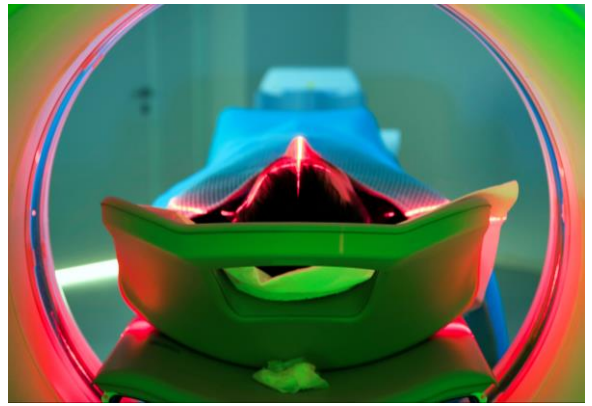
NIST X-RAY (10 kV to 300 kV) Air-Kerma Calibration Service

by
Michelle O'Brien
Physicist, Dosimetry Group

The HOME of the US realization of the SI unit of Radiation Dose for x-rays

MQSA medical traceability

diagnostic and therapeutic radiology



dose traceability for radiation protection and personnel dosimetry

NIST NATIONAL INSTITUTE OF STANDARDS AND TECHNOLOGY
U.S. DEPARTMENT OF COMMERCE

NIST Mission: To promote U.S. innovation and industrial competitiveness by advancing measurement science, standards, and technology in ways that enhance economic security and improve our quality of life.

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17025 Quality Management System

NIST QMI 4.1 Impartiality 4.1.1 Impartiality NIST conducts its measurement services in a fair and open-minded manner that is free of conflict of interests, bias or prejudice ensuring impartiality in the operations and measurements of the laboratory.

NIST QMI 4.2 Confidentiality 4.2.1 NIST is legally obligated to provide protection of confidential or proprietary information obtained or created during the performance of laboratory measurement services activities.

Department of Commerce

NIST PML

Radiation Physics Division

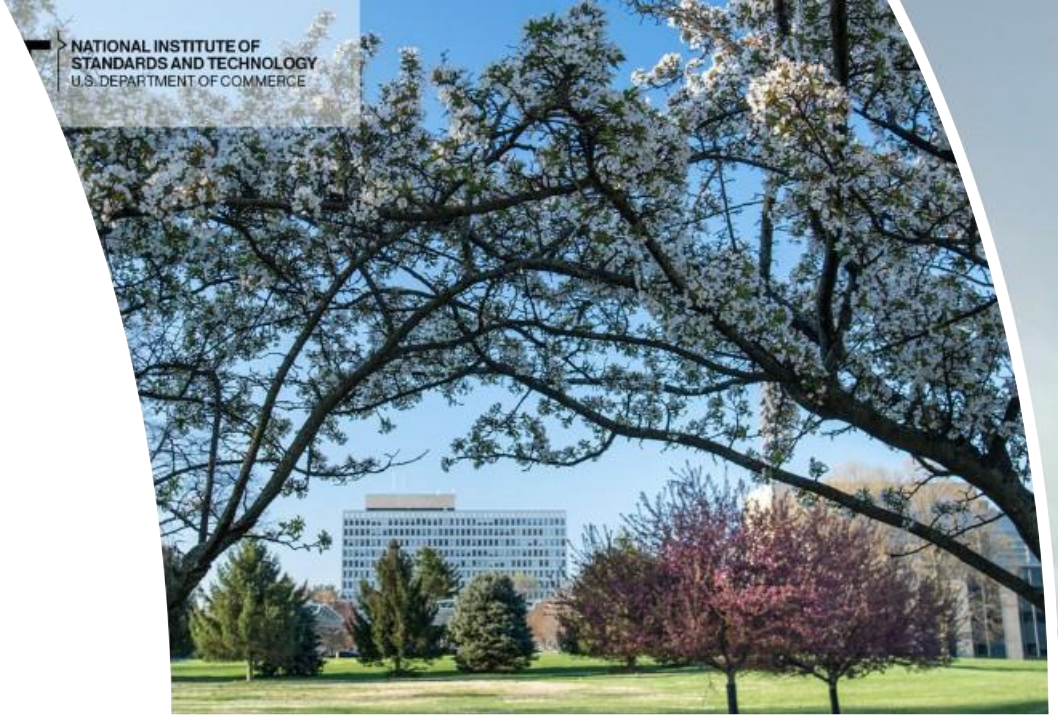
Dosimetry Group

Mission: To develop standards by realizing the SI unit of dose, the gray, and advance the measurement of quantities important in the radiological sciences through programs in the dosimetry of x rays, gamma rays, electrons and other charged particles.

1 Gy ≡ 1 J / kg

Radiation Physics Building

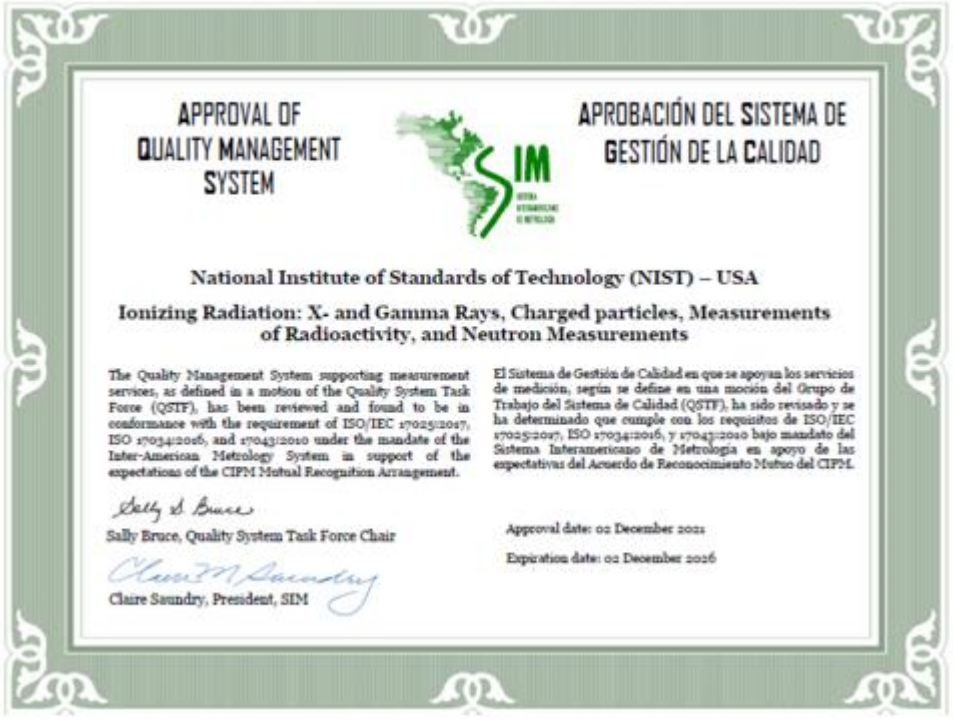
NIST
Gaithersburg, MD
H-wing of the Radiation Physics Building 245



Calibration and Measurement Capabilities (CMCs)

The goal for **Medical Physics Applications** is to provide traceability of radiation dose to clinical end users to ensure safety and efficacy of diagnostic and therapeutic procedures that involve ionizing radiation.

- 17025 and 17043 Quality management system
- BIPM.RI(I)-K2: Low energy x ray (10 kV to 50 kV)
- BIPM.RI(I)-K3: Medium energy x ray (50 kV to 300 kV)
- BIPM.RI(I)-K7: Mammography
- AAPM ADCL traceability and TG-61
- ISO 4037: Reference Radiation x-ray beams
- FDA-MQSA
- ANSI: personnel dosimetry performance standards, DHS



APPROVAL OF QUALITY MANAGEMENT SYSTEM

APROBACIÓN DEL SISTEMA DE GESTIÓN DE LA CALIDAD

National Institute of Standards of Technology (NIST) – USA

Ionizing Radiation: X- and Gamma Rays, Charged particles, Measurements of Radioactivity, and Neutron Measurements

The Quality Management System supporting measurement services, as defined in a motion of the Quality System Task Force (QSTF), has been reviewed and found to be in conformance with the requirement of ISO/IEC 17025:2017, ISO 17034:2016, and 17043:2010 under the mandate of the Inter-American Metrology System in support of the expectations of the CIPM Mutual Recognition Arrangement.

El Sistema de Gestión de Calidad en que se apoyan los servicios de medición, según se define en una moción del Grupo de Trabajo del Sistema de Calidad (QSTF), ha sido revisado y se ha determinado que cumple con los requisitos de ISO/IEC 17025:2017, ISO 17034:2016, y 17043:2010 bajo mandato del Sistema Interamericano de Metrología en apoyo de las expectativas del Acuerdo de Reconocimiento Mutuo del CIPM.

