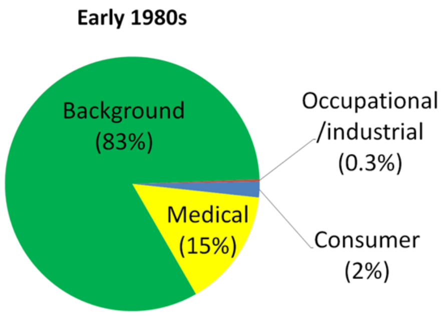
Cancer and non-cancer risks among medical workers

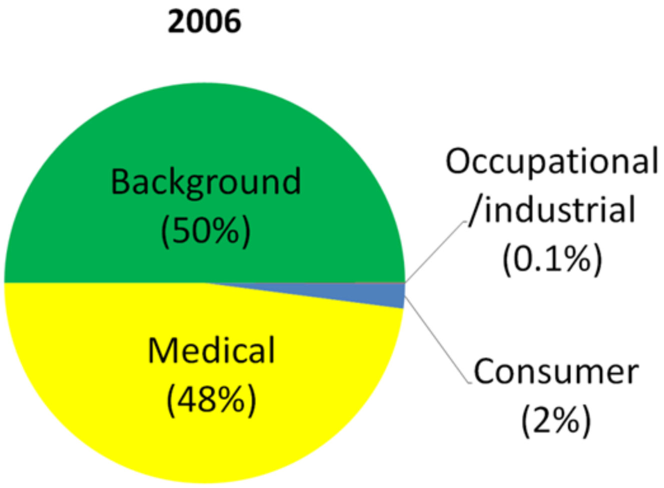
Cari M. Kitahara, PhD, MHS
Investigator
Radiation Epidemiology Branch

Radiation Epidemiology & Dosimetry Course 2019

Medical radiation: Growing source of exposure



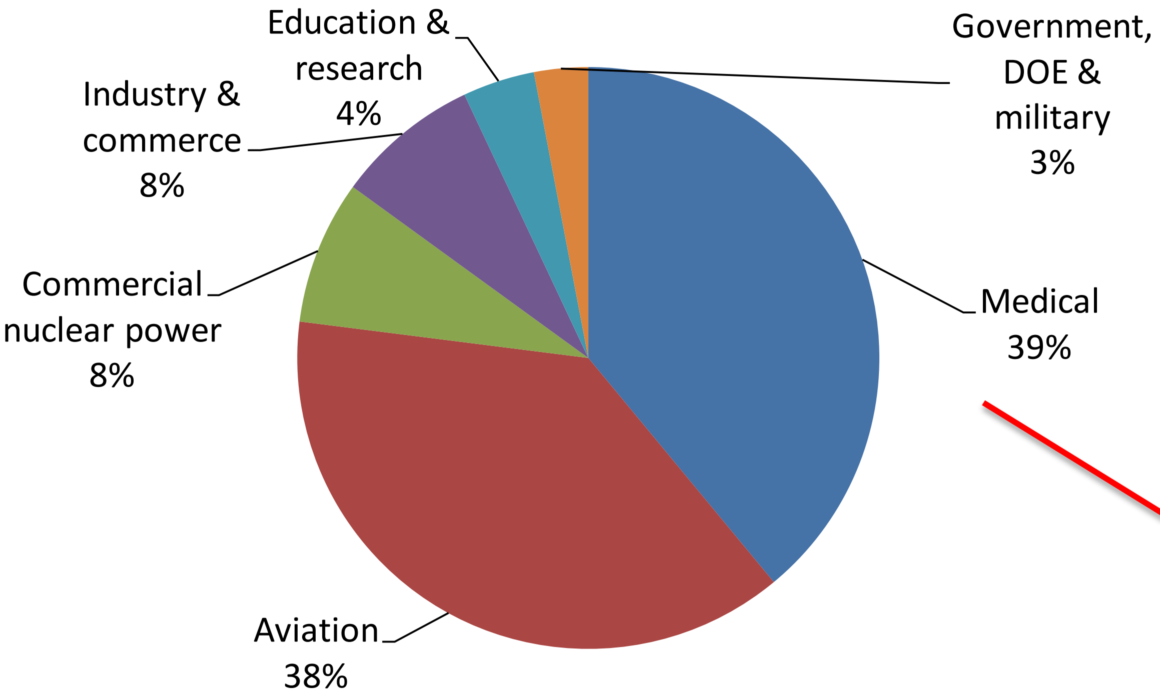
3.6 mSv/year
(per individual)



6.2 mSv/year
(per individual)

National Council on Radiation Protection and Measurements, Report 160 (2009)

Distribution of collective exposure (person-Sv) by occupationally-exposed groups (U.S., 2006)



Only group with potentially increasing exposure

National Council on Radiation Protection and Measurements, Report 160 (2009)

Why study medical workers? (1)

- One of the largest occupationally-exposed groups
  - 7 million medical workers worldwide (33% of all exposed workers)
  - 2.5 million in the United States
- To inform and improve occupational radiation protection standards and practices

NRC Occupational Dose Limits

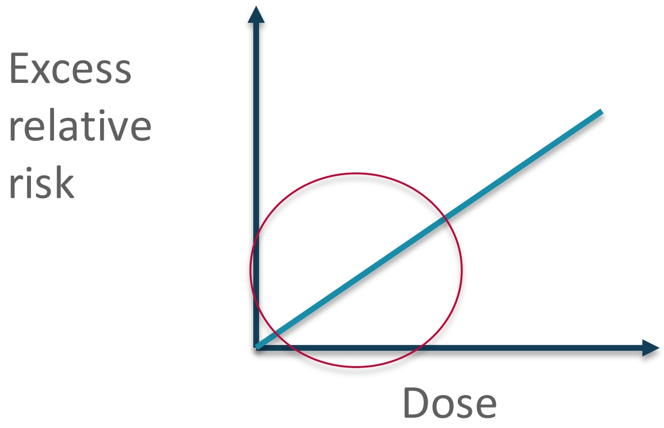
Whole Body (TEDE)	5,000 mrem/yr
Any Organ (TODE)	50,000 mrem/yr
Skin (SDE)	50,000 mrem/yr
Extremity (SDE)	50,000 mrem/yr
Lens of Eye (LDE)	15,000 mrem/yr
Embryo/Fetus of DPW	500 mrem/yr
Member of the Public	100 mrem/yr

Note: 1,000 mrem = 1 rem

UNSCEAR 2008 Report. Volume I: Sources and Effects of Ionizing Radiation 2010; NCRP Report 160 2009.

Why study medical workers? (2)

- To directly assess radiation risks associated with protracted, low-dose exposures (<100 mSv)
  - Difficult to study in general population (no routine monitoring)
  - Current knowledge based on studies of single acute exposures (A-bomb survivors)



Why study medical workers? (3)

- Occupational radiation exposure to medical workers can be quantified
  - Badge doses
  - Work history questionnaires
  - Simulations

Medical radiation workers – major research questions

Exposures

- What are the doses (badge dose, organ doses)? Have they changed over time? Which workers receive the highest exposures?

