^{137}Cs used in Metrology: Standardization and Calibrations

for Radiation Protection & Homeland Security Applications

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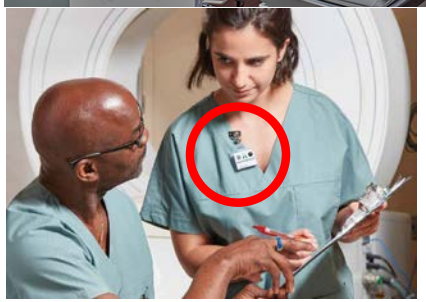
Use of Detectors Calibrated with ^{137}Cs: "A Few Examples …"

Radioactive shipments arrive at ports of entry by cargo ships, rail and trucks. Measurements are made with Radiation Detector instruments tested with ^{137}Cs

Radiation workers at Nuclear Power plants monitor surroundings for radiation levels using detectors calibrated with ^{137}Cs



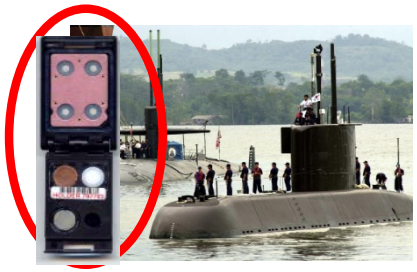
Radiation monitoring is essential at medical facilities to ensure safety of patients and medical staff. Safety is ensured by health physics staff who use area monitors, personnel dosimetry, survey meters, all calibrated with ^{137}Cs

Use of Detectors Calibrated with ^{137}Cs: "A Few Examples …"

Emergency responders monitoring radiation levels w. Radiation Detectors calibrated with ^{137}Cs

At Fukushima Nuclear Reactor incident

Potential radiation incident



Soldiers and Military personnel wear electronic and passive dosimetry to measure potential exposure to radiation

Nearly 4 million occupational workers are monitored annually for radiation dose

NCRP 160 (2006) - Table 7.1, page 201

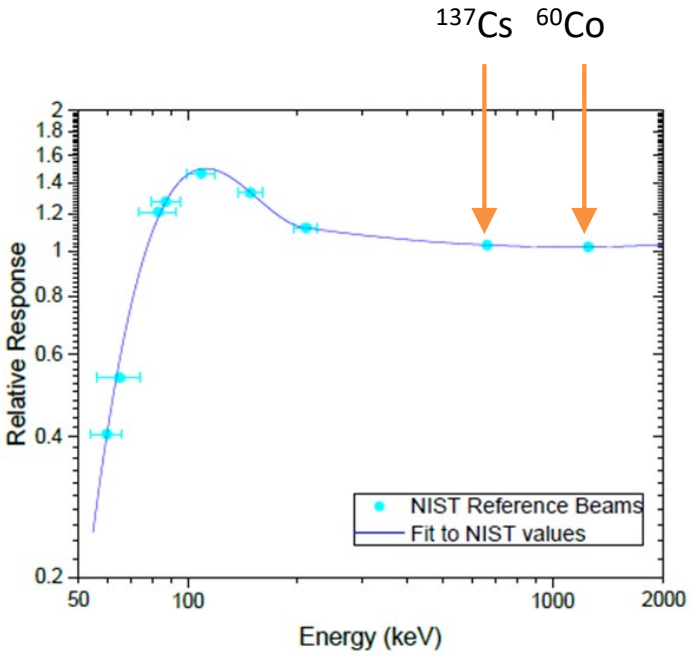
Other users of detectors calibrated with Cs-137