Sally Bruce, Quality System Task Force Chair

Claire Saundry, President, SIM

Approval date: 02 December 2021

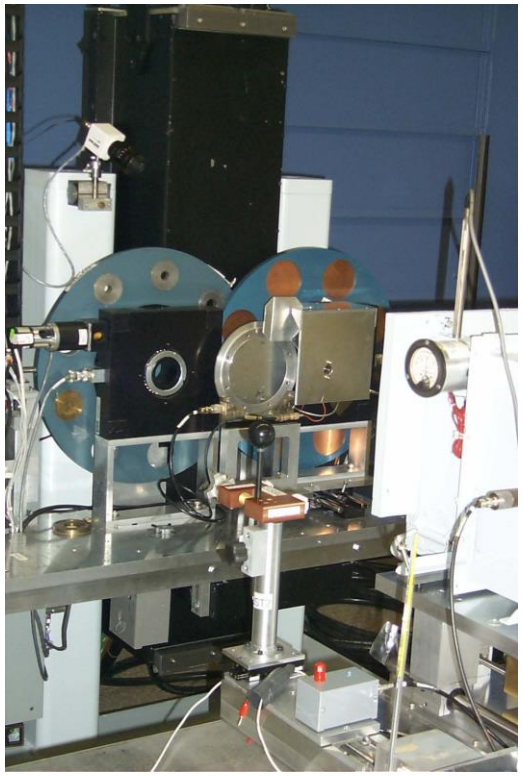
Expiration date: 02 December 2026

Control Room

Equipment Room

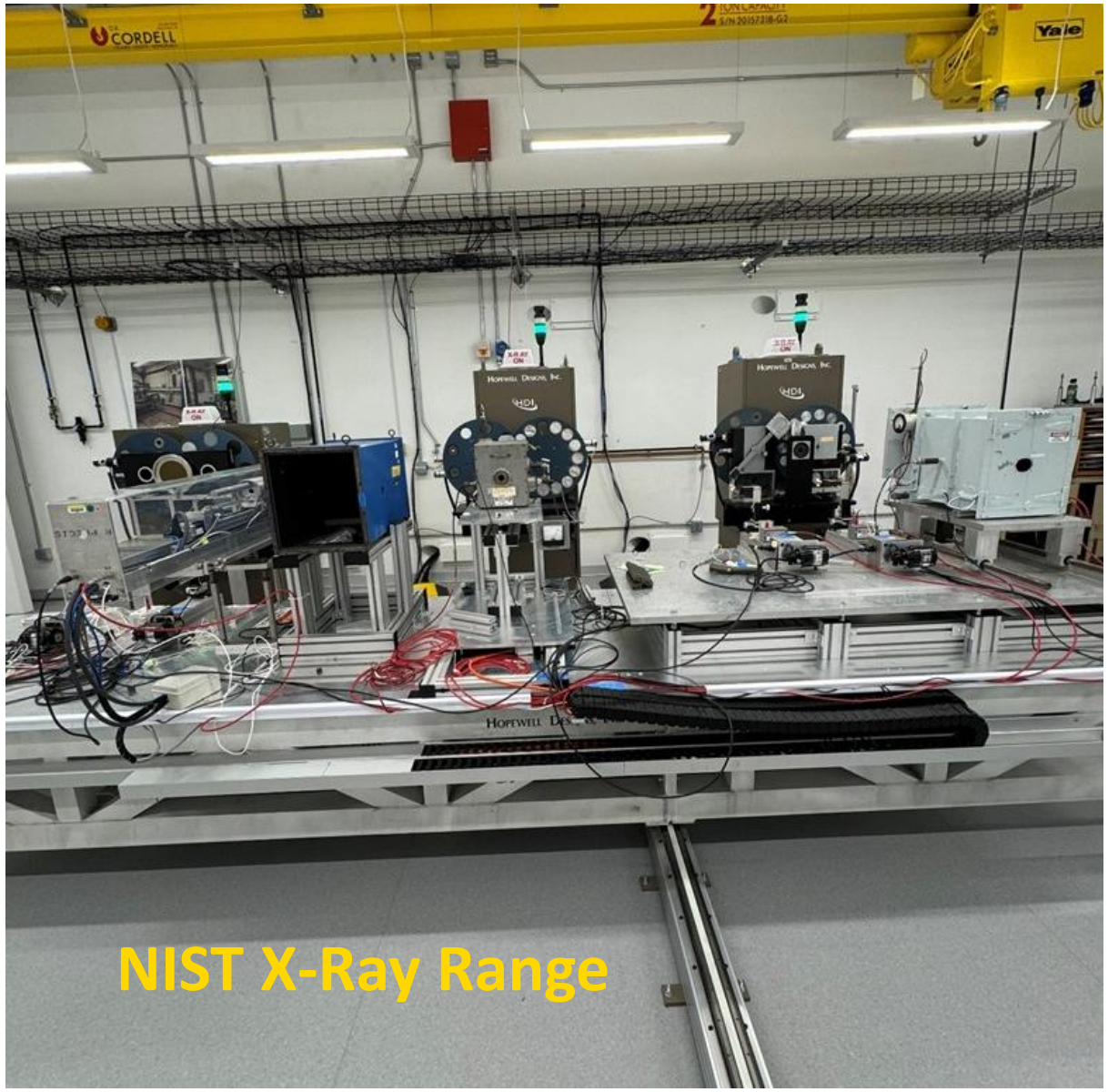
X-Ray Range

100 kV

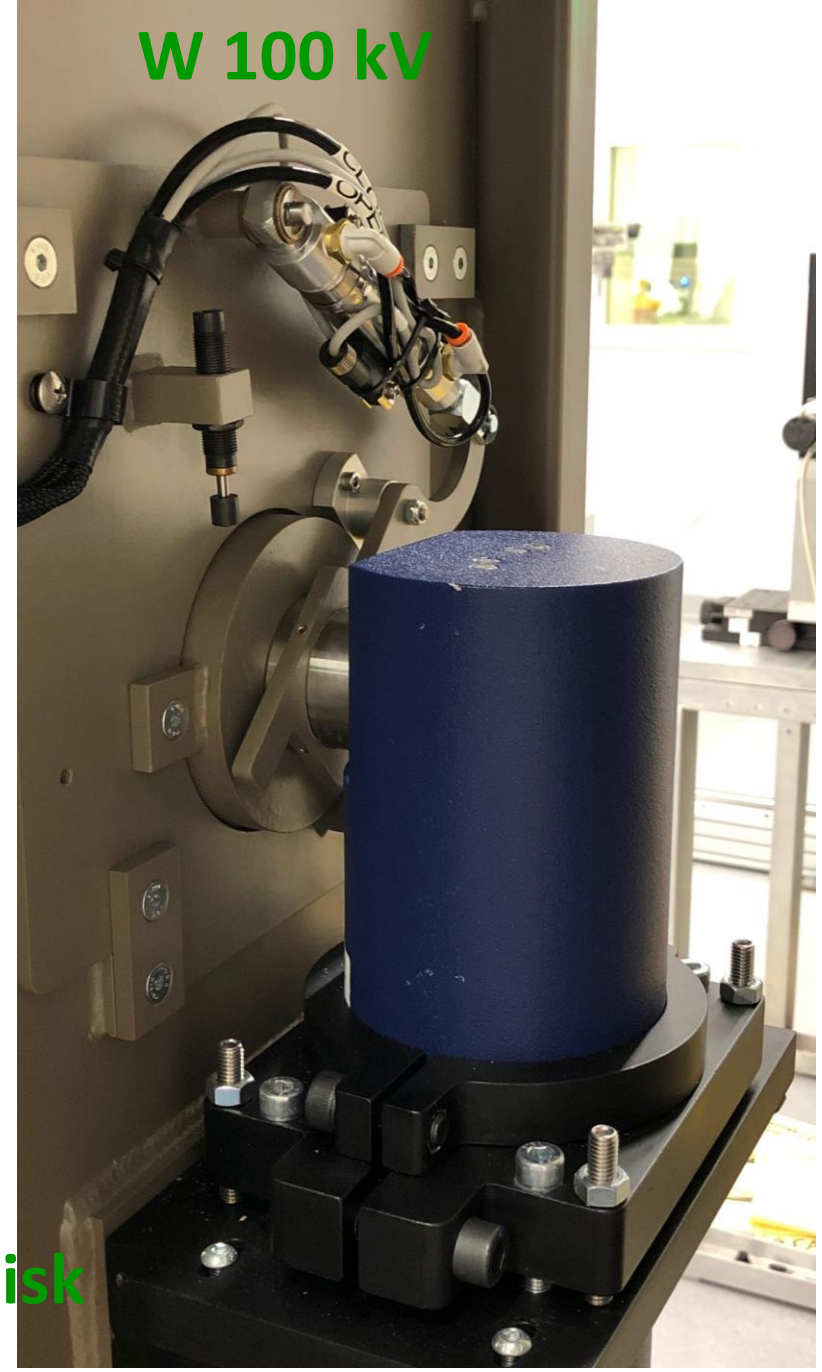


300 kV

mammography

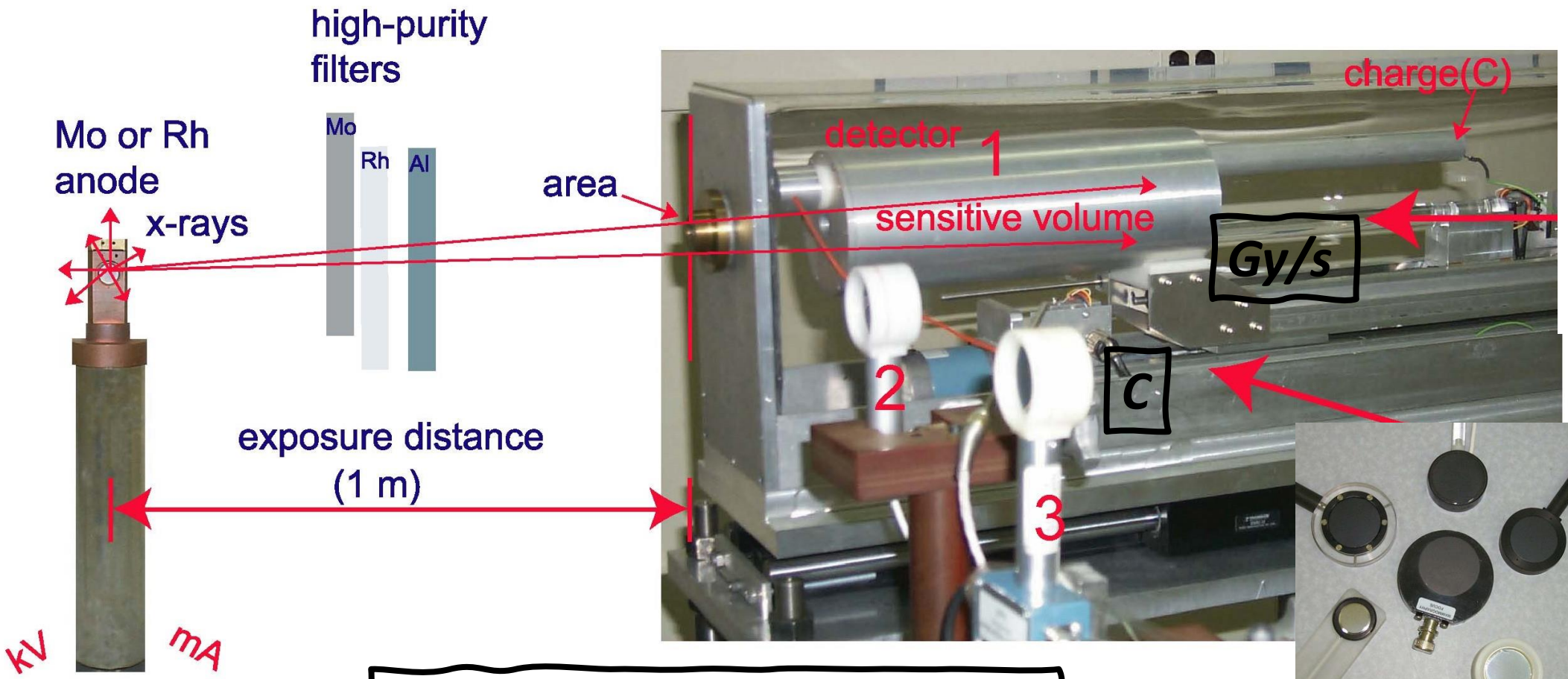


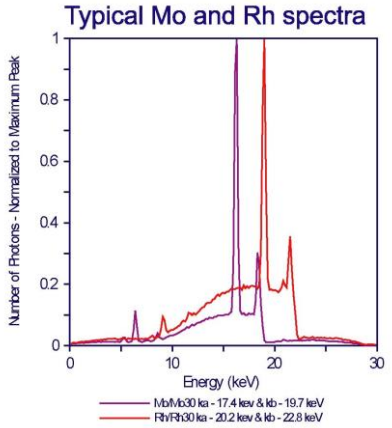
Three sub-basement spaces
became one first floor facility

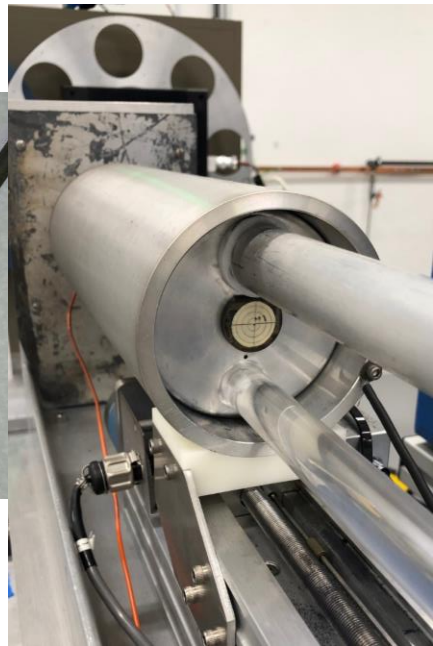


Identical shutter W disk
150 msec

Air-Kerma Rate (Gy/s) Measurement

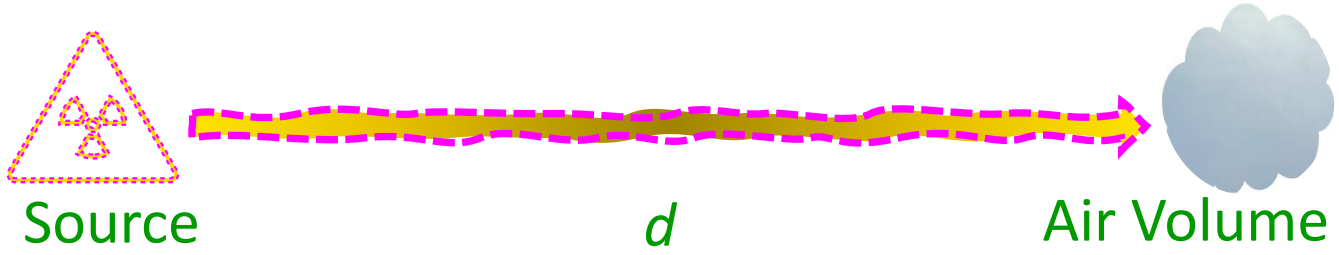






