# UNCERTAINTIES REPORTING IN MEDICAL PHYSICS

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# OUTLINE

- *Basic concepts*
  - *Uncertainty reporting*
    - *Class A: evaluated by statistical methods*
    - *Class B: evaluated by other means*
    - *Coverage factor*
    - *Uncertainty budget*
- *Examples in Medical Physics*
  - *Uncertainties in TG 51*
  - *Uncertainties in TG 43 → 138*
- *Summary*

# ACKNOWLEDGEMENTS

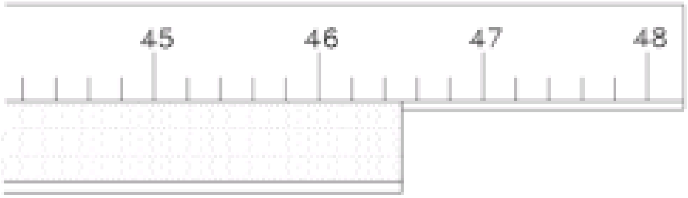

- *Malcolm McEwen, Ph.D. (Ionizing Radiation Standards, NRC)*
  - *"Updating reference dosimetry  a decade after TG-51", AAPM 2010*
  - *In-depth discussion of uncertainties in the Addendum to TG-51 that has now been submitted to MP and should be published by the end of 2013*
- *Michael G. Mitch, Ph.D. (Dosimetry Group, NIST)*
  - *"Treatment Uncertainties in Radiation Dosimetry", AAPM 2009 summer school*
- *Fanqing Guo, Ph.D. (Yale University)*
- *Dan Ruan, Ph.D. (UCLA)*

# ERRORS VS. UNCERTAINTY

- *Error: Difference between a measured or calculated value of a quantity and the "true" value (unknowable)*
- *Uncertainty: An interval about the average value of a series of measurements or calculations which, within a certain level of confidence, is believed to contain the "true" value of a quantity*
- *NOTE: A measurement or calculated result with a low uncertainty is not necessarily a result of high quality.*

# EXAMPLE OF REPORTING LENGTH MEASUREMENT

Most of our measuring devices in this lab have scales that are coarser than the ability of our eyes to measure.




For example in the figure above, we can definitely say that our result is somewhere between 46.4 cm and 46.6 cm. We assume as an *upper* bound of our uncertainty, an amount equal to half this width (in this case 0.1cm). The final result can be written

$$l = (46.5 \pm 0.1)\ \text{cm}.$$

# METHORD OF CLASSIFYING UNCERTAINTIES

- *Type A Uncertainty = calculated by statistical methods*
  - *Finite degree of freedom*
  - *Normal (Gaussian) distribution*
- *Type B Uncertainty = evaluated by other means*
  - *Systematic*
  - *Infinite degree of freedom*
  - *Non-normal distribution*

- *1981-CIPM (Comité International des Poids et Mesures)*
- *1993, 2010 – GUM (Guide to the Expression of Uncertainty in Measurement), ISO (International Organization for Standardization)*
- *1994 – NIST (National Institute of Standards and Technology) Technical Note 1297*

