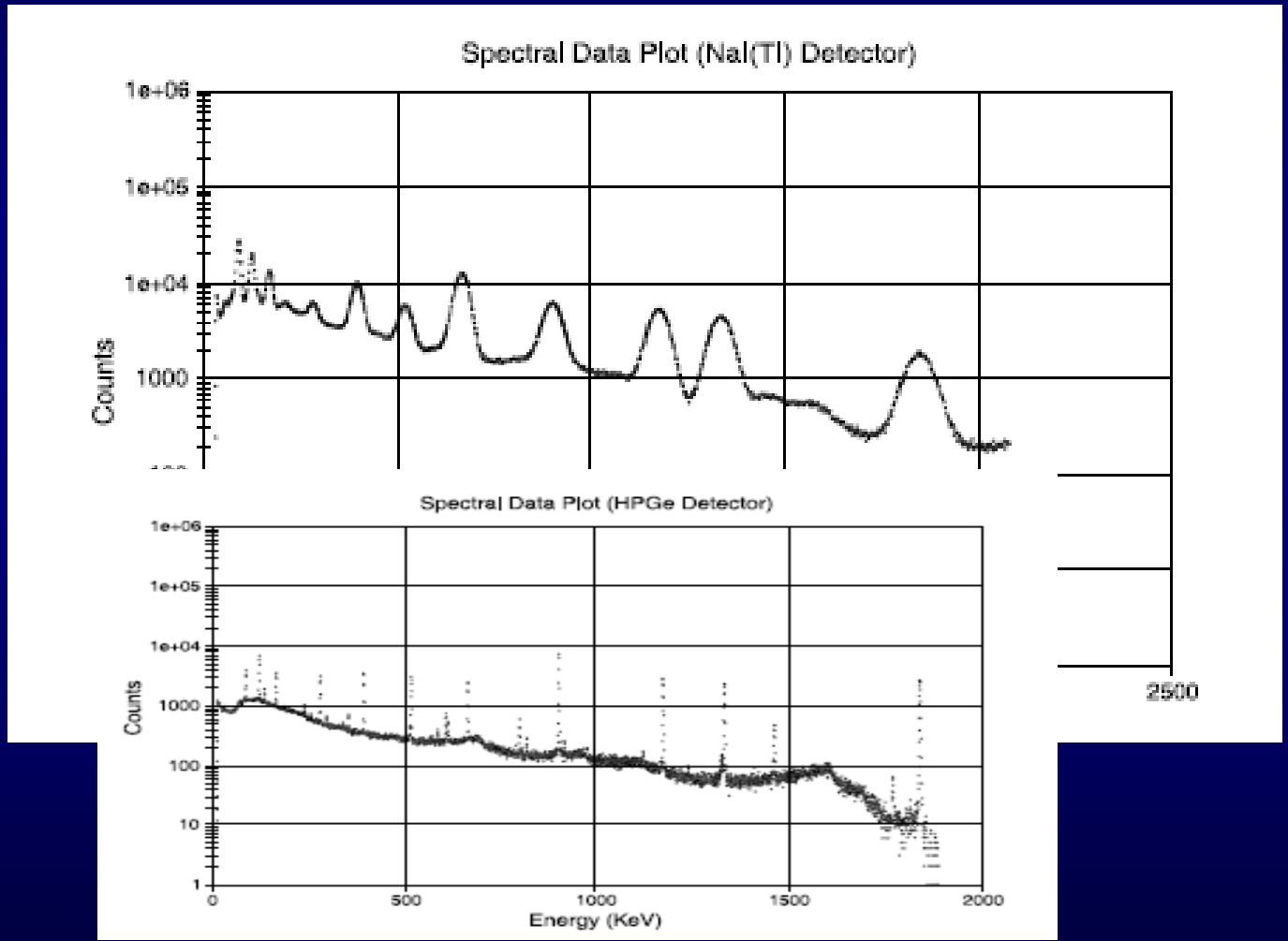
- Calibrate to 1 channel/1 keV

- When calibrating a whole body counter, use isotopes that will encompass the range of peaks you expect to encounter