Calibration Coefficient Gy/C

Dosimetry of X Rays ($E < 300$ keV)



$$K_{\text{air}} = Q_{\text{air}} \left(\frac{\overline{W}_{\text{air}}}{e} \right) \frac{1}{\rho_{\text{air}} V}$$

KERMA = Kinetic Energy Released per unit MAss

Secondary electrons → liberated charge in a given mass of air

$$\text{C} \cdot \left[33.97 \frac{\text{J}}{\text{C}} \right] \cdot \frac{1}{\text{kg}} = \frac{\text{J}}{\text{kg}} = \text{Gy}$$

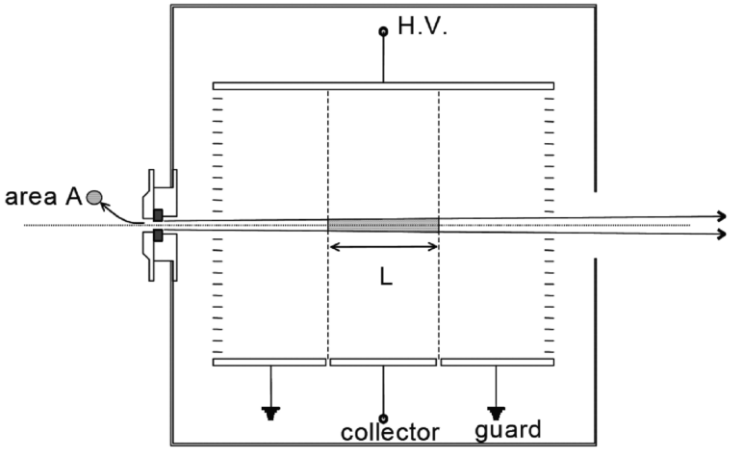
Air kerma can be measured absolutely with a free-air ionization chamber

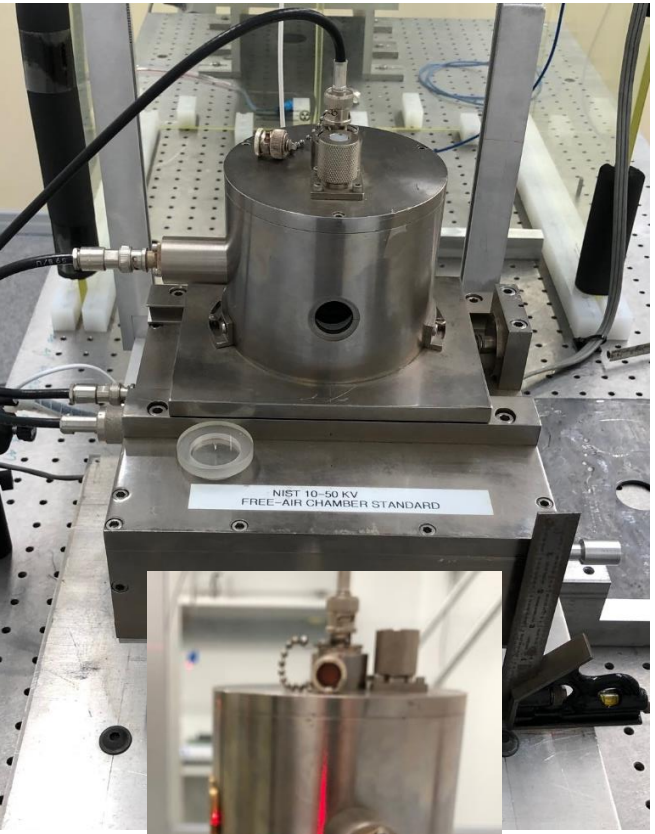
NIST Primary Free-Air Ionization Chambers