Outcomes

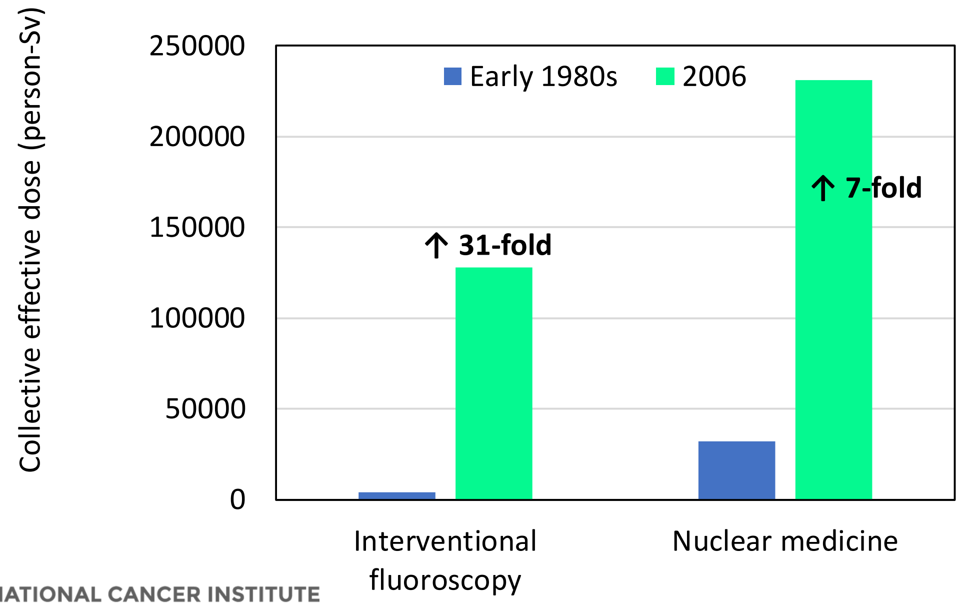
- Do medical workers exposed to radiation have increased risks of certain health outcomes? How do these risks vary by dose? Is it possible to reduce these risks? *How* and by *how much*?

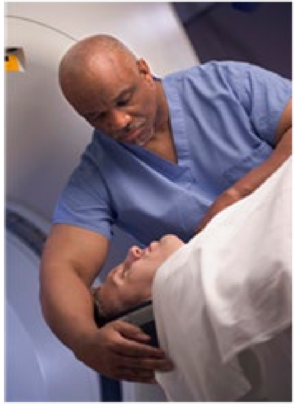
What are the doses to medical radiation workers?

- More widespread utilization of ionizing radiation in medicine
  - No longer limited to radiologists, radiation oncologists, and related staff
- Improvements in radiation protection standards have dramatically **reduced** doses for most medical workers
- *Continuous* and *accurate* dose monitoring is needed
  - For use in epidemiologic studies of radiation-related risks
  - To inform radiation protection guidelines and practices
  - To identify and monitor workers with potentially higher and increasing exposures

Highest occupational exposures in medicine?

- Nuclear medicine technologists
  - Particularly in U.S. (leading performer of NM procedures)
- Interventional cardiologists/radiologists



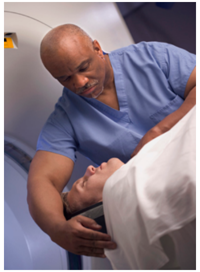


Tasks performed by nuclear medicine technologists

Prepare radiopharmaceuticals

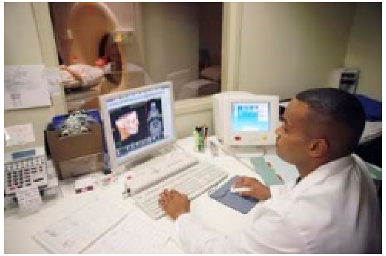
Administer radiopharmaceuticals

Scan and monitor patients



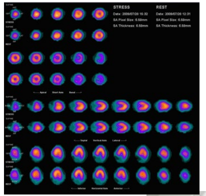
Transfer patients

Generate images



Nuclear medicine procedures

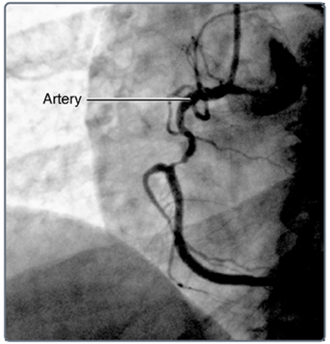
- Non-invasive
- Combine radiopharmaceuticals with imaging to diagnose and treat diseases
- 13 million procedures/year (U.S.)



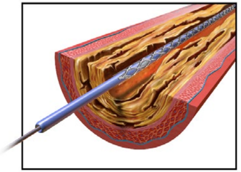
Fluoroscopically-guided interventional procedures

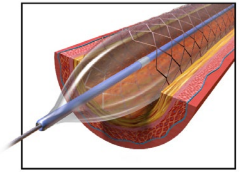
- Minimally-invasive
- Combine catheters and wires with imaging to diagnose and treat diseases
- >20 million procedures/year (U.S.)

Angiogram

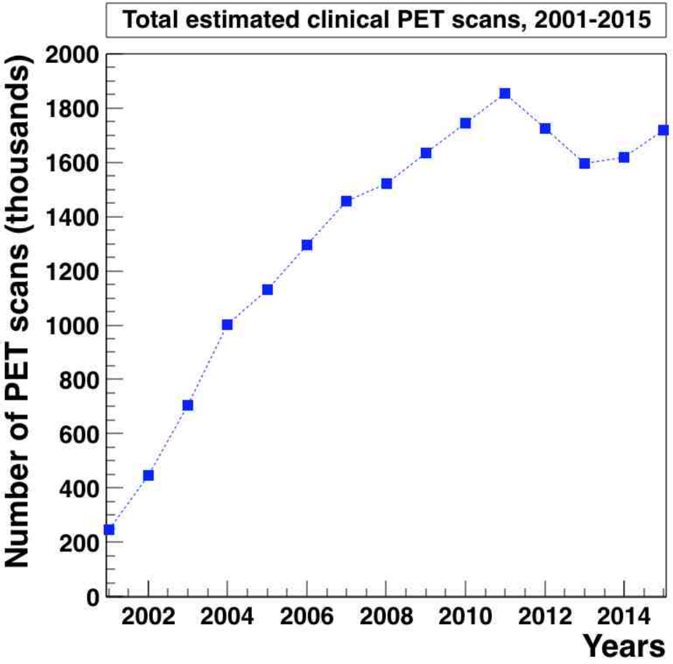


Balloon angioplasty

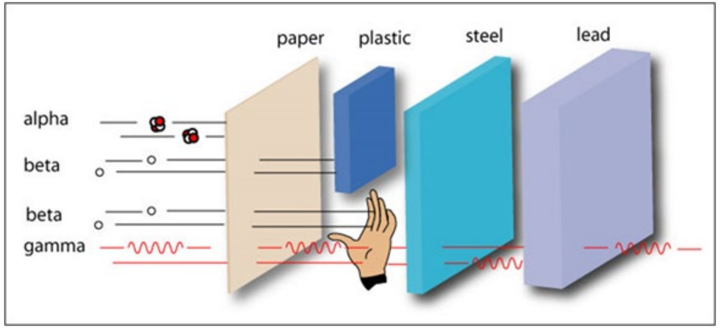




Increasing exposures to techs performing positron emission tomography (PET)?