WBC Calibrations

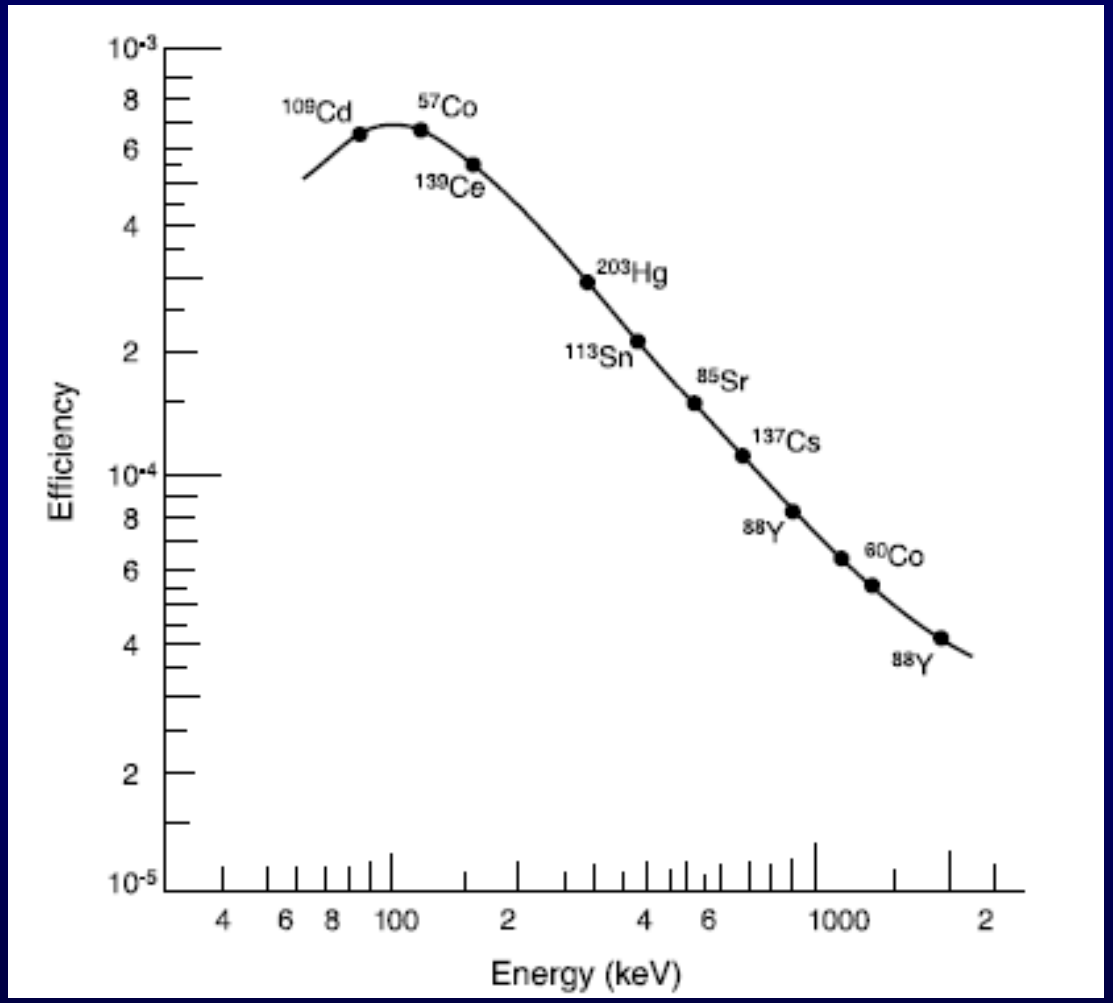
- Mixed gamma standard: ^{109}Cd; ^{57}Co; ^{139}Ce; ^{203}Hg; ^{113}Sn; ^{137}Cs; ^{88}Y; and ^{60}Co
- Select an isotope with a range of photons for daily response check, e.g. ^{152}Eu
- Develop a control chart and plot daily response on the control chart
- Conduct daily background counts
- Look for ^{40}K peak as a real time energy check

Energy Calibration



Show example of FWHM in Turner's text

Efficiency Calibration



Chi - Squared Statistic

- The null hypothesis is that the counting system is working properly.
- Take n repetitive measurements of a long-lived source, the observed counts, C_i, will vary about some mean, μ. The standard deviation, σ, describes the variation of the counts about the mean.