# NORMAL DISTRIBUTION

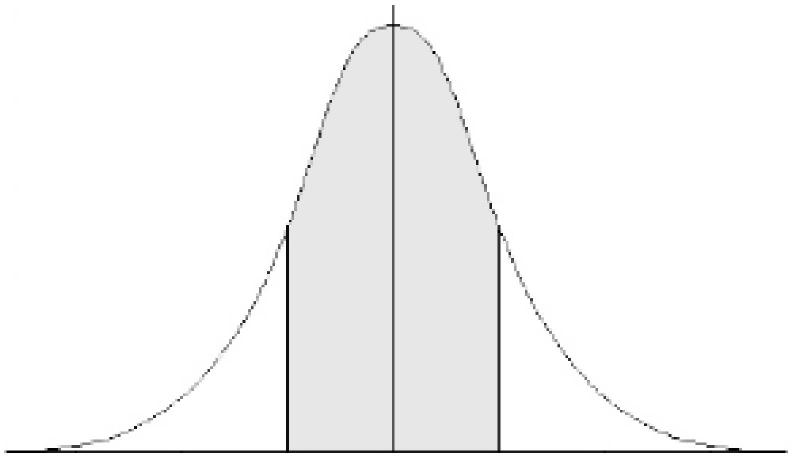


Figure 4

The normal, or Gaussian, probability distribution. This is obtained when a number of distributions, of any form, are combined and the conditions of the Central Limit Theorem are met. In practice, if three or more distributions of similar magnitude are present, they will combine to form a reasonable approximation to the normal distribution. The size of the distribution is described in terms of a *standard deviation*. The shaded area represents 1 standard deviation from the centre of the distribution. This corresponds to approximately 68% of the area under the curve.

# COVERAGE FACTOR

| Coverage probability (*p*) | Coverage factor (*k*) |
|---|---|
| 68% | 1.00 |
| 90% | 1.64 |
| 95% | 1.96 |
| 95.45% | 2.00 |
| 99% | 2.58 |
| 99.73% | 3.00 |

# UNCERTAINTY BUDGET

- *List of sources of uncertainty and their associated standard uncertainties, compiled with a view to evaluating a combined standard uncertainty associated with a measurement (or calculation) result*

- *Consider every step and aspect of the measurement and calculations*

$$\dot{D}_{\mathrm{w}} = 14.28\ \mathrm{mGy/s}$$

$$\dot{D}_{\mathrm{w}} = (14.28 \pm 0.12)\ \mathrm{mGy/s}$$

| **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 % | |

# AAPM Working Group on TG-51

- Formed November 2006

- Charge includes, "The WG will thus present a review of measured and calculated $k_Q$ data as well as a clarification document for TG-51 that contains tables of $k_Q$ for chambers currently not listed in the protocol."

- Comprises: Malcolm McEwen (Chair, National Research Council Canada), David Rogers (Carleton University), Jan Seuntjens (McGill University), Larry DeWerd (UWisc ADCL), Geoff Ibbott (RPC), Steve Seltzer (NIST), Hugo Palmans (NPL, UK)

- Due to report in 2011

# TG-51 reminder

- TG-51 is a procedure to give you a measurement of the absorbed dose to water at a point in a water phantom

- It's based on measurements with a calibrated ion chamber:

$$D_{w,Q} = N_{D,w}^{^{60}Co} \, k_Q \, M_{ion}$$

- $N_{D,w}$ is obtained from an ADCL or primary standards laboratory (e.g., in Canada)

- $k_Q$ is the factor that converts from the calibration beam ($^{60}$Co) to the uses linac beam, defined by beam quality $Q$

- $Q$ can represent a photon or electron beam

# C. Uncertainties

1. TG-51 made the deliberate decision not to include uncertainties.
2. Other protocols have included uncertainty budgets and/or detailed reviews of uncertainty components.
3. It's time to give some guidance on:
   i. How to develop an uncertainty budget
   ii. Typical values for individual components.
4. The ISO GUM is the starting point
5. Improved, uniform uncertainty reporting in radiotherapy dosimetry will lead to improved QA of treatment delivery and allow better comparisons between cancer centres.

# C. Uncertainty budget

- Discussion of Type A and B uncertainties (distinct from 'random' and 'systematic')
- Uncertainty budget broken down into:
  - Measurement
  - Calibration data
  - Influence quantities
- Typical values discussed but emphasis on individual users constructing site-specific uncertainty budgets for their calibration situations

**Note - table is deliberately blank. The important point is to identify the components of uncertainty in the realization of dose.**

| Component of Uncertainty | Type A | Type B |
|---|---|---|
| **Measurement** | | |
| SSD setting | | |
| Depth setting | | |
| Charge measurement | | |
| $P_{TP}$ correction | | |
| **Calibration data** | | |
| Co-60 $N_{D,w}$ | | |
| $k_Q$ factor | | |
| Assignment of $k_Q$ factor | | |
| **Influence quantities** | | |
| $P_{pol}$ | | |
| $P_{ion}$ | | |
| Pre-irradiation history | | |
| $P_{leak}$ | | |
| Calibration coefficient (chamber stability) | | |
| Linac stability | | |
| OVERALL | | |

