Designing and Implementing an External Dosimetry Program for Research and Medical Facilities

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HARVARD MEDICAL SCHOOL
TEACHING AFFILIATE

New RSO

- You're the new RSO of an Academic-Medical Institution

What do you mean a pay cut ?

Scope of Academic Program

- On the academic side you have an active:
  - Biomedical research program
  - Physics research program
    - A 5 MV Linear Accelerator
    - X-Ray diffraction
    - Variety of sealed sources

Scope of Medical Program

- On the medical side you have:
  - Nuclear medicine
    - PET/CT
    - SPECT
  - Radiation Oncology
    - 18 MV Linear Accelerators
    - Brachytherapy
  - CT Scanners, fluoroscopy, radiographic machines, DEXA units

Why Review the Dosimetry Program?

- Are we monitoring all the people that need to be monitored?
- Are we monitoring too many people?
- Are we paying too much for the dosimetry service?
- Are we managing the program appropriately?

Answering these questions

Outline

- Purpose of dosimetry
- Regulatory requirements for external dosimetry
- Specifics about dosimetry
- Characterizing radiation hazards
- Practical elements of a dosimetry program
- Common pitfalls and mistakes

From the beginning

- What are some of the features and characteristics of external dosimetry?
  - Passive versus Active (real time)
  - Interactions result in stored energy or damage to the medium.
  - Require processing to obtain response
  - Requires correlating response to radiation types and intensities
  - Provides information on radiation intensities for the environment in which it was exposed.

Purpose

- What is the purpose of dosimetry?
  - To demonstrate that you are in compliance with applicable external requirements.
- Significant limitations?
  - Results are after-the-fact
  - May not be representative of exposure
    - Highest exposed body region
    - Type of radiation

Regulations

- 15A NCAC 11 .0101 SCOPE
  - these Rules apply to all persons who receive, possess, use, transfer, own or acquire any *source of radiation* within the State of North Carolina
- 15A NCAC 11 .0104 DEFINITIONS
  - (13) "Annually" means either:
    - (a) at intervals not to exceed 12 consecutive months; or
    - (b) once per year at the same time each year (completed during the same month each year over a period of multiple years).

Monitoring

- DDE - Assigned deep dose equivalent to part of whole body receiving highest exposure
- LDE - Dose averaged over the contiguous 10 square centimeters of skin receiving the highest exposure
- Extremity – highest exposure to extremity
- Lead apron – on collar over apron, one under apron
- X-ray diffraction – wrist or whole body dosimeter if beam configuration is open

Definitions

- (33) "Deep-dose equivalent" (H_d), which applies to external whole-body exposure, is the dose equivalent at a tissue depth of one cm (1000 mg/cm^2) .
- (53) "Extremity" means hand, elbow, arm below the elbow, foot, knee, or leg below the knee.
- (71) "Lens dose equivalent" or "LDE" applies to the external exposure of the lens of the eye and is taken as the dose equivalent at a tissue depth of 0.3 cm (300 mg/cm^2).
- (133) "Shallow-dose equivalent" (H_s), which applies to the external exposure of the skin of the whole body or the skin of an extremity, is taken as the dose equivalent at a tissue depth of 0.007 centimeter (7 mg/cm^2).
- (163) "Whole body" means, for purposes of external exposure, head, trunk (including male gonads), arms above the elbow, or legs above the knee.

Applicability

- **15A NCAC 11 .0603 GENERAL REQUIREMENTS**
  - (J) All persons who are associated with the operation of an x-ray system are subject to the occupational exposure limits as defined in Rules .1604 and .1638 of this Chapter, and personnel monitoring procedures in Rule .1614 of this Chapter.
  - when protective clothing or equipment is worn on portions of the body and a monitoring device(s) is required at least one such monitoring device shall be utilized as follows:
    - (i) When an apron is worn the monitoring device shall be worn at the collar outside the apron.
    - (ii) The dose to the whole body shall be recorded in the reports required in Rule .1640 of this Chapter. If more than one device is used, each dose shall be identified with the area where the device was worn on the body.