- Lead shielding less effective for higher-energy gamma radiation

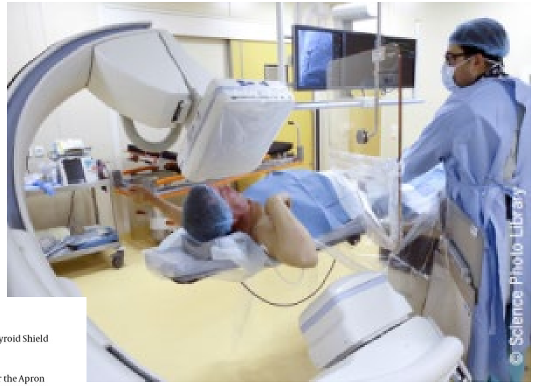


- PET technologists: 50% greater occupational doses than general NM technologists

Source: IMV Benchmark Reports 2011, 2015 (courtesy of Daphnée Villoing)

Medical staff performing fluoroscopically-guided interventional (FGI) procedures

- Physician operators closest to radiation source
  - Many other staff also exposed
- Increasing workloads and increased complexity
- Wide variability in operator technique
- Non-uniform exposures
  - Doses to hand > trunk > neck > eye
  - Higher left vs right-sided dose
- 2-badge monitoring protocols → greater chance for inaccurate readings



Reported adverse effects in medical radiation workers

- Early 1900s: reports of skin ulcers, dermatitis, cataracts, skin carcinomas, leukemia, aplastic anemia
- 1st cohort studies: increased risks of **leukemia** and certain **solid cancers** in radiologists and radiologic technologists who began working <1950s
- Late 1990s-2000s: **Cataracts** in interventional radiologists
- Case reports of **brain tumors** in cardiologists and interventional radiologists

Berrington A, et al. Br J Radiol 2001; Matanoski GM, et al. Am J Epidemiol 1975; Yoshinaga S, et al. Radiology 2004; Linet MS, et al. Radiat Res 2010

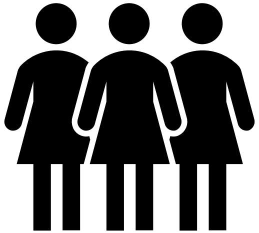
Cohort studies of medical radiation workers

Study	Subjects	% male	Dosimetry	Follow-up
U.S. radiologic technologists	146,000	30%	Badges, work hx	1983-2015
U.S. interventional radiologists/cardiologists	46,000	85%	None	1979-2008
U.S. radiologists	44,000	80%	None	1979-2008
Korean medical workers	81,000	60%	Badges, work hx	1996-2015
Million Worker Cohort	250,000	?	Badges	?
Canadian medical workers	67,000	34%	Badges	1951-1987
Chinese diagnostic x-ray workers	27,000	74%	Simulated measurements	1950-1995
Japanese radiologic technologists	12,000	100%	Badge readings	1969-1993
U.S. radiologists	6,500	100%	None	1920-1969
Danish radiation therapy workers	4,200	19%	Badges	1968-1985
UK radiologists	2,700	100%	None	1897-1997

Yoshinaga, et al., Radiology 2004; Linet MS, et al. Radiat Res 2010

Epidemiologic studies of medical radiation workers

Common limitations



- Small study populations (especially women)
- Inactive or short period of follow-up
- Poor quality (or no) badge monitoring data
- Limited (or no) work history
    - Job title, apron use, years worked, badge placement, etc.
- Limited power to study rare health outcomes (e.g. cancer)
- High potential for bias
    - Lack of information on confounding factors
    - Non-ideal comparison groups (e.g. general population)
    - **Few studies capable of assessing radiation dose-response**

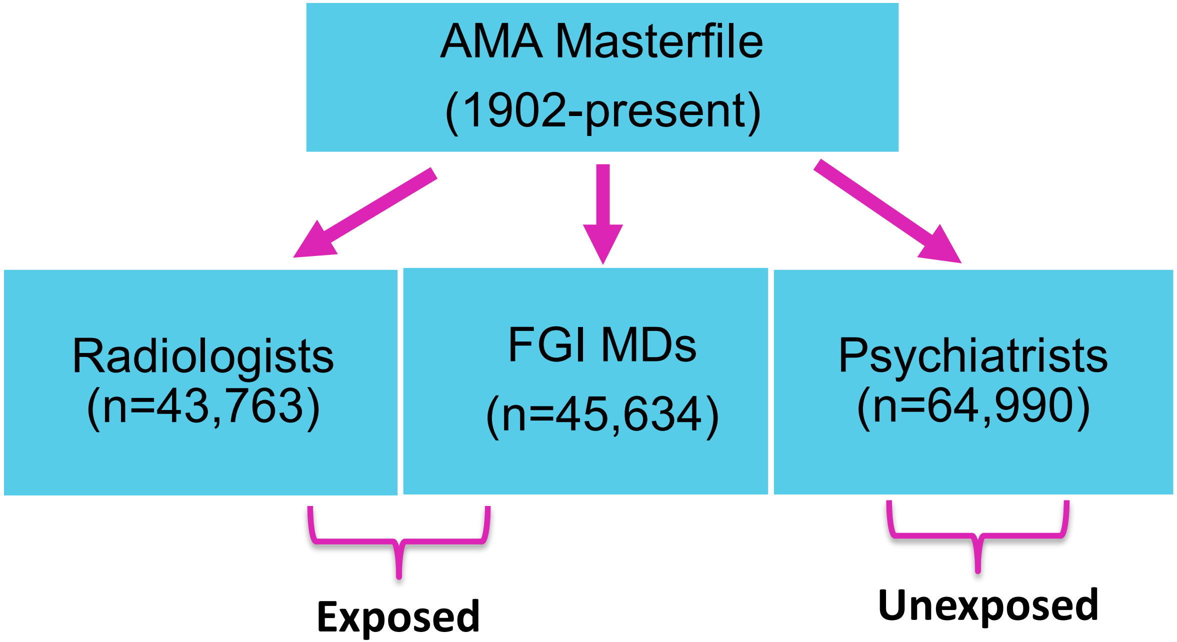
Linet MS, et al. Radiat Res 2010;174:793-808. Ko S, et al. J Vasc Interv Radiol 2018;29:353-66.