Electronic Brachytherapy

Lamperti 10 kV to 60 kV

Air-path length 39 mm



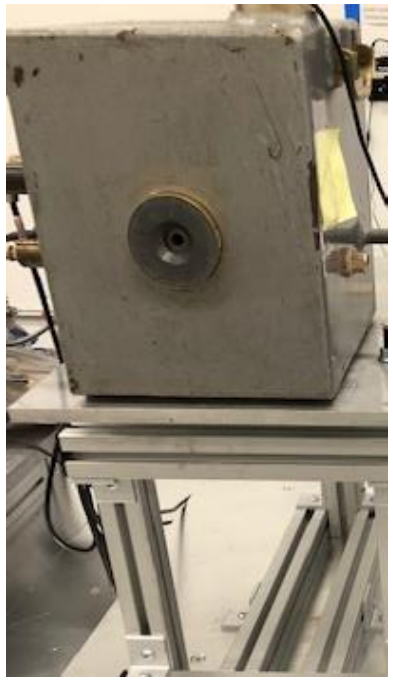


Wyckoff-Attix 60 kV to 300 kV

308 mm

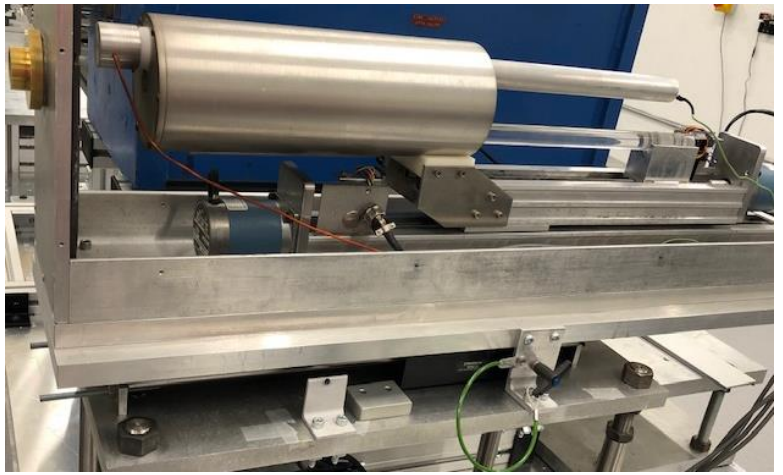
* Ritz 10 kV to 100 kV

127 mm

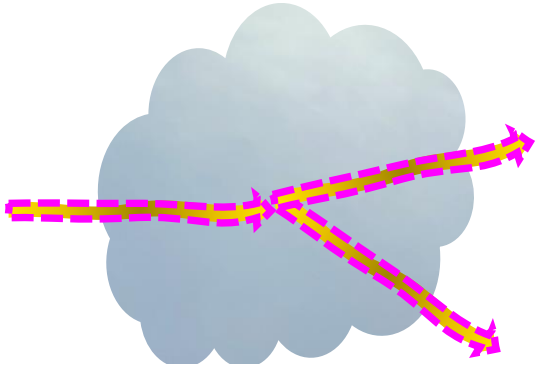


* Attix 10 kV to 50 kV

212 mm



The SI unit of dose, Gy,
Air-Kerma Rate (Gy/s) as Realized by Free-Air Chambers



$$\dot{K} = \frac{I}{\rho_{\text{air}} V} \frac{W_{\text{air}}}{e} \frac{1}{1 - g_{\text{air}}} \prod_i k_i$$

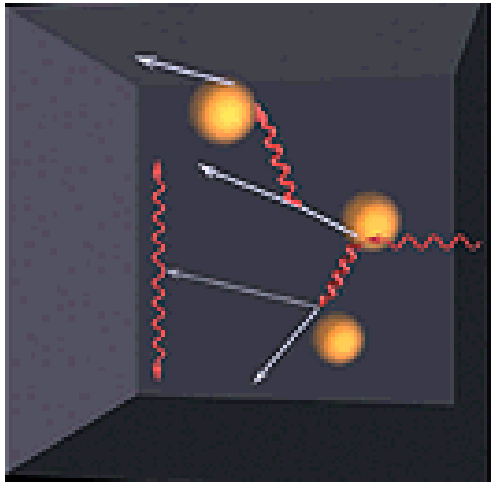
$\dot{K}$ is the air-kerma rate at a given distance in air.

$I / (\rho_{\text{air}} V)$ is the measured ionization current divided by the mass of air in the measuring volume.

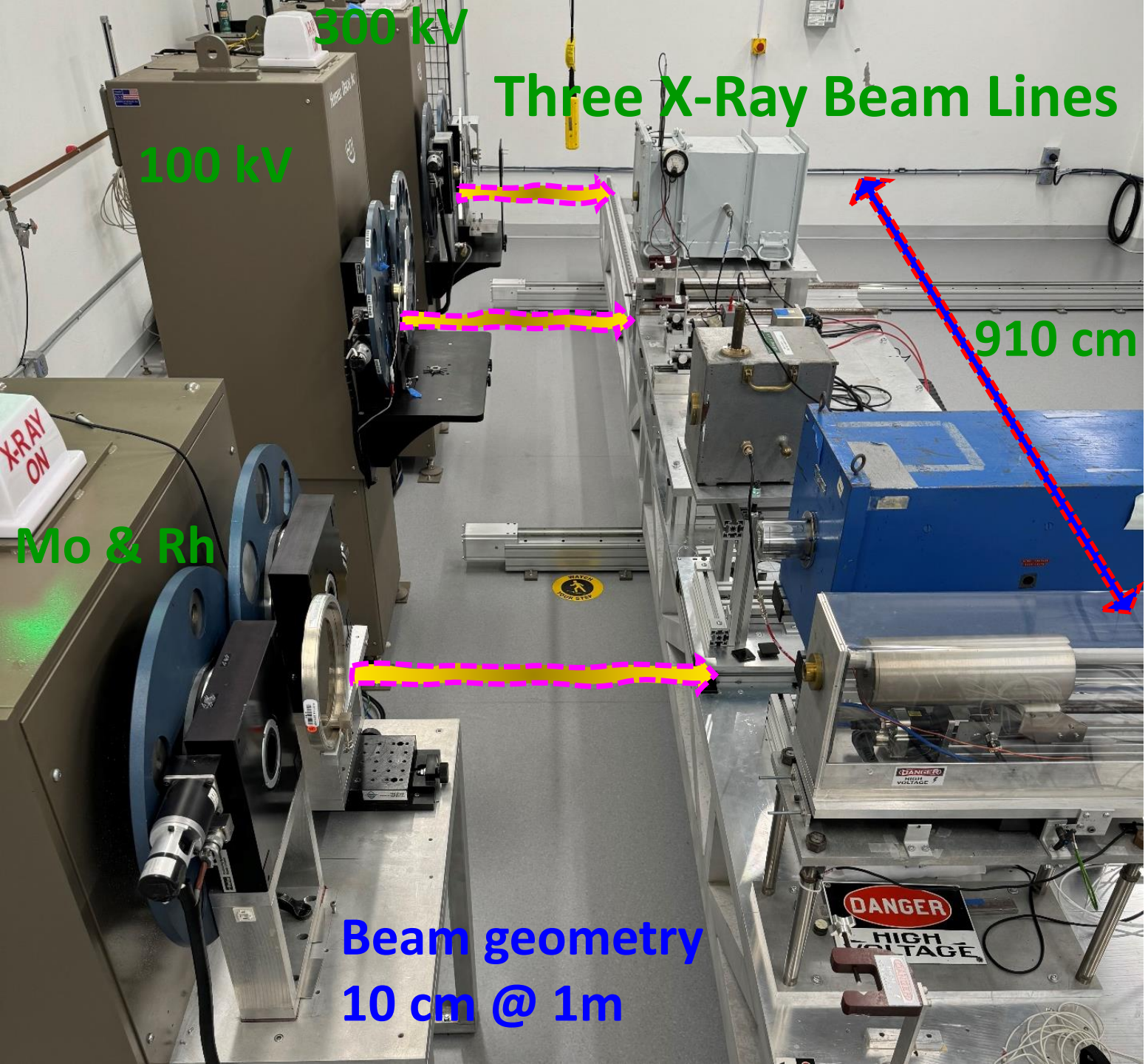
W_{air} is the mean energy expended by an electron of charge e to produce an ion pair in dry air. The value used at NIST is W_{air}/e = 33.97 J/C.

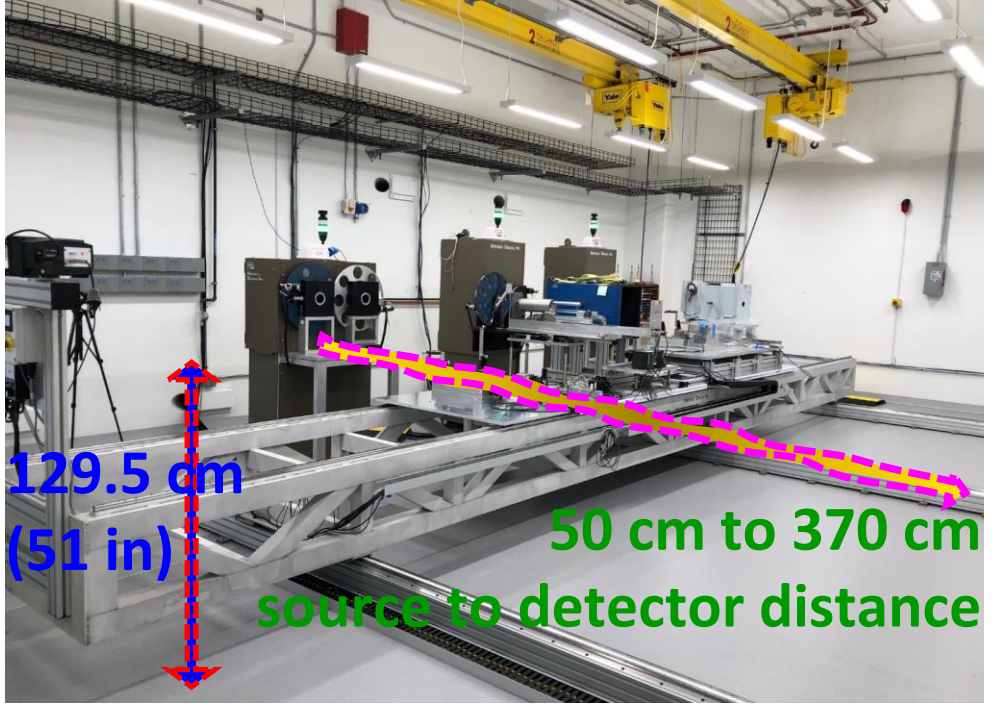
g_{air} is the fraction of the initial kinetic energy of secondary electrons dissipated in air through radiative processes, which is 0.0 (negligible) for x rays with energies less than 300 keV.