Specific to X-Ray Diffraction

- **15A NCAC 11 .0806 PERSONNEL REQUIREMENTS**
  - (b) Personnel monitoring or wrist dosimetric devices shall be provided to, and shall be used by:
    - (1) analytical x-ray equipment workers using systems having an open beam configuration and not equipped with a safety device; and
    - (2) personnel maintaining analytical x-ray equipment if the maintenance procedures require the presence of a primary x-ray beam when any local component in the analytical x-ray system is disassembled or removed.

Dose Limits

- 15A NCAC 11 .1604 OCCUPATIONAL DOSE LIMITS FOR ADULTS
  - (c) The assigned deep-dose equivalent shall be for the **part of the body receiving the highest exposure**
  - The assigned shallow dose equivalent shall be the dose averaged over the **contiguous 10 square centimeters of skin receiving the highest exposure**
  - The deep-dose equivalent, eye dose equivalent and shallow-dose equivalent **may be assessed from surveys or other radiation measurements for the purpose of demonstrating compliance** with the occupational dose limits, if the individual monitoring device was not in the region of highest potential exposure, or the results of individual monitoring are unavailable

Monitoring requirements

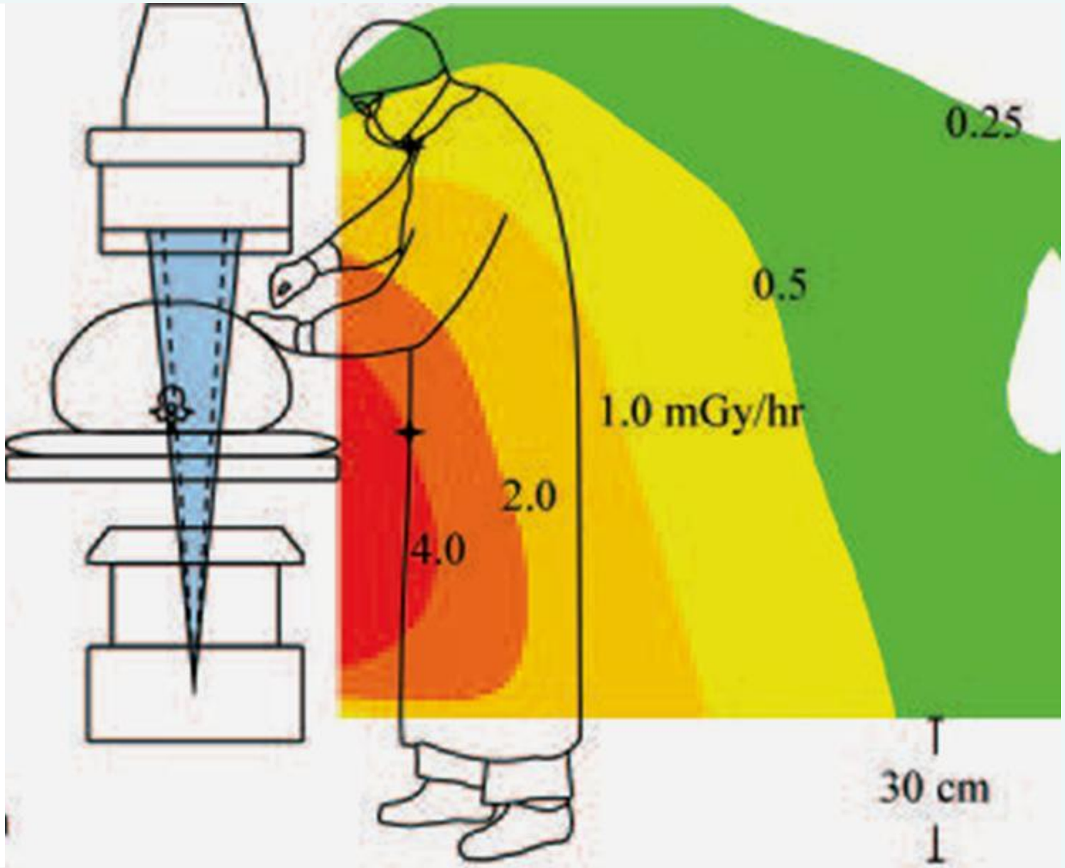
- 15A NCAC 11 .1614 MONITORING OF EXTERNAL AND INTERNAL OCCUPATIONAL DOSE
  - Each licensee or registrant **shall monitor exposures** to radiation and radioactive material at levels sufficient to demonstrate compliance with the occupational dose limits of this Section
  - (1) Each licensee or registrant shall monitor occupational exposure to radiation and shall supply and require the use of individual monitoring devices by
    - (a) adults **likely** to receive, in one year from sources external to the body, a dose **in excess of 10 percent of the limits**
    - (d) **individuals entering a high or very high radiation area**