Cohort studies of medical radiation workers (2)

Study	Subjects	% male	Dosimetry	Follow-up
U.S. radiologic technologists	146,000	30%	Badges, work hx	1983-2015
U.S. interventional radiologists/cardiologists	46,000	85%	None	1979-2008
U.S. radiologists	44,000	80%	None	1979-2008
Korean medical workers	81,000	60%	Badges, work hx	1996-2015
Million Worker Cohort	250,000	?	Badges	?
Canadian medical workers	67,000	34%	Badges	1951-1987
Chinese diagnostic x-ray workers	27,000	74%	Simulated measurements	1950-1995
Japanese radiologic technologists	12,000	100%	Badge readings	1969-1993
U.S. radiologists	6,500	100%	None	1920-1969
Danish radiation therapy workers	4,200	19%	Badges	1968-1985
UK radiologists	2,700	100%	None	1897-1997

Yoshinaga, et al., Radiology 2004; Linet MS, et al. Radiat Res 2010

Mortality among U.S. radiologists and physicians conducting FGI procedures: 1979-2008



Berrington de Gonzalez Radiology 2016. Linet MS Radiology 2017

Mortality risks in radiologists (1979-2008)

- 4,260 deaths (10%)
- Overall, no increased mortality risks, except for acute myeloid leukemia and/or myelodysplastic syndrome (RR=1.62)
- Among older physicians (graduated before 1940):
  - Acute myeloid leukemia and/or myelodysplastic syndrome (RR=4.7)
  - Melanoma (RR=8.8)
  - Non-Hodgkin lymphoma (RR=2.7)
  - Stroke (RR=1.49)

Berrington de Gonzalez A, et al. Radiology 2016.

Mortality risks in interventional radiologists/cardiologists (1979-2008)

- 3,506 deaths (8%) overall

	Men	
	Deaths	RR (95% CI)*
All causes	3,420/7,307	0.80 (0.77-0.83)
All cancers	1,140/2,154	0.92 (0.85-0.99)
Brain and CNS cancers	54/112	0.74 (0.53-1.03)
Leukemia	74/99	1.30 (0.96-1.76)
Circulatory disease	1,299/2,642	0.87 (0.82-0.93)

*Adjusted for attained age, year of birth, and year of medical school graduation

Linet MS, et al. Radiology 2017.

Mortality risks in interventional radiologists/cardiologists (1979-2008)(2)

- 3,506 deaths (8%) overall

	Men		Men who graduated <1940	
	Deaths	RR (95% CI)*	Deaths	RR (95% CI)*
All causes	3,420/7,307	0.80 (0.77-0.83)	376/624	0.93 (0.82-1.06)
All cancers	1,140/2,154	0.92 (0.85-0.99)	98/153	1.00 (0.77-1.28)
Brain and CNS cancers	54/112	0.74 (0.53-1.03)	1/8	0.19 (0.02-1.55)
Leukemia	74/99	1.30 (0.96-1.76)	10/4	3.86 (1.21-12.3)
Circulatory disease	1,299/2,642	0.87 (0.82-0.93)	197/312	0.98 (0.82-1.17)

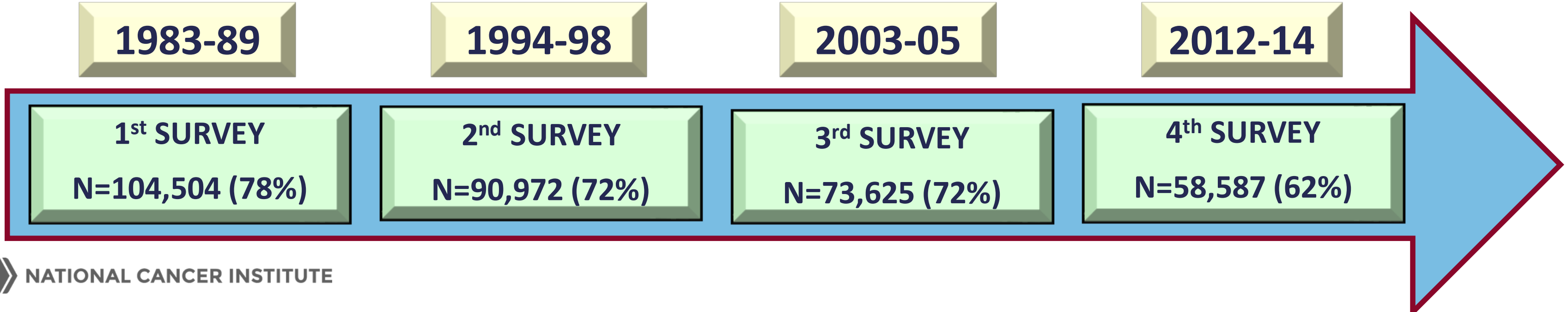
*Adjusted for attained age, year of birth, and year of medical school graduation

Major limitation: no dosimetry

Linet MS, et al. Radiology 2017.

U.S. Radiologic Technologists Study (USRT)

- Largest cohort study of medical workers
  - 146,000 radiologic technologists, 70% women
  - First certified in 1926-1980
- >30 years of incidence and mortality follow-up
- Individualized dosimetry
- Comprehensive information on work history and confounding factors
- Biological samples (blood, buccal cells)



USRT cohort dosimetry

Individualized organ/tissue doses (1916-1997)

- Based on 921,134 badge readings, limited work history, literature review
- 110,374 techs with (and 35,648 techs without) estimated annual doses
- Doses estimated for 12 organs: apron use, period-specific conversion coefficients
- Assumptions about early exposures (before badges), types of exposures

Badge Doses

Time span	Source/Numbers
Before 1960	Literature based only
1960 - 1966	3,228
1967 - 1976	12,444
1977 - 1984	324,039
1985 - 1997	581,423

Cumulative Doses (mGy)

Statistic	Badge	Breast	Bone Marrow
Mean	76	37	8.7
SD	120	88	15

Simon SL, et al. Radiat Res 2014

Substantial decline in estimated cumulative doses in USRT

	1910s	1920s	1930s	1940s	1950s	1960s	1970s	1980s	1990s
Mean badge dose (mSv)	1,700	1,500	710	270	110	69	36	15	5.5
Mean female breast dose (mGy)	1,200	1,200	560	180	54	27	14	6.2	2.8

Simon SL, et al. Radiat Res 2014;182:507-28

USRT: dose-response assessment in the full cohort

First author, year	Outcome	Main results
Lee T. Occup Environ Med 2015	Basal cell carcinoma incidence	ERR/Gy= -0.01 (not significant) **ERR/Gy before 1960 = 2.92 (95% CI 1.39-4.45)**
Preston DL. Br J Cancer 2016	Breast cancer incidence	ERR/100 mGy= 0.07 (not significant) **ERR/100 mGy for techs born before 1930= 0.16 (95% CI 0.03-0.39)**
Kitahara CM. Int J Cancer 2018	Thyroid cancer incidence	ERR/100 mGy= -0.05 (not significant)
Kitahara CM. AJR 2017	Brain cancer mortality	ERR/100 mGy= 0.1 (not significant)
Little MP. Eur J Epidemiol 2018	Cataract incidence	**EHR/Gy=0.69 (95% CI 0.27-1.16)** **Dose-response remained significant at <100 mGy**
Little MP. Sci Rep 2018	Glaucoma and macular degeneration	ERR/Gy = -0.57 and 0.32, respectively (not significant)

Cancer and other disease risks associated with nuclear medicine work history: USRT