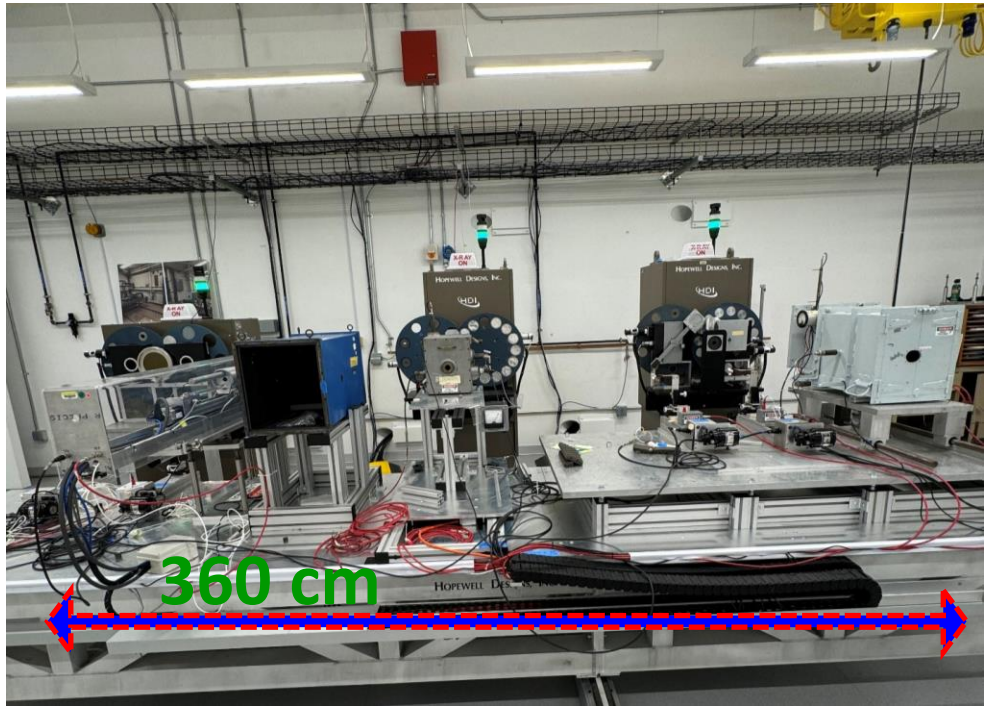
$\Pi\, k_i$ is the product of various correction factors.

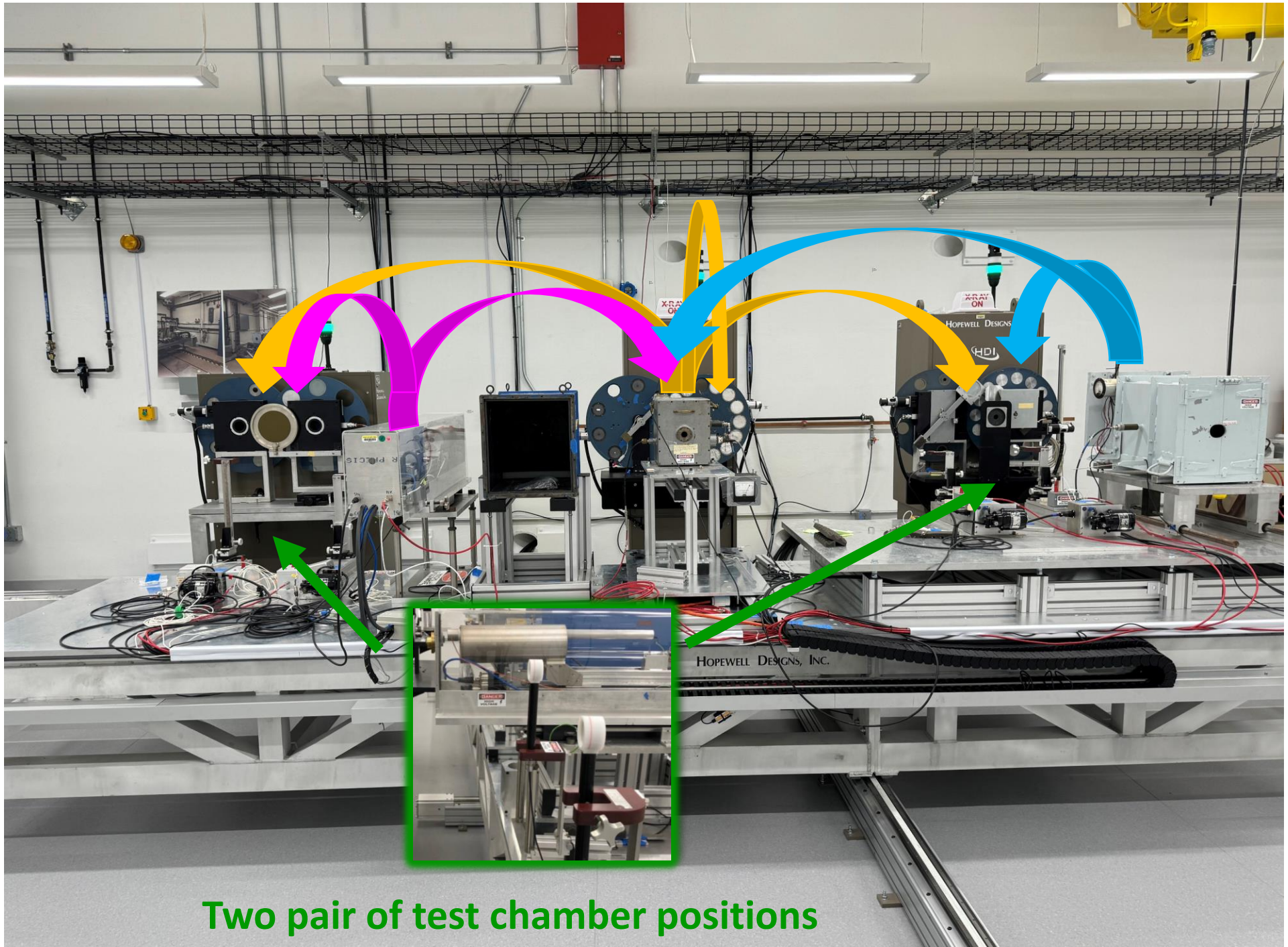


Range of corrections: 0.983 to 1.13
Air attenuation: 1.005 to 1.05


300 kV
Three X-Ray Beam Lines
100 kV
910 cm
X-RAY ON
Mo & Rh
Beam geometry
10 cm @ 1m
DANGER
HIGH VOLTAGE