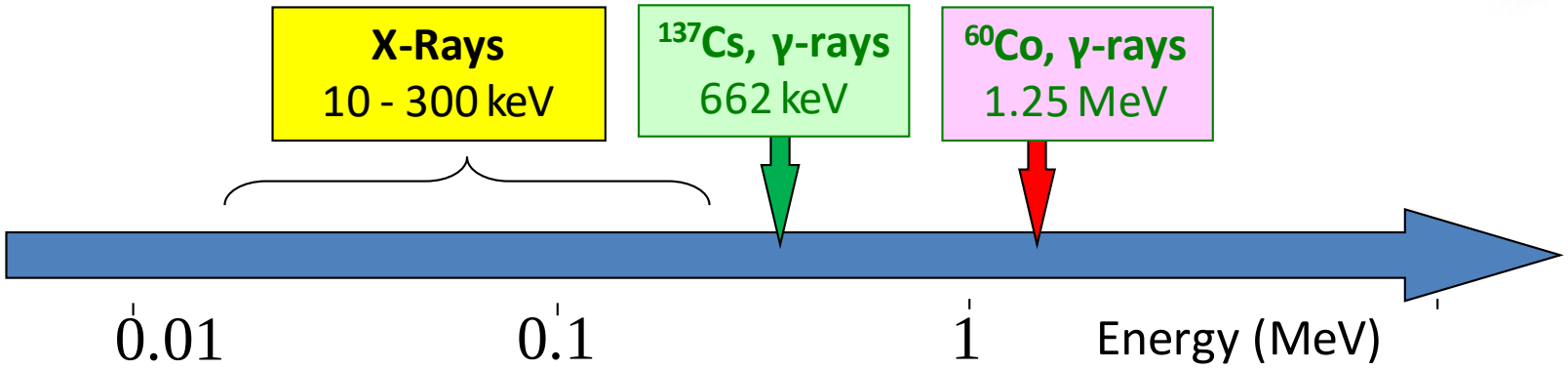
- Manufacturer of Instruments
- Radiation Workers and HAZMAT teams
- Emergency Responders (Federal, State, Local,)
- Coast Guard, TSA, CBP, …
- Others …

^{137}Cs has been the standard for 50+ years

Detectors and Radiation Measuring Instrumentation are calibrated in terms of air kerma (dose to air) in open ^{137}Cs beams to ensure that all these devices measure accurately, and their measurement is traceable to the national standard.

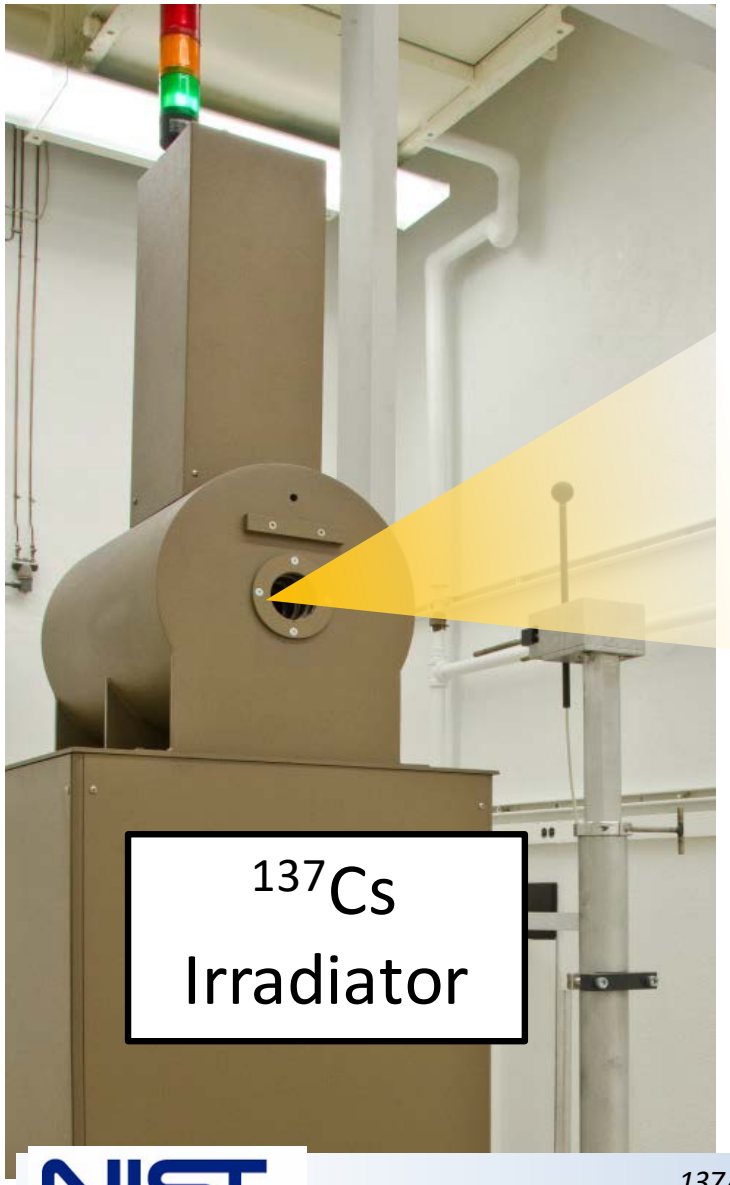
For this metrological application, the ^{137}Cs irradiators used have *ACTIVITY* values up to 1.85 TBq (500 Ci), which fall within the mid-range of Category 2 sources as defined by the Nuclear Regulatory Commission (NRC)





