NIST Traceability

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Ionizing Radiation Division

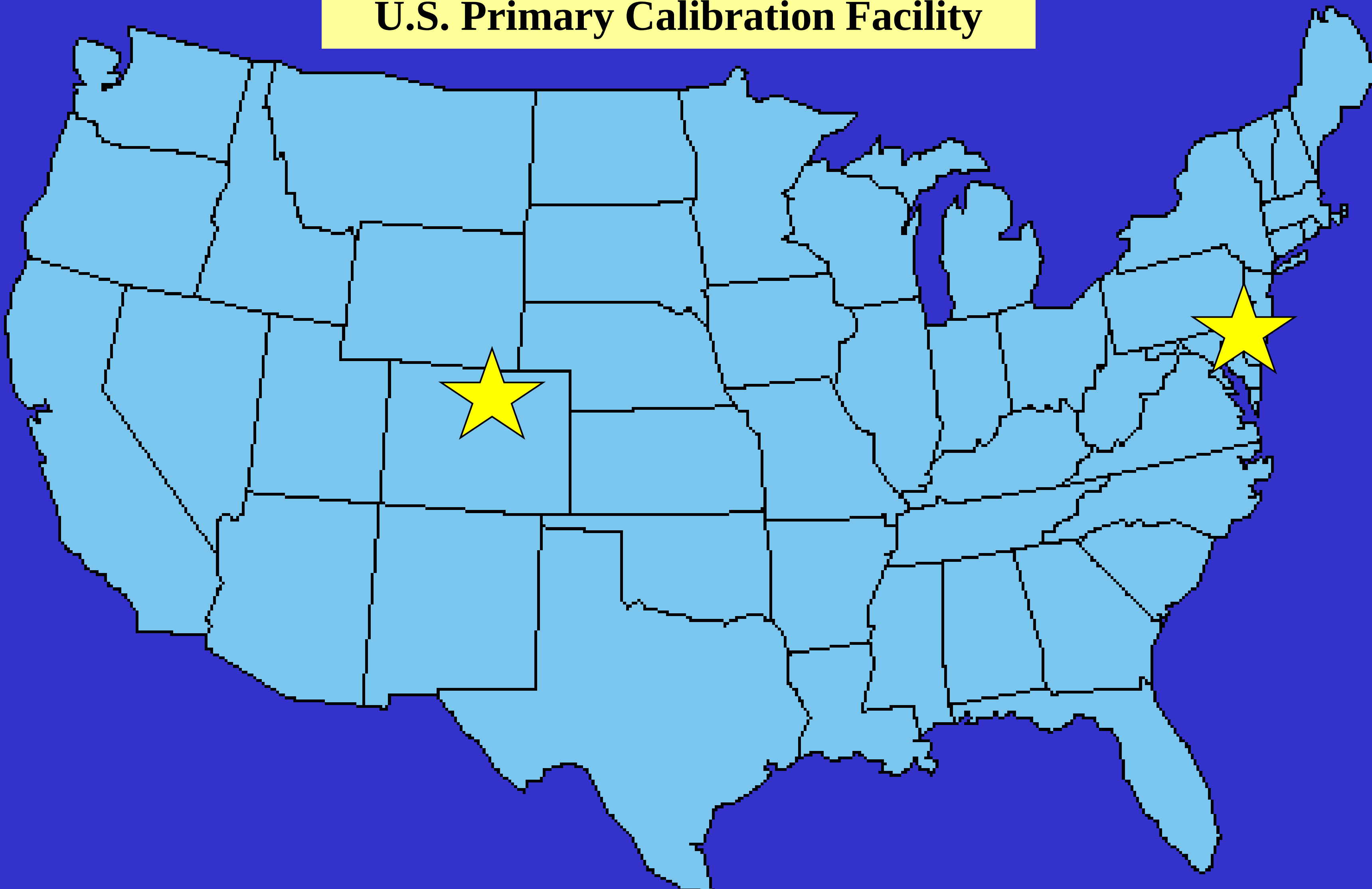
Physical Measurement Laboratory

National Institute of Standards and Technology (NIST)

Calibration Network

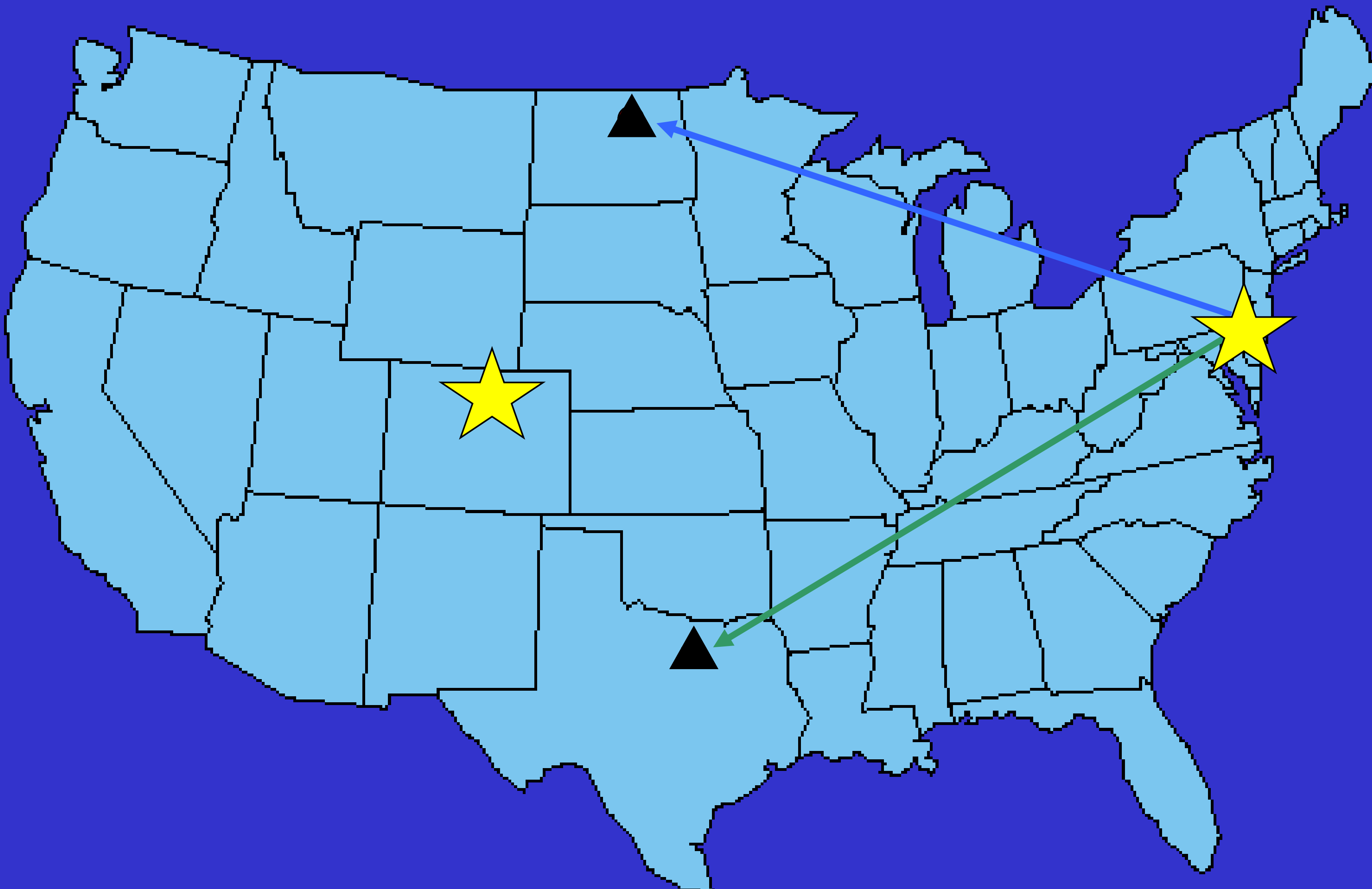
NIST

U.S. Primary Calibration Facility



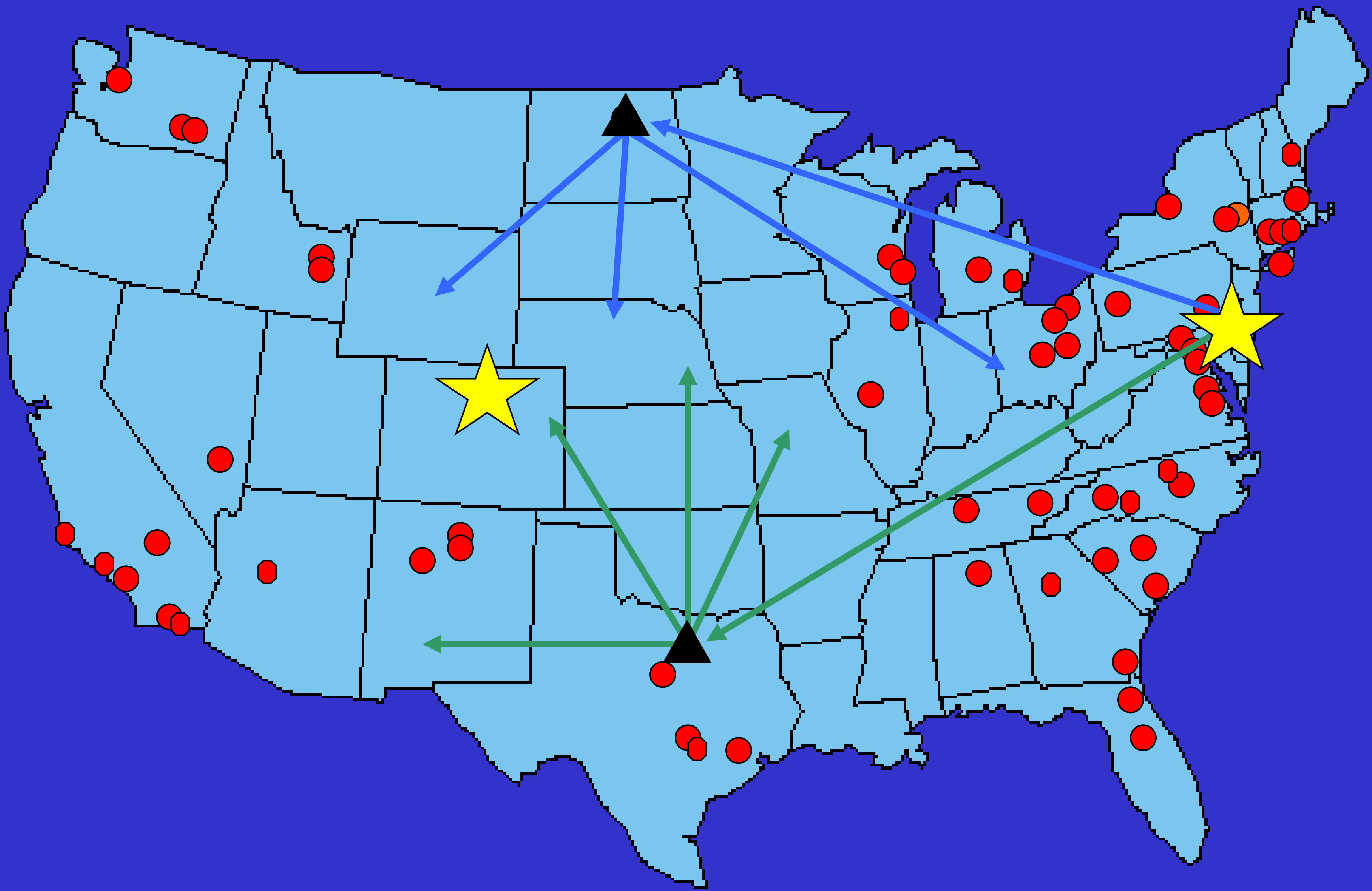
Calibration Network

Secondary Calibration Facilities



Calibration Network

End Users



NIST Policy on Metrological Traceability

- “Property of a measurement result whereby the result can be related to a reference through a documented unbroken chain of calibrations, each contributing to the measurement uncertainty."

International Vocabulary of Metrology - Basic and General concepts and Associated Terms (VIM), definition 2.41

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- Establishes metrological traceability of the results of its own measurements and of results provided to customers in NIST calibration and measurement certificates, operating in accordance with the NIST Quality System for Measurement Services.

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- Establishes metrological traceability of the results of its own measurements and of results provided to customers in NIST calibration and measurement certificates, operating in accordance with the NIST Quality System for Measurement Services.

- Asserts that providing support for a claim of metrological traceability of the result of a measurement is the responsibility of the provider of that result, whether that provider is NIST or another organization; and that assessing the validity of such a claim is the responsibility of the user of that result.

Dosimetry Traceability Chain

Primary Standard Dosimetry Laboratory — **PSDL**

$$D_{\mathrm{w}}$$

↓

Secondary Standard Dosimetry Laboratory — **SSDL**

$$\left(\frac{D_{\mathrm{w}}}{Q}\right)_{SSDL}$$

↓

User

$$D_{\mathrm{w}}^{User} = Q^{User}\left(\frac{D_{\mathrm{w}}}{Q}\right)_{SSDL}$$

$$D_w = 14.28 \text{ mGy}$$

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$$D_w = (14.28 \pm 0.12) \text{ mGy}$$

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Uncertainty Component	**Type A (%)**	**Type B (%)**
Heat defect		0.30
Reproducibility of measurement groups	0.15	
Beam attenuation from glass wall		0.10
Beam attenuation from calorimeter lid	0.05	
Field size		0.23
Vessel positioning		0.02
Thermistor calibration		0.01
Water density		0.02
Quadratic sum	0.16	0.39
Relative combined standard uncertainty	0.42 %	
Relative expanded uncertainty (k = 2)	0.84 %	

Strategic Element

Develop dosimetric standards for x rays, gamma rays, and electrons based on the SI unit, the gray, for homeland security, medical, radiation processing, and radiation protection applications.