# D.1 Chamber spec

## Based on objective assessment of chamber performance

| Measurand | Specification |
|---|---|
| Chamber settling | Must be less than a 0.5% change in reading from beam-on to stabilization |
| $P_{leak}$ | < 0.1 % of chamber reading |
| $P_{pol}$ | < 0.4 % correction<br>< 0.5 % maximum variation with energy (total range) |
| $P_{ion}$ | Correction must be linear with dose per pulse<br>Initial recombination must be < 1.002 at 300 V<br>Correction follows Boag theory for chamber dimensions.<br>Difference in initial recombination correction between opposite polarities <0.1% |
| $k_Q$ | < 0.5% difference between measured and calculated (TG-51) factors |

Note - the last point is clearly less objective as it assumes the calculation is correct. Useful, however, in the absence of any other data.

# A dosimetric uncertainty analysis for photon-emitting brachytherapy sources: Report of AAPM Task Group No. 138 and GEC-ESTRO

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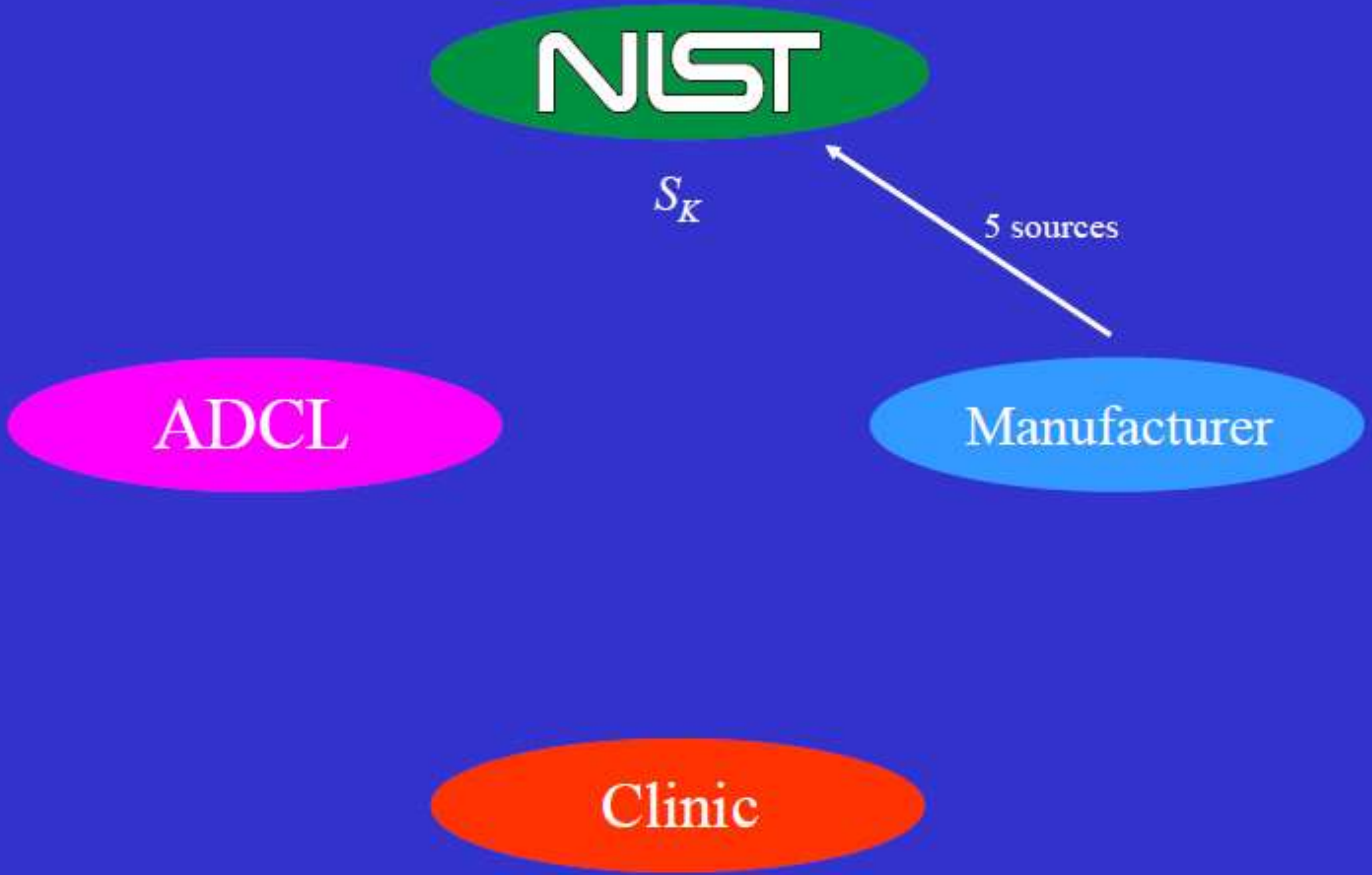
(Received 24 June 2010; revised 6 December 2010; accepted for publication 14 December 2010; published 14 January 2011)