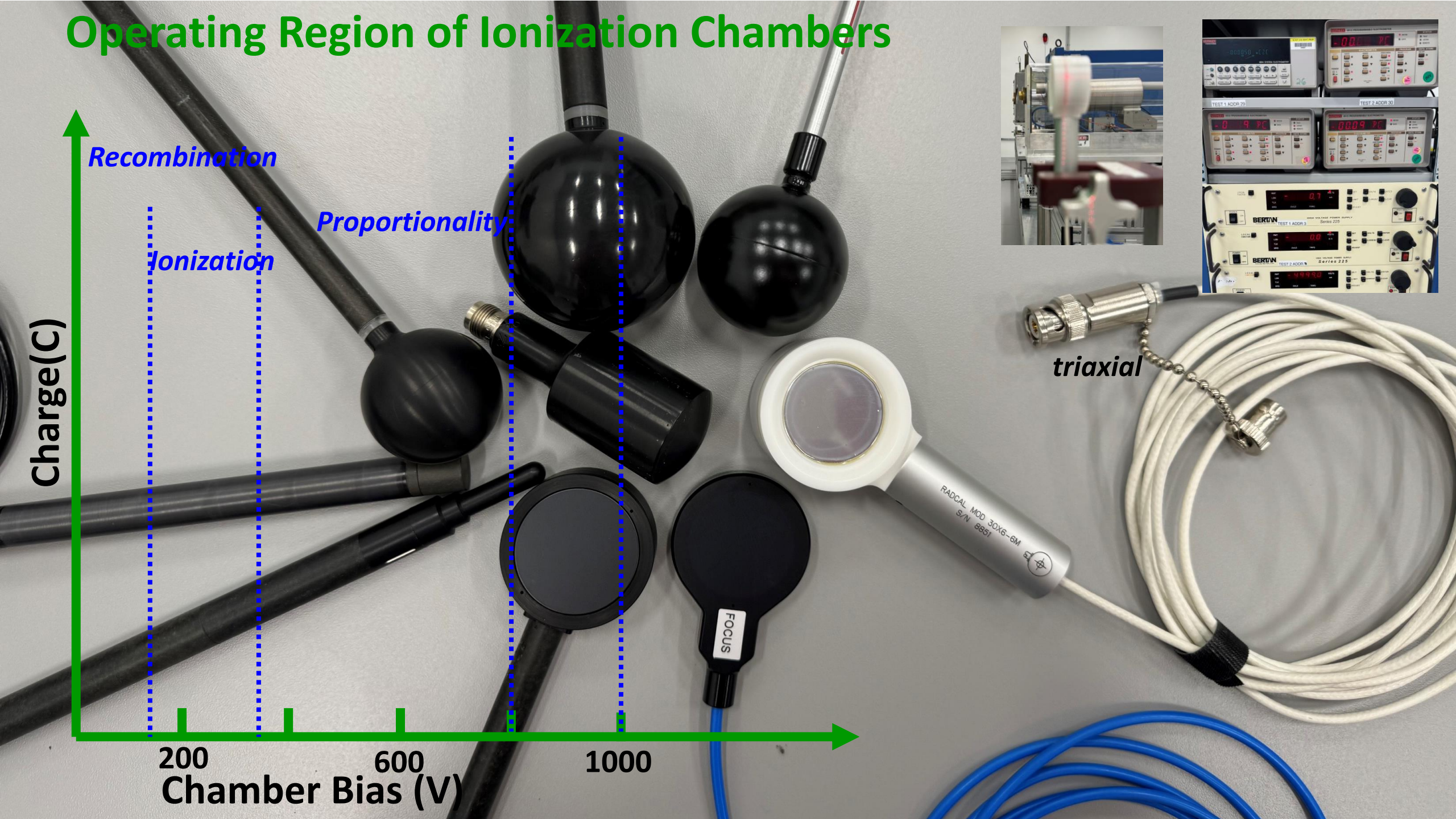

129.5 cm
(51 in)
50 cm to 370 cm
source to detector distance


360 cm

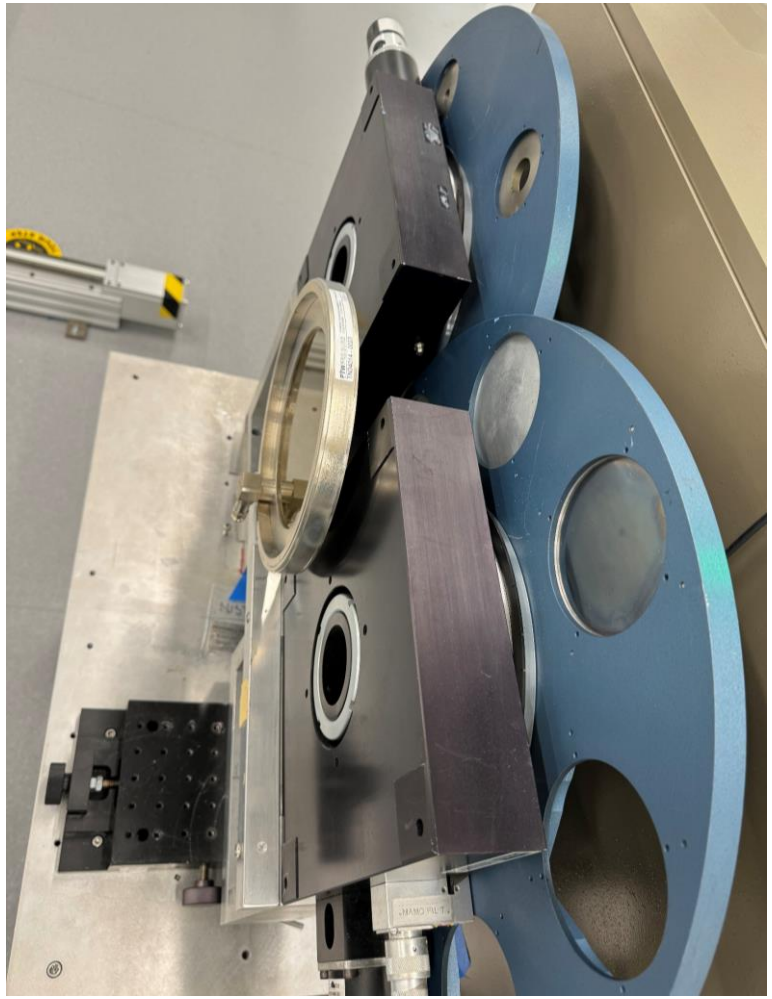


Two pair of test chamber positions

Operating Region of Ionization Chambers



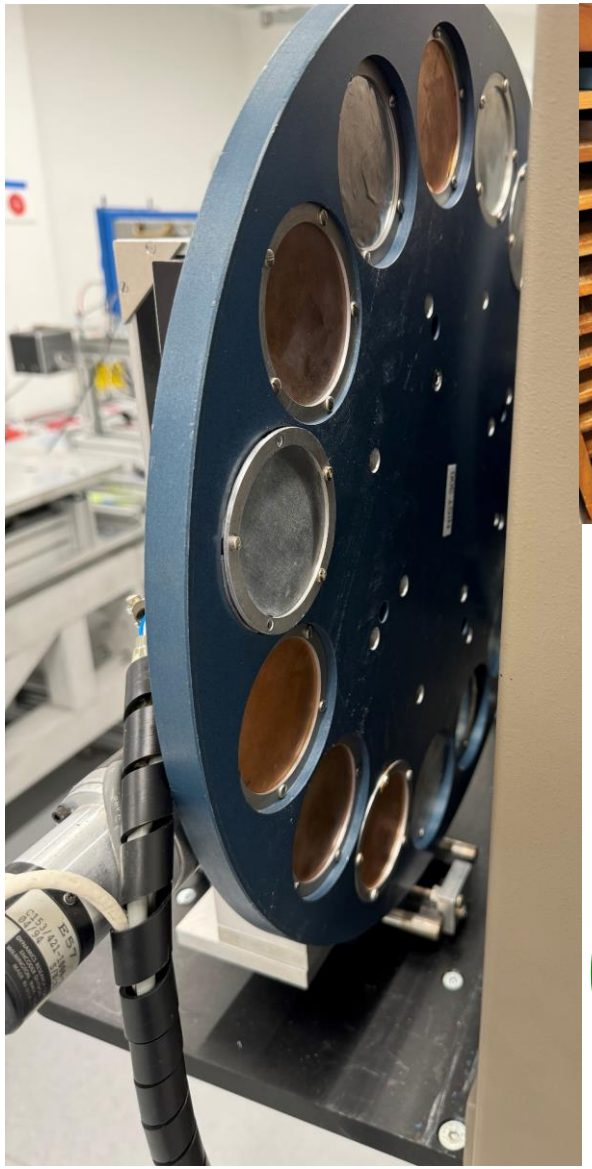
NIST MQSA Beam Parameters



CIRMS History: 1994 MPD A.1

Beam code	Tube voltage (kV)	Filtration (mm)	Half-value layer (mm Al)
Mo Anode			
Mo/Mo23	23	0.032 Mo	0.288
Mo/Mo25	25	0.032 Mo	0.313
Mo/Mo28	28	0.032 Mo	0.346
Mo/Mo30	30	0.032 Mo	0.370
Mo/Mo35	35	0.032 Mo	0.404
Mo/Rh28	28	0.029 Rh	0.420
Mo/Rh32	32	0.029 Rh	0.453
Mo/Mo25x	25	0.030 Mo + 2.0 Al	0.551
Mo/Mo28x	28	0.030 Mo + 2.0 Al	0.589
Mo/Mo30x	30	0.030 Mo + 2.0 Al	0.633
Mo/Mo35x	35	0.030 Mo + 2.0 Al	0.715
Rh Anode			
Rh/Rh25	25	0.029 Rh	0.351
Rh/Rh30	30	0.029 Rh	0.438
Rh/Rh35	35	0.029 Rh	0.512
Rh/Rh40	40	0.029 Rh	0.559
Rh/Rh30x	30	0.029 Rh + 2.0 Al	0.814
Rh/Rh35x	35	0.029 Rh + 2.0 Al	0.898

NIST H Series Beam Parameters



Beam code	Additional filtration				Half-value layer (HVL)	
	Al (mm)	Cu (mm)	Sn (mm)	Pb (mm)	Al (mm)	Cu (mm)
H10	0.105				0.051	
H15	0.5				0.16	
H20	1.01				0.36	
H30	4.50				1.2	
H40	4.53	0.26			2.93	
H50	4.0			0.1	4.16	0.14
H60	4.0	0.61			6.06	0.25
H100	4.0	5.2			13.51	1.15
H150	4.0	4.0	1.51		16.93	2.43
H200	4.0	0.6	4.16	0.77	19.72	4.1
H250	4.0	0.6	1.04	2.72	21.59	5.19
H300	4.1		3.0	5.0	23.55	6.19

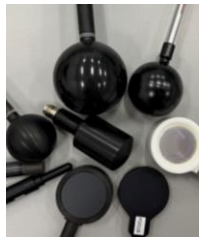
CIRMS History:
1998 MPD A.5
M80 and M120
diagnostic x-ray

Beam Series
NIST L, M, & H
ISO 4037
CCRI – BIPM
Mammography: (Mo/Mo, Mo/Rh, Rh/Rh)
Mammography with W/ (Ag, Mo, Rh, Al)

REPORT OF AIR-KERMA CALIBRATION

OF

Customer Name
Customer Address
Chamber Model and SN



Calibration Conditions

Chamber orientation: The cavity was positioned in the center of the beam with the stem of the chamber perpendicular to the beam direction.

Chamber potential: 500 volts was applied to the chamber and negative charge was collected.

Chamber rotation: The high voltage wire faced the source of radiation.

Background current: The background current is less than 0.01 % of the exposure current.

Current ratio: The current ratio at the full to half collection potential is 1.003 using the S60 beam.