Strategic Element

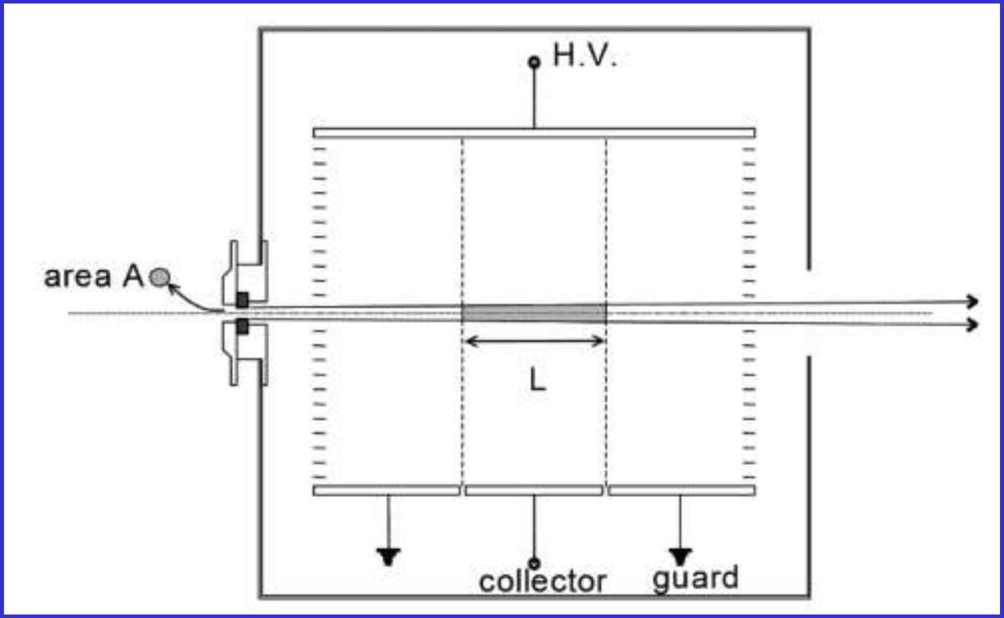
Develop dosimetric standards for x rays, gamma rays, and electrons

based on the SI unit, the gray, 1 Gy ≡ 1 J / kg

kV x rays	MV x rays	gamma rays	electrons
x-ray tube	linac	irradiator	linac, Van de Graaff
radioactive source		(^{60}Co, ^{137}Cs)	radioactive source

Free-Air Ionization Chamber (< 300 keV)

20 keV to 100 keV



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

$$\frac{\text{C}}{\text{kg}} \text{ x } 33.97 \frac{\text{J}}{\text{C}}$$

Air Kerma as Realized by Free-Air Chambers

$$K_{\text{air}} = \frac{Q_{\text{air}}}{\rho_{\text{air}} V} \frac{W_{\text{air}}}{e} \frac{1}{1 - g_{\text{air}}} \prod_i k_i$$

K_{air} is the air kerma at a given distance in air.

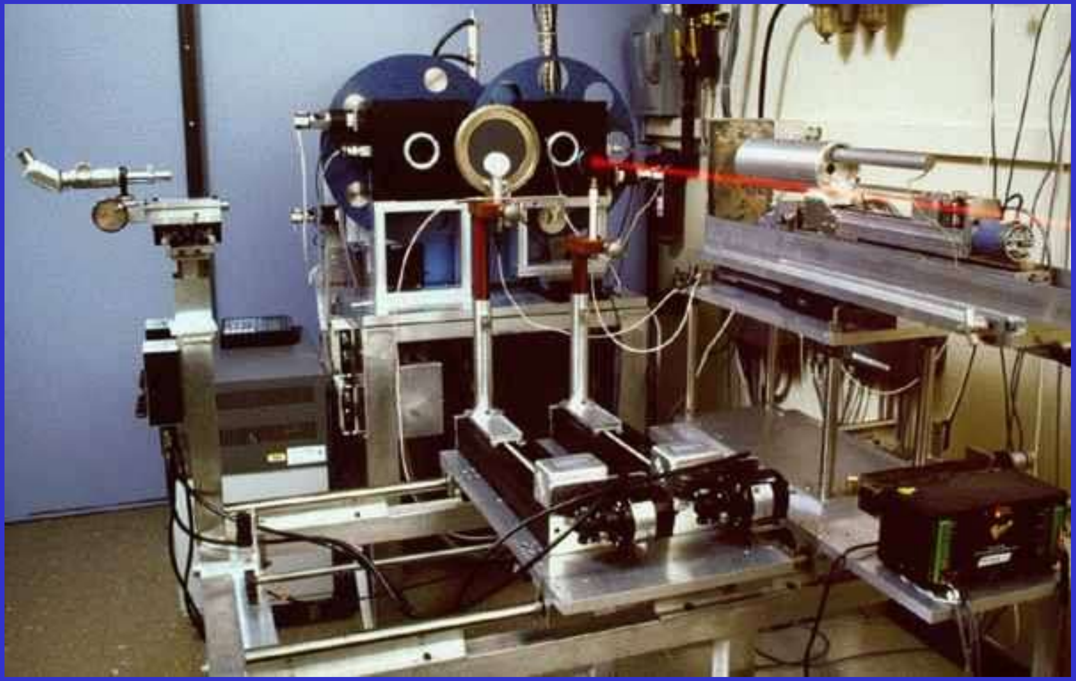
$Q_{\text{air}} / (\rho_{\text{air}} V)$ is the measured charge due to ionization divided by the mass of air in the measuring volume.

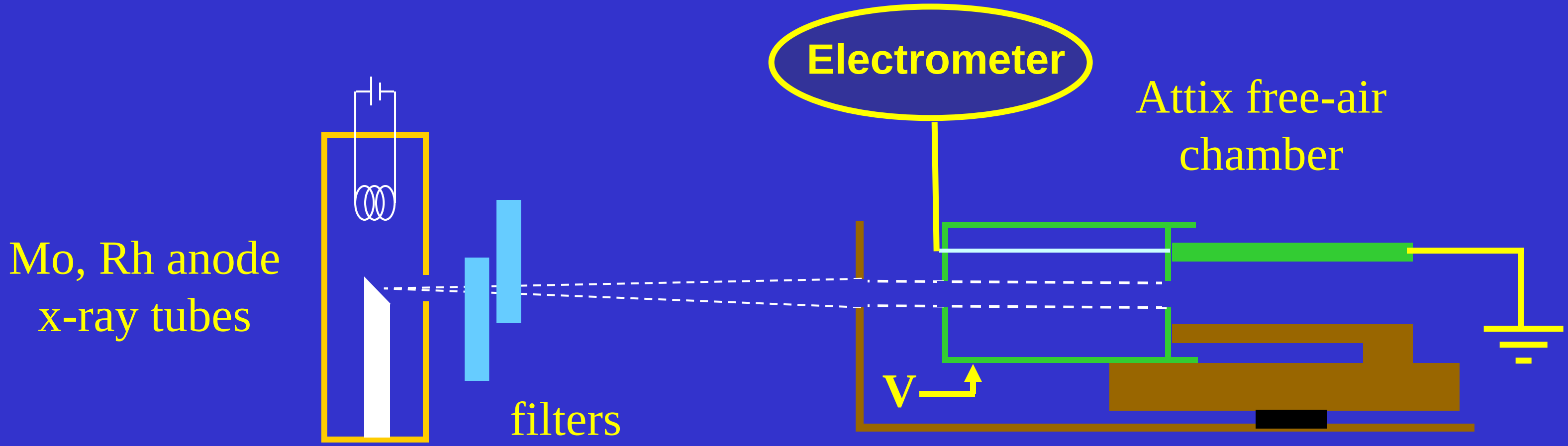
W_{air} is the mean energy expended by an electron of charge e to produce an ion pair in dry air. The value used at NIST is W_{air}/e = 33.97 J/C.

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.

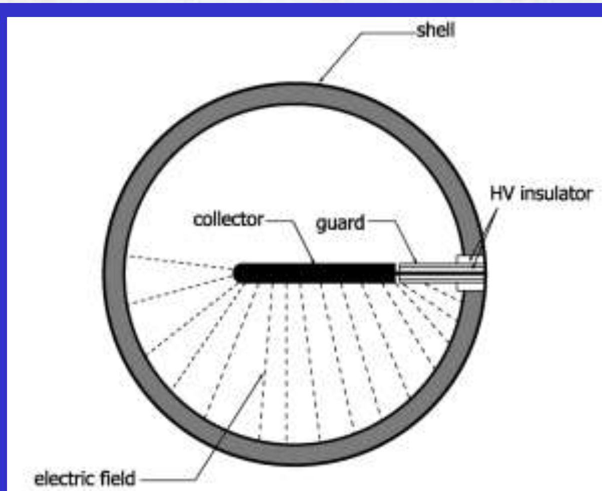
$\Pi\ k_i$ is the product of various correction factors.

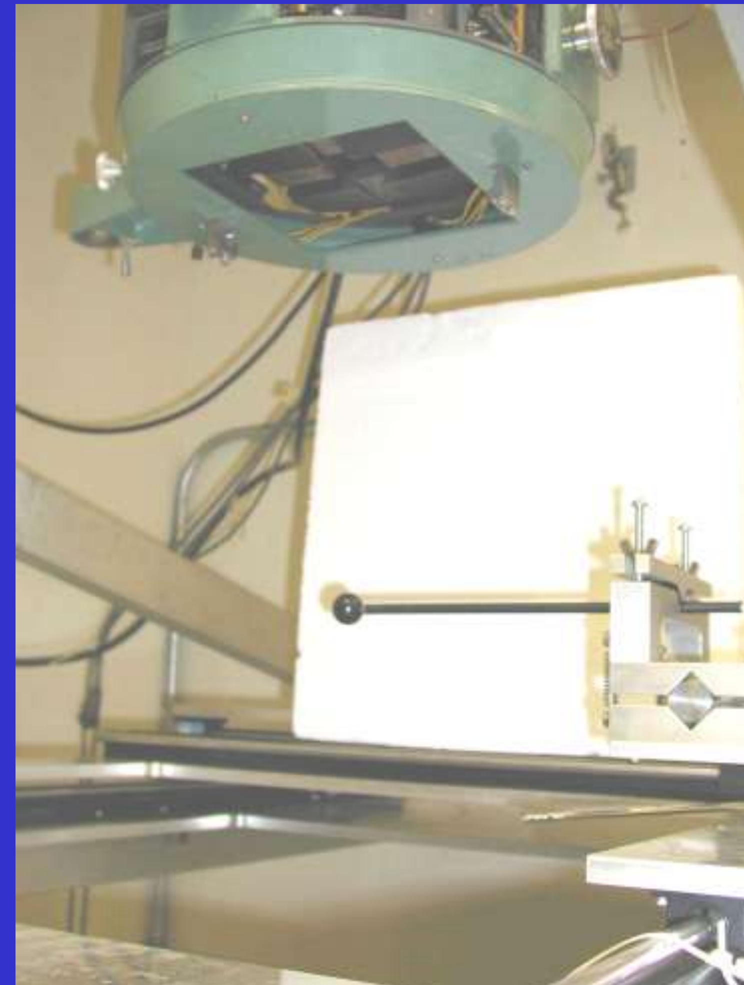
Primary Standard for Mammography X Rays (≤ 50 kV)





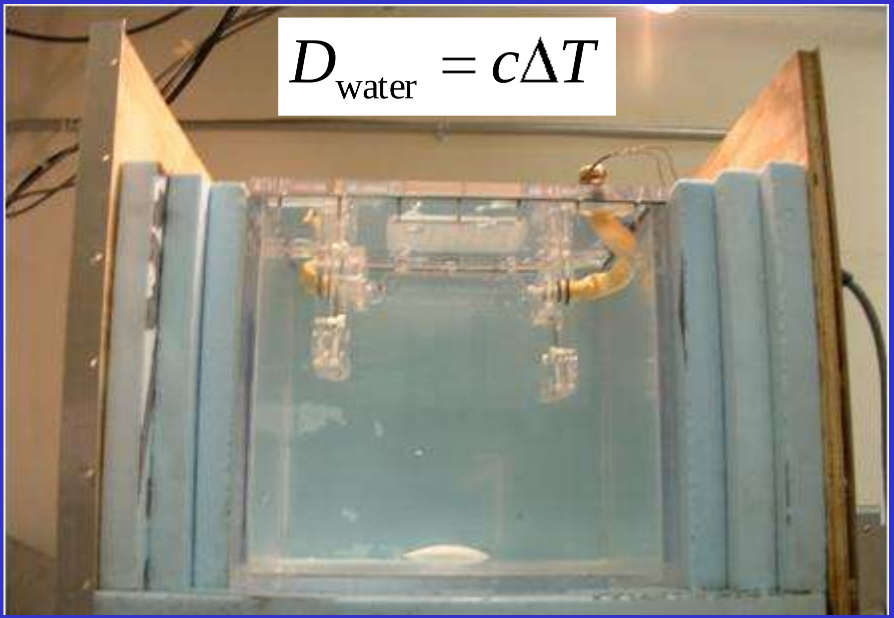
Cavity Ionization Chamber (> 300 keV)

