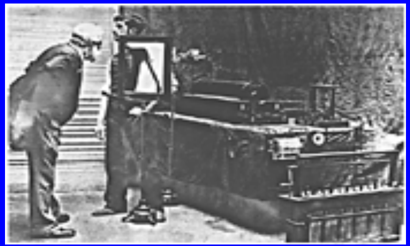
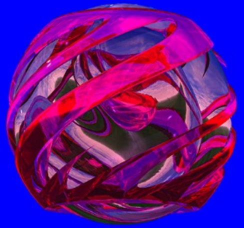
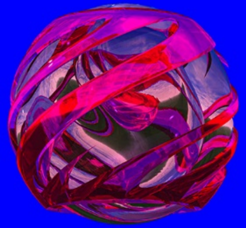
Evolving Fluoro Worker Dosimetry

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TELE – Podium – Athens – November 2019

COLUMBIA UNIVERSITY
IN THE CITY OF NEW YORK

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Καλημέρα σας!

Είμαι πολύ χαρούμενος που έχω την ευκαιρία να σας παρουσιάσω σήμερα.

Λυπάμαι που δεν μπόρεσα να είμαι στην Αθήνα μαζί σας.

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- **Background Information**
- **US Fluoroscopy Monitoring Results – published online 25 Nov 19**
- **Measurements of protection factors of leaded eyewear obtained during clinical cardiology procedures - Work in progress**

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ALARA for Interventional Fluoroscopy

- Patients are presumed to benefit from the procedure.
- Patients and staff are exposed to radiation and other risks during the performance of the procedure.
  - Radiation risk is almost always one of the smallest patient's procedural risks.
- Engineering controls may reduce staff risks at the cost of increasing patient risks.
- Engineering controls should optimize all risks.

  e.g. Increasing lead thickness in PPE reduces radiation risk but increases orthopedic risk.

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Fluoroscopy worker monitoring program

TASKS
- Comply with regulatory requirements
- Estimate stochastic risk
- Estimate risk of cataract
- Management of fetal risk
- Worker safety assurance

FACTORS
- Patients
  - morphology
  - disease
- Imaging equipment
- Working patterns
- Effects of PPE
- Effects of other radioprotective devices

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Monitoring deliverables

- **Trigger investigations and actions when greater than satisfactory levels of irradiation can be safely reduced.**

- **Provide timely alerts to minimize or avoid radiogenic tissue reactions.**

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Currently: Personal dose monitors

- Single monitor
  - Collar level, outside PPE - US Practice
  - Chest level, inside PPE – Several Countries
- Dual monitor
  - Collar level, outside PPE
  - Chest level (or near waist), inside PPE
- Fetal dose monitor
  - Abdominal level, inside PPE

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Conversion of measurements to H_E or E estimates

- Calculation of protection quantities, Effective Dose Equivalent (H_E) or Effective Dose (E), requires data on the dose delivered to each organ in the body.
  - Several different sets of organ weighting factors are in current use.
- Personal monitoring devices provide measurements of operational quantities, such as the personal dose equivalent [Hp(3) & Hp(10)], at the location of the device.
- Several algorithms are available to convert measured operational quantities to immeasurable protection quantities; used for radiological protection purposes.

There is no consensus on the best algorithm!

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Calculation of effective dose equivalent H_E

- In the United States, guidance provides methods to determine H_E for compliance with regulatory dose limits among medical staff.

For workers monitored with the **one-badge** protocol:

$$H_E = 0.3 \times H_p(10)_{over}$$

For workers monitored with the **two-badge** protocol:

$$H_E = 0.04 \times H_p(10)_{over} + 1.5 \times H_p(10)_{under}$$

Where the operational quantity, personal dose equivalent:

$H_p(10)_{over}$ is measured at the collar level above the lead apron

$H_p(10)_{under}$ is measured at the waist underneath the lead apron

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Variations of H_E & E [mSv] for $H_p(10)_{outer}$ = 100

Radiation Monitors	Quantity	5% PPE Transmission	10% PPE Transmission	20% PPE Transmission
Two	H_E	11.5	19.0	34.0
NCRP-122	E	2.5	5.0	10.0
	H_E / E	4.6	3.8	3.4
One	H_E [$H_p(10)/5.6$]	17.9	17.9	17.9
NCRP-122	E [$H_p(10)/21$]	4.8	4.8	4.8
	H_E / E	3.8	3.8	3.8
H_E One/Two	Percentage	155%	94%	53%
SSR - One	H_E [0.3 x $H_p(10)$]	30.0	30.0	30.0
H_E SSR/Two	Percentage	260%	158%	88%