Some of the finer details about dosimetry

- What does the dosimeter measure?
- Under what conditions is it an accurate representation of dose?
- What dose are we most interested in?
- How does what the dosimeter measure compare to the dose we are most interested in?

Absorbed doses

- External Radiation – tissues and organs receive different absorbed doses
- Want to determine detriment to person exposed



DDE

The U.S. Nuclear Regulatory Commission has stated, “the DDE is a surrogate operational quantity intended to be used, in monitoring situations, as an approximation to the effective dose equivalent, which cannot be measured directly. . . ” (U.S. NRC 2004).

Low LET Radiation

DDE

Deep dose equivalent

Dose equivalent at a depth of 1 cm (1,000 mg/cm^2)

H_E

Effective dose equivalent

$$\sum (w_t \times H_T) \ (ICRP, 1977)$$

E

Effective dose

$$\sum (w_t \times H_T) \ (ICRP, 1991)$$

ICRP Weighting factors changed

- ICRP, 1977
  - Average cancer mortality risk coefficients for males and females ranging in age from 20 to 60 y.
- NCRP Report 122 (on w_t in ICRP, 1977)
  - "Takes into account only the mortality risks from cancer and risk of severe hereditary effects."
  - "A limited measure of radiation detriment."
- ICRP, 1977 radiation detriment = 1.65×10^{-2} Sv^{-1}

Effective Dose

- ICRP, 1991
  - w_t is the tissue weighting factor for the relative radiosensitivity of the tissue
  - Takes into account 1991 risk estimates of mortality from cancer, risk of severe hereditary effects, AND risk of nonfatal cancer and length of life lost if cancer occurs.
  - Includes equal number of females and males having a wide range of ages.

Effective Dose

- NCRP Report 122
  - Effective dose is "a more inclusive measure of radiation detriment."

Same Tissue Dose - Different H_E and E

Tissue	Dose (mSv)	ICRP, 1977		ICRP, 1991	
		w_t	$D \times w_t$	w_t	$D \times w_t$
Breast	2	0.15	0.30	0.05	0.10
Lungs	1	0.12	0.12	0.12	0.12
Bone Marrow	0.2	0.12	0.024	0.12	0.024
Skin	0.2	-	-	0.01	0.02
Remainder	Neg.	Neg.	Neg.	Neg.	Neg.
TOTAL			0.44 mSv		0.26 mSv

(What would dosimeter worn on chest read?)

Tissue/Organ	Tissue Weighting Factor		
	ICRP 26, 1977	ICRP 60, 1991	ICRP 103, 2007
Gonads	0.25	0.20	0.08
Red Bone Marrow	0.12	0.12	0.12
Lung	0.12	0.12	0.12
Colon		0.12	0.12
Stomach		0.12	0.12
Breast	0.15	0.05	0.12
Bladder		0.05	0.04
Liver		0.05	0.04
Esophagus		0.05	0.04
Thyroid	0.03	0.05	0.04
Skin		0.01	0.01
Bone Surface	0.03	0.01	0.01
Brain			0.01
Salivary glands			0.01
Remainder	0.30	0.05	0.12
TOTAL	1.00	1.00	1.00

Special case of worker wearing lead apron

- Protective Apron is worn during diagnostic and interventional medical procedures using fluoroscopy
  - Badge on neck,
    - H_E (estimate) = $H_N/5.6$
    - E (estimate) = $H_N/21$
  - Badge on waist, one on neck:
    - H_E (estimate) = $1.5\ H_W + 0.04\ H_N$
    - E (estimate) = $0.5\ H_W + 0.025\ H_N$

NRC Regulatory Issue Summary 2003-04

- When personal dosimetry is unavailable
  - NRC recognizes that DDE is a surrogate
  - NRC provided guidance on situations in which it is permissible to use effective dose equivalent in place of the deep dose equivalent in showing compliance with regulatory requirements.