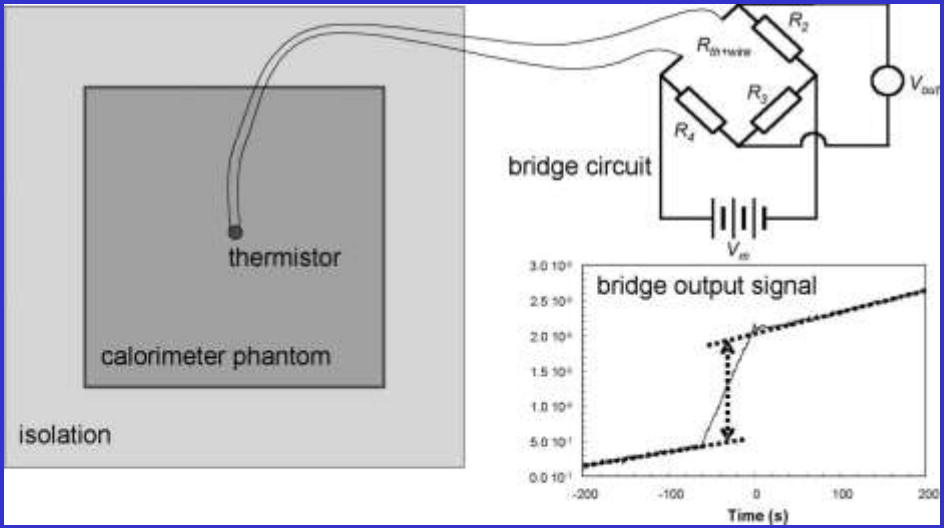




$$K_{air} = \frac{Q_{air}}{\rho_{air} V} \left(\frac{W_{air}}{e} \right) \left(\frac{1}{1-\bar{g}} \right) \left[\frac{(\bar{S}/\rho)_{graphite}}{(\bar{S}/\rho)_{air}} \right] \left[\frac{(\mu_{en}/\rho)_{air}}{(\mu_{en}/\rho)_{graphite}} \right] \prod_i k_i$$

Water Calorimetry (MV photons, electrons)





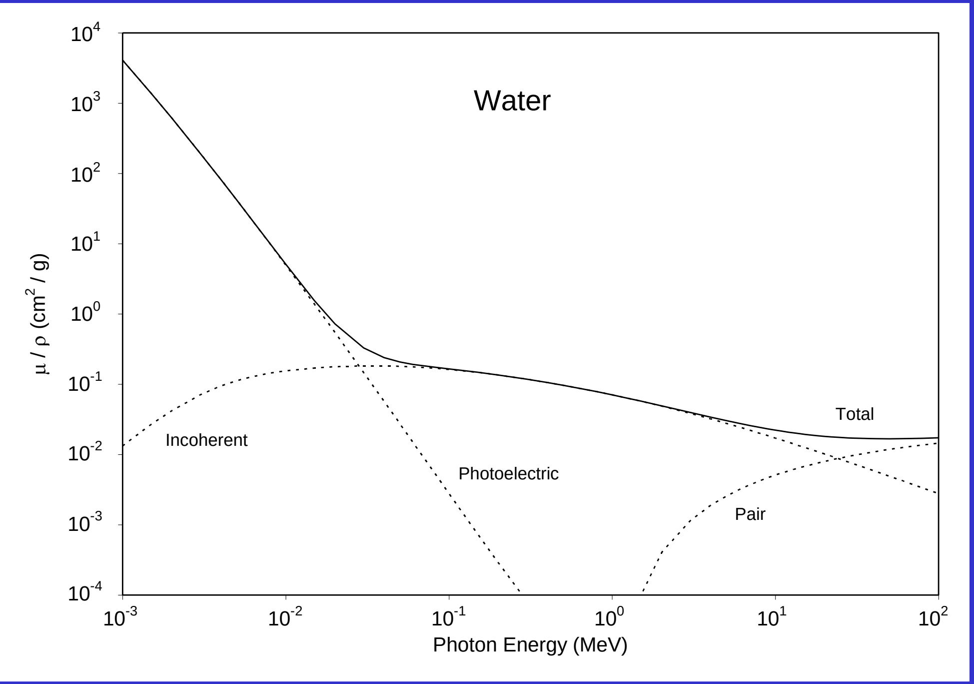
Vessel with thermistors

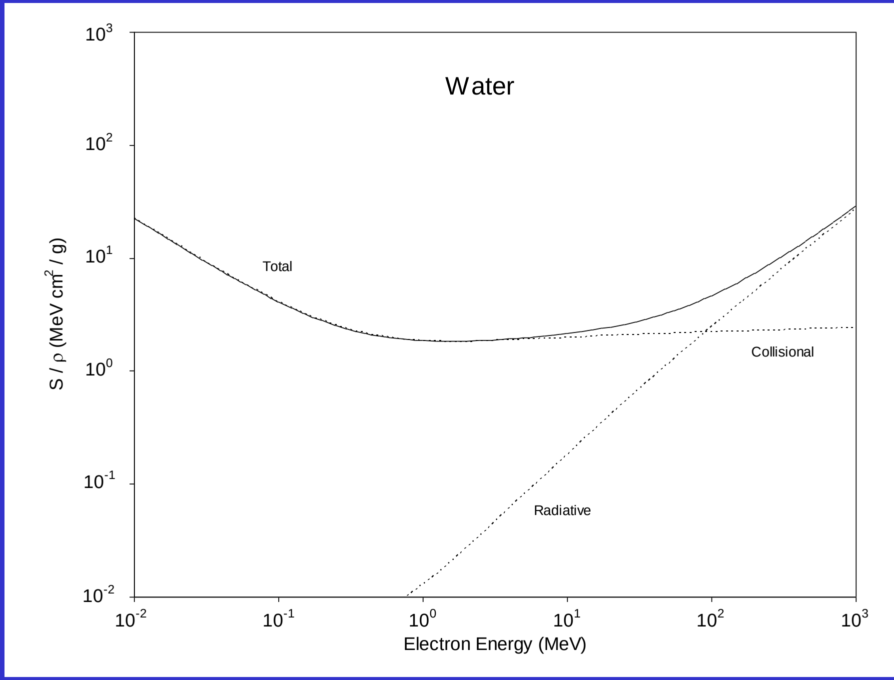
Vessel with an ion chamber

Monte Carlo Simulations

- Photon and electron source modeling
- Detector response calculations
- Ionization chamber correction factors k_{wall}
- Stopping power ratios $\left[\dfrac{(\bar{S}/\rho)_{\mathrm{graphite}}}{(\bar{S}/\rho)_{\mathrm{air}}}\right]$
- Mass-energy absorption coefficient ratios $\left[\dfrac{(\mu_{\mathrm{en}}/\rho)_{\mathrm{air}}}{(\mu_{\mathrm{en}}/\rho)_{\mathrm{graphite}}}\right]$

Photon and Charged-Particle Data Center





$$\frac{\mu}{\rho} = \frac{\sigma_{\text{pe}} + \sigma_{\text{coh}} + \sigma_{\text{incoh}} + \sigma_{\text{pair}} + \sigma_{\text{trip}} + \sigma_{\text{ph.n.}}}{uA}$$

$$\frac{S}{\rho} = \frac{S_{\text{col}}}{\rho} + \frac{S_{\text{rad}}}{\rho}$$

Web-based Photon and Electron Databases

XCOM

XCOM: Photon Cross Sections Database

http://www.nist.gov/pml/data/xcom/index.cfm

Photon Cross Sections Bibliography

http://www.nist.gov/pml/data/photon_cs/index.cfm

estar

stopping-power and range tables for electrons

http://physics.nist.gov/PhysRefData/Star/Text/ESTAR.html

How do we know what to do?

- Council on Ionizing Radiation Measurements and Standards (CIRMS)
- Consultative Committee for Ionizing Radiation (CCRI)
- National Academy of Sciences review panel
- Membership in professional societies and committees
- Feedback from colleagues and calibration customers

How do we know that our standards are accurate?

Bureau International des Poids et Mesures (BIPM)

- "The task of the BIPM is to ensure world-wide uniformity of measurements and their traceability to the International System of Units (SI)."
  www.bipm.org

- Calibration and Measurements Capabilities (CMCs)

- Key comparisons between NIST and the BIPM

Calibration and Measurement Capabilities (CMCs)

Quantity	Parameter	Reference Standard	Key Comparison BIPM.RI(I)-	Calibration Service?
Air Kerma	x ray (10 to 50) kV	free-air chamber	K2	Yes
	mammography	free-air chamber	K7	Yes
	x ray (50 to 300) kV	free-air chamber	K3	Yes
	Cs-137	graphite cavity chamber	K5	Yes
	Co-60	graphite cavity chamber	K1	Yes
Absorbed Dose to Water	Co-60	water calorimeter	K4	Yes
	Co-60 (high dose)	water calorimeter	CCRI(I)-S2	Yes
	MV x rays	water calorimeter	K6	No
	Sr-90/Y-90	extrapolation chamber		Yes
Air Kerma Strength	Cs-137 brachy	graphite cavity chamber		Yes
	Ir-192 brachy	graphite cavity chamber		Yes
	HDR Ir-192 brachy		K8	No
	I-125 brachy	WAFAC		Yes
	Pd-103 brachy	WAFAC		Yes
	Cs-131 brachy	WAFAC		Yes

How do we disseminate our standards?

Calibration Services in Radiation Dosimetry at NIST

- X-Ray and Gamma-Ray Measuring Instruments
  - Air kerma - ^{60}Co, ^{137}Cs, x-ray beams
  - Irradiation of passive dosimeters
  - kV measuring devices
  - Absorbed dose to water - ^{60}Co

- Gamma-Ray and Beta-Particle Sources and Measuring Instruments
  - Air kerma strength - photon brachytherapy sources: ^{125}I, ^{103}Pd, ^{131}Cs, ^{192}Ir, ^{137}Cs
  - Absorbed dose to water - beta brachytherapy sources: $^{90}Sr/Y$, $^{106}Ru/Rh$
  - Surface dose rate – $^{90}Sr/Y$, ^{147}Pm, ^{204}Tl sources and extrapolation chambers

- High-Dose Dosimetry
  - Irradiation of dosimeters in high-dose gamma ray fields (^{60}Co)
  - Alanine/EPR dose measurements

How do we disseminate our standards?

Secondary Standard Dosimetry Laboratory (SSDL)

- Accredited laboratory that provides NIST-traceable dosimetry calibrations to end users

- An example: Accredited Dosimetry Calibration Laboratories (ADCLs)

  - Accredited by the American Association of Physicists in Medicine (AAPM)

  - Calibrate clinical dosimetry instrumentation and radioactive sources used in medical diagnostic and therapeutic applications of ionizing radiation

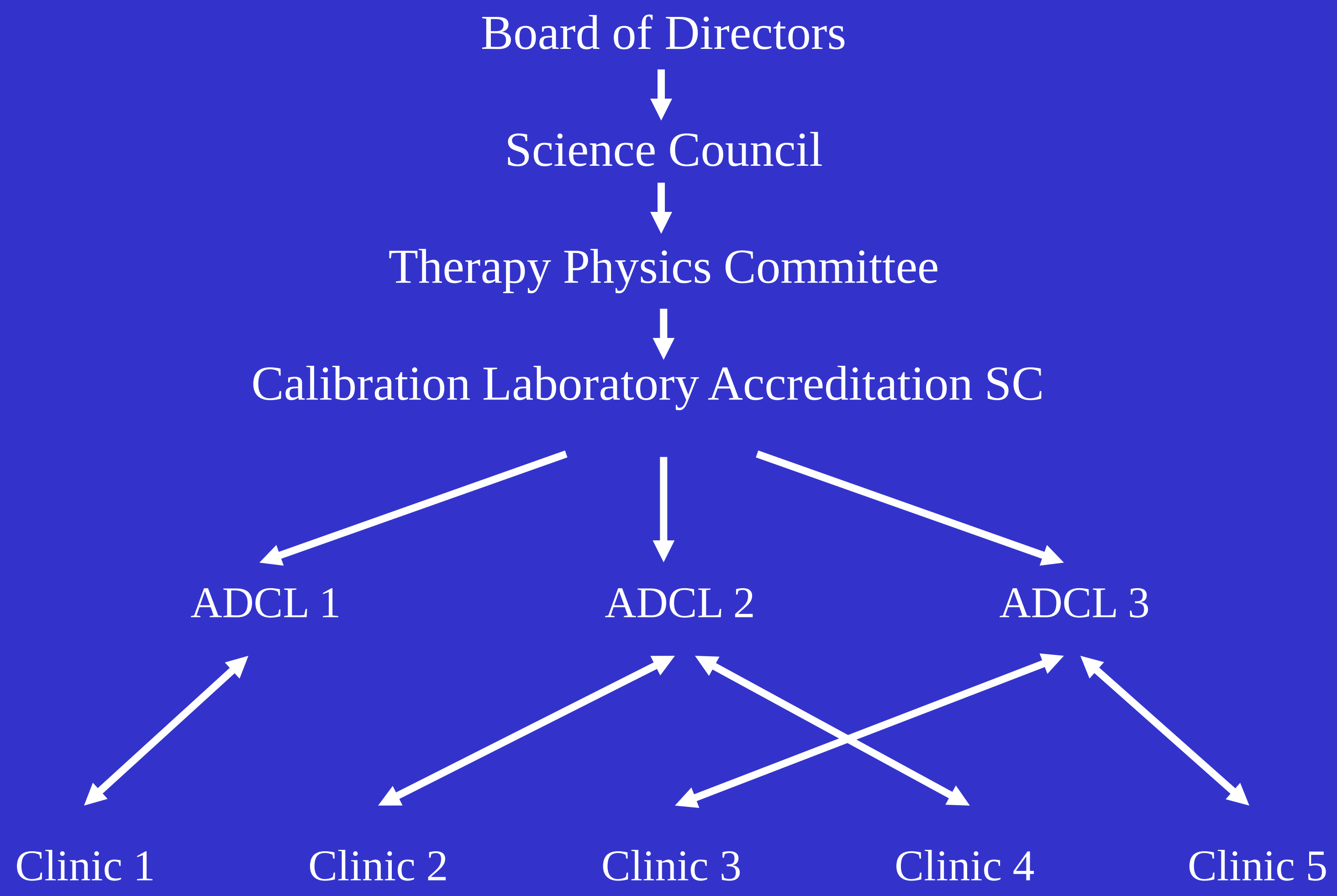
  - Establishment and maintenance of NIST traceability of ADCL calibrations overseen by the Calibration Laboratory Accreditation (CLA) Subcommittee

