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Title: Neutron Calibration at LANL and other DOE Sites

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Neutron Calibration At LANL and other DOE sites

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IAEA Technical Meeting on Modern Neutron Detection Methods, Vienna, 9/2017

Outline

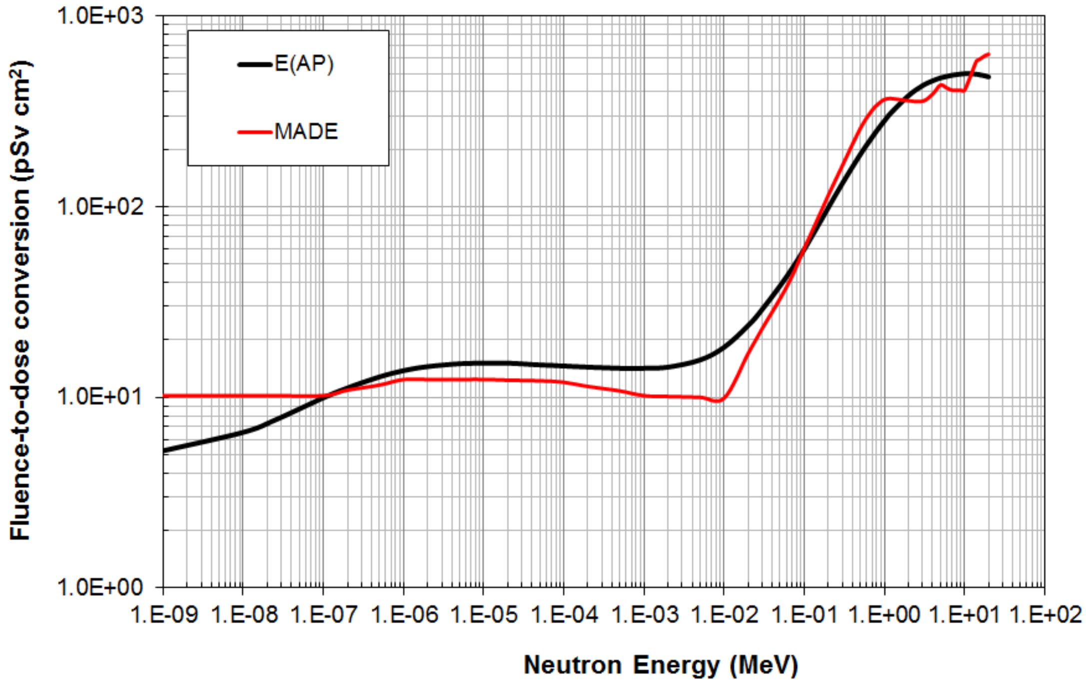
- **Brief overview of DOE Radiation Protection Program**
- **Neutron instrument calibrations**
  - NIST (National Institute of Science and Technology)
  - LANL
  - Other DOE sites
  - Vendor facilities
- **Brief overview of Neutron dosimetry calibrations**
- **Alternatives to ^{252}Cf**

Overview of DOE Radiation Protection Program

- **10CFR835, "Occupational Radiation Protection"**
  - States mandatory requirements of all aspects of a Radiation Protection Program at DOE facilities
- **DOE Implementation guide**
  - Suggests practices that could be adopted to be in compliance with 10CFR835
  - Also suggests relevant Consensus Standards that could be referenced
- **DOE site issues a Radiation Protection Plan (RPP)**
  - Outlines how the DOE site will comply with 10CFR835
  - Plan is approved by DOE
- **DOE site writes a detailed Procedure that documents how the RPP is to be implemented**

Overview of DOE Radiation Protection Program

- ICRP-60 recommendations adopted about 10 years ago by DOE
  - ICRP-74/ ICRU-57 dose quantities in current use
  - Replacing the Maximum Dose Equivalent Quantity (NCRP-38, 1971)
    - Interestingly, MADE compares well with E(AP)



But non-SI units still in vogue

Neutron calibration services at NIST

- **National Institute of Standards and Technology (NIST)**
  - Located in Gaithersburg, MD
  - Provides a wide range of metrology-grade calibration services
    - Including ionizing radiation

- **Neutron calibration services include:**
  - Neutron source calibration (Q= 10^5 – 10^{10} n/s) using Mn bath
  - RaBe source (NBS-1) is the primary reference standard
  - Typical uncertainties of 3-4% (k=2) in stated source emission rates

  - Remmeter calibration in bare and D_2O-moderated ^{252}Cf fields
  - Based on modified empirical approach (ISO8529)
  - Typical uncertainties of 8% (k=2) in calibration factor (cpm per mrem/h)