^{137}Cs irradiators are used for the standardization of air kerma measurements

^{137}Cs irradiator unique properties



- ^{137}Cs sources provide a monoenergetic photon beam at 662 keV.
- Irradiator output: Outstanding reproducibility (~ 0.1 % over periods of months to years)
- Enable low uncertainty measurements required for standardization at NIST and subsequently in transferring Standards to Calibration Facilities and end users (*these are referred to as metrology applications*)
- Broad range of air kerma rates
- Long half life of 30 years.
- Practically no maintenance costs after installation. Small footprint.

Use of ^{137}Cs to meet requirements for Calibrating and/or Testing Instruments

Because of the unique properties of ^{137}Cs irradiators many National and International regulations, recommendations and document standards rely on its use for instrument testing & calibration: ANSI, NCRP, ISO, IEC, IAEA ….

U.S. accreditation programs rely on the use of irradiators: In the U.S. accreditation programs include those managed by: The Department of Energy (DOELAP), the National Voluntary Laboratory Accreditation Program (NVLAP), AAPM, etc.…

Proficiency Tests (blind tests) using ^{137}Cs are required to demonstrate the degree to which calibration facilities are capable of transferring the national standard. This is required by accreditation programs and/or other external/ internal regulatory needs.

NRC requirements for ensuring the safety of radiation workers and the public

35.61 Calibration of survey instruments.
"A licensee shall calibrate the survey instruments used to show compliance with this part and 10 CFR Part 20 before first use, annually, and following a repair that affects the calibration."
https://www.nrc.gov/reading-rm/doc-collections/cfr/part035/part035-0061.html
To meet this NRC requirement ^{137}Cs irradiators are used for standardization and calibration

§ 20.1501 General (PART 20, subpart F: STANDARDS FOR PROTECTION AGAINST RADIATION, Surveys and Monitoring)
"(d) All personnel dosimeters ….. that require processing to determine the radiation dose and that are used by licensees to comply with § 20.1201, ……. must be processed and evaluated by a dosimetry processor—
(1) Holding current personnel dosimetry accreditation from the National Voluntary Laboratory Accreditation Program (NVLAP) of the National Institute of Standards and Technology; and
(2) Approved in this accreditation process for ***the type of radiation or radiations included in the NVLAP program that most closely approximates the type of radiation or radiations for which the individual wearing the dosimeter is monitored."***
https://www.nrc.gov/reading-rm/doc-collections/cfr/part020/full-text.html#part020-1101
To meet this NRC requirement ^{137}Cs irradiators are used for standardization and irradiation

Examples of Standard Documents for Calibrating and/or Testing Instruments That Use ^{137}Cs irradiators

- **ANSI N13.11, Personnel Dosimetry Performance**

- **ANSI N323AB**
  - Radiation Protection Instrumentation, Test and Calibration, Portal Survey Instruments

- **ISO 4037**
  - X and Gamma Reference Radiation For Calibrating Dosemeters & Doserate Meters

- **ANSI N42.32 (PRDs)**
  - Performance Criteria for Alarming Radiation Detectors for Homeland Security (PRDs)

- **ANSI N42.34 (RIDs)**
  - Performance Criteria for Hand-held Instruments for the Detection and Identification of Radionuclides

- **ANSI N42.43 (Mobile)**
  - Standard for Mobile and Transportable Systems Including Cranes used for Homeland Security Applications
















^{137}Cs irradiators required in document standards, regulations, guidelines, etc.