CLA Criteria – Traceability to NIST

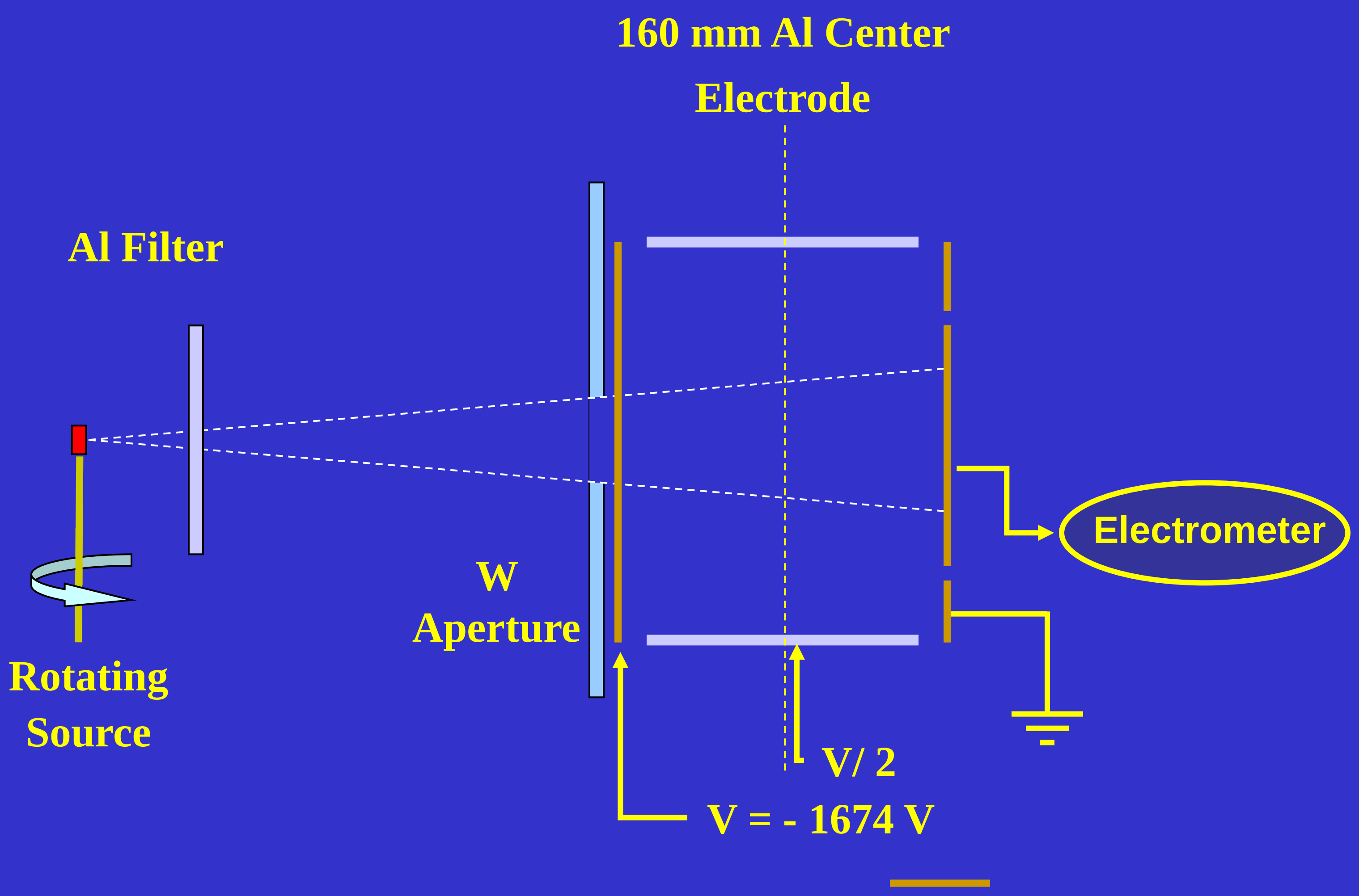
The only type of laboratory accredited by the AAPM is a secondary standard laboratory with the capability of providing direct traceability to the National Institute of Standards and Technology (NIST). Such a laboratory is referred to as an Accredited Dosimetry Calibration Laboratory (ADCL).

A3.6.1.6 Calibration traceability to NIST dosimetry standards shall be maintained by participation in NIST measurement quality assurance tests and in ADCL intercomparisons at intervals prescribed by the Subcommittee.

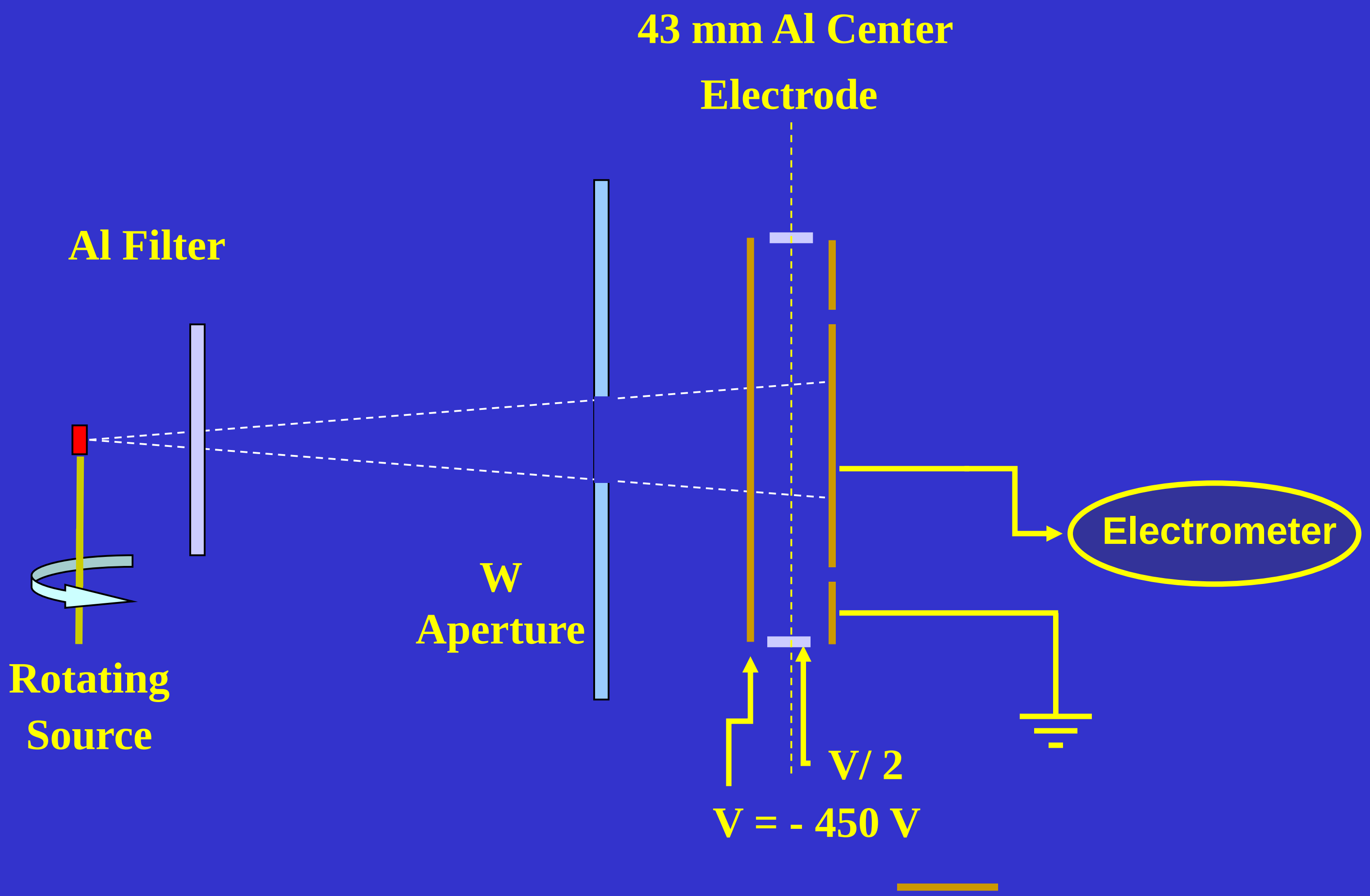
AAPM


Board of Directors
Science Council
Therapy Physics Committee
Calibration Laboratory Accreditation SC
ADCL 1
ADCL 2
ADCL 3
Clinic 1
Clinic 2
Clinic 3
Clinic 4
Clinic 5

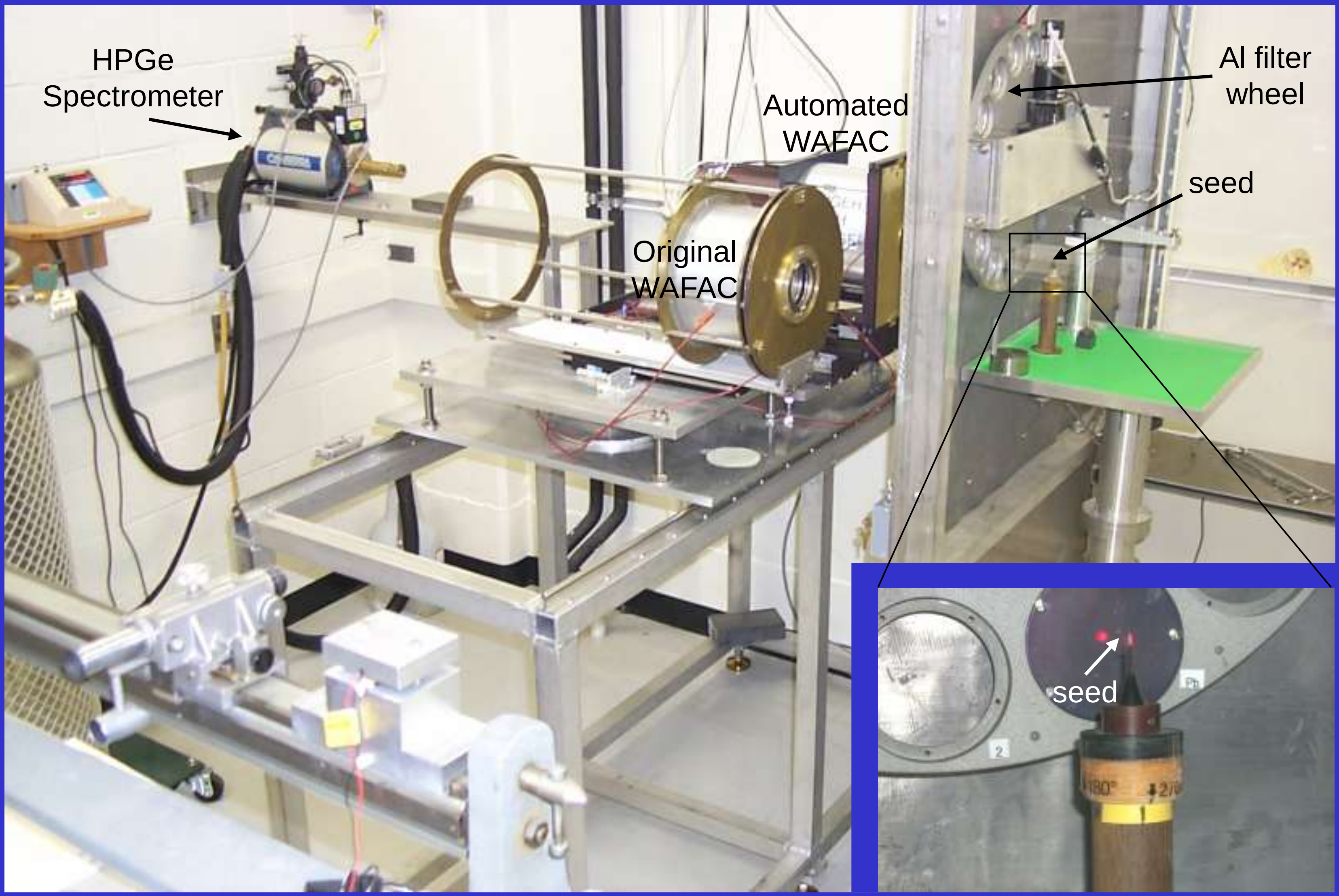
Wide-Angle Free-Air Chamber (WAFAC)