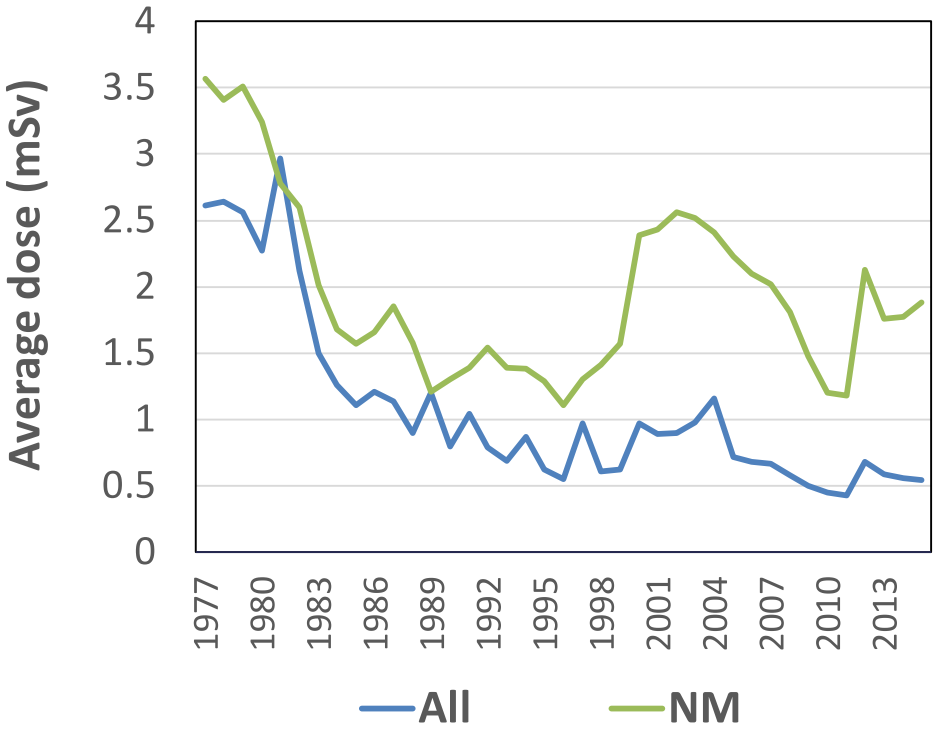
- Work history from 2^{nd} (1994-98) or 3^{rd} (2005-2008) mailed surveys
- Ever vs never working in nuclear medicine:
  - Breast cancer mortality (RR=2.7)
  - Lung cancer mortality (RR=1.4)
  - Squamous cell carcinoma incidence (RR= 1.3)
  - Myocardial infarction mortality (RR=1.8)
  - Cataract incidence (RR=1.1)

Risks ↑ with greater #s of procedures performed/week

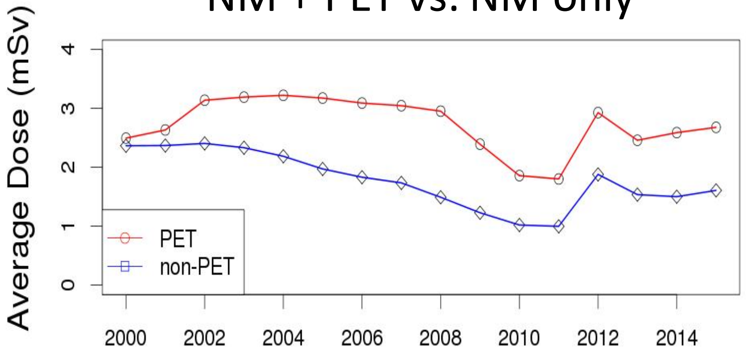
Is there a dose-response relationship?

Kitahara CM, et al., *Occup Environ Med* 2015
Bernier MO, et al. *Radiology* 2018