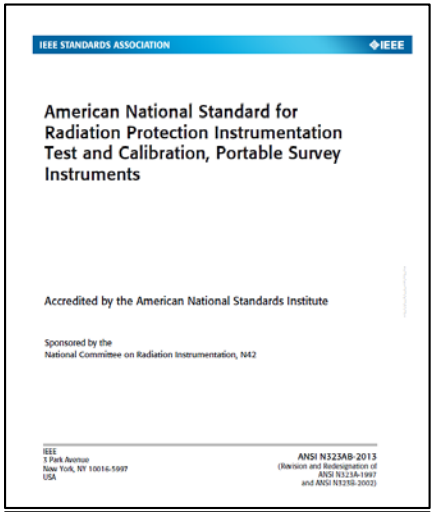
Examples of Requirements in Standard Documents

Tests require high air kerma rates from ^{137}Cs sources (provided by ^{137}Cs irradiators)

- ACCURACY TEST:

*(Example: **ANSI N323AB**-2014, Section 5.2.1.1)*

- *"Instrument readings shall be within +/- 10% of the Conventional True Value (CTV) for air kerma rates between 1.0 mGy/h (100 mrad/h) … to … 10 Gy/h (1000 rad/h)*

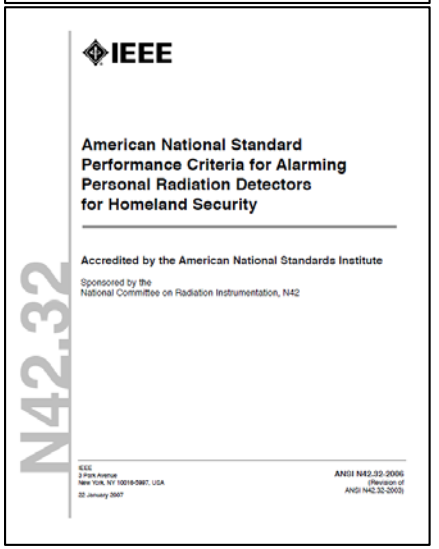


- OVER-RANGE TEST:

Response of the instrument if tested above upper detection limit

*(Example: **ANSI N42.32**-2007, Section 6.8.2)*

- "Expose the instrument to a ^{137}Cs field that is twice the maximum range specified by the manufacturer"



^{137}Cs irradiators required in document standards, regulations, guidelines, etc.

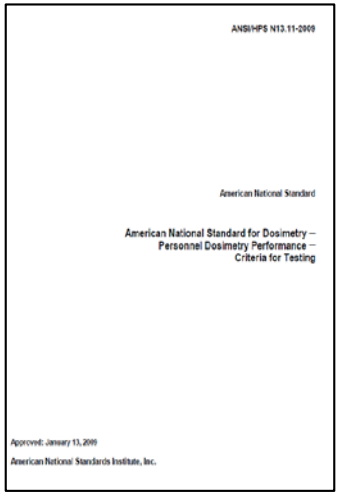
Examples of use of ^{137}Cs in Standard Documents

- **ANSI N13.11** ***Irradiation of Personnel Dosimeters***

Dosimeters shall be tested in high rate ^{137}Cs fields.

Table 1a. Test categories, test irradiation ranges, and tolerance levels

	Test irradiation range	Tolerance level (*L*)	
		Deep	Shallow
I. Accidents, photons			
A. General (B and C, random)			
B. ^{137}Cs	0.05 to 5 Gy (5 to 500 rad)	0.24	No test
C. M150			