Phantoms

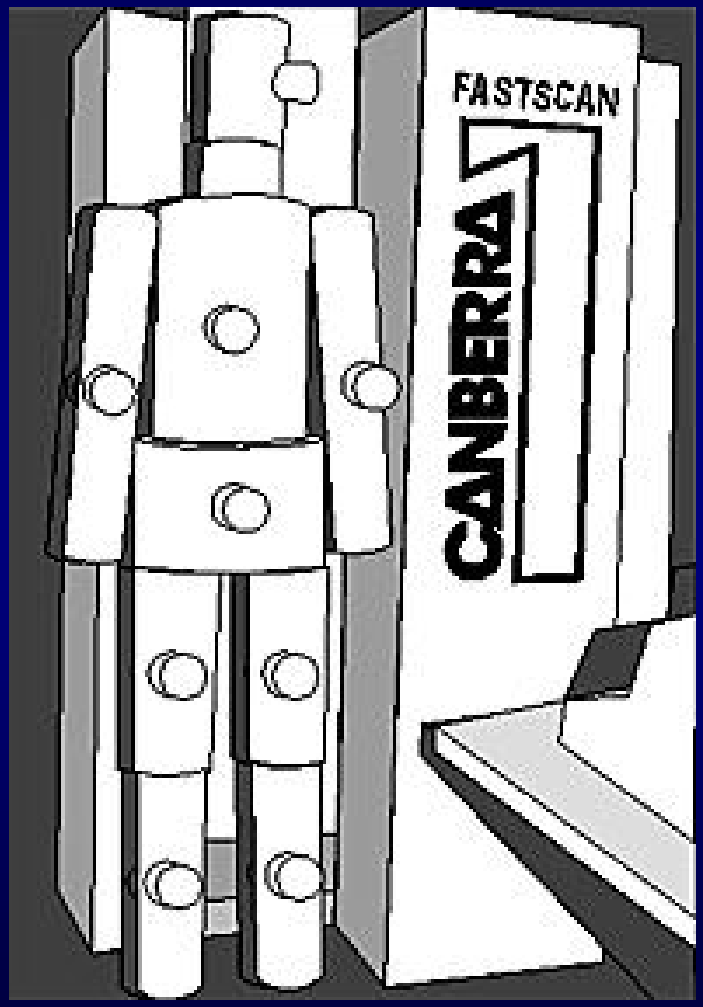
- Phantoms are used to simulate the body or organs of the body.
- Known activity of known isotopes are placed in a phantom. The phantom is counted. The number of counts is used to develop and efficiency calibration. The LLNL phantom is the consensus “de facto” phantom.
- LLNL phantom is based on a cadaver 1.77 m tall and weighing 76 kg.