Trends in badge dose readings in USRT: by NM work history

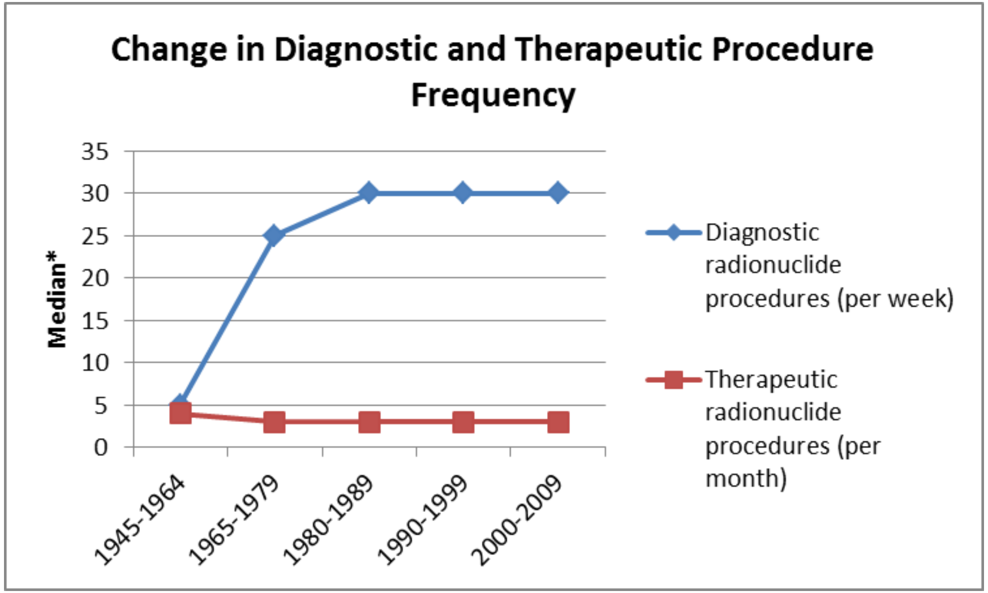


Doses to techs who performed NM + PET vs. NM only



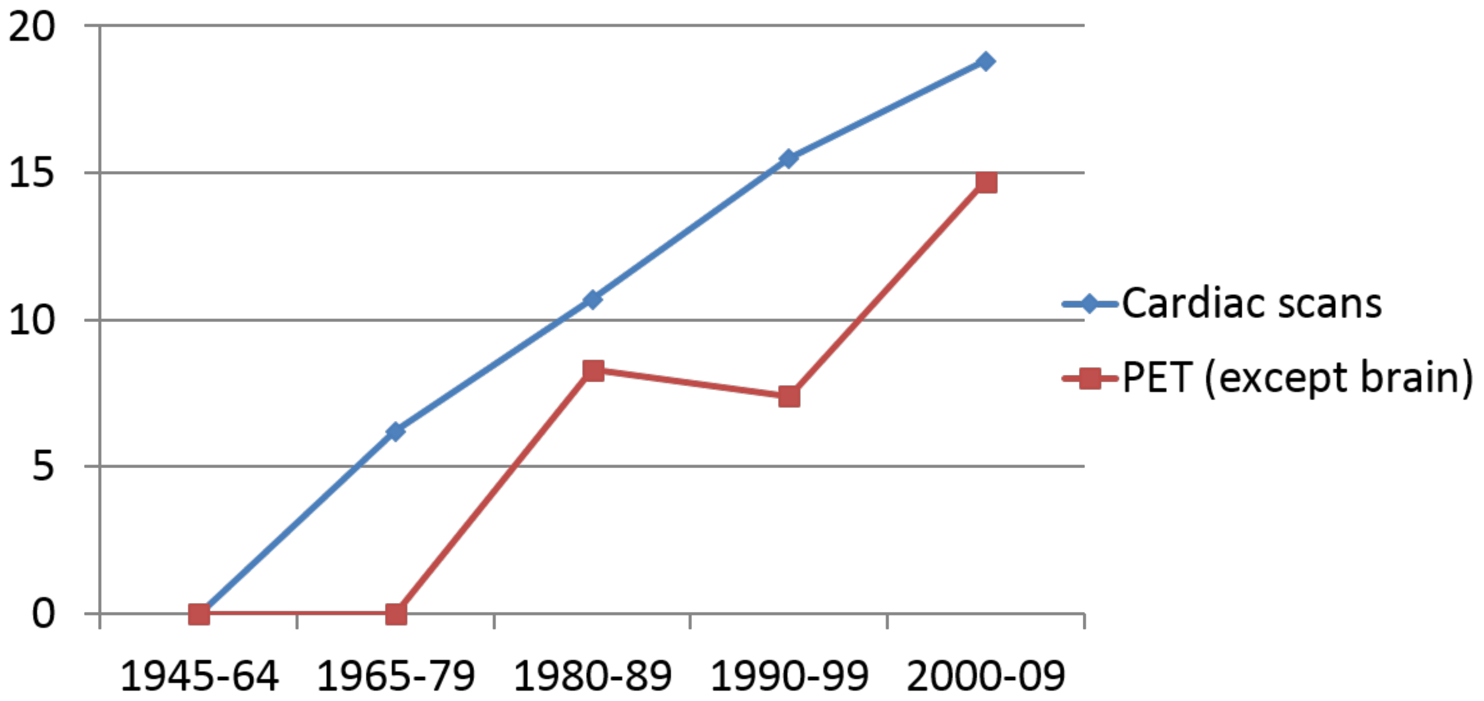
Villoing D, et al. *In progress*

Increasing performance of diagnostic nuclear medicine: USRT nuclear medicine survey (2013-14)



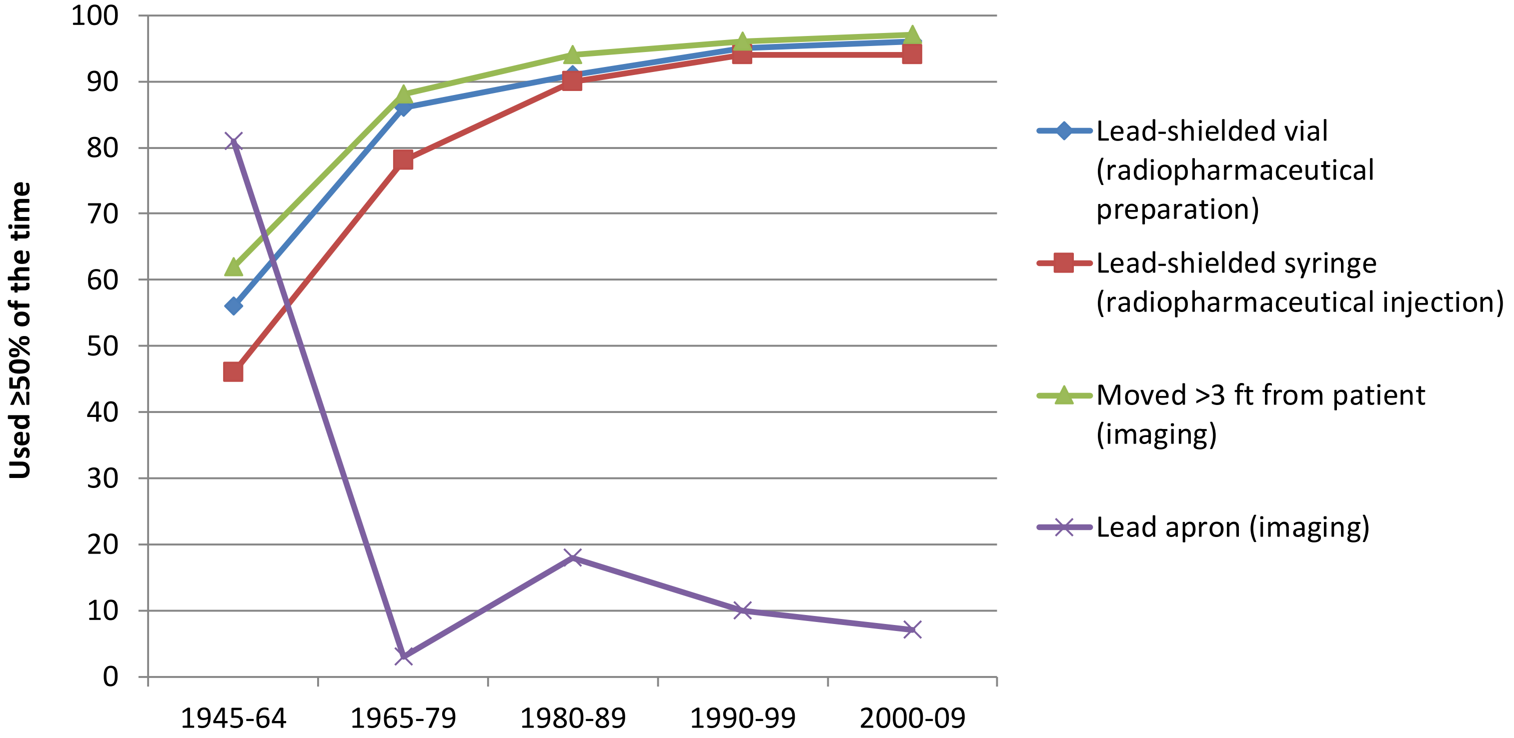
Van Dyke M, et al. Health Physics 2016

Increasing performance of diagnostic cardiac and PET scans: USRT nuclear medicine survey (2013-14)



Van Dyke M, et al. Health Physics 2016

Increasing use of (most) radiation safety practices: USRT nuclear medicine survey (2013-14)



Van Dyke M, et al. Health Physics 2016

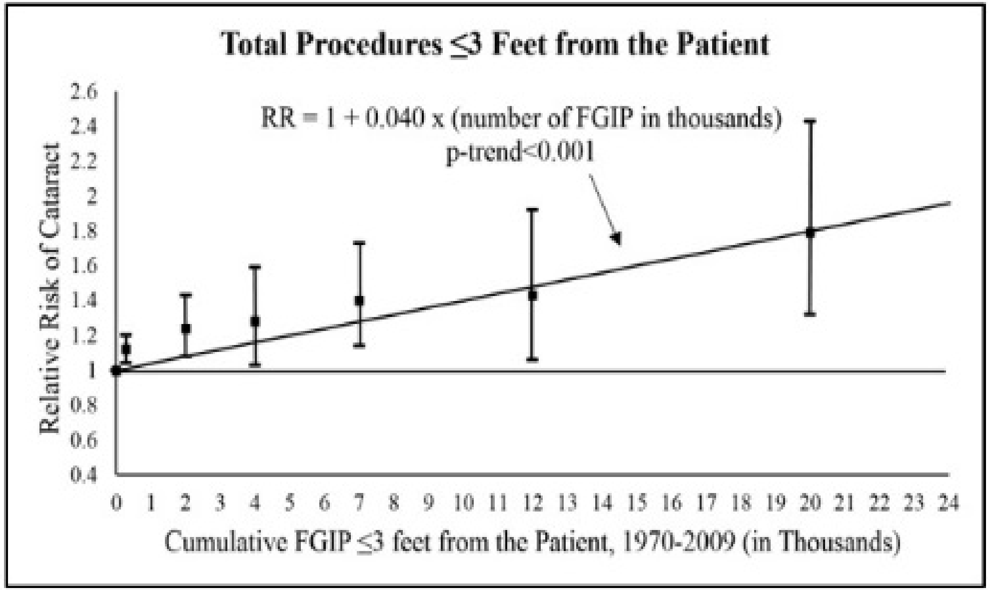
Cancer and other disease risks associated with FGI procedures: USRT