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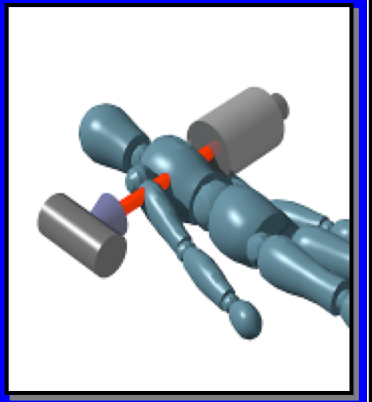
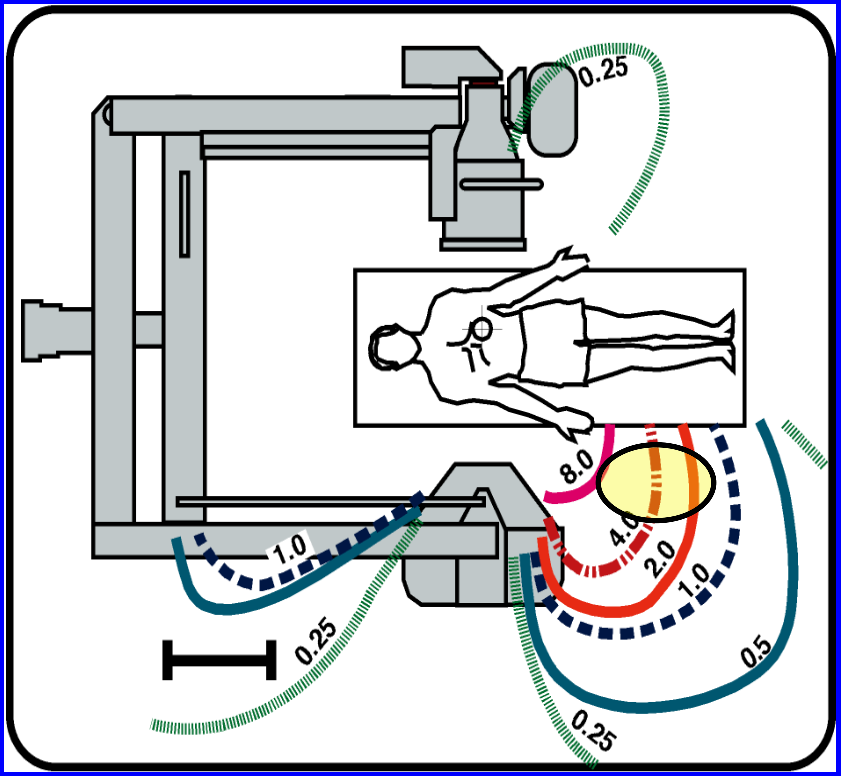
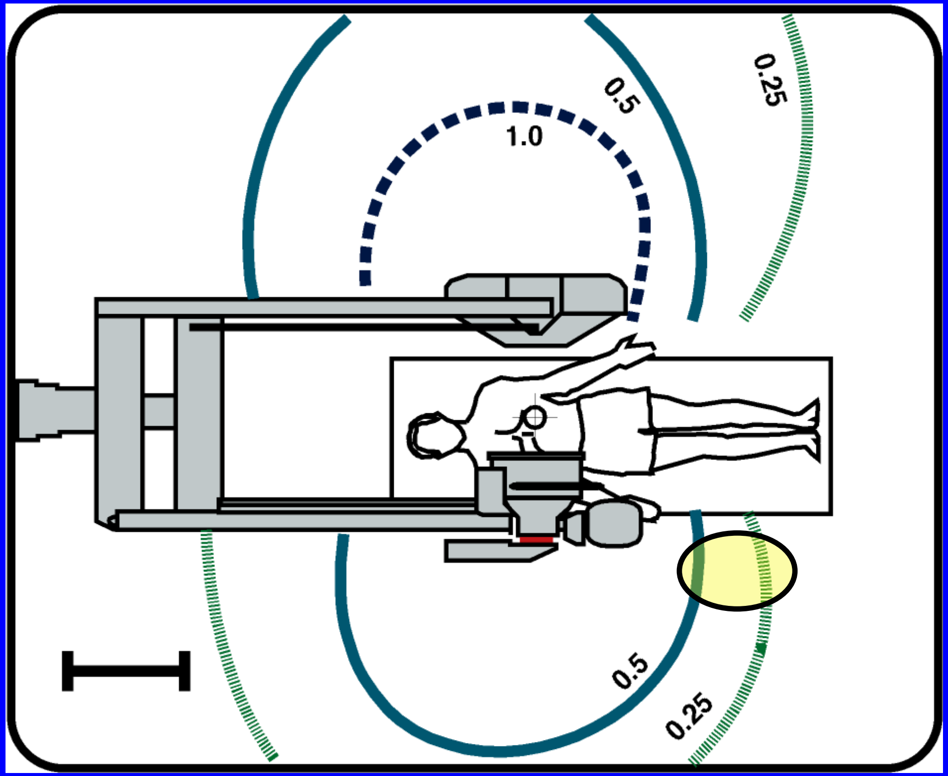
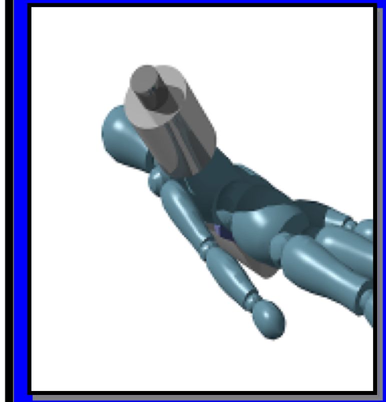
Scatter radiation field is highly heterogeneous <u>in both time and space.</u>









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- Background Information

• US Fluoroscopy Monitoring Results

Radiology

ORIGINAL RESEARCH • MEDICAL PHYSICS

Occupational Doses to Medical Staff Performing or Assisting with Fluoroscopically Guided Interventional Procedures

David Borrego, PhD • *Cari M. Kitahara, PhD, MHS* • *Stephen Balter, PhD* • *Craig Yoder, PhD*

From the Radiation Epidemiology Branch, Division of Cancer Epidemiology and Genetics, National Cancer Institute, National Institutes of Health, 9609 Medical Center Dr, Bethesda, MD 20892-9778 (D.B., C.M.K.); Departments of Radiology and Medicine, Columbia University Medical Center, New York, NY (S.B.); and Independent consultant, Weddington, NC (C.Y.). Received January 3, 2019; revision requested February 25; revision received September 30; accepted October 2. **Address correspondence to** D.B. (e-mail: *david.borrego@nih.gov*).