Wide-Angle Free-Air Chamber (WAFAC)



Original and Automated WAFACs

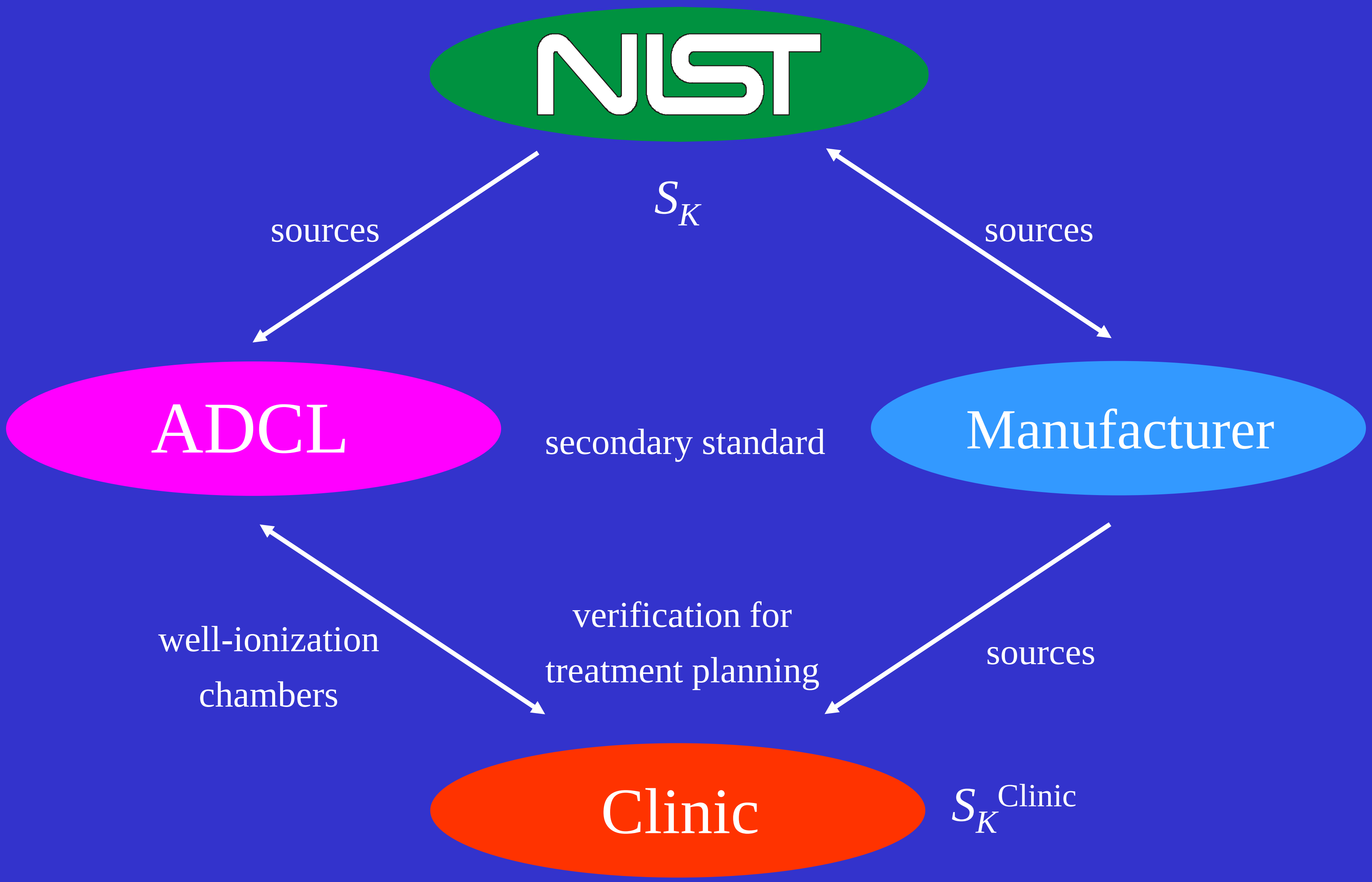


Air Kerma Strength (S_K) Standard for ^{125}I seeds

$$S_K = \dot{K}_{air}(Q)d^2 = \left(\frac{\overline{W}}{e}\right)\left(\frac{d^2}{\rho_{air}V_{eff}}\right)K_{dr}(\dot{K})M_{det}(\dot{K},Q)\prod_i K_i \prod_j K_j(Q)$$

	Value	Type A (%)	Type B (%)
Net current, $M_{\text{det}}(\dot{K},Q)$		s	0.06
$\overline{W}/e$	33.97 J / C	-	0.15
Air density, ρ_{air}	1.196 mg / cm^3	-	0.03
Aperture distance, d		-	0.24
Effective chamber volume, V_{eff}		0.11	0.01
Decay correction, K_1	$T_{1/2}$ = 59.43 d	-	0.02
Recombination, $K_{dr}(\dot{K})$	< 1.004	-	0.05
Attenuation in filter, $K_3(Q)$	1.0295	-	0.61
Air attenuation in WAFAC, $K_4(Q)$	1.0042	-	0.08
Source-aperture attenuation, $K_5(Q)$	1.0125	-	0.24
Inverse-square correction, K_6	1.0089	-	0.01
Humidity, $K_7(Q)$	0.9982	-	0.07
In-chamber photon scatter, $K_8(Q)$	0.9966	-	0.07
Source-holder scatter, K_9	0.9985	-	0.05
Electron loss, K_{10}	1.0	-	0.05
Aperture penetration, $K_{11}(Q)$	0.9999	-	0.02
External photon scatter, $K_{12}(Q)$	1.0	-	0.17
Combined standard uncertainty, u_c		$(s^2 + 0.762^2)^{1/2}$	
Expanded uncertainty, V		$2u_c$	

Measurement Traceability for Brachytherapy Sources



Recommendations of the Calibration Laboratory Accreditation SC:

New source

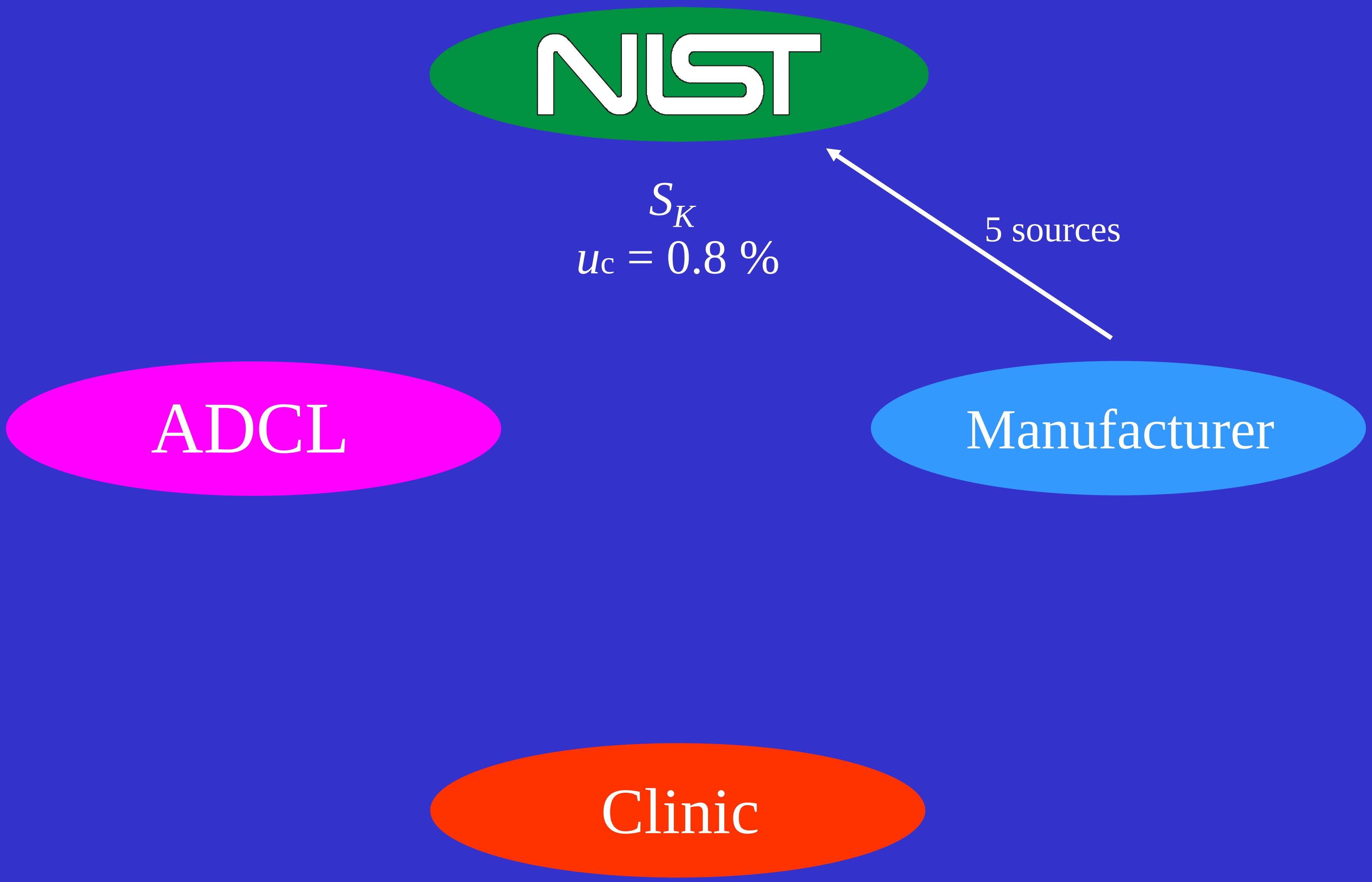
1. 5 sources are sent to NIST for S_K calibration, well chamber measurements (S_K / I), and spectrum analysis

2. If (S_K / I) for each source is within ± 1.00 % of average, 3 sources are sent to the ADCLs, and 2 sources are returned to the manufacturer or sent to a dosimetry investigator for measurement of $\dot{D}(r, \theta)$

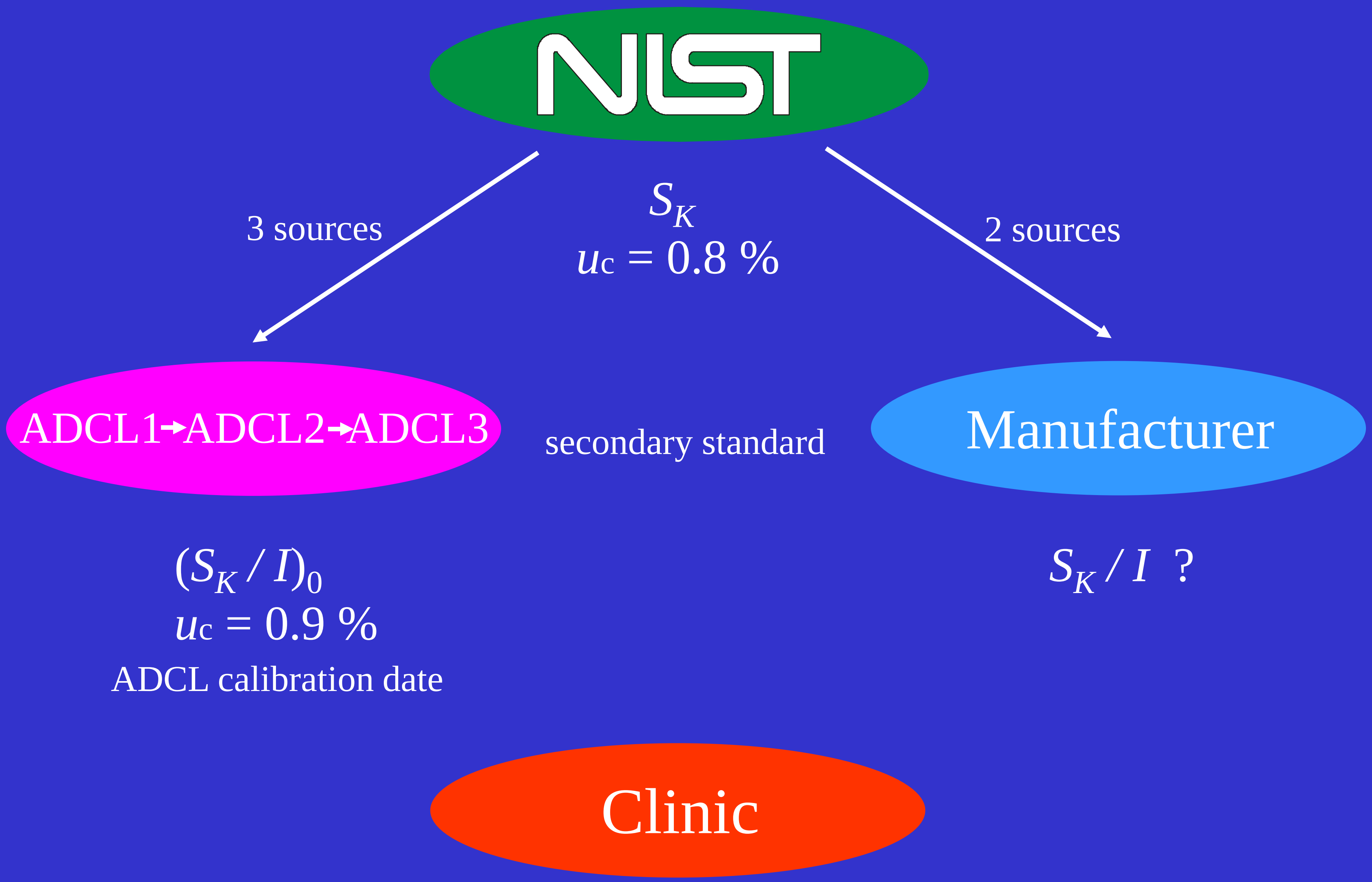
3. If (S_K / I) is out of tolerance for one or more sources, another set of 5 sources is sent by the manufacturer to NIST

ref: Med. Phys. 31 (3), March 2004, pp. 675-681.