Break

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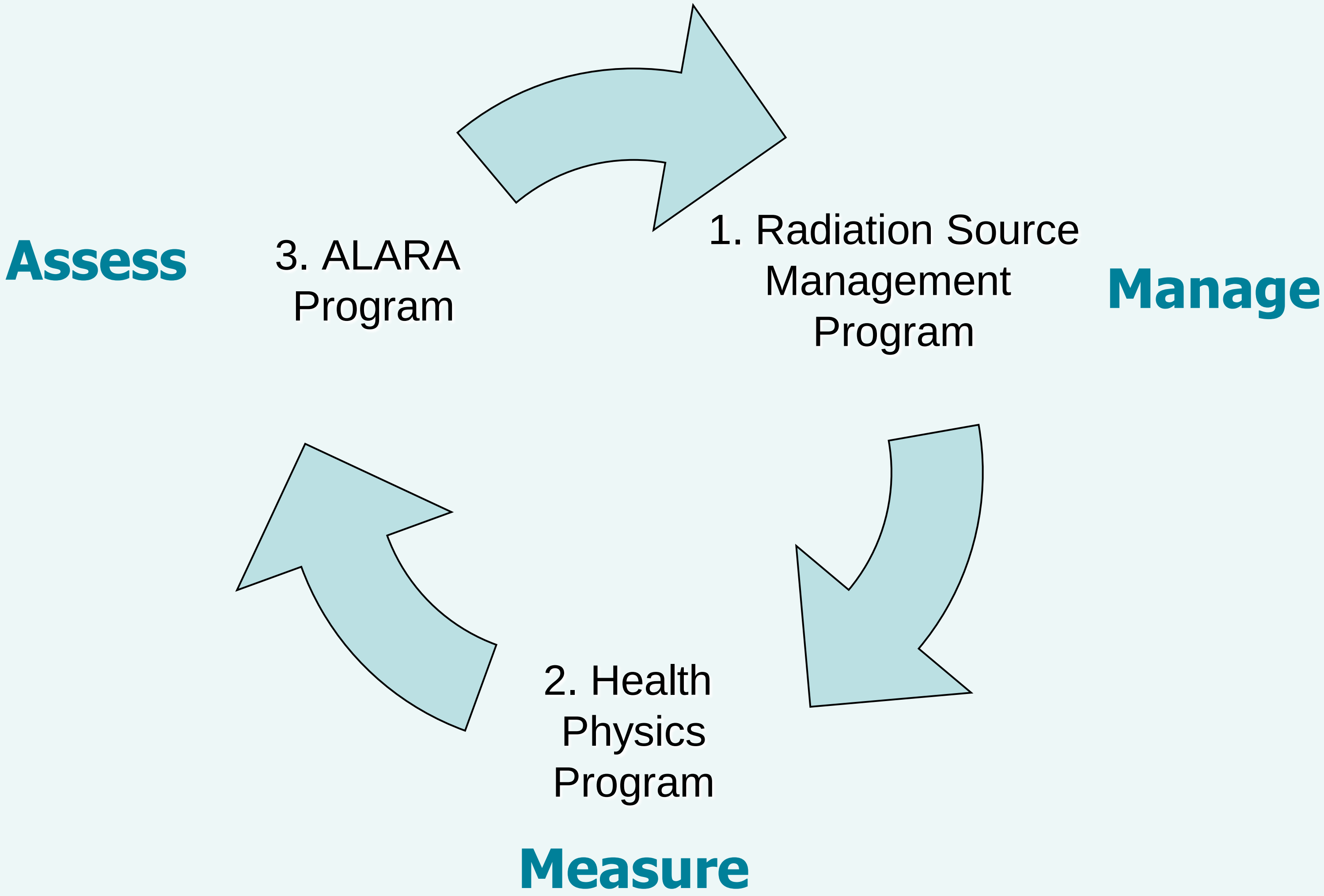
Radiation Safety Management



Logical Progression

- Step One: Understand the Sources
  - Characterize the radiation environment
    - Type(s) of radiation
    - Radiation Field Uniformity - Homogeneous versus non-homogeneous
- Step Two: Understand the Source/Human Interaction
  - Evaluate what people are doing in the radiation environment
- Step Three: Understand the Exposure
  - Identify highest exposed body region(s)