Study supported by the Intramural Research Program of the National Cancer Institute, National Institutes of Health.

See also the editorial by Karellas in this issue.

Radiology 2019; 00:1–7 • https://doi.org/10.1148/radiol.2019190018 • Content code: PH

- Measurements of protection factors of leaded eyewear obtained during clinical cardiology procedures - Work in progress

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Occupational doses to medical staff in FGI procedures

- Used the largest dosimetry provider in the United States (Landauer, Inc.), to retrospectively collect 2,054,648 badge entries.
- Analyzed data from 2009, 2012, and 2015, corresponding to 49,991, 81,561, and 125,669 medical staff believed to have worked with FGIPs.
- Reported occupational doses according to institutional use of a one-badge or two-badge monitoring protocol.

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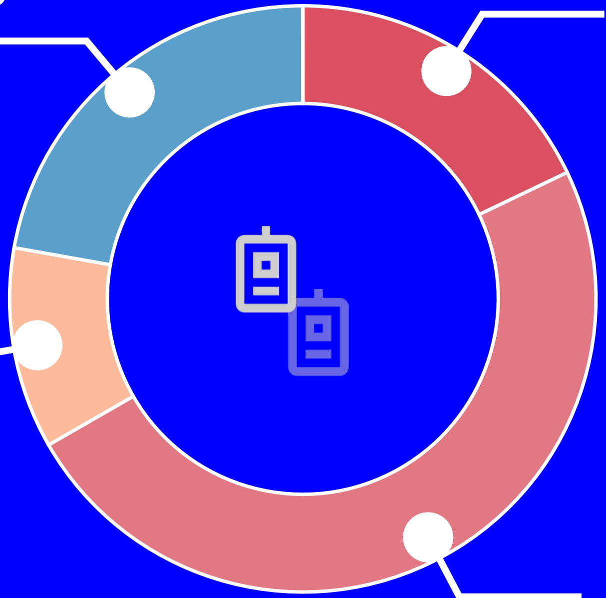
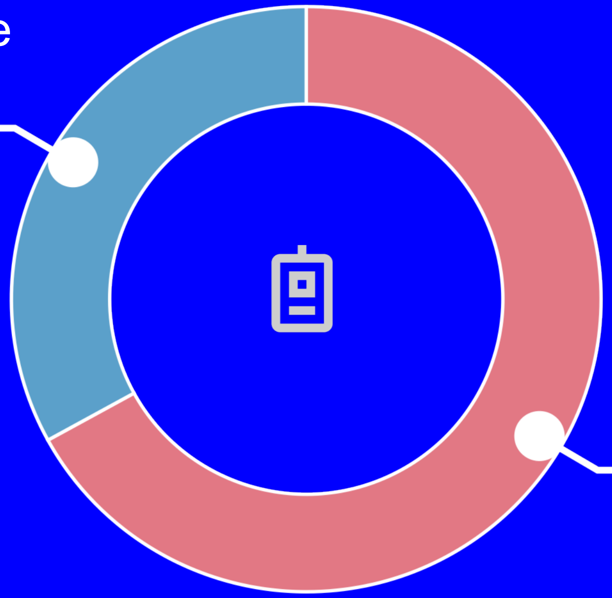
Excluding uninformative readings

$N_{two\text{-}badge}$ = 687,912

$N_{one\text{-}badge}$ = 1,366,736





[1-5]ICRP Publication No. 139 (2018); Chida et al. (2018); Vaño et al. (2011); Padovani et al. (2011); NCRP Report No. 168 (2010)

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Inclusion criteria for reporting of annual data

- A worker must have had 12 valid monthly entries for that year.
- For workers monitored under the two-badge protocol:
  - We report all eligible data.
  - Additionally, we report data restricted to workers consistently (9+ months of the year) recording a dose above the lower LOD in the under-apron badge.
- We analyzed the doses to this restricted group, who represent the highest exposed, to better understand what the radiation safety office may expect if they elected to switch from a two-badge to the more conservative one-badge protocol.

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Monitoring data summary

Monitors	Year	Persons	H_E Effective Dose Equivalent (mSv) 25th %	median	75th %	95th %	Hp(3) Lens Dose Equivalent (mSv) 25th %	median	75th %	95th %
One	2009	2,008	1.2	2.2	4.1	12.2	4.0	7.2	13.8	40.5
All	2012	2,836	1.2	2.1	4.3	12.2	3.9	7.1	14.4	40.7
	2015	3,189	1.2	2.1	4.5	11.8	3.9	7.1	14.9	39.3
Two	2009	382	0.2	0.4	0.7	3.2	4.6	6.9	10.9	27.0
All	2012	703	0.2	0.4	0.8	3.9	4.6	7.6	12.0	30.4
	2015	629	0.2	0.4	0.7	3.7	4.6	6.9	10.6	31.7
Two	2009	35	2.3	3.5	5.2	15.1	17.6	29.0	54.5	125.0
High	2012	79	2.5	3.4	5.2	10.7	17.2	25.2	41.5	120.0
	2015	76	2.0	2.9	4.9	8.8	17.2	27.0	40.3	79.5