# TG-138

- *Reference Standards: GUM and NIST TN 1297*
- *The uncertainty propagation from the primary calibration standard through transfer to the clinic for air-kerma strength*
- *Uncertainties in each of the brachytherapy dosimetry parameters of the TG-43 formalism*
- *Dosimetric uncertainties during treatment delivery are considered breifly*
- *Ristricted to the determination of dose to water in water without consideration of material heterogeneities, interseed attenuation, patient scatter conditions.*
- ➔ *combined dosimetric uncertainty < 5% (k =1)*

## Measurement Traceability for Brachytherapy Sources – New Source



# Measurement Traceability for Brachytherapy Sources – New Source

NIST

$S_K$

3 sources

2 sources

ADCL1→ADCL2→ADCL3

secondary standard

Manufacturer

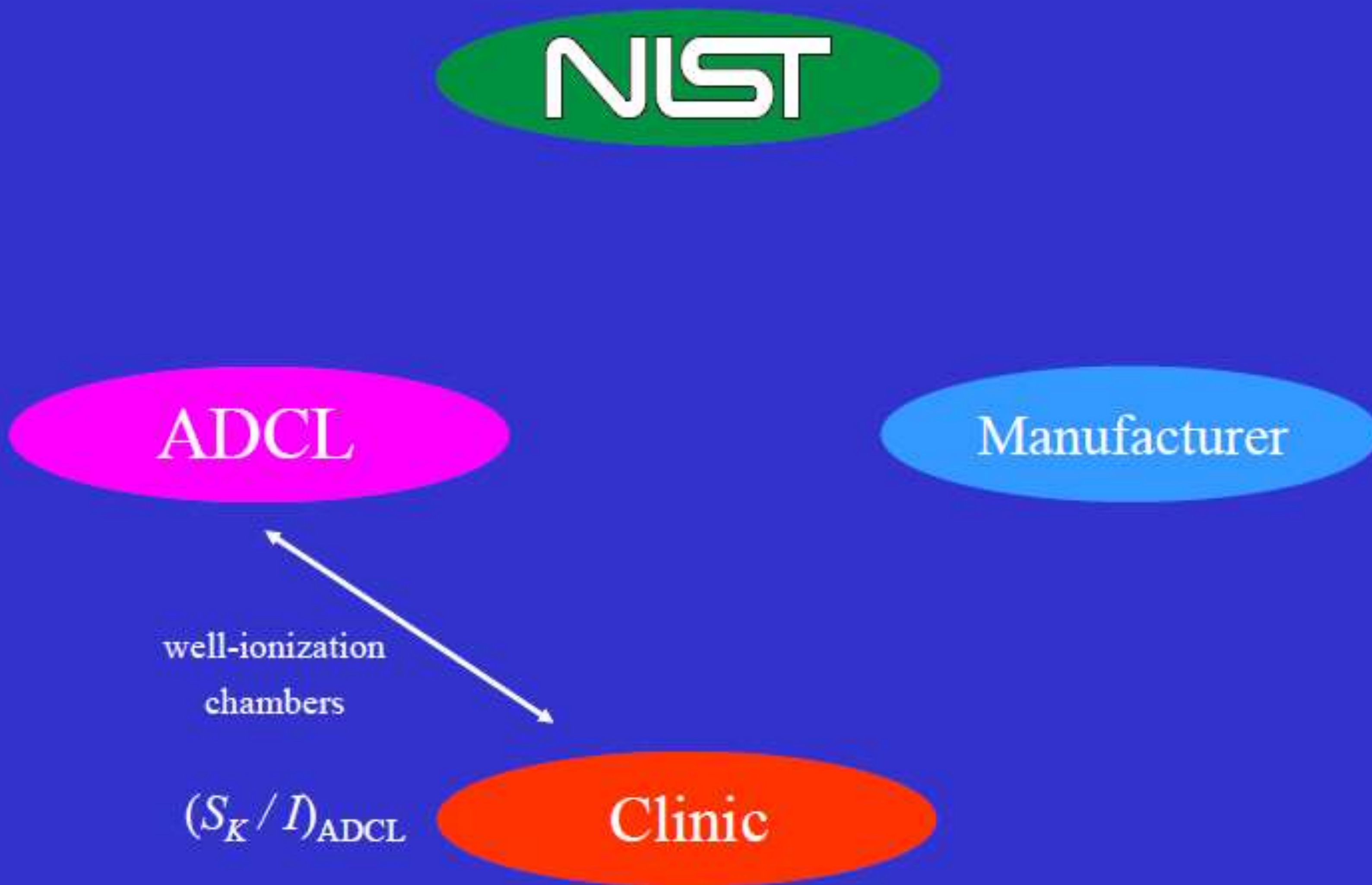
$(S_K / I)_0$

$S_K / I$ ?