Logical Progression

- Step Four: Measure the Exposure
  - Place dosimeters in the body region(s) of highest exposure.
  - Measure the Exposure
  - Monitor for a period of time
- Step Five: Assess the Doses
  - Compare Expected to Observed doses
  - Refine Steps Two and Three
- Step Six:
  - Make adjustments to managing sources
- Step Seven:
  - Document the basis for the decisions made

Research Environment

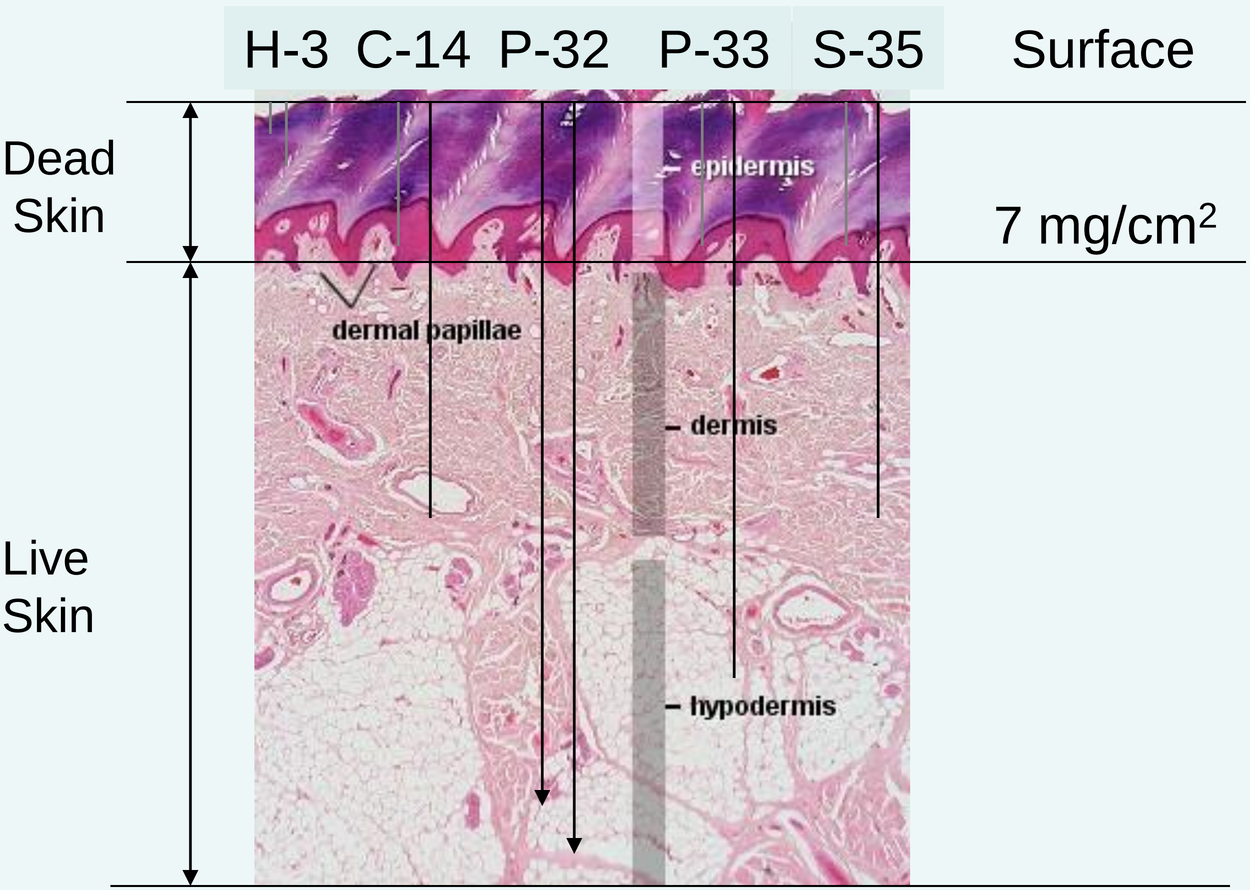
- Biomedical research
  - CHIPPS
  - (C-14, H-3, I-125, P-32, P-33, S-35)
- Agricultural studies
  - C-14, H-3
- Physics
  - Sealed sources

Characterize the Radiation Environment

- Hazard Analysis
  - Type of Radiation
  - Energy of Radiation
  - Homogeneity of radiation fields
  - Dosimeter location

Research Environment

- Will beta emitters really result in absorbed dose to tissues (other than skin)?