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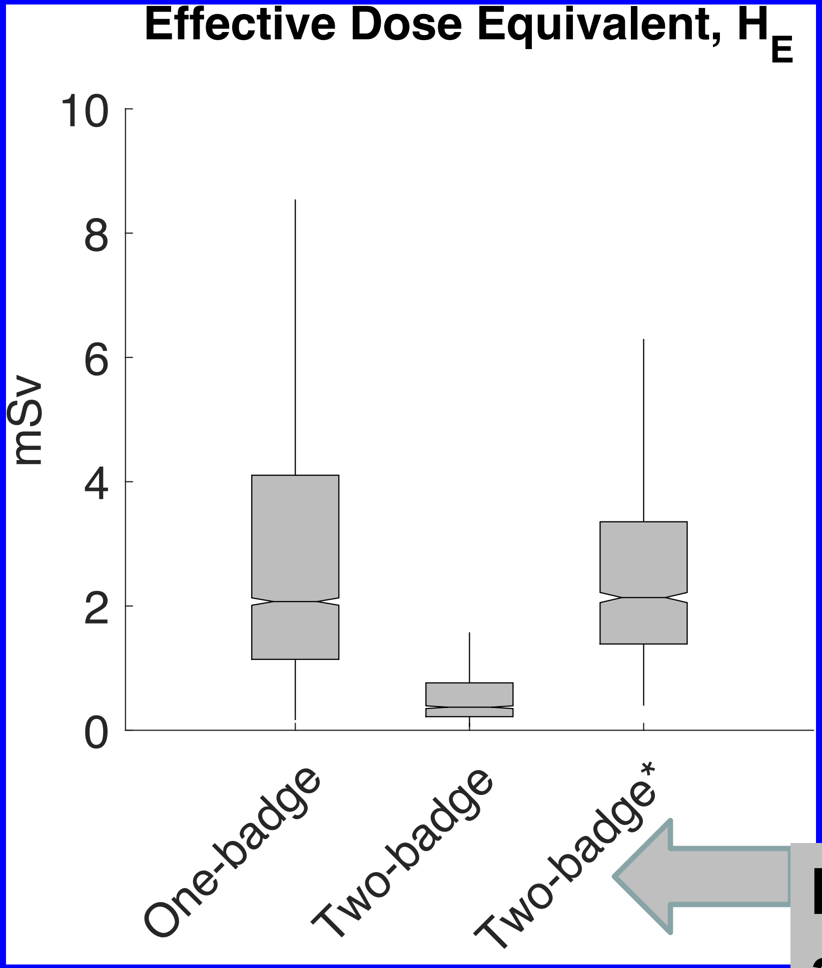
Summary of annual doses (all workers)



- **The difference ($p<0.001$) in effective dose equivalents is due to different formulas used in these calculations.**
- **75% of workers (1,084/1,449) in our dataset monitored with the use of a two-badge protocol consistently (9+ months/year) registered a dose below the LOD in the under-apron badge.**

Recalculating H_E using the same algorithm as for the one-badge workers ($H_E = 0.3 \times H_p(10)_{over}$)

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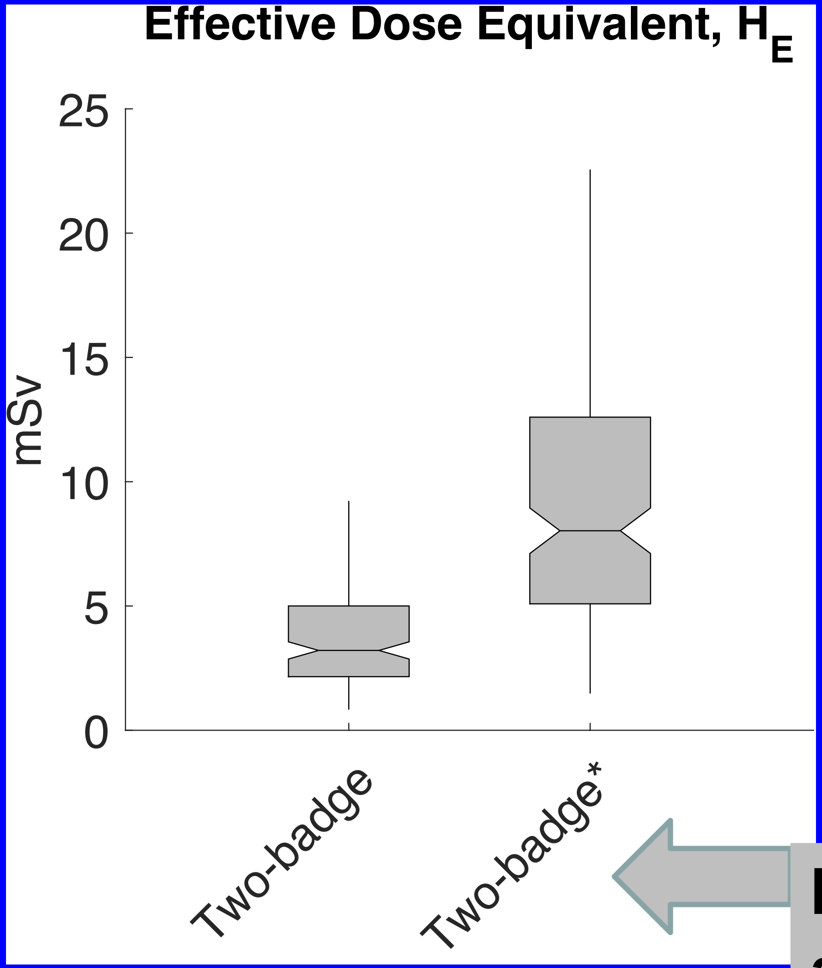
Summary of annual doses (restricted workers)



- This high exposed group consistently (9+ months of the year) recorded a dose above the lower LOD in the under-apron badge.
- Using the above-apron badge to assign H_E would increase the doses by no more than a factor of three;
  the resulting doses would still be within regulatory limits in the U.S.