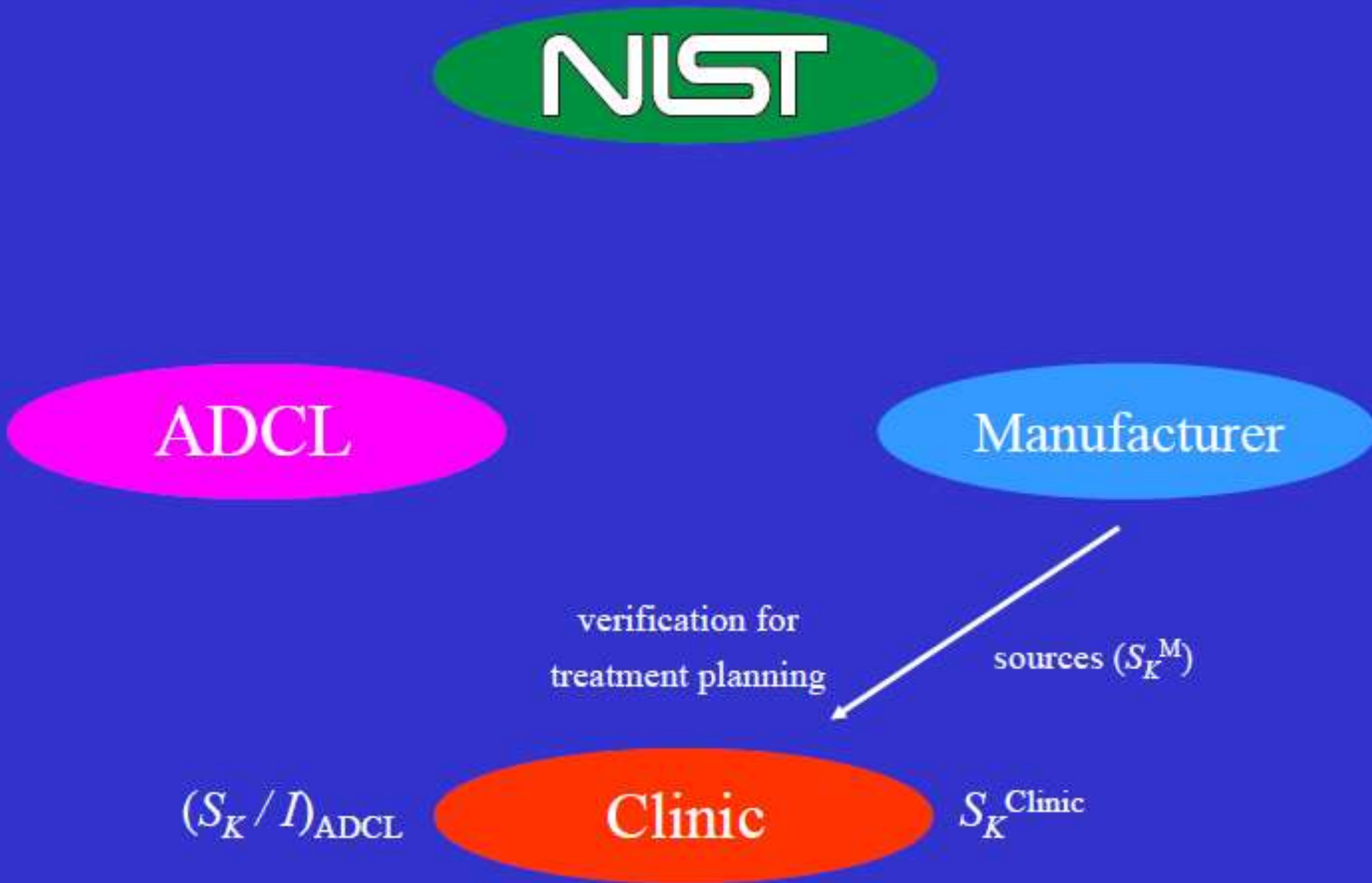
ADCL calibration date

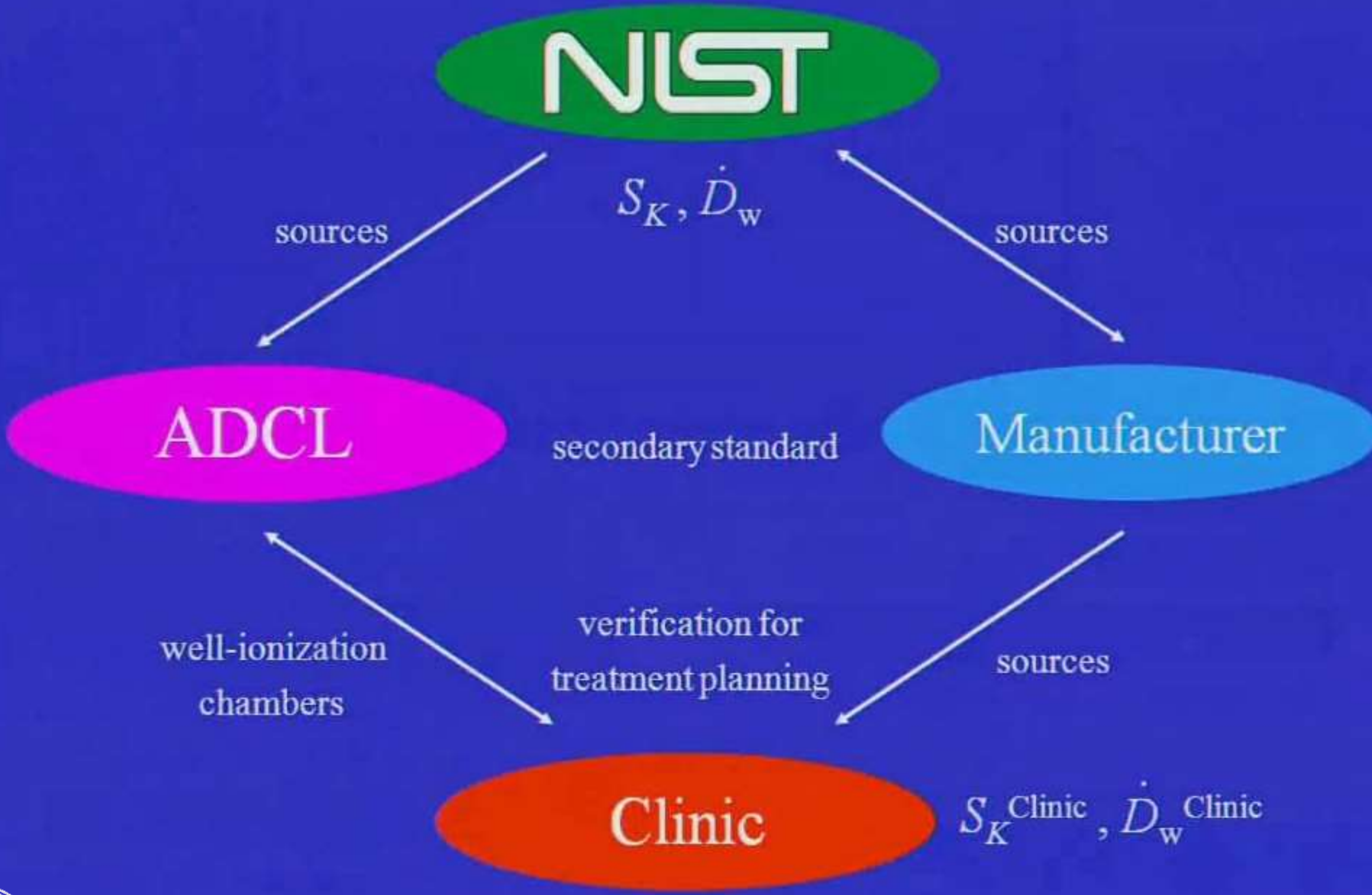
Clinic

# Measurement Traceability for Brachytherapy Sources - Clinics



# Measurement Traceability for Brachytherapy Sources - Clinics





NIST
$S_K, \dot{D}_w$
sources
sources
ADCL
secondary standard
Manufacturer
well-ionization
chambers
verification for
treatment planning
sources
Clinic
$S_K^{Clinic}, \dot{D}_w^{Clinic}$

# TG-138

TABLE IV. Propagation of best practice uncertainties ($k=1$ unless stated otherwise) associated with the transfer of air-kerma strength from a traceable NIST coefficient from the ADCL to the clinic for HDR high-energy brachytherapy sources.

| Row | Measurement description | Quantity (units) | Relative propagated uncertainty (%) |
|---|---|---|---|
| 1 | ADCL calibration | $S_{K,\mathrm{NIST}}$ (U) | 1.1 |
| 2 | ADCL well ion chamber calibration | $S_{K,\mathrm{NIST}}/I_{\mathrm{ADCL}}$ (U/A) | 1.2 |
| 3 | ADCL calibration of source from manufacturer | $S_{K,\mathrm{ADCL}}$ (U) | 1.3 |
| 4 | ADCL calibration of clinic well ion chamber | $S_{K,\mathrm{ADCL}}/I_{\mathrm{CLINIC}}$ (U/A) | 1.4 |
| 5 | Clinic measures source air-kerma strength | $S_{K,\mathrm{CLINIC}}$ (U) | 1.5 |
| | Expanded uncertainty ($k=2$) | $S_{K,\mathrm{CLINIC}}$ (U) | 2.9 |