Regulatory Definition

Using a density for skin of 1 gm/cm^3, thickness to live layer of skin is 0.007 cm.

- In 2007, 210 Protocols at Boston University were reviewed in detail and included the isotope and quantity used in each protocol.

Isotope	Range (uCi)
H-3	10 -14,000
C-14	2 – 4,200
P-32	30 – 85,000
P-33	500 – 1,100
S-35	75 – 3,400

Sample from report

Catalogue #	Compound	Purchased	Used with Protocol	T(μCi)	%Disp
TRK921	Testosterone	1mCi ^3H	Label Tissue-testosterone assay	105	10.5
NET027A	Thymidine	^3H	Label Cells-DNA Synthesis	100	NA
TRK445	Glutamic Acid	1.250mCi ^3H	H3 Glutamate release from synaptosomes	165	13.2
TRK636	Leucine	5.0mCi ^3H	Cell culture - labeling protein	756	15.12
D4539	Deoxy Glucose	250μCi ^3H	Label Cells-Glucose uptake	84	33.6
TRK582	Dopamine	250μCi ^3H	Dopamine Release	80	32
NET027A	Thymidine	2.0mCi ^3H	Label T Cells DNA for proliferation	1000	50
ART 0131	UDP Galactose	250μCi ^3H	Label Cells-Nucleotide-Sugar Transport	100	40
ART 0128	UDP Glucosamine	250μCi ^3H	Label Cells-Nucleotide-Sugar Transport	100	40
ART 0127	UDP Glucose	500μCi ^3H	Label Cells-Nucleotide-Sugar Transport	300	60
NET027	Thymidine	1.0mCi ^3H	Label Cells-3H Incorporation	1000	100
NET027Z	Thymidine	3.0mCi ^3H	Label Cells-3H Incorporation	2000	66.7

Beta emitters

Isotope	mrad/hr at 1 foot per mCi (unshielded)
C-14	0
S-35	0
P-32	740
Sr-90/Y-90	821

BWH Isotopes Ordered vs. Dose 2010

Permit Number	Isotope	Activity (mCi)	Collective Dose in 2010 (mrem)			
			Deep	Lens	Shallow	Extremity
27 (n=14)	I125	4.9	M	M	6	M
38 (n=13)	P32	4.5	3	3	3	
54 (n=6)	I125	3.6	M	1	1	
97 (n=11)	I125	5.6	52	53	49	80
103 (n=13)	CR51	4	M	M	6	
153 (n=9)	P32	9.8	12	14	14	M
172 (n=6)	P32	2.8	3	3	3	M
186 (n=16)	P32	8	104	118	111	?
232 (n=10)	P33	52	1	1	1	M
240 (n=9)	P32	29.3	2	2	3	M

Research Dosimetry

- Individuals rarely receive enough dose to require dosimetry (i.e., <<10% Annual Dose Limits)
- For P-32 use, is it appropriate to assign a whole body dose based on the dosimeter results?
- NRC recommends that user of >1 mCi of P-32 be issued an extremity (ring) dosimeter.