Recalculating H_E using the same algorithm as for the one-badge workers ($H_E = 0.3 \times H_p(10)_{over}$)

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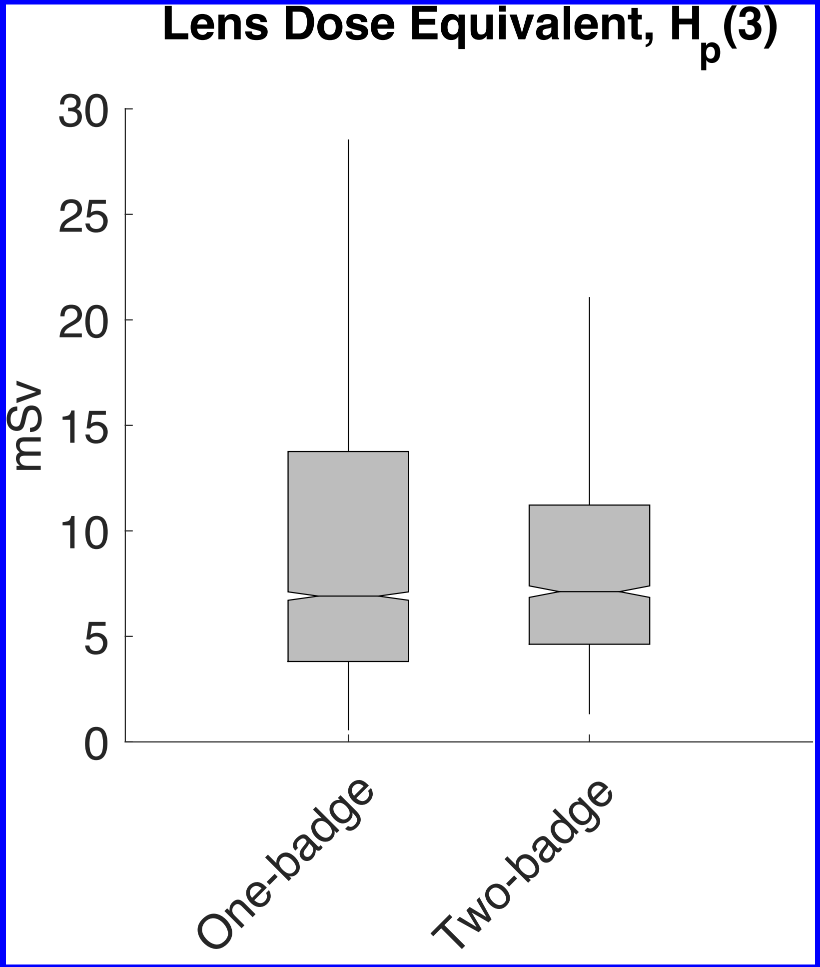
Summary of annual lens doses



- Annual lens dose equivalents for one badge (median=6.9, n=6,218) were similar to those wearing two badges (median=7.1, n=1,449) (p=0.18), suggesting a similar radiation environment.
- From 2009 to 2015 there was no change in lens dose equivalent values among the staff
  - who wore one-badge (p=0.96)
  - or those with two-badges (p=0.23).

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Main findings and conclusions

- Occupational doses to medical staff performing or assisting with fluoroscopically-guided interventional procedures in 2009, 2012, and 2015 were below U.S. regulatory occupational dose limits for most workers (H_E = 50 mSv/y)
- 15% *collar* doses exceeded the occupational *eye* dose limits recommended by the International Commission on Radiological Protection ($H_p(3)$ = 20 mSv/y).
- FGI fluoro workers are a population that requires consistent and accurate dose monitoring.
  However, failure to return one or both badges, reversal of badges, or improper badge placement are major hindrances.

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- Background Information
- US Fluoroscopy Monitoring Results – published online 25 Nov 19
- **Measurements of protection factors of leaded eyewear obtained during clinical cardiology procedures - Work in progress**

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Objectives

- Measure the lens-of-eye protection factor provided by shielded eye PPE during the performance of clinical FGI.
  - Interventional Cardiology – various procedures
  - Attending, fellows, angioplasty specialists
  - Wide range of eye PPE currently used in lab (most pieces *do not* have side shielding).
- Measure the ratios of dose at the collar badge to dose at the workers' eyes.

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Methods and materials

- **PPE eyewear currently used by participating individuals were equipped with four dosimeters.**
  - **Wide variety of designs, most without side-shielding**
  - **nanoDot™ (Landauer) attached to the inside and outside of the left and right lenses of the PPE.**

    Pilot evaluation of spectral dependence over the clinical beam range
  - **Additional nanoDot™ attached to routine collar dosimeter**
- **Participants performed cases in their usual manner/**
- **Human observer tracked participant motion during some cases.**
- **Enough to obtain above 0.1 mGy to the lowest nanoDot™.**
  - **Few weeks of data collection seems adequate for key individuals**