Phantoms

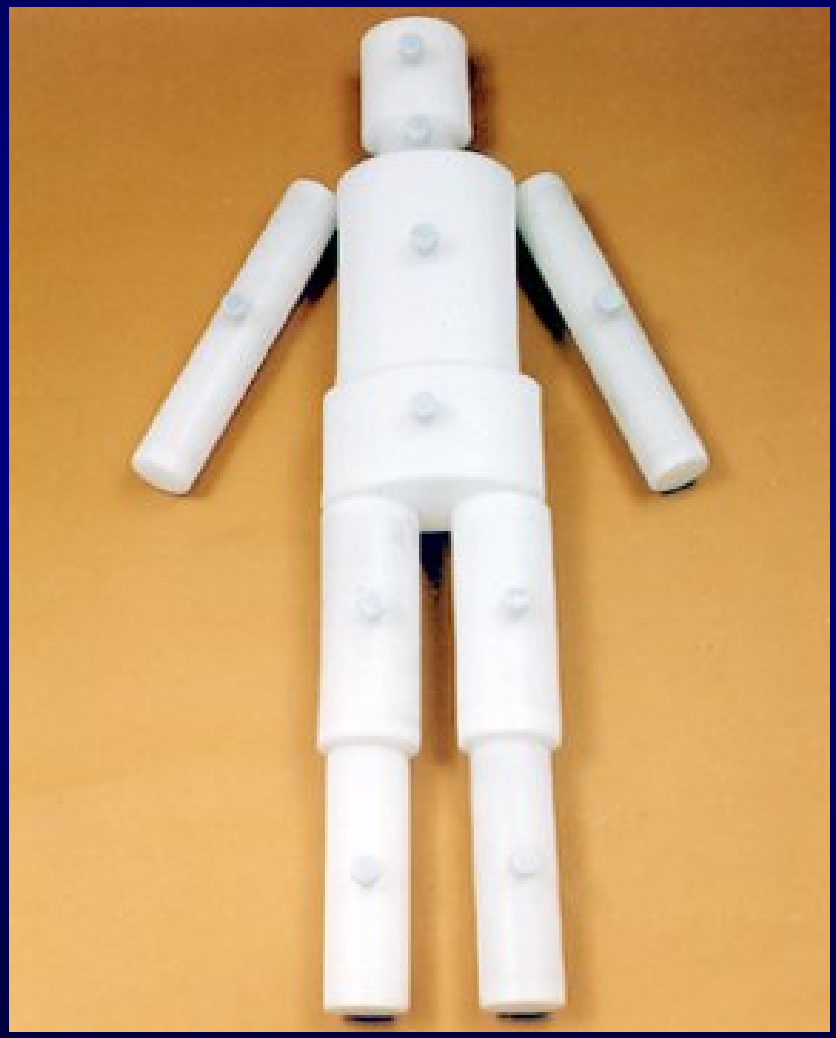
- JAERI (Japanese Atomic Energy Research Institute) phantom was developed to represent an adult Japanese male, 1.68 m tall, 63.5 kg.
- Others: BOMAB, ANSI N44.3 Neck, Transfer
- ICRP-23 (1975) reference man weighs 70 kg, and is 170 cm in height.
- ICRP-66 (1994) reference man weighs 73 kg and is 176 cm in height.

BOMAB Phantom

- ANSI N13.30 reference for uniformly distributed soluble depositions
- Simulates standard man (ICRP-23)
- 10 cylinders - calves, thighs, lower torso, upper torso, neck, head, arms
- Distribute calibration source in each container



BOMAB Phantom



Livermore Lung Phantom

- ANSI N13.30 reference phantom
- Basic torso - lung, lymph node, abdominal inserts
- Developed by LLNL for transuranics in workers

Livermore Lung Phantom

Canberra "Transfer" Phantom

- Replicates ANSI N13.30 phantom (Livermore Lung, BOMAB, and Thyroid)
- For linear geometry applications only
- Not appropriate for low energy measurements.
- Uses 20 ml liquid scintillation vials for all geometries

Detectors

Sodium Iodide (NaI)

- Low cost
- High efficiency
- Low resolution

Germanium (GeLi)

- High cost (must be cooled with liquid nitrogen)
- Low efficiency
- High resolution

FASTSCAN

- Linear geometry counter
- MDL < 5 nCi for ^{137}Cs or ^{60}Co on 1-minute count in a person with 120 nCi of ^{40}K
- No moving parts
- 2 NaI detectors of 4”x4”x16”

Lung Counting

- Phoswich detectors are used in lung counting for actinides (14 - 80 keV) and lower energy photons from uranium (90 - 185 keV)
- Challenges for lung counting are:
  - Photons of interest have low abundance
  - Attenuating by the chest wall, and
  - Compton scatter background from ^{40}K