Medical Environment

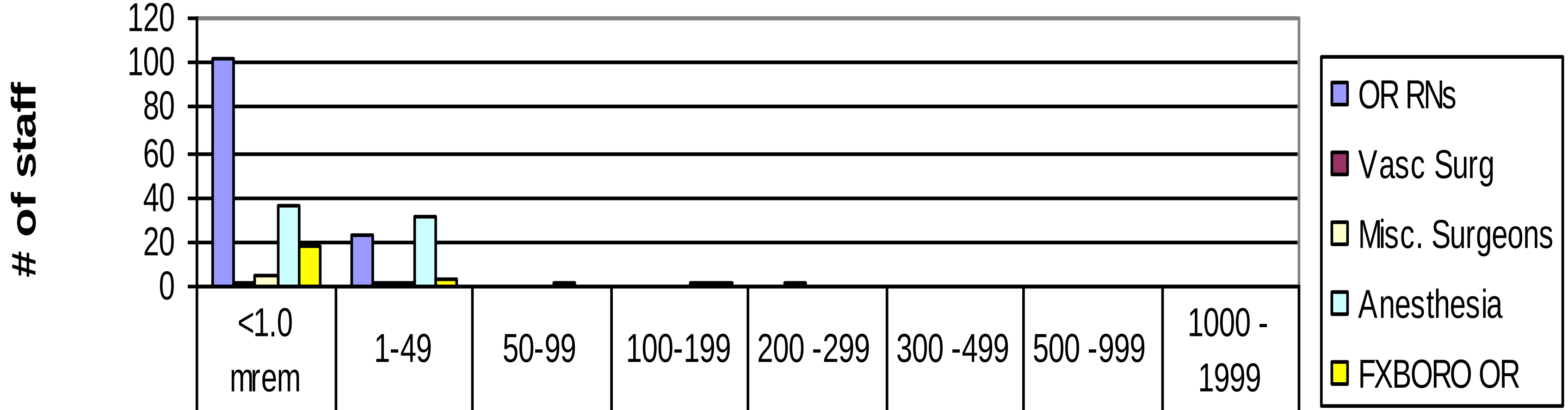
- Diagnostic studies
  - Unsealed isotopes
  - X-rays
- Therapy
  - Unsealed isotopes
  - Sealed Isotopes
  - Linear accelerators

Medical: Characterize Environment

Gamma emitting Isotope	mR/hr at 1 foot per mCi (unshielded)
F-18	6.1
Cr-51	0.19
Co-57	0.99
Co-60	14.0
Cu-64	1.1
Ga-67	0.69
Tc-99m	0.85
I-125	1.9
Cs-137	3.5

Operating Room Environment

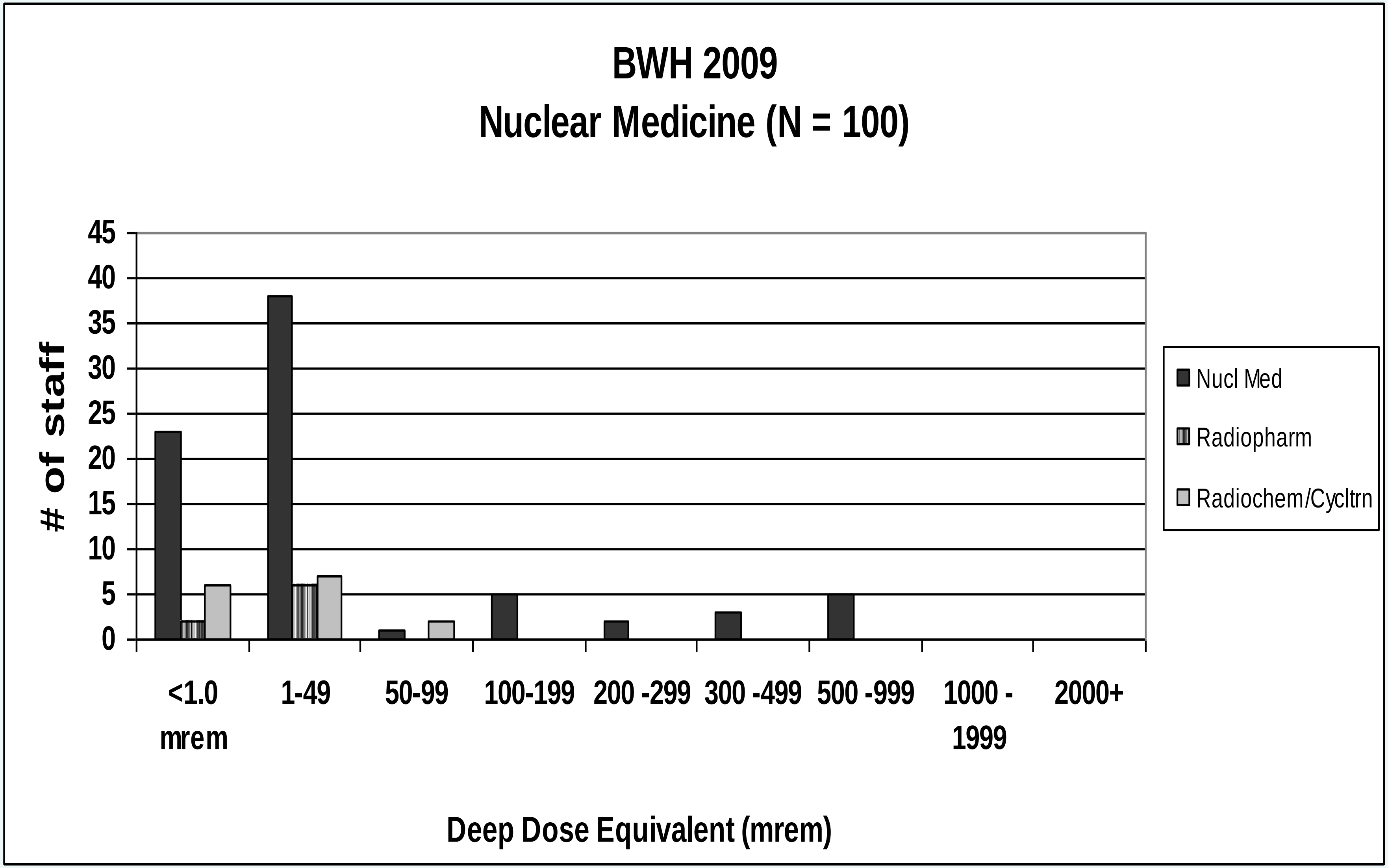
2009 OR (N = 227)