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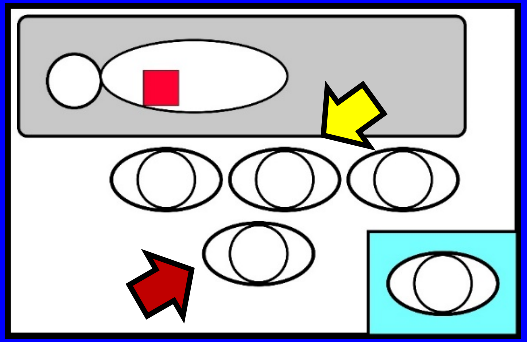
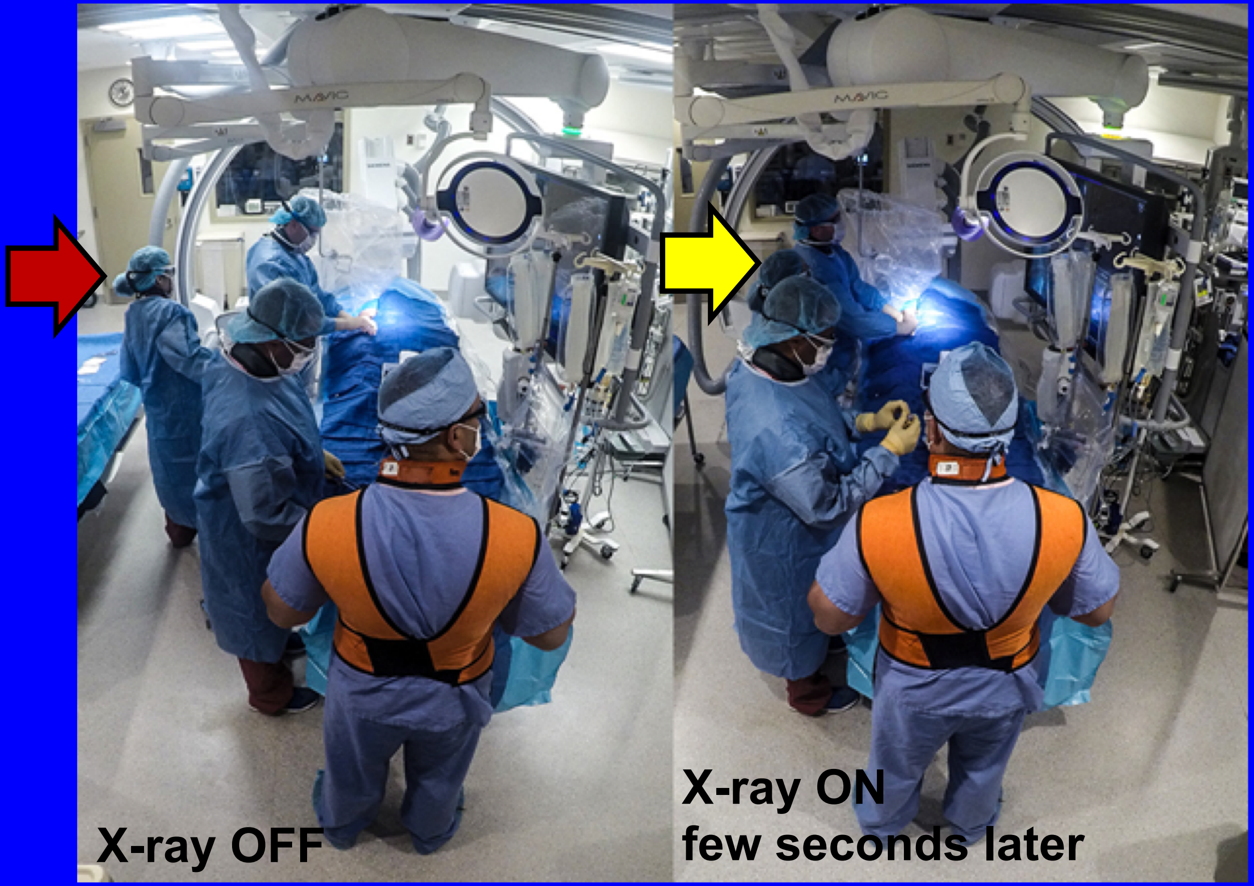
Observational Methods



- Investigator visually tracked individuals as they moved
  and changed positions during procedures.

- Feasibility of video and time-lapse photography using a wall mounted camera.