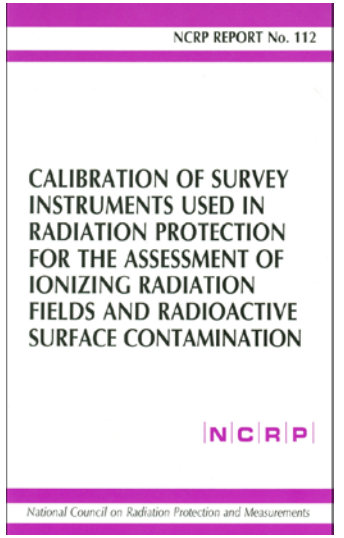


- **NCRP-112** ***Calibration of Survey Meters***

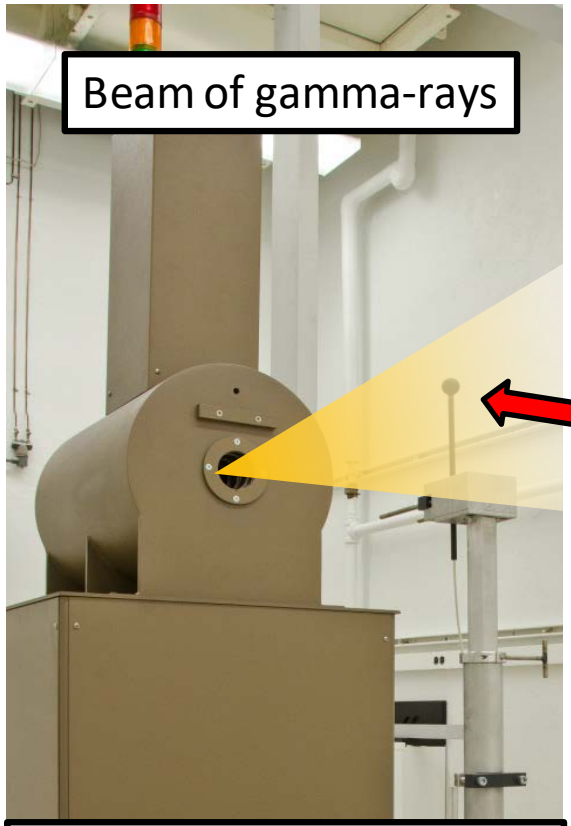
Section 2.2.4 (Page 12) discusses that ^{137}Cs sources of sufficient activity are used to provide adequate field intensities for calibration on all ranges of concern"

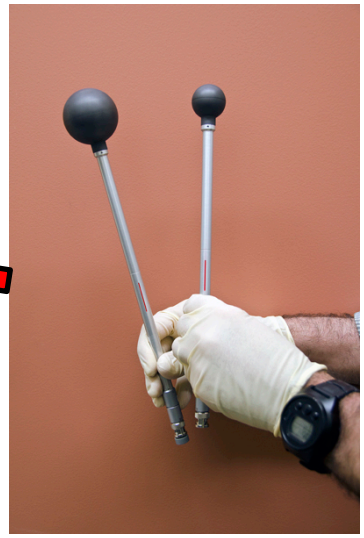
Section 2.5.4 (Page 17) discusses:

- the traceability network in the US: the practice of standard laboratories in establishing reference fields to calibrate radiation measuring instruments
- The role of NIST, secondary and tertiary calibration laboratories
- The further the traceability is removed from the Primary Calibration lab, the greater the uncertainty



^{137}Cs used at NIST for disseminating the air kerma standard





Multilevel security

Primary Instruments used to realize the air kerma rate, $\dot{K}_{NIST}$, (in Gy/s), at NIST

$$\dot{K}_{NIST} = \frac{dE}{dm} = \frac{\Delta I}{\Delta V \rho_{air}} \frac{(W_{air}/e)}{1-\bar{g}} \frac{\overline{(S/\rho)}_m}{\overline{(S/\rho)}_{air}} \frac{\overline{(\mu_{en}/\rho)}_{air}}{\overline{(\mu_{en}/\rho)}_m} \prod_i k_i$$

Calibration of cavity chambers in ^{137}Cs beams

An air kerma calibration coefficient $\mathbf{N_K}$ is determined for a given chamber at NIST as:

$$N_K\left(\frac{Gy}{C}\right) = \frac{\dot{K}_{NIST}\left(\frac{Gy}{s}\right)}{I_{NIST}\ \left(\frac{C}{s}\right)}$$

- $\dot{K}_{NIST}\left(\frac{Gy}{s}\right)$: NIST reference air kerma rate from ^{137}Cs irradiator
- $I_{NIST}\ \left(\frac{C}{s}\right)$: Ionization current produced in the chamber