	<1.0 mrem	1-49	50-99	100-199	200 -299	300 -499	500 -999	1000 - 1999
OR RNs	102	23						
Vasc Surg	1	1			1			
Misc. Surgeons	5	1						
Anesthesia	36	31	1	2				

Deep Dose Equivalent (mrem)

Nuclear Medicine



PET Handling

NM Staff, effective dose/task from ^{18}F-FDG (10 mCi)

Task	Time (m)	Dose (μSv)
dosage prep	1-2	1.7
dosage admin	2-4	2.6-4.3
syringe disposal	<2	<1.7
pt to toilet	2-4	0.9-1.7
position pt	2-5	1.7
reposition pt for PET	1	<0.9
remove pt from scanner	1-2	0.9

$\Sigma = 11.5\ \mu$Sv/patient

Zeff & Yester, *Medical Physics*, 2005

Reported values

Effective dose from ^{18}F-FDG ($\mu Sv/MBq$)

0.01-0.023	Chiesa, *et al.* 1997
0.01	Roberts, *et al.* 2005
0.025	Robinson, *et al.* 2005
0.009	Guillet, *et al*. 2005
0.024-0.038	Biran, *et al*. 2004
0.007	Orio, *et al*. 2006

PET Data

- 75 patients undergoing PET study with 350 MBq 18F-FDG
- Dose rate at 2 hrs. post injection ($\mu Sv\ h^{-1}\ MBq^{-1}$):

....

0.1m = 0.31 $\mu Sv\ h^{-1}\ MBq^{-1}$

0.5 m = 0.11 $\mu Sv\ h^{-1}\ MBq^{-1}$

1.0 m= 0.04 $\mu Sv\ h^{-1}\ MBq^{-1}$

Cronin, *et al. Eur J Nucl Med* 1999

Common Mistakes and Corrective Actions

- Forgetting to assign doses to people with lost badges
  - Landauer can determine an average dose per month or quarter which can be used.
  - Correct way is to ask person if their activities during month that badge was lost were normal or not.
- Do not end fetal dosimeter once the pregnancy status changes
  - Conduct a monthly review of all fetal badges
  - Issue them a monthly report (a really good practice to get into)

Common Mistakes and Corrective Actions

- Using dosimeters to track who is trained
  - An expensive and resource intense method when all you need to do is track the training.
- Establishing one-size-fits-all ALARA levels
  - ALARA levels are intended to identify when something is out of the norm.
  - Establish ALARA levels for different groups based on estimated exposures
  - Lower ALARA levels over time to encourage dose reduction

The End