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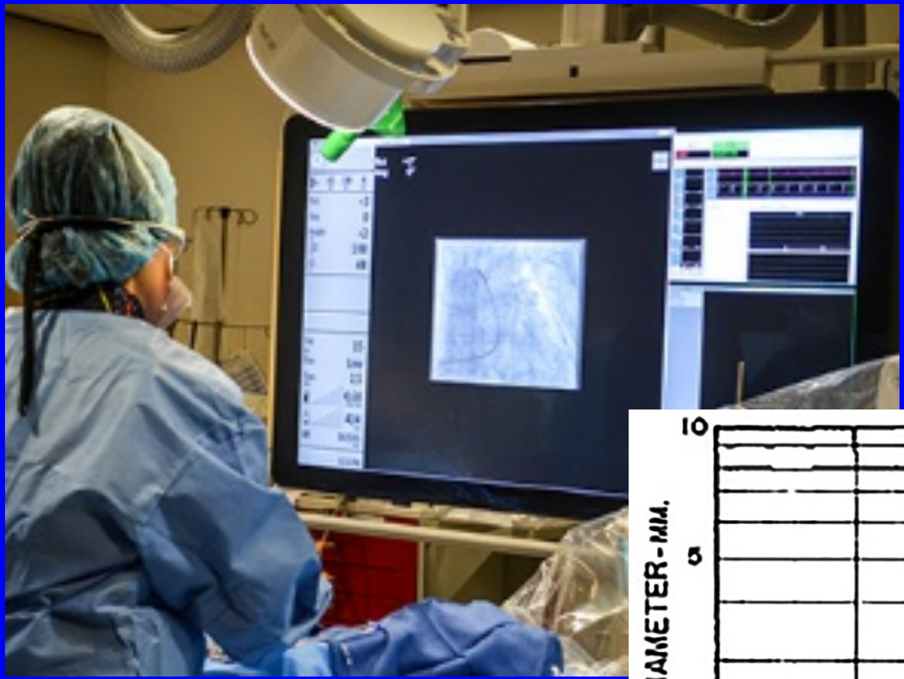
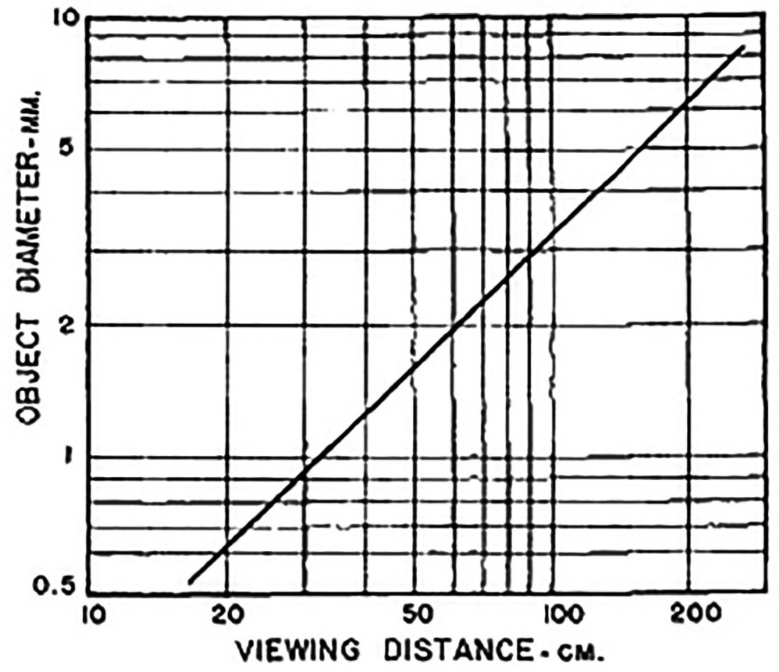
Effects of image receptor and monitor sizes





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Dosimeter Locations

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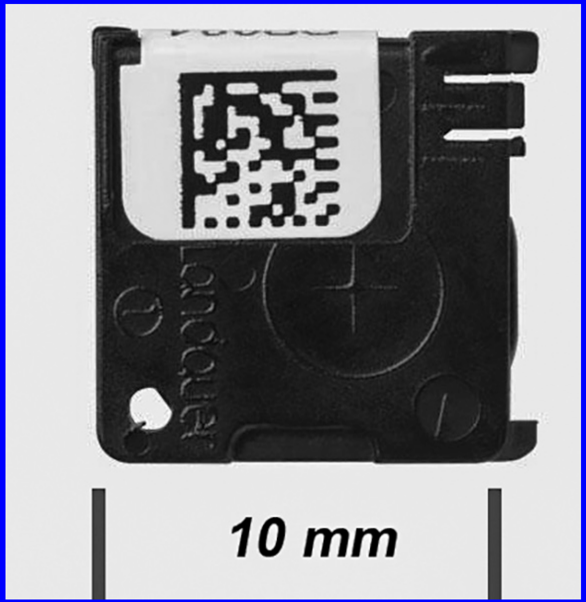
Landauer nanoDot™ Dosimeter

Dose operating range	For general applications, useful dose range 5 mRad to 1500 rad (50 μGY to 1500 cGy); for medical dosimetry applications, linear response with dose up to 300 rad (cGy), software-supported non-linear calibration up to 1500 rad (cGy)
Lower Limit of Detection (LLD)	5 mrad (50μGy)
Useful Energy Range	From 5 keV to 20 MeV
Energy Dependence	Accurate within ±10% over diagnostic energy range 70-140 kvP; within ±5% for photons and electrons from 5 MeV-20MeV
Accuracy (total uncertainty - single measurement)	±10% with standard nanoDot; ±5.5% with screened nanoDot



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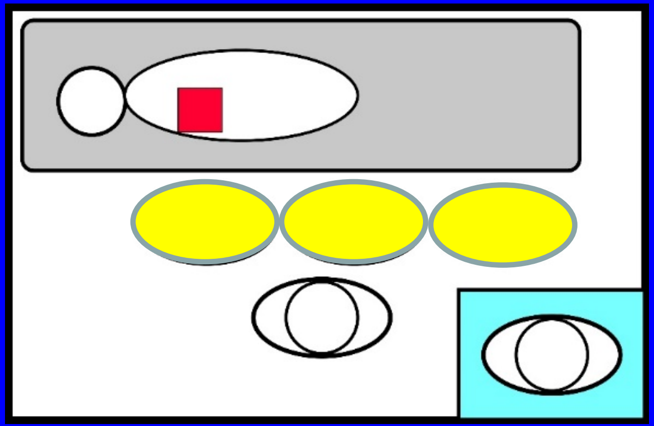
Practical Observations