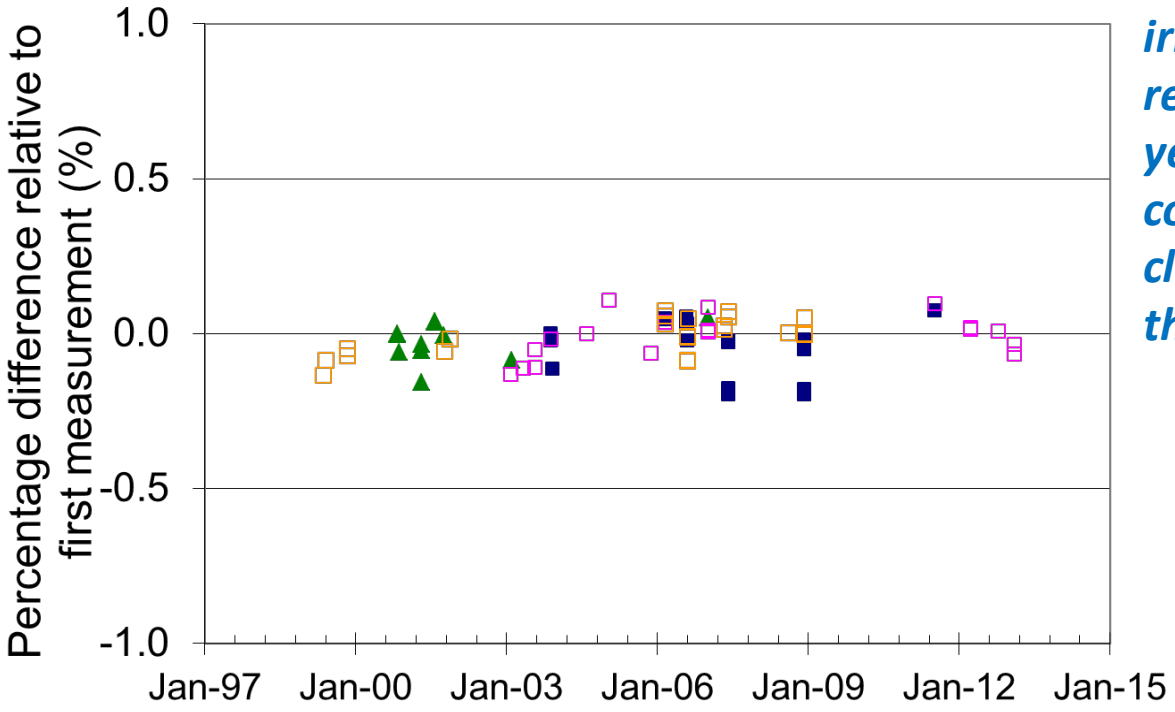
The end user of the chamber can later use the value of $\mathbf{N_K}$ (provided by NIST) to measure the air kerma rate, $\dot{K}_{user}$ (in Gy/s) of a radiation field as:

$$\dot{K}_{user}\left(\frac{Gy}{s}\right) = N_K\left(\frac{Gy}{C}\right) \cdot I_{user}(C/s)$$

Reproducibility provided by ^{137}Cs Irradiators

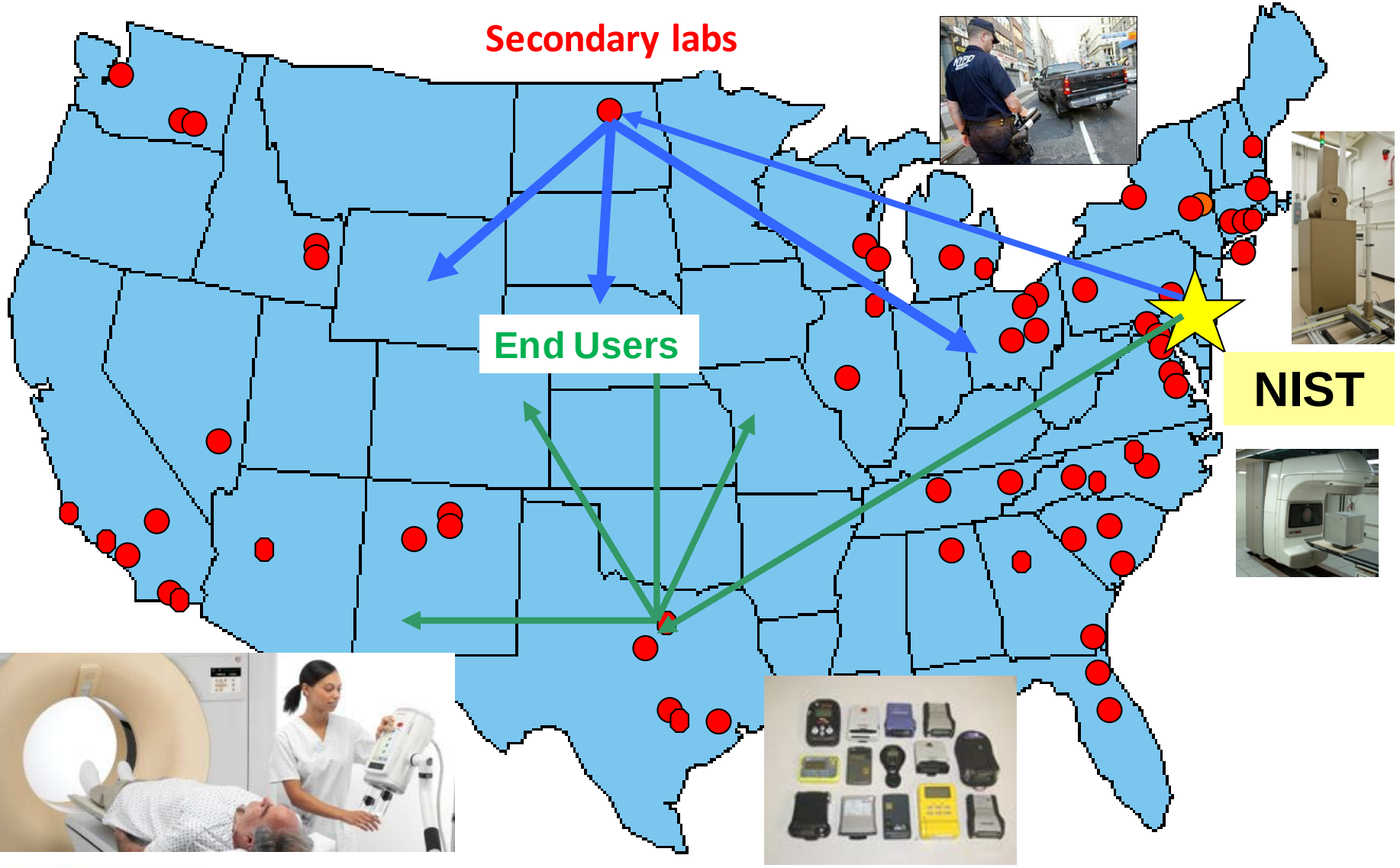
*It is important for **measurement uncertainties** provided by primary calibration facilities to be low to minimize propagation down the traceability chain. For this, the output of the irradiator source needs to be reproducible over long periods of time (months, years ….)*