Measurement Traceability for Brachytherapy Sources – New Source



Measurement Traceability for Brachytherapy Sources – New Source



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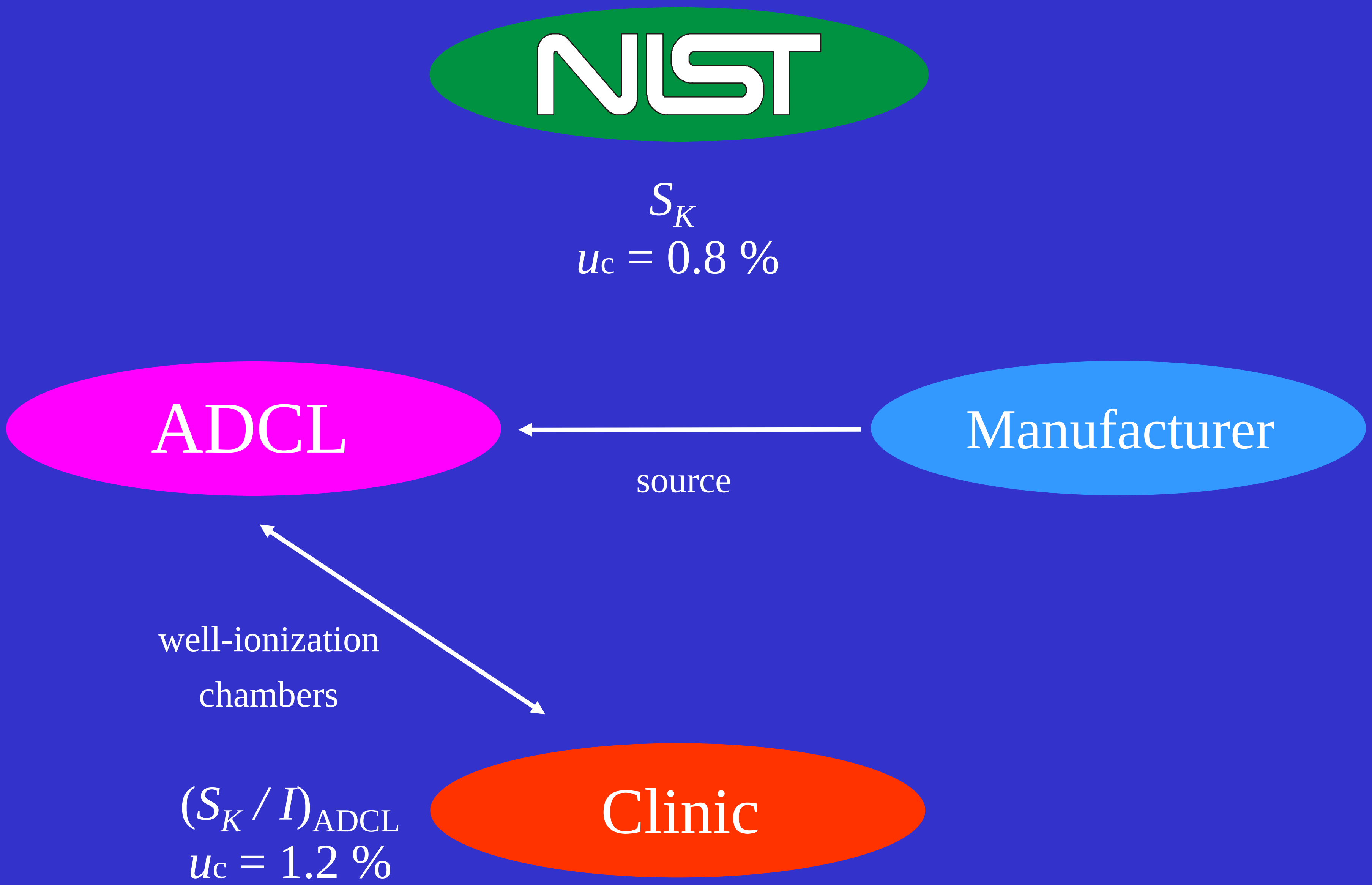

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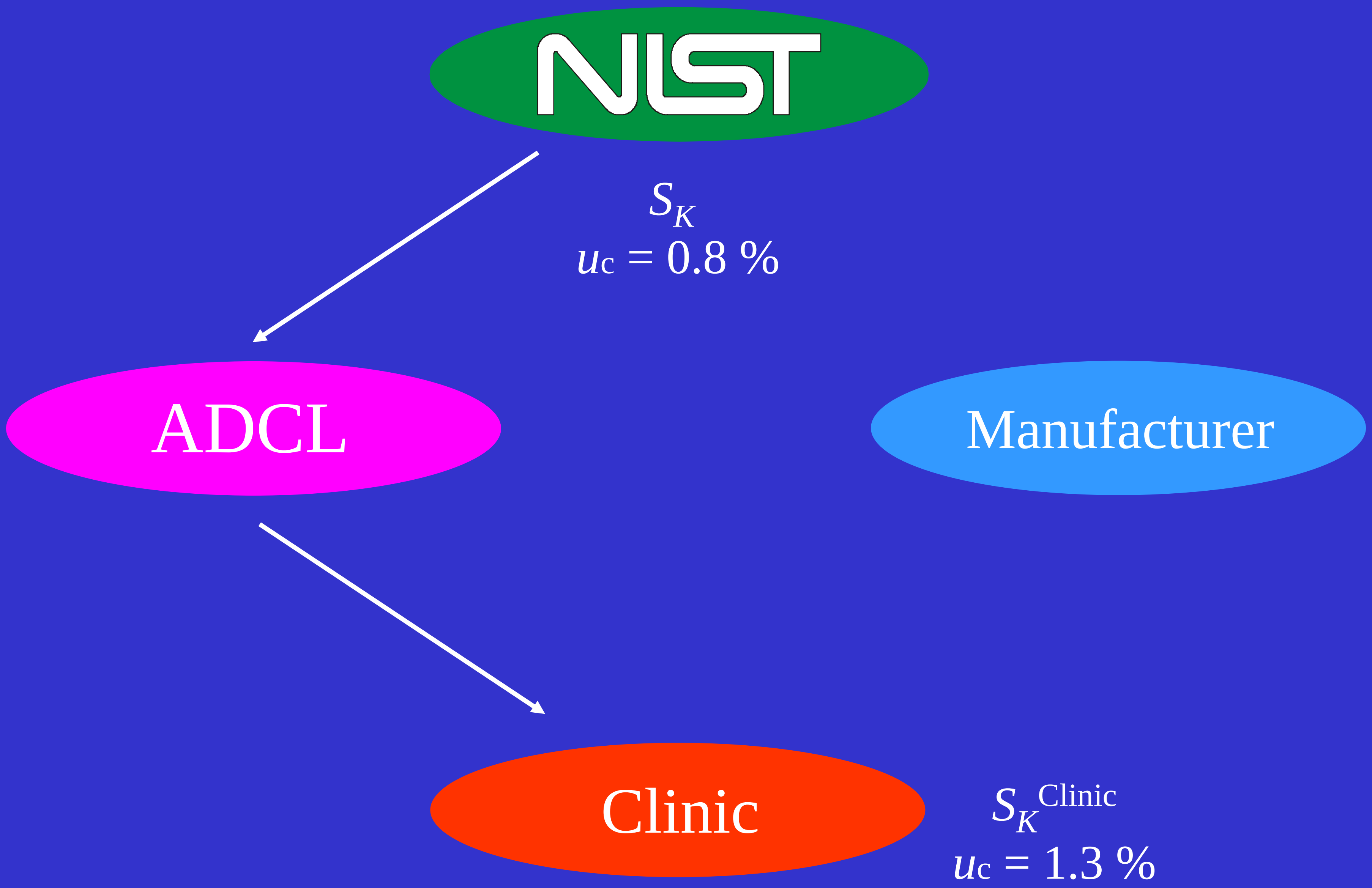
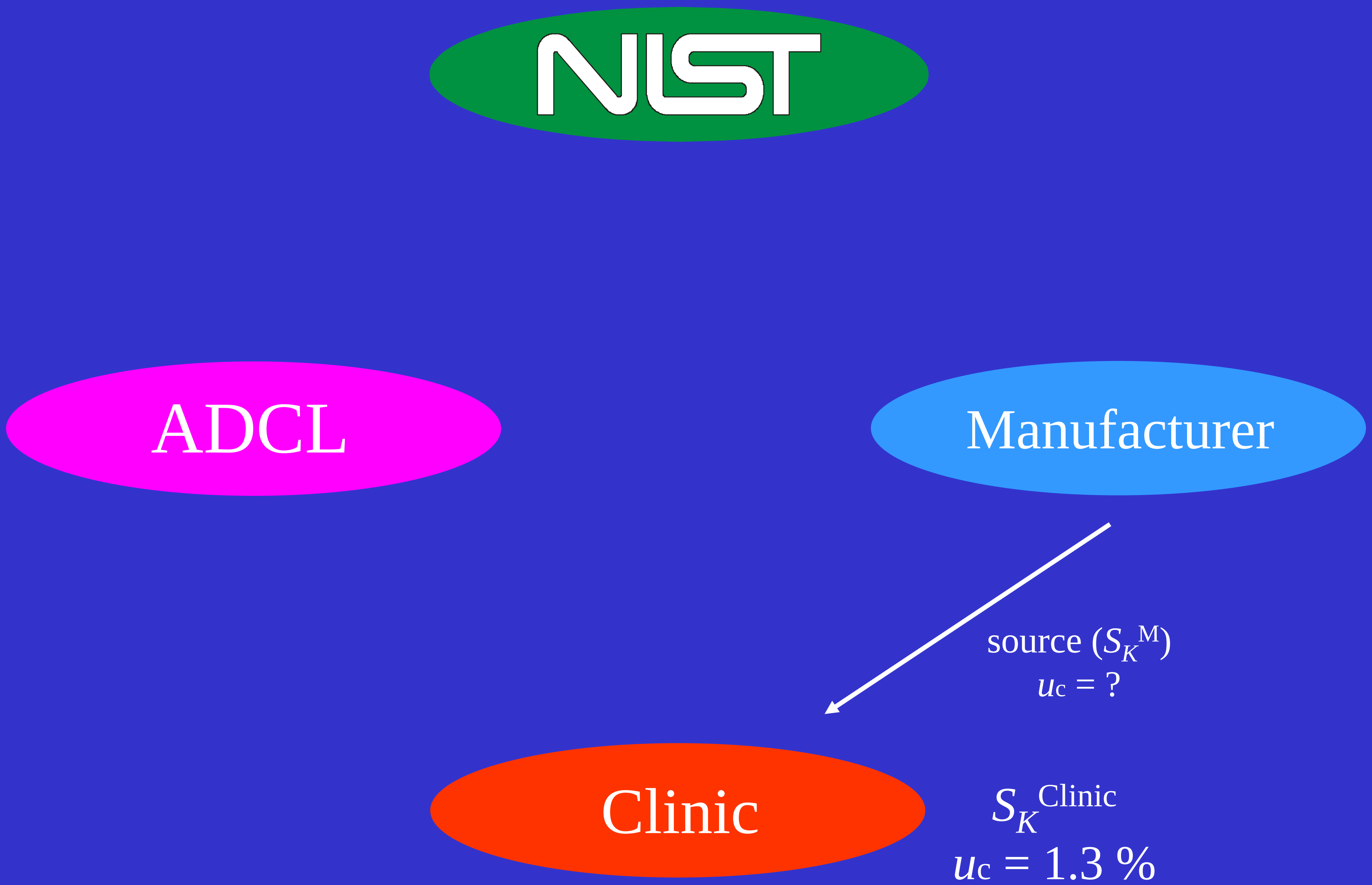


Measurement Traceability for Brachytherapy Sources – New Source



Recommendations of the Calibration Laboratory Accreditation SC:

QA for sources with established NIST S_K standard

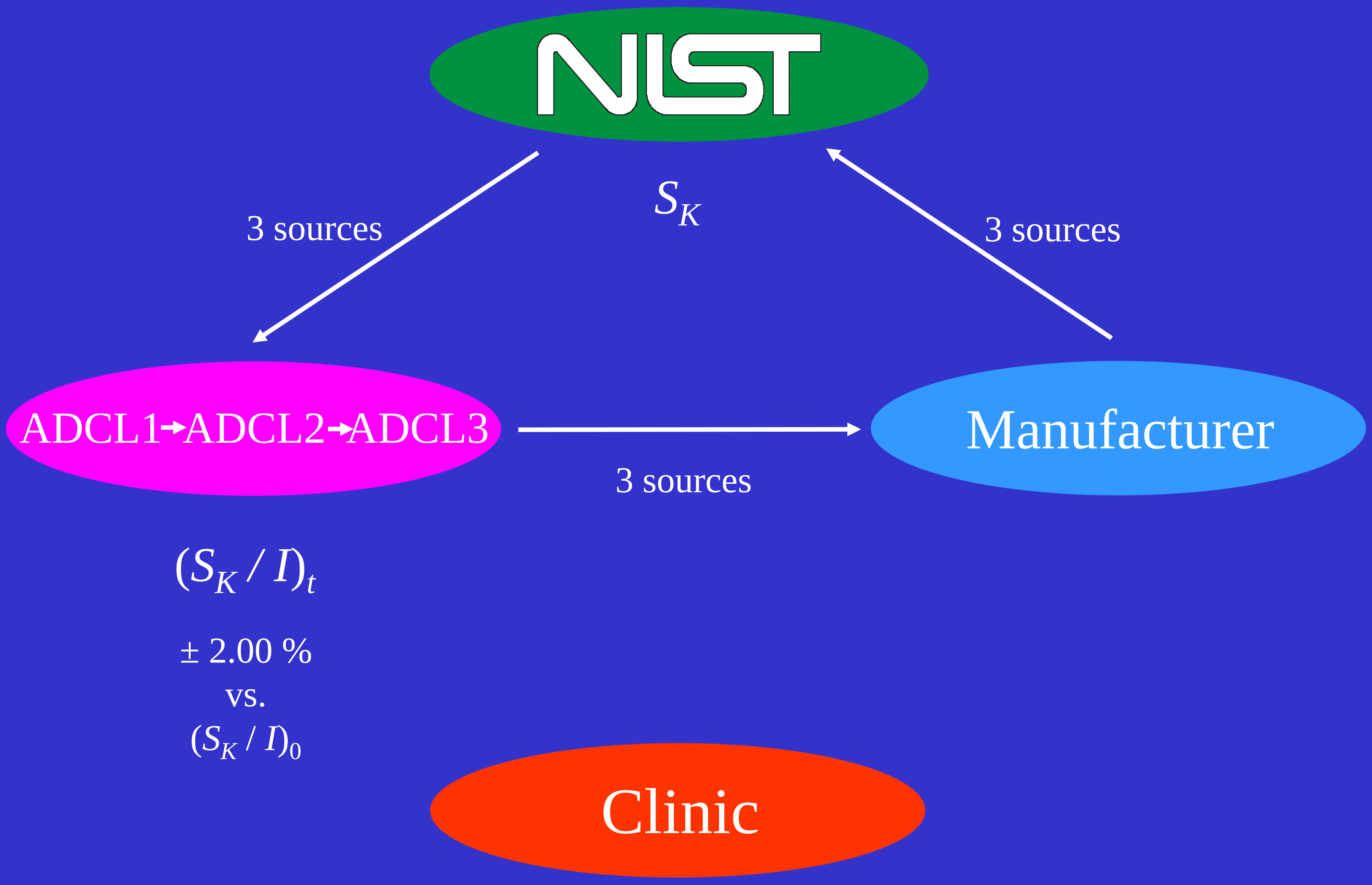
1. 3 sources sent to NIST (preferably within 6 months but not exceeding 1 year) for S_K calibration and (S_K / I) evaluation

2. If (S_K / I) for each source is within ± 2.00 % of established (S_K / I) at NIST or the ADCLs, no action needs to be taken

3. If (S_K / I) is out of tolerance, the cause should be investigated, and another set of 3 sources is sent by the manufacturer to NIST and the ADCLs

4. If (S_K / I) remains out of tolerance for the second set of source measurements, discrepancies among the ADCLs and NIST should be resolved quickly

Measurement Traceability for Brachytherapy Sources – Annual QA

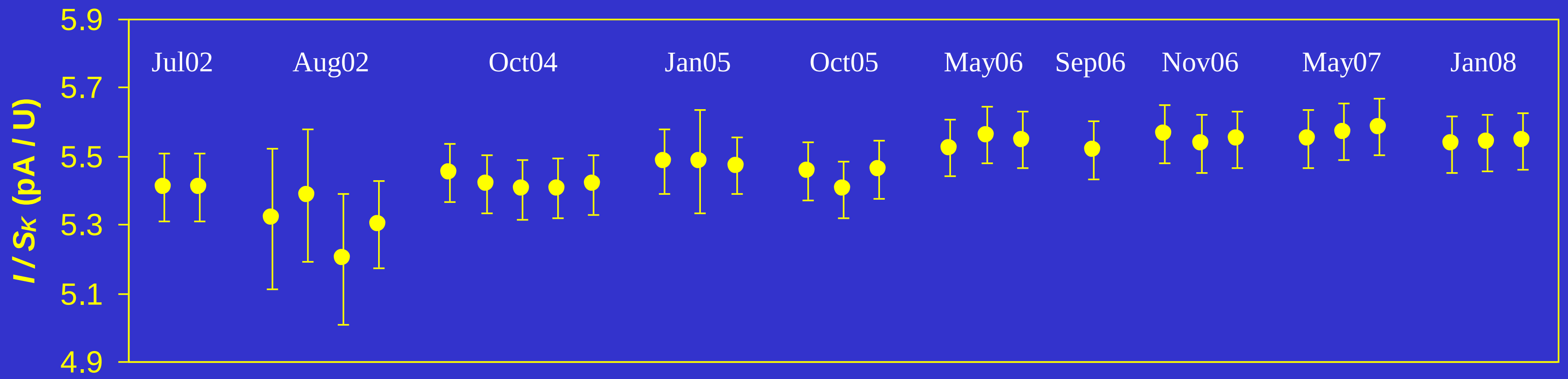


Clinical Brachytherapy Source Measurements

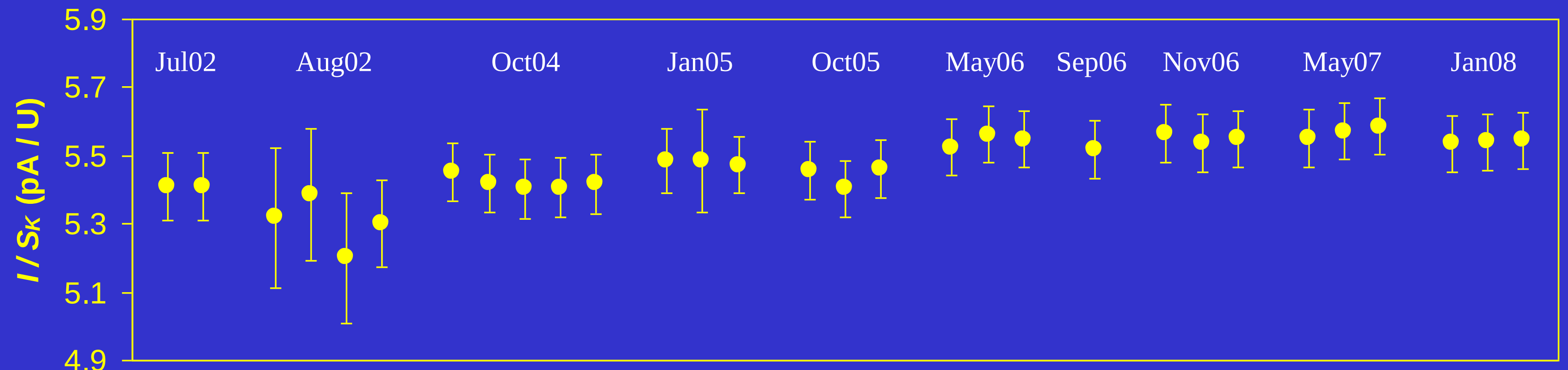
Well-ionization chambers, calibrated by an ADCL

$$S_K^{Clinic} = I^{Clinic}\left(\frac{S_K}{I}\right)_{ADCL}$$

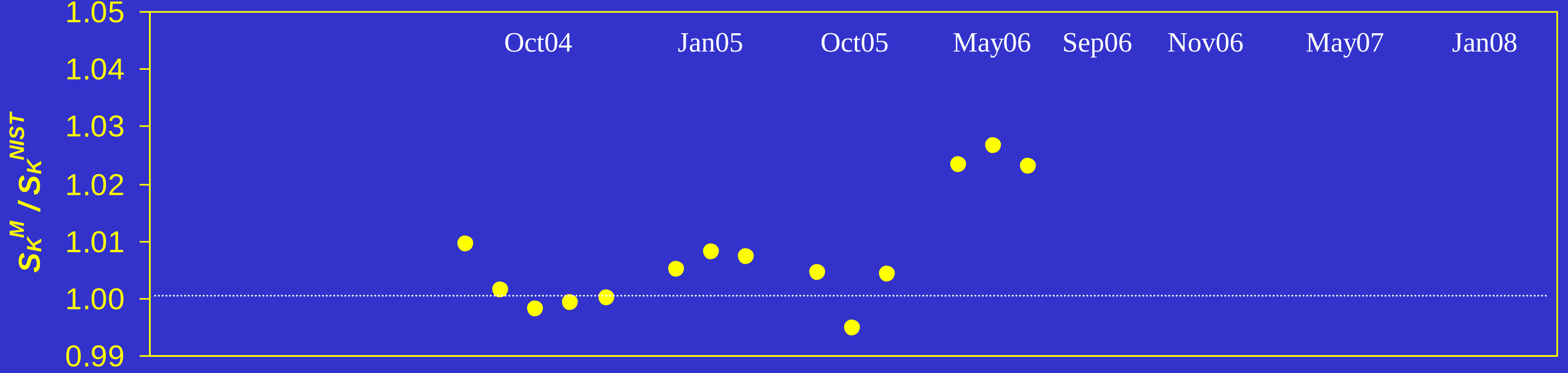
Control Chart, I / S_K, seed “E”



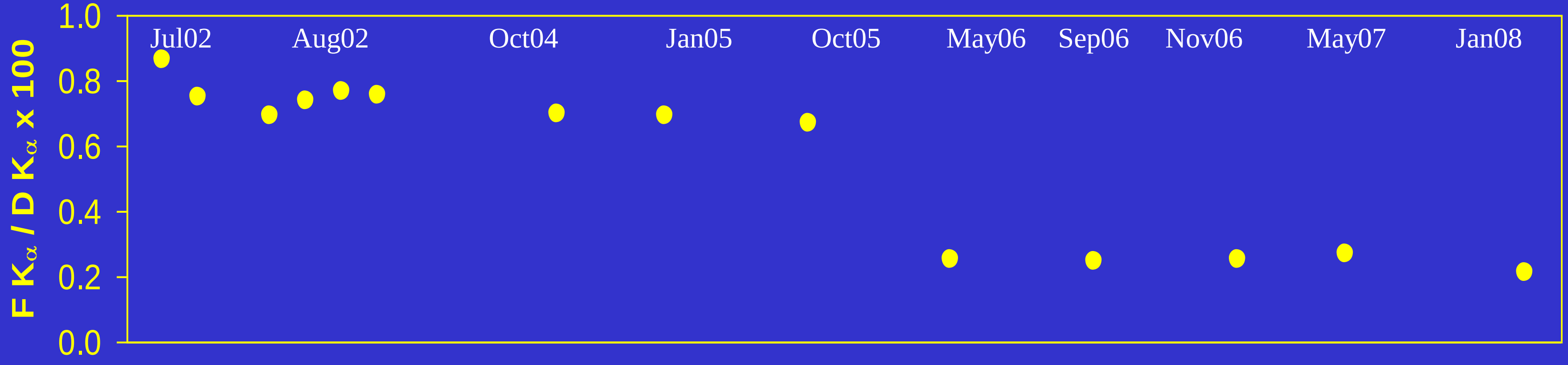
Control Chart, I / S_K, seed "E"