- Observations from 20 procedures
- Protective eyewear is still not worn by all physicians
- Schematic is representative of worker positions during a majority of each procedure
  - Trial involved workers that spent time in the highlighted positions
  - Time is split between looking downward toward the patient and up towards the screens
  - Head attitude (left, frontal, right) changes often
  - Screen position varies between procedure rooms and procedures
- Workers distant from the beam show the greatest variability in position throughout procedures

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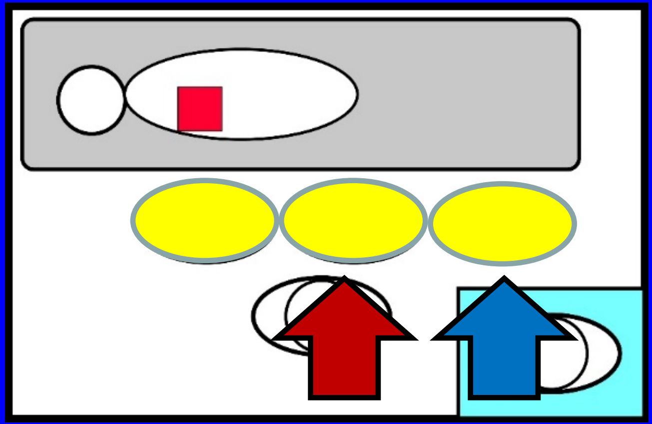
Pilot Data

Location	Position	Angioplasty Asst. 1 day (μGy)	Angioplasty Asst. 1 day Out/In	Fellow (MD) 5 day (μGy)	Fellow (MD) 5 day Out/In
Right Side	OUT	11	1.8	**392**	1.5
	IN	6		**268**	
Right Lens	OUT	8	2.0	**315**	5.2
	IN	4		60	
Left Lens	OUT	15	---	**304**	5.9
	IN	0		52	
Left Side	OUT	7	7.0	**285**	1.1
	IN	1		**262**	



Eye PPE sides had no radiation shielding

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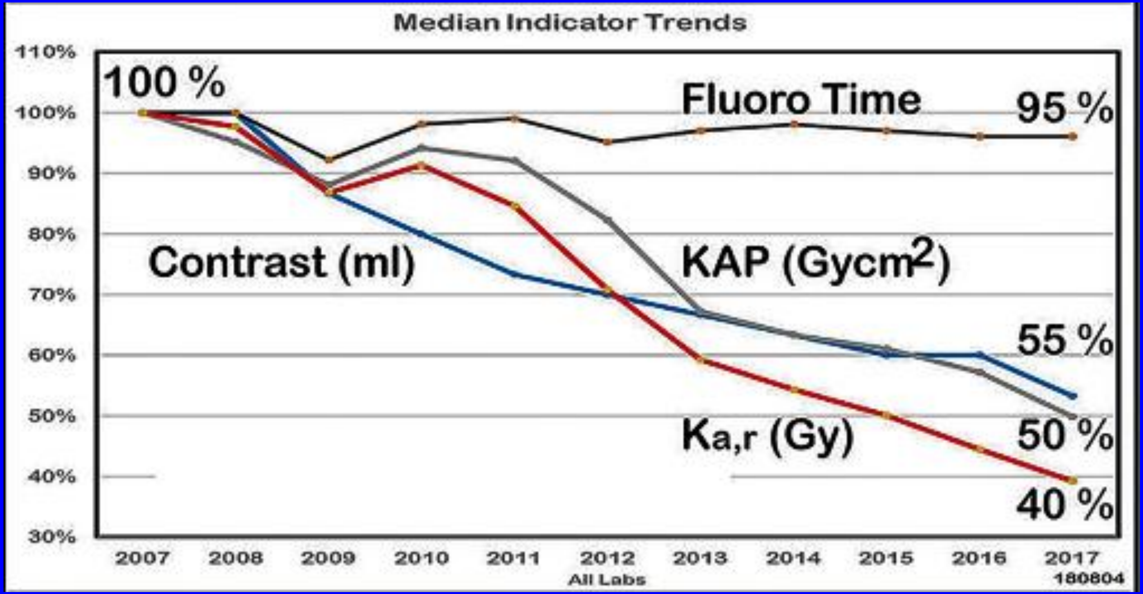
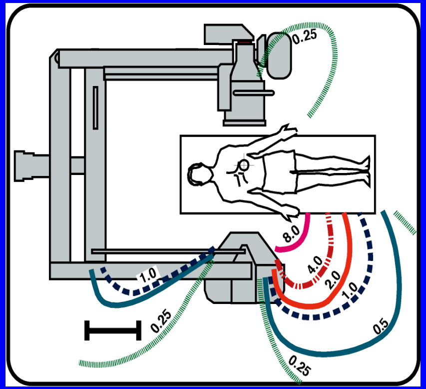
Thoughts about the Source Term

- In principle, risk can be computed by using worker posture, geometric factors, use of protective devices and the source term.
- The fluoroscopic scatter radiation field (source term) is highly heterogeneous in both time and space.
- The fluoroscopic source term is proportional to KAP.
- Per procedure KAP has decreased by 50% in the past decade.

CUMC
Cath Lab
Data





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Summary

- Consensus is needed for an applicable protection quantity, and its calculation from operational quantities.
- Irradiation of fluoroscopic staff is measurable.
  - Reported data inconsistency partially due to different methodologies
  - Few exceed 10% of whole-body regulatory limits
  - Protecting the lens of the eye needs attention

- Methodologies to passively monitor fluoroscopic workers, and estimate worker risks, are desirable.
  - Badge usage?
  - Better risk estimates?

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