Calibration date: Date range

Temperature range: 294.2 K (21.1 °C) to 294.6 K (21.5 °C) ***Pressure range:*** 99.8 kPa to 100.1 kPa

RESULTS

Beam Code	Half-Value Layer		Calibration Coefficient (Gy/C) at 295.15 K (22 °C) and 101.325 kPa (1 Atm)	Air-Kerma Rate (Gy/s)	Beam Diameter (cm)	Calibration Distance (cm)
	mm Al	mm Cu				
M150	10.30	0.66	1.034E+06	4.48E-04	10	100
M200	14.73	1.64	1.042E+06	4.98E-04	10	100
M300	21.77	5.3	1.058E+06	1.84E-04	10	100
S60	2.81	0.09	1.037E+06	3.82E-04	10	100

Expanded, Combined Uncertainty, in Percent

Beam Code	Air-Kerma Rate (Gy/s)	Calibration Coefficient (Gy/C)
M150	0.91	0.93
M200	0.92	0.94
M300	0.92	0.95
S60	0.92	0.94

The results relate only to the instrument calibrated in this report.

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Dosimetry Group Number DG:12345-YR
NIST ID 46011C Order Number: 682.02/O-0000012345
Report Date: MM/DY/YR
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X-ray air kerma uncertainties

Components	Type A	Type B
Primary standard		
air density	0.01	0.07
FAC stdev charge	0.02	0.06
humidity		0.03
volume	0.04	0.01
g		0.02
W/e (ICRU90)		0.35
ICRU90 kiikw		0.05
air attenuation, k_a	0.05	0.02
electric field distortion		0.20
electron loss, k_e		0.10
penetration of aperture		0.04
penetration of chamber face		0.01
polarity difference	0.05	
recombination loss, k_s	0.10	
fluorescence k_{fl}		0.03
scattered photons, k_p		0.07
quadratic sum	0.13	0.44
combined standard uncertainty	0.46	
FAC expanded uncertainty	0.92	
Test Chamber		
air kerma rate	0.13	0.44
air density	0.01	0.07
Test stdev charge	0.06	0.06
distance	0.01	
humidity		0.03
radiation background		
quadratic sum	0.14	0.45
combined standard uncertainty	0.47	
Test expanded uncertainty	0.94	

Calibration: chamber ships to NIST

NIST delivers calibration report with a Calibration Coefficient (Gy/C) and uncertainty to customer.

REPORT OF PROFICIENCY TEST
FOR AIR-KERMA CALIBRATIONS

OF

Customer Name
Customer Address

Radiation Detection Chamber: NIST chamber Model and SN

Participant's Calibration Conditions as reported by Participant

Calibration distance:
Chamber orientation:
Chamber collection potential:
Chamber rotation:
Beam size:
Nominal Air-Kerma rates:
Uncertainty:

Customer provided data

Comparative Results for the NIST Transfer Standard

NIST Beam Code	NIST Calibration Coefficient 295.15 K (22 °C) and 101.325 kPa (1 Atm) (Gy/C)	Participant Calibration Coefficient 295.15 K (22 °C) and 101.325 kPa (1 Atm) (Gy/C)	Difference in Percent (%)
Mo/Mo23	NIST CC	Customer CC	-0.05
Mo/Mo25	NIST CC	Customer CC	-1.44
Mo/Mo28	NIST CC	Customer CC	-0.60
Mo/Mo30	NIST CC	Customer CC	-1.16
Mo/Mo35	NIST CC	Customer CC	0.33

FDA MQSA
Calibration: +/-6 %
PT: +/- 3 %
2-year frequency

Dosimetry Group Number DG:12345-YR
NIST ID 46050S Order Number: 682.02/O-0000012345-YR
Report Date: MM/DY/YR
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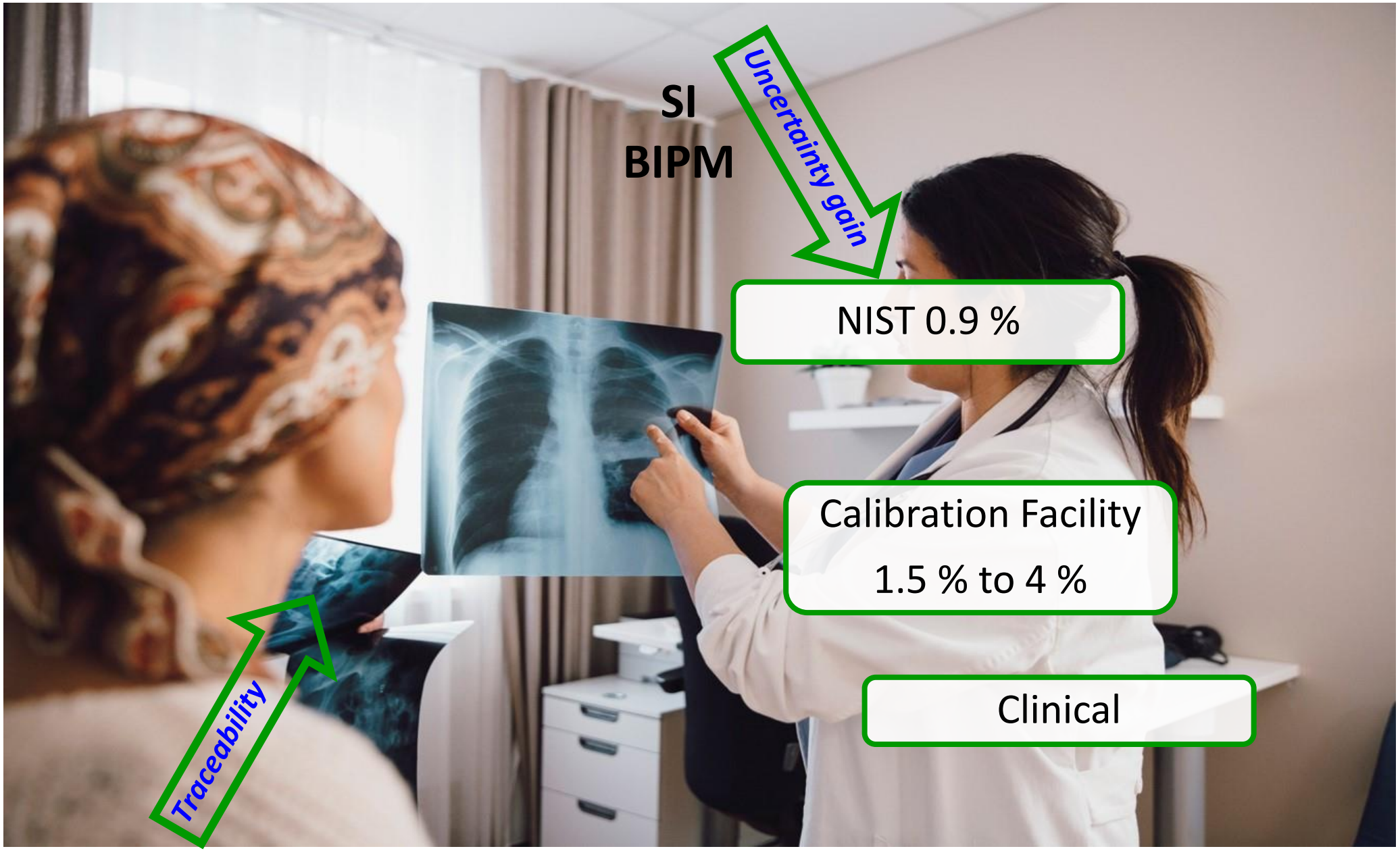
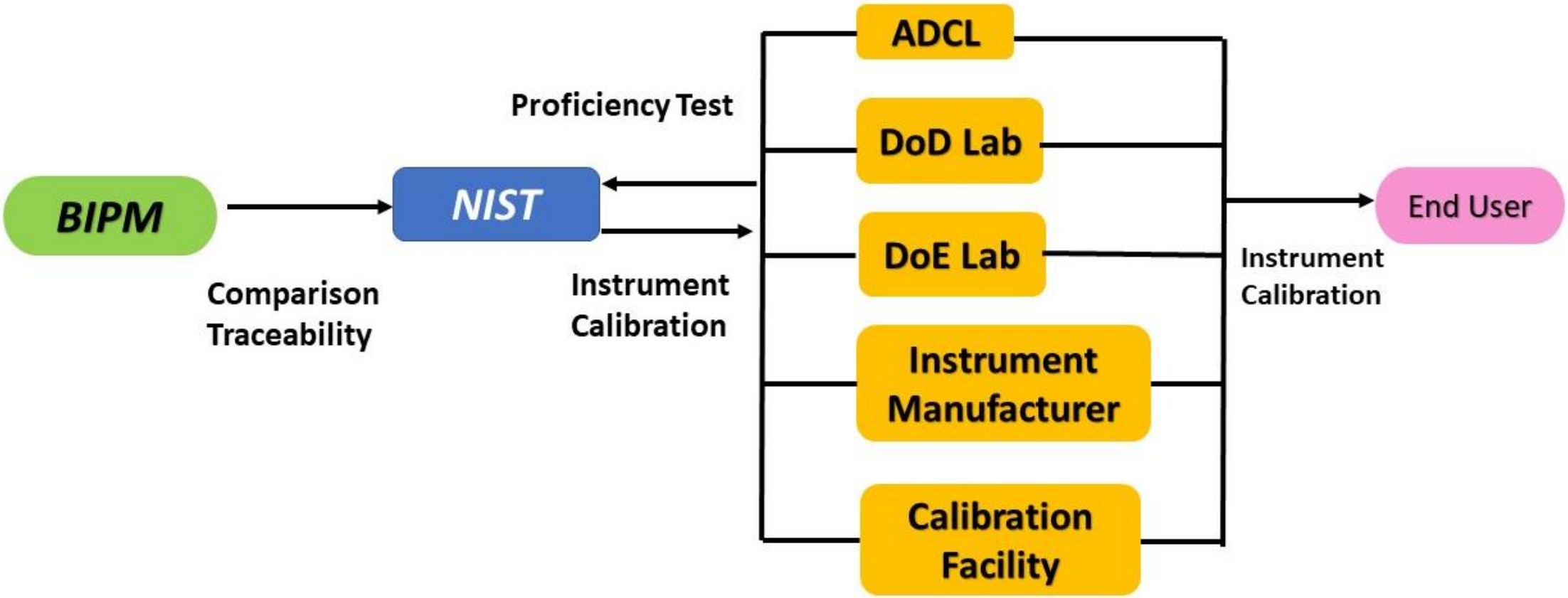
NIST technical support for the Mammography Quality Standards Act (MQSA)