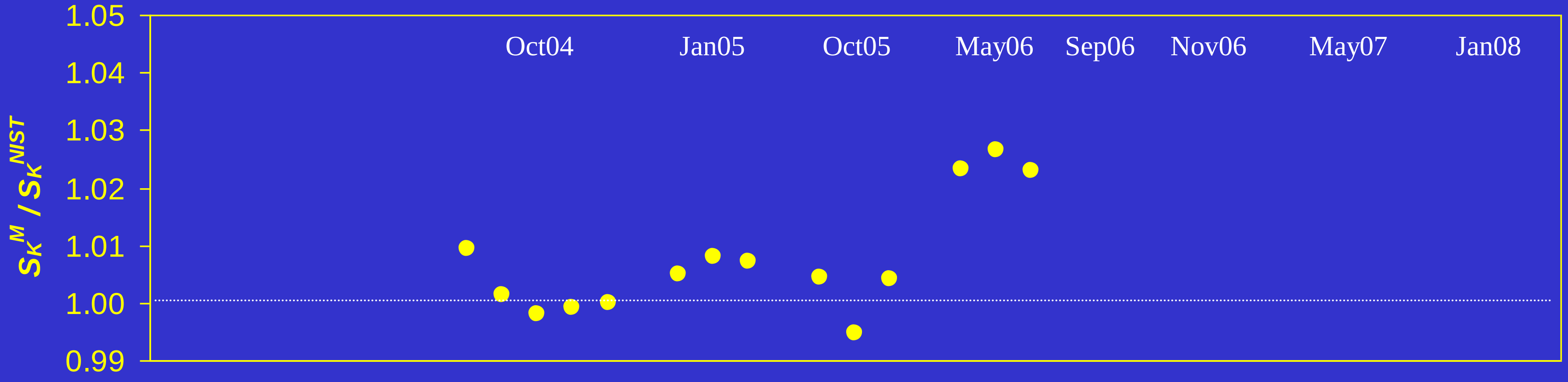
Manufacturer vs. NIST (S_K^M / S_K^{NIST})



Fluorescence K_α / Decay K_α, seed "E"



Manufacturer vs. NIST (S_K^{M} / S_K^{NIST})



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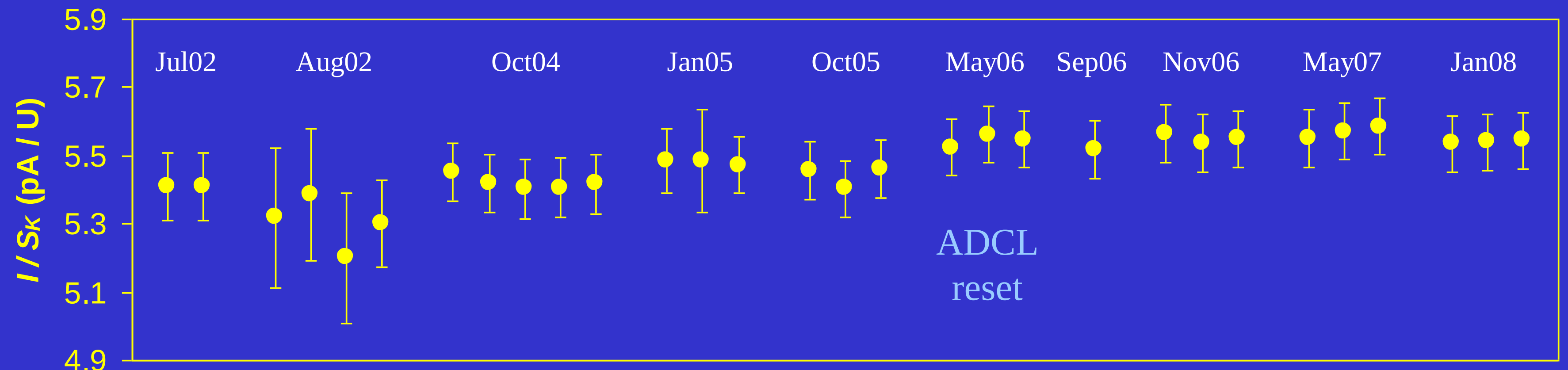
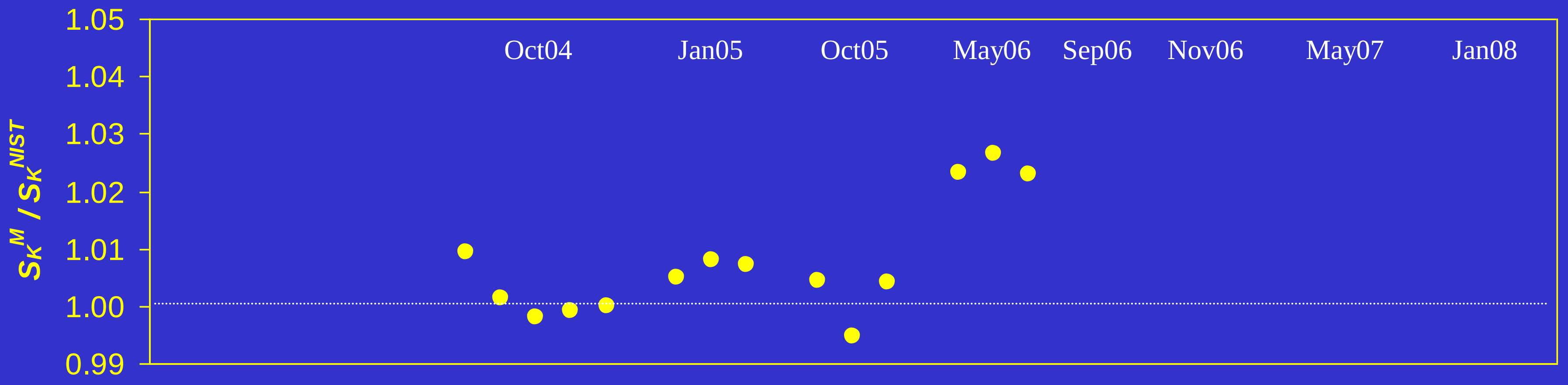
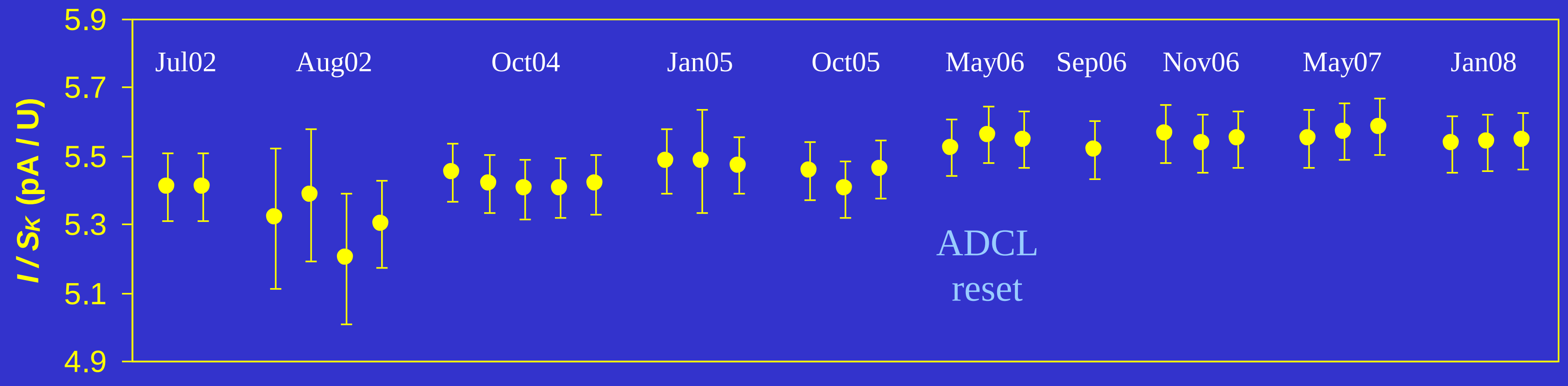


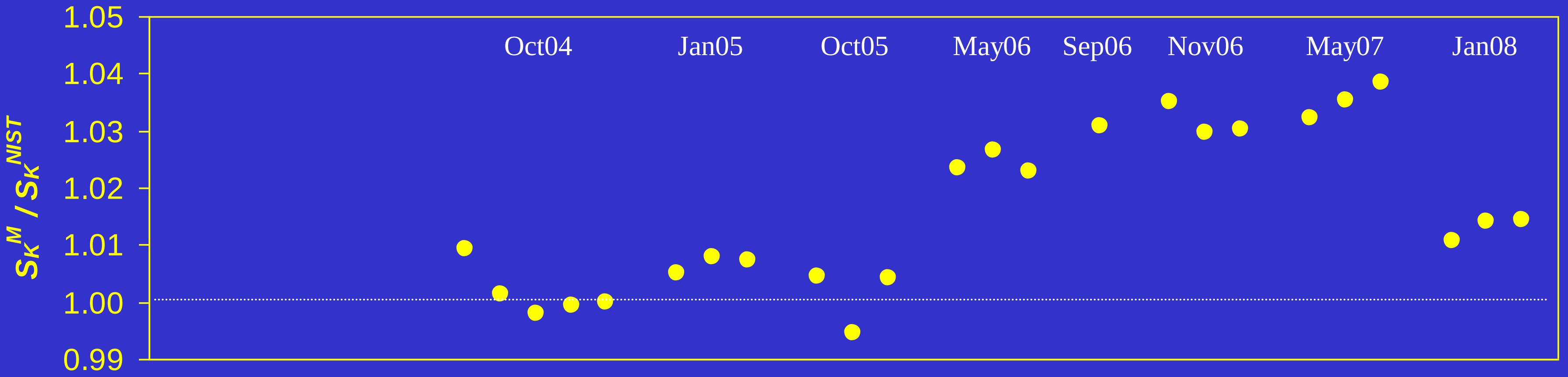
Manufacturer vs. NIST (S_K^M / S_K^{NIST})



Control Chart, I / S_K, seed “E”



Manufacturer vs. NIST (S_K^{M} / S_K^{NIST})



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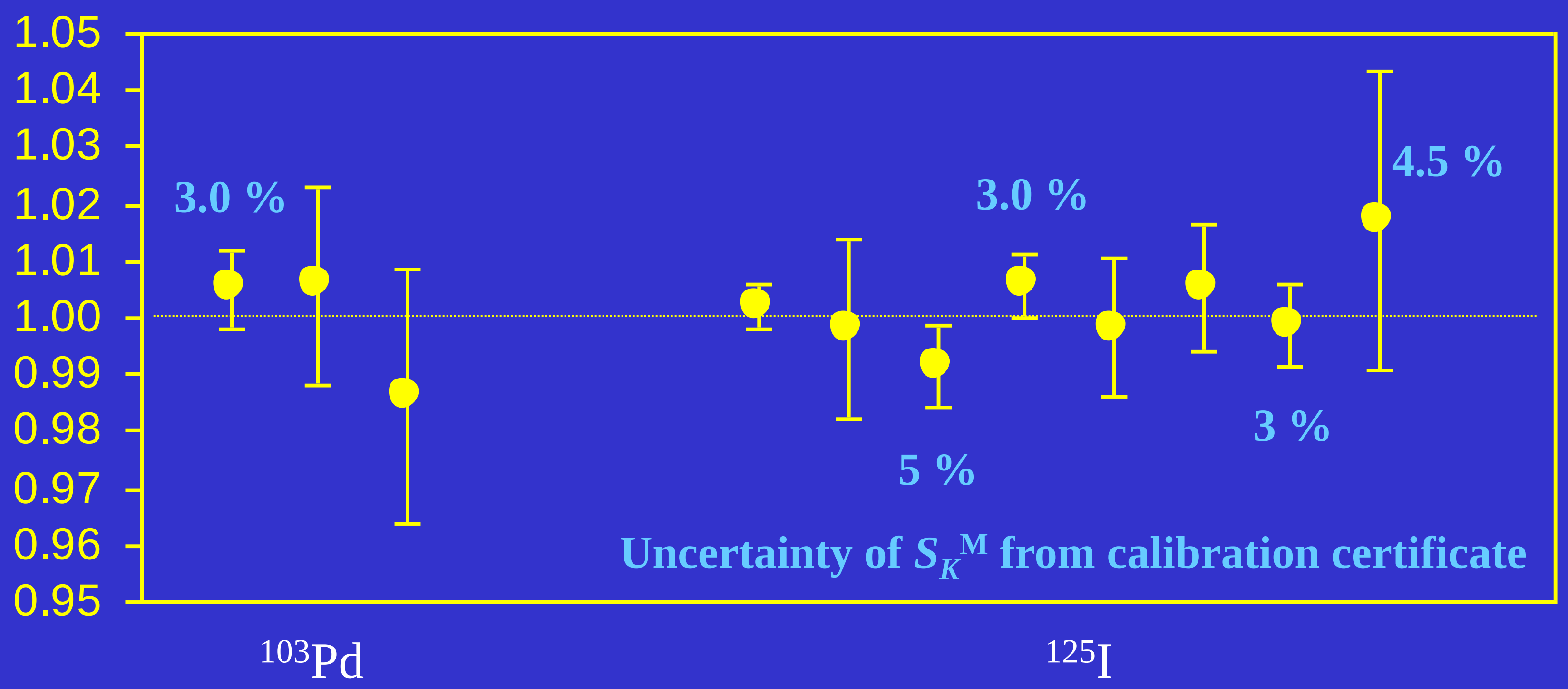

Overall Average = 1.001, σ = 0.008

Source manufacturers have generally been successful in transferring the NIST S_K standard to their facilities. However, there is much variation with respect to the magnitude and precision of reported uncertainties on calibration certificates, if uncertainties are reported at all.

Summary

- A measurement is “NIST traceable” if it is part of a documented and unbroken chain of measurements from the user to NIST, including uncertainties.

- Uncertainty analysis is not only a critical element of the science of metrology, but is required for a valid traceability chain.

- NIST provides traceability to users both directly and through accredited secondary calibration laboratories.

- Once established, traceability must be maintained through the use of intercomparisons and proficiency tests.

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