N_K measured over years for a given reference chamber



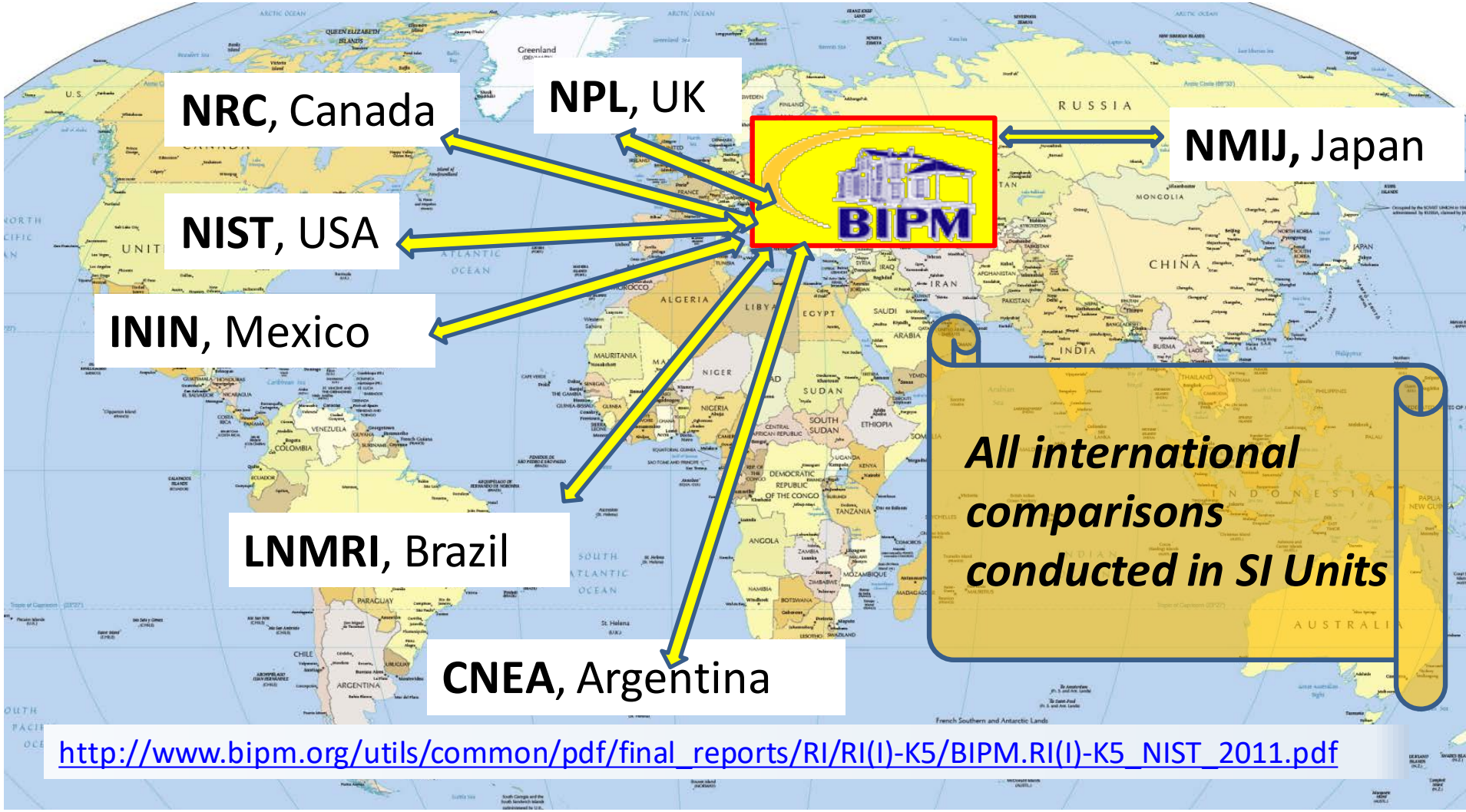
Reproducibility of the ^{137}Cs irradiators is reflected in the reproducibility observed over years of the air kerma coefficient N_K of reference class chambers calibrated in these gamma-ray beams