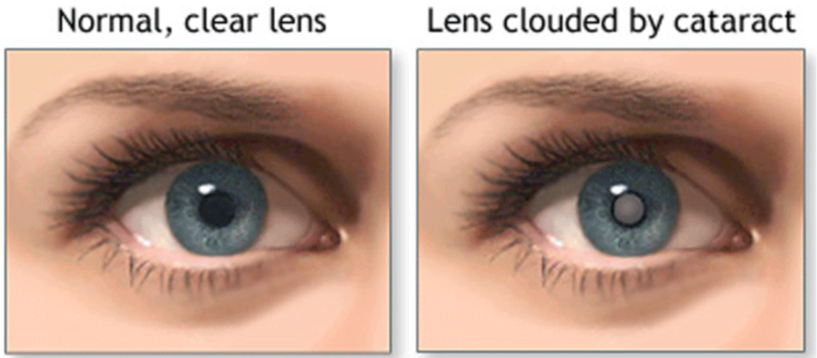
- Work history from 2nd (1994-98) mailed survey
- Ever vs never worked with fluoroscopically-guided interventional procedures
  - Brain cancer mortality (RR = 2.2)
  - Melanoma (RR = 1.3)
  - Stroke (RR= 1.4)
  - Cataracts (RR = 1.2)

Is there a dose-response relationship?

Rajaraman et al., Occup Environ Med 2016; Rajaraman et al., Am J Roetgenol 2016; Velazquez-Kronen R, et al. Occup Environ Med 2019

Cataract risk by FGI procedure work history: USRT

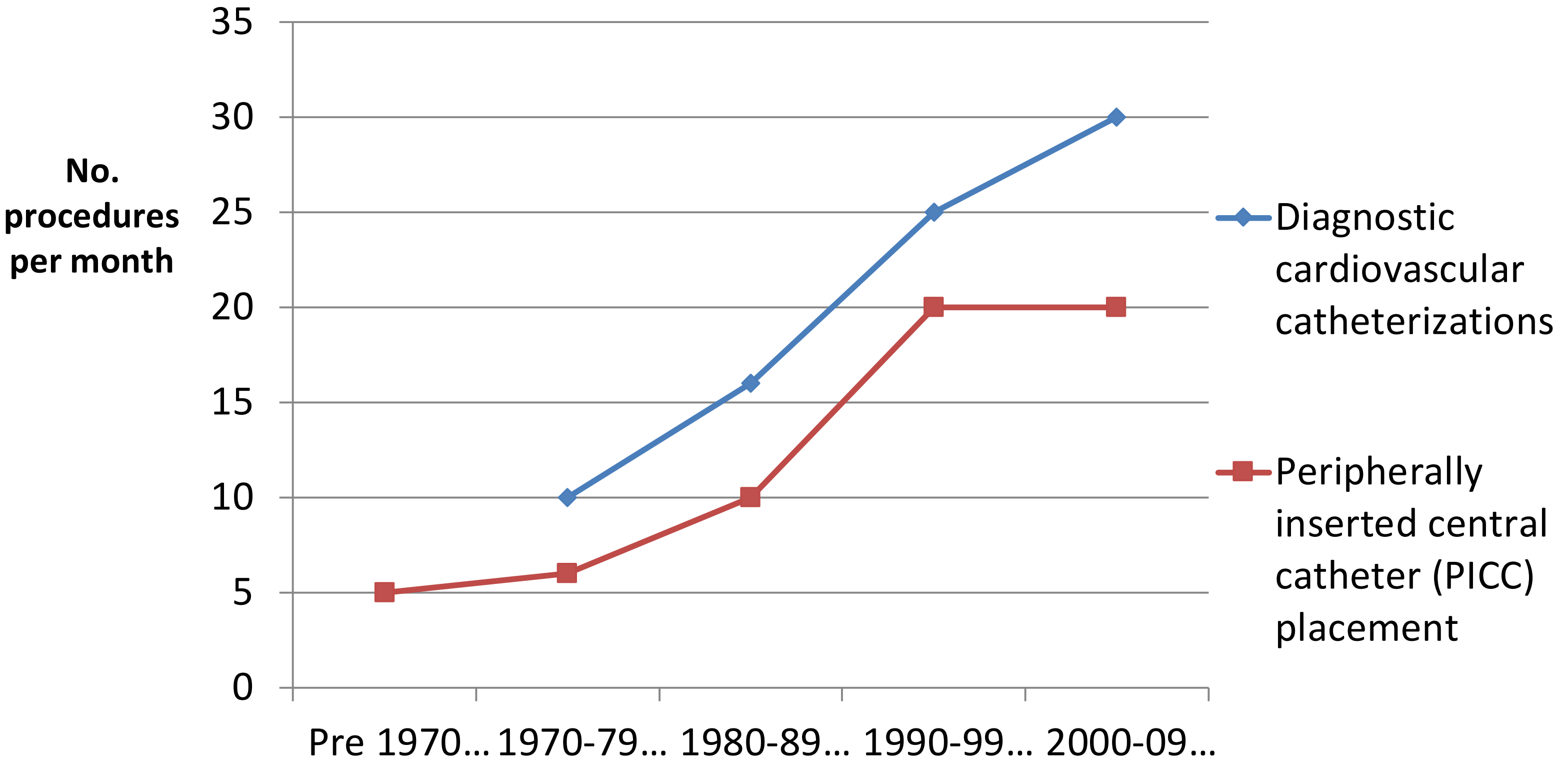




Does the risk of cataract increase with greater estimated lens dose?