Chest-Wall Thickness

- ^{239}Pu has average X-ray of 17 keV. The half-value thickness for 17-keV photons is about 6 mm for muscle, 12 mm for adipose, 0.3 mm for bone. Current CWT is based on male data, use of a "phoswich" (NaI-CsI) detection system, in supine position
- Phoswich seldom used, counts not conducted in supine position, males have more muscle and less adipose than females. Results in errors of +284% to -73% of ^{239}Pu and +42% to -39% for ^{241}Am
- (HP Vol.70, No.3, Mar. 1996)

Lung Counter

- LLD of 4 Bq (0.1 nCi) for ^{235}U or ^{241}Am
- 2 to 8 Ge detectors
- 6 inch low background steel shield option
- Shielded detector precludes need for a Pb/Cd/Cu graded shield

Thyroid Phantom

Internal Dose Techniques

- Techniques for determination of internal dose are:
  - Bioassay: 1) Whole body counting (in vivo) and, 2) In Vitro (urine or fecal depending on solubility of the material)
  - Air Sampling: Collect an air sample, determine the concentration of each isotope by determining the activity and the volume of air sampled; compare the concentration to the DAC (use conservative values if the chemical form is not known) to determine the DAC fraction; use the relationship of 2.5 mrem/DAC-hr or 25 mrem/DAC-hr, as appropriate

Confirming Internal Dose Calculation

- There are techniques for determining if bioassay dose calculations are acceptable (Regulatory Guide 8.25, "Air Sampling in the Workplace," June 1992, Rev. 1). These use:
  - Lapel air sampling results,
  - Area air monitoring results, and
  - Bioassay results

END OF BIOASSAY

Chapter 11

- **Air Sampling**

Air Sampling

- Sampling techniques include:
  - Grab samples
  - Continuous sampling
  - Lapel sampling (breathing zone)
- Locations of samplers should consider air flow patterns

Limitations/Considerations

- Measurements of the activity in the air are used to determine the amount of activity inhaled
- Challenges include:
  - Obtaining representative sampling of inhaled airborne concentrations
  - Determining the chemical form of the material, which determines solubility, e.g., how fast the material is processed through the body
  - Determining the particle size of the material
  - Determining when the intake occurred and how long it occurred

Personal Air Sampler

- Compact, Rugged and Quiet
- Flows up to 4 LPM for special cyclone requirements

Personal Air Sampler

- Can sample for asbestos, lead and other airborne contaminants
- Adjustable flow rate
- Digital display shows flowrate, accumulated volume, elapsed time etc.

Breathing Zone - Continuous

- Flow rates can be varied
- Adjustable units permit sampling at heights varying from 4' to 7' (122 cm - 213 cm) above floor level
- Have onboard pumps and air regulators to hold a constant pressure
- Pumps mounted on a wheeled cart to permit transportation of the unit