Traceability Chain in the U.S. - Starts at NIST



International Comparisons

BIPM coordinates and documents all international comparisons. Examples shown.



http://www.bipm.org/utils/common/pdf/final_reports/RI/RI(I)-K5/BIPM.RI(I)-K5_NIST_2011.pdf

Questions about alternative technologies?

Are there any alternative technologies for this Metrological Application (dose standardization and calibration/testing of instruments)?

Unfortunately, to our knowledge, there are ***currently*** no alternative technologies (such as x-rays or accelerators) that can meet the technical requirements for this metrological application.

Given this fact, the Radiation Protection and Homeland Security community face the following challenges if Cs-137 irradiators would become unavailable:

- ***How can it be ensured that million of detectors that are calibrated and tested annually continue to measure correctly?***

- ***This has a direct impact on the safety of radiation workers and the public as well as meting many security needs that rely on the accuracy of detectors used***

- ***How will requirements be met in tens of published regulations, guidelines, reports and standard documents (and used for decades) to ensure traceability to the National Standard And, for the Standard to continue to exist?***

Considerations of Alternative Technologies to ^{137}Cs for Dose Standardization, Calibration & Testing of Instruments

	^{137}Cs Irradiators	X-Ray Tubes
• Spectrum similar to that of ^{137}Cs with energy around 662 keV	YES	300 keV is the limit so far
• Reproducibility of machine output over time to the 0.1 % level (over periods of months to years)	YES	Not as good
• Low uncertainty in transferring calibrations to secondary facilities (0.5 % or better)	YES	Larger uncertainties
• Broad range of air kerma rates	YES	YES (but expensive and in some ranges not as stable)
• Primary Instrument for realizing Air Kerma for establishing traceability	Cavity chambers	Need to be addressed (due to changes in spectra)

Summary

- ^{137}Cs irradiators has been the gold standard for calibrating instruments for more than 50 years due to its unique energy spectrum, high reproducibility & other properties.

- Regulatory requirements, many document standards and accreditation programs rely on ^{137}Cs irradiators for calibrating & testing instruments. ***A well-established network of calibration & testing facilities across the U.S. ensures all detectors in use are traceable to the national standard and measure accurately.***

- ***Currently, non-radionuclide alternatives to replace ^{137}Cs for this metrological application are not available.*** Any new alternatives would need to meet the technical requirements for metrology discussed for ^{137}Cs irradiators.

- Proposed alternatives would need to ensure the continuity of well-established programs that ***guarantee*** the accuracy of measurements made with radiation detection instruments used in radiation protection and homeland security applications ***to ensure the safety of radiation workers and safety and security of the public***.

- *Given that no alternative technologies exist, enhancing security of ^{137}Cs irradiators could allow maintaining the availability of current ^{137}Cs irradiators used for this particular metrological application (dose standardization and traceability).*

Thank you for your attention!