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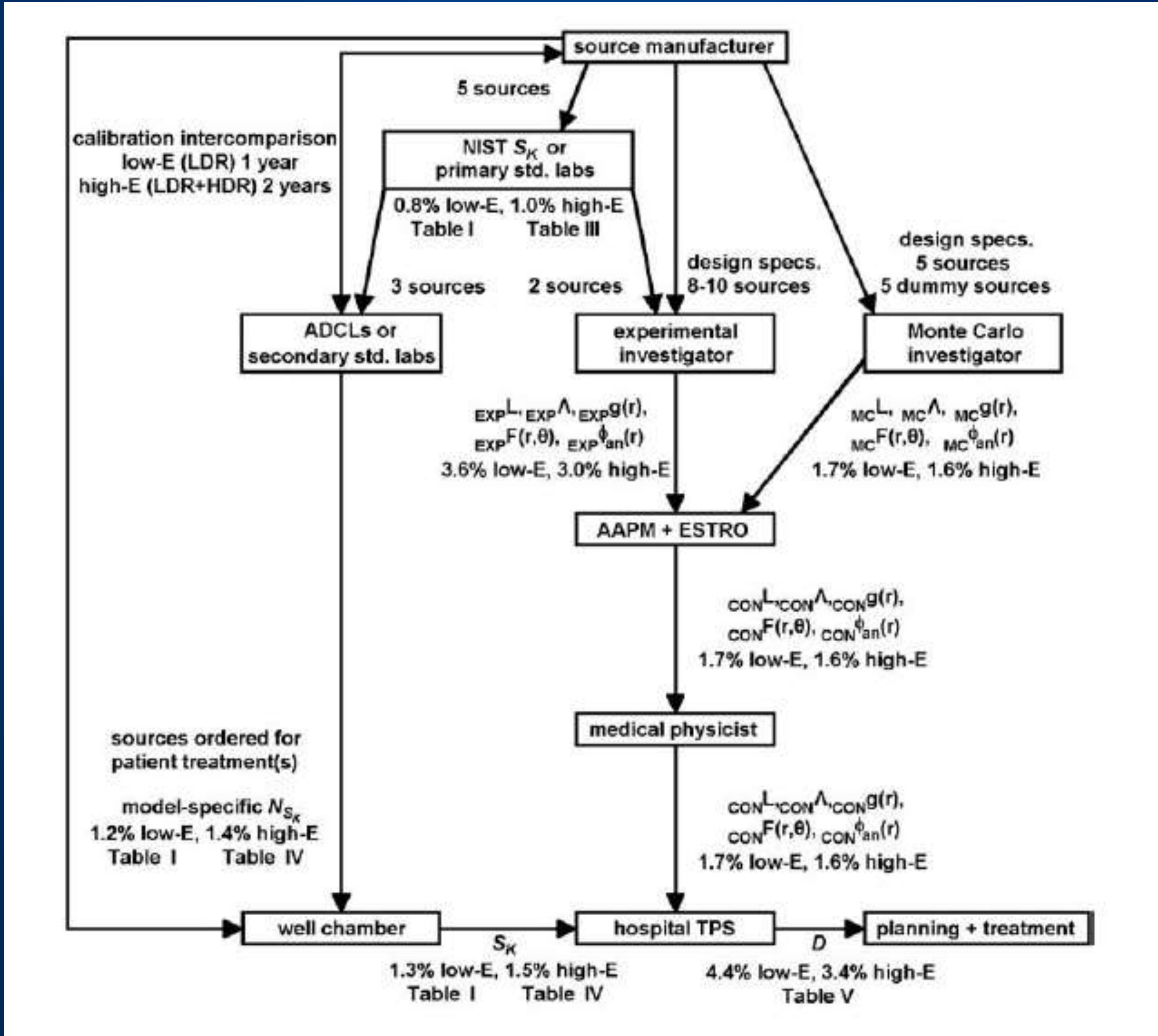
# TG-138 BRACHYTHERAPY SOURCE DOSIMETRY DATA CHAIN ($k$=1)

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# Uncertainty Budget, NIST $S_K$ Standard for $^{125}$I seeds

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

| | Value | Type A (%) | Type B (%) |
|---|---|---|---|
| Net current, $M_{det}(\dot{K},Q)$ | | $s$ | 0.06 |
| $\overline{W}/e$ | 33.97 J / C | - | 0.15 |
| Air density, $\rho_{air}$ | 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, $K_{sat}(\dot{K})$ | $< 1.004$ | - | 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, $U$** | | $2u_c$ | |

# SUMMARY

- *Review basic statistics*
- *The applications of statistics*
- *Avoid misuse of statistics*
- *All factors that could possibly influence the result of a measurement or calculation should be considered*
- *An uncertainty budget quantifies Type A and Type B components*
- *Expanded uncertainties ($k$ = 2) should be used in clinical dosimetry ; (TG-138 uses $k$=1)*

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