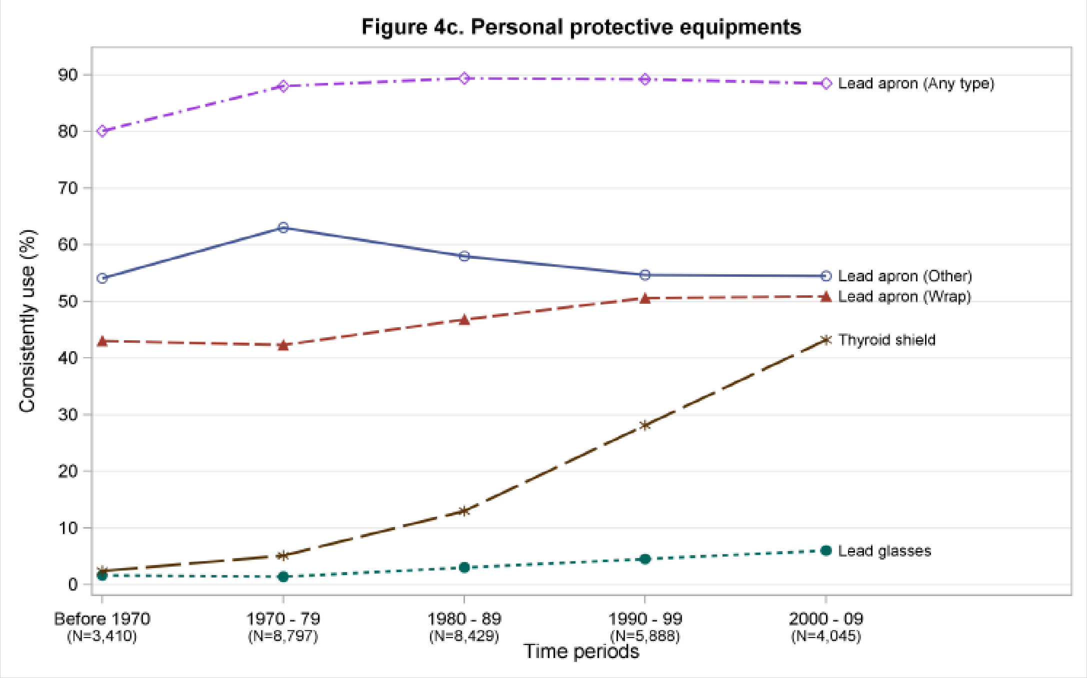
Velazquez-Kronen R, et al. Occup Environ Med 2019;76(5):317-325

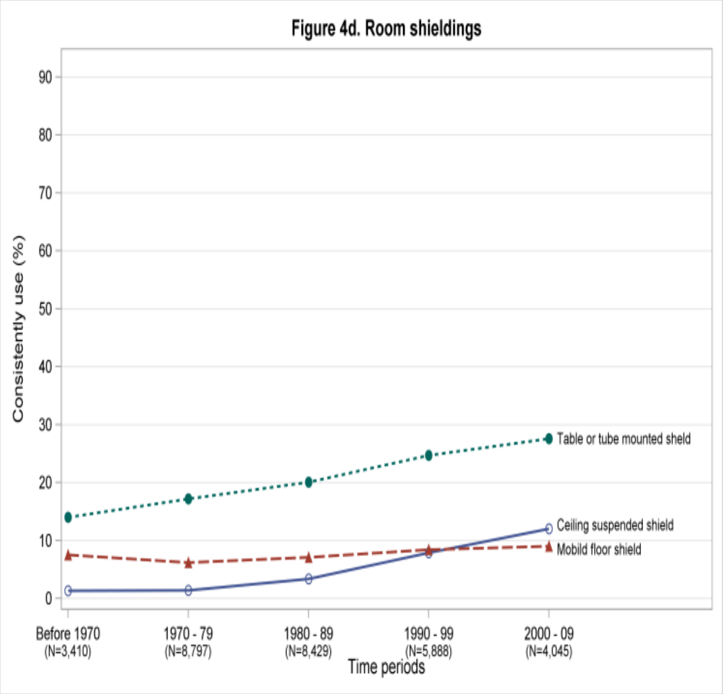
Increasing frequency of cardiac FGI procedures in USRT



Lim H, et al. Am J Roentgenol 2016

Increasing use of radiation safety during FGI procedures in USRT





Lim H, et al. Am J Roentgenol 2016

USRT dosimetry update (in progress)

- Goal: to update organ absorbed dose estimates for wide range of radiosensitive organs
  - >750,000 recently-collected annual badge readings for years 1998-2015
  - Recent lifetime work history survey data, including detailed info on nuclear medicine and FGI procedures
  - Period-specific and modality-specific conversion coefficients

South Korean medical radiation worker study (1996-2015)

- Includes 94,396 diagnostic medical radiation workers
  - Rad techs, radiologists and other physicians, dentists, dental hygienists, nurses, medical assistants
  - Does not include nuclear medicine or therapeutic departments
- Major strengths
  - Organ dosimetry derived from dosimeter readings maintained by National Dose Registry (1996+)
  - Cohort linked with nationwide cancer registry – complete cancer incidence follow-up
- Major limitations
  - Relatively short follow-up
  - Relatively low cumulative radiation exposures
  - Lack of information on potential confounders (BMI, smoking, etc)

Lee WJ, et al. Occup Environ Med 2018

South Korean medical radiation worker study (1996-2015)

- SMRs for all-cause mortality
  - 0.45 (95% CI 0.42-0.48) in men
  - 0.49 (95% CI 0.41-0.58) in women

Healthy worker effect?

- SMRs for cause-specific mortality all <1
  - SMR for cancer mortality was significantly higher *relative to* SMR for all-cause mortality
    - rSMR = 1.60 (95% CI 1.41-1.82) in men
    - rSMR = 1.70 (95% CI 1.17-2.46) in women

Lee WJ, et al. Occup Environ Med 2018

South Korean medical radiation worker study (1996-2015) (2)

Thyroid cancer incidence (827 cases)

- SIR for men = 1.72 (95% CI 1.53-1.91)
- SIR for women = 1.18 (95% CI 1.08-1.28)

Medical surveillance bias?
Legally mandated annual medical exams for med workers

- ERR/100 mGy (5-year lag) = 0.04 (95% CI -0.35, 0.43)

Lee WJ, et al. Environ Health 2019

NEW prospective cohort study of interventional medical workers in South Korea

Goal: to further understand work practices and association between protracted occupational radiation exposure and health risks among these workers

- ~4,000 to be identified from medical societies
  - Self-administered survey linked with radiation dosimetry data, National Health Insurance claims data, cancer registry, and mortality data
- ~100 workers for more focused study
  - Blood tests, clinical exams (e.g. thyroid and carotid artery scans, ophthalmological tests), validation of badge doses, and biodosimetry

Ko S, et al. Occup Environ Med 2017

Summary

- Medical workers are a large and growing occupationally-exposed population
- Exposures have declined dramatically due to improvements in radiation protection
- Epidemiologic studies of medical workers needed to:
  - Continue to inform/improve radiation safety guidelines for workers
  - Contribute to understanding of health effects of protracted, low-dose radiation exposures
- Challenges: heterogeneous exposures, changing technologies and practices
- Continuous follow-up of ongoing studies are needed to evaluate lifetime health risks
- New studies are urgently needed to study exposures and health risks from emerging, higher-dose procedures

Occupational doses to medical workers are much higher today than in the past.

- True
- False

Occupational doses to medical workers are much higher today than in the past.

- True
- False

What can medical workers do to minimize their radiation exposure?

- Maximize time near the radiation source
- Minimize distance from the radiation source
- Use personal protective equipment (e.g. lead aprons, glasses, shields)
- All of the above

What can medical workers do to minimize their radiation exposure?

- Maximize time near the radiation source
- Minimize distance from the radiation source
- Use personal protective equipment (e.g. lead aprons, glasses, shields)
- All of the above

U.S. Department of Health & Human Services

National Institutes of Health | National Cancer Institute

dceg.cancer.gov/

1-800-4-CANCER

Produced September 2019