"Goose neck" sampler

Low-Volume Air Sampling

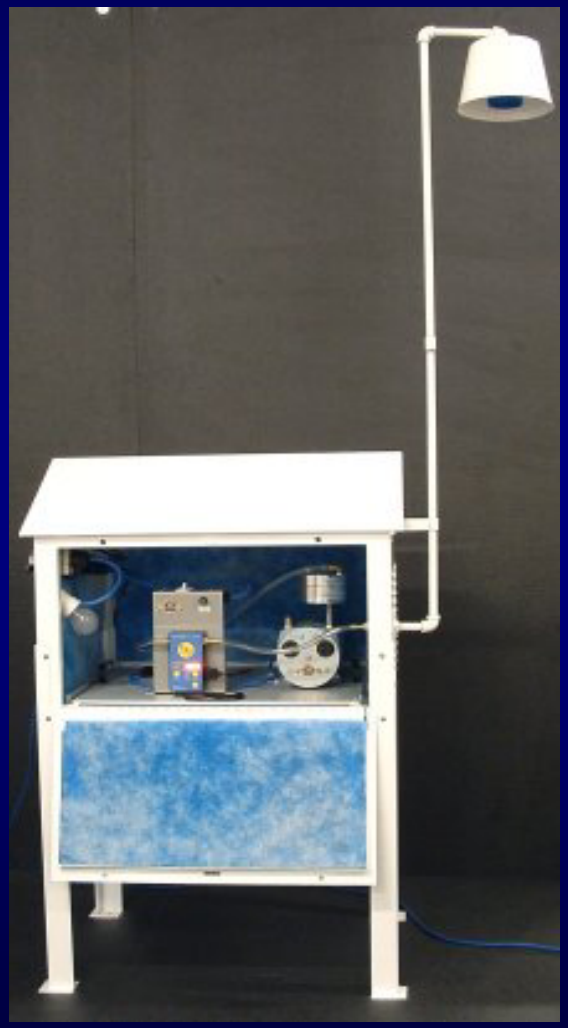
- Flow rate: 10-100 lpm (3.5 – 35 cfm)
- 1/4 H.P. oil-less, carbon vane vacuum pump with a flow meter, a vacuum gauge and a constant air flow regulator for use where a nearly constant air flow is desirable

Low-Volume Indoor

- Designed for continuous indoor use
- Flow rates can be varied between 3.5 – 35 cfm
- Include a vacuum pump with a flow meter, a vacuum gauge, and a constant airflow regulator
- The regulator holds a constant pressure drop across an in-line orifice by varying the flow through a bypass valve

Low-Vol Environmental

- Low-volume air sampler consisting of an oil-less, carbon vane vacuum pump, with a constant air flow regulator
- The pump is usually mounted within a GFCI protected aluminum environmental weatherhouse.
- These systems are designed for continuous outdoor use
- Typical flow rates of 0.5 to 4 CFM



Digital Low-Vol

- RS-232 input
- Indoor/Outdoor use
- Data storage: 60 days
- Flow range: 0.5 to 4 cfm

Tritium Sampling

- Diaphragm pump with 2 removable polycarbonate silica gel columns
- Other tritium absorbing media may be utilized, such as molecular sieve, water or ethylene glycol
- RS-232 Port for real-time data
- Flow range: 0.03 – 0.3 LPM (30 - 300 sccm)

Tritium Sampling
Liquid Scintillation

- Sample gas enters the instrument and flows through two (2) standard scintillation counter ready vials filled with ethylene glycol, which retain the HTO component.
- The sample gas, now less the tritiated water vapor, flows through a heated palladium sponge catalyst bed, which oxidizes the sample gas.
- The oxidized sample gas flows through two (2) more vials with ethylene glycol that retain the remaining tritium components (originally HT and tritiated organics).

High Volume Sampling

- Single or Dual Rotometer(s)
- Flow Adjustment via Motor Speed Control

Emergency Response Sampling System

- Operating Modes
  - — Line Power (110VAC – 250VAC)
  - — On-Board Batteries
  - — Automobile Cigarette Lighter
- Long-lasting Lead Acid Battery
- Lightweight — ~17 lbs. (7.7 kg)
- High Flow — 40 LPM Maximum
- Bright LED Display
- Auto shut-off on time or volume

Particulate Sampling: Filter Paper

- High particulate efficiency: 98% - 99.98% (0.3 µm particles)
- Chemically and physically inactive
- High temperature resistance
- Transparency facilitates visual particle identification

Radioactive Iodine Sampling

- Common media used is silver zeolite (pictured) and activated charcoal

- Retention efficiency is dependent on:
  - Species: efficiency is greater for elemental iodine (I_2) than for methyl iodide (CH_3I)
  - Temperature: efficiency is greater at higher temperature,
  - Humidity: efficiency is lower at higher humidity,
  - Flow rate: efficiency decreases with high flow rates,
  - Bed Depth: efficiency increases with increase bed depth,
  - Sample Duration: efficiency decreases with increase in sample duration, and,
  - Particle Size: efficiency increases with a decrease in particle size.

END OF
AIR SAMPLING

END OF CHAPTER 11