Quantity	MQSA Final Regulation Citation	Regulation or Action Levels		NIST Support
Beam quality (HVL)	900.12(*e*)(5)(*iv*)	Operating Voltage (kV)	Minimum HVL (mm Al)	17 reference beam qualities between 23 kVp and 40 kVp
		20	0.20	
		25	0.25	
		30	0.30	
Dose	900.12(*e*)(5)(*vi*)	**Cannot exceed 3.0 mGy (0.3 rad) per exposure**		Air-kerma calibration
Instrument calibration	900.12(*e*)(12)	Instruments used by medical physicists in their annual survey to measure the air kerma or air kerma rate from a mammography unit shall be calibrated at least once every 2 years and each time the instrument is repaired. The **instrument calibration** must be traceable to a national standard and calibrated with an accuracy of ±6 percent (95 percent confidence level) in the mammography energy range.		Air-kerma calibration and technical support to calibration facilities
Radiation output	900.12(*e*)(5)(*x*)	**Minimum output of 4.5 mGy/s** using Mo/Mo28 at any SID where the system is designed to operate with the detector center located 4.5 cm above the breast support surface with compression paddle in between. After October 28, 2002, the system, under the same measuring conditions shall be capable of producing a minimum output of 7.0 mGy/s.		Air-kerma calibration
Traceability	900.2(*xx*)	Instrument must be calibrated at either NIST or at a calibration laboratory that participates in a **proficiencytest** with NIST at least once every 2 years and the agreement must be within **+/- 3 %** of the NIST value.		NIST proficiency test
KVp	900.12(e)(5)*ii*	**Cannot exceed +/- 5% of indicated kVp**		Proposed calibration service

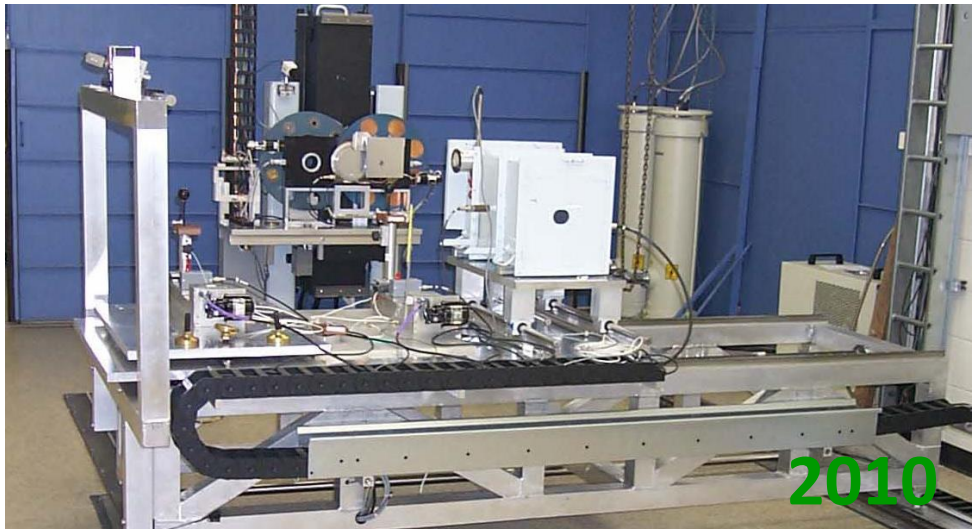


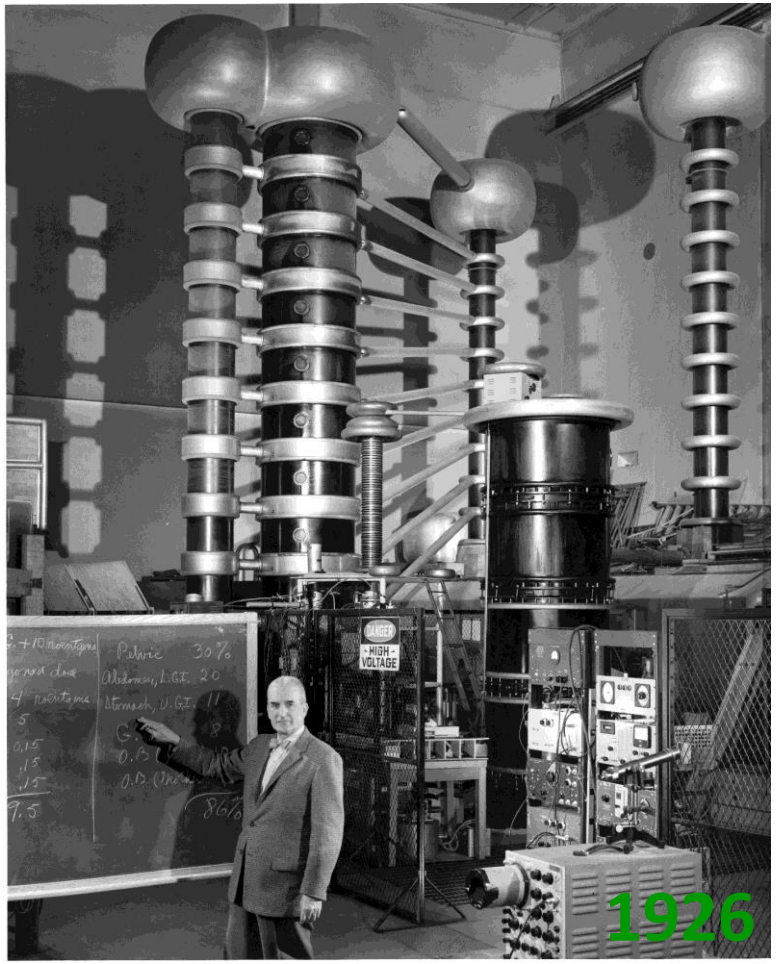
A calibration provides traceability.
A proficiency test demonstrates ability to transfer air kerma but requires a linking calibration.

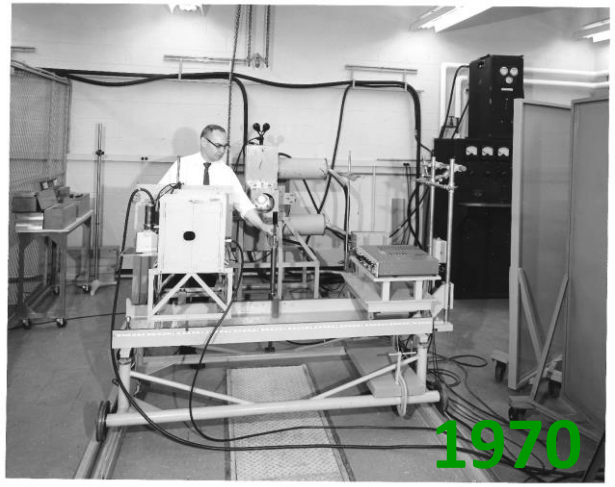
Measurement Traceability for X-Ray Air-Kerma

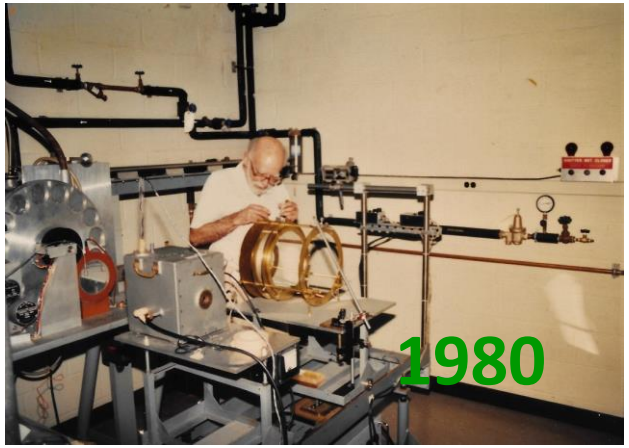


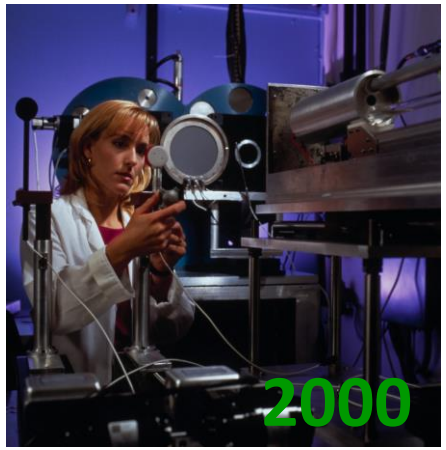
X-ray Air-Kerma Calibration Capabilities over the decades











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