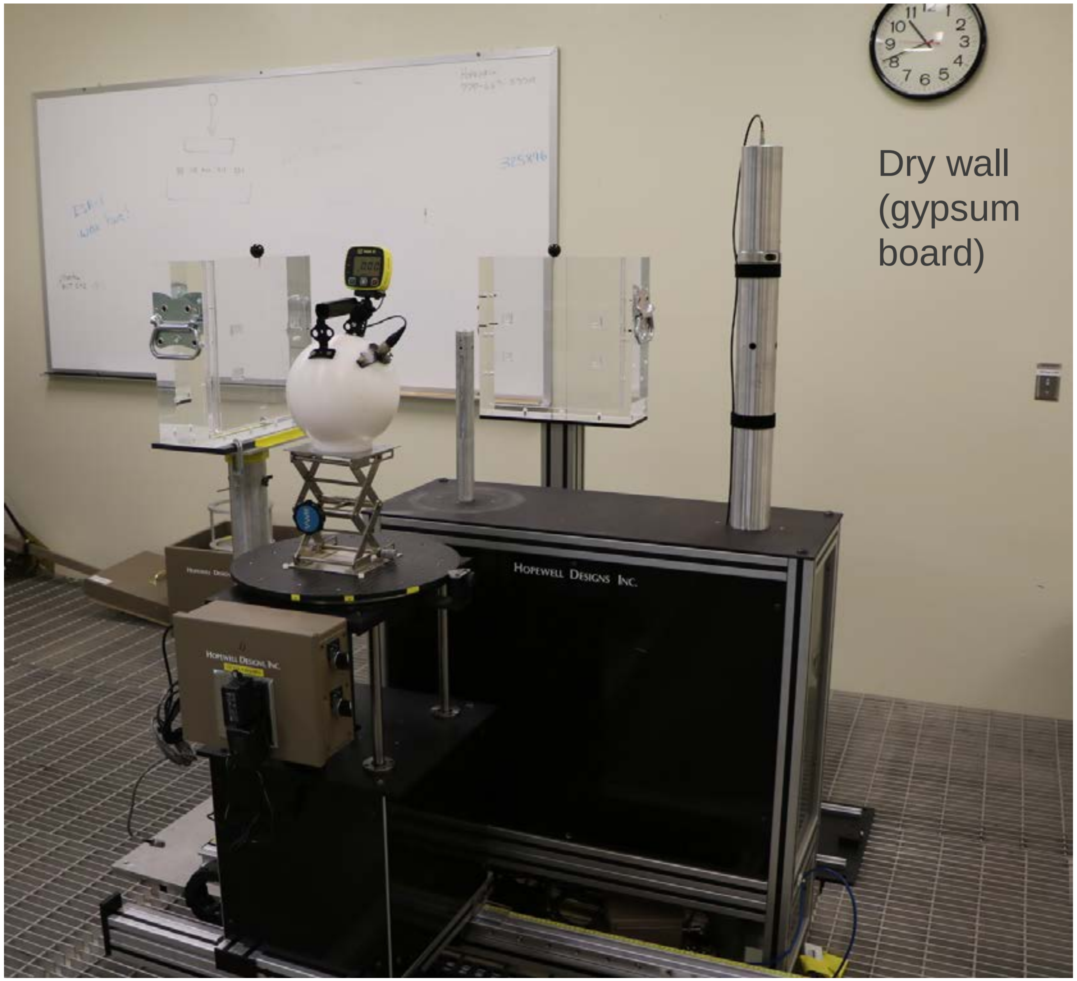
Neutron calibrations at LANL

- **Source emission rates calibrated at NIST**
  - AmBe and ^{252}Cf sources

- **Two calibration ranges in calibration facility**
  - Neutron Free-in-air (NFIA)
    - Low scatter reference fields (AmBe, ^{252}Cf & D_2O-Cf)
    - Characterized using MCNP
      - source anisotropy & room return components calculated
    - Validated using ROSPEC and Bonner Sphere (PTB-C set) measurements

  - Neutron Well Irradiator (NWI)
    - Characterized using a NFIA-calibrated transfer instrument (working standard)

LANL Neutron free-in-air (NFIA) calibration range



- AmBe (12 Ci) and two ^{252}Cf sources (2 & 33 mCi) raised pneumatically from below-grade storage location
- Mezzanine 10ft (3m) above floor.
- LPS has 50–250 cm range of motion.
- Laser alignment system
- Remote operation from console outside calibration room (LPS movement, source selection, count time, …)
- Probe data transmitted using serial or Ethernet connection to console

LANL Neutron well irradiator (NWI)

- AmBe source (11 Ci)
- Well depth = 13 ft (4.0 m)
- Dose rates up to 730 mrem/h (7.3 mSv/h)
- Source raised and lowered from adjacent console station
- Lucite shield limits dose to operator
- Instruments are calibrated annually and/or after any major repair (e.g. ^{3}He tube replacement)

Neutron calibrations at LANL

- **NFIA range characterized using following expression:**
  - $Dose\ equivalent\ rate\ \left(\frac{mrem}{h}\right) = Q * F * A * S * D/(4\pi r^2)$
  - where:
    - Q = source emission rate (n/s)
    - F = fluence-weighted dose conversion coefficient (mrem/h per n/(cm^2 s))
    - A = source anisotropy for lateral irradiation (MCNP calculated)
    - S = scatter factor (includes room return, in-scatter and out-scatter terms)
    - D = geometry correction factor (typically unity)
    - r = source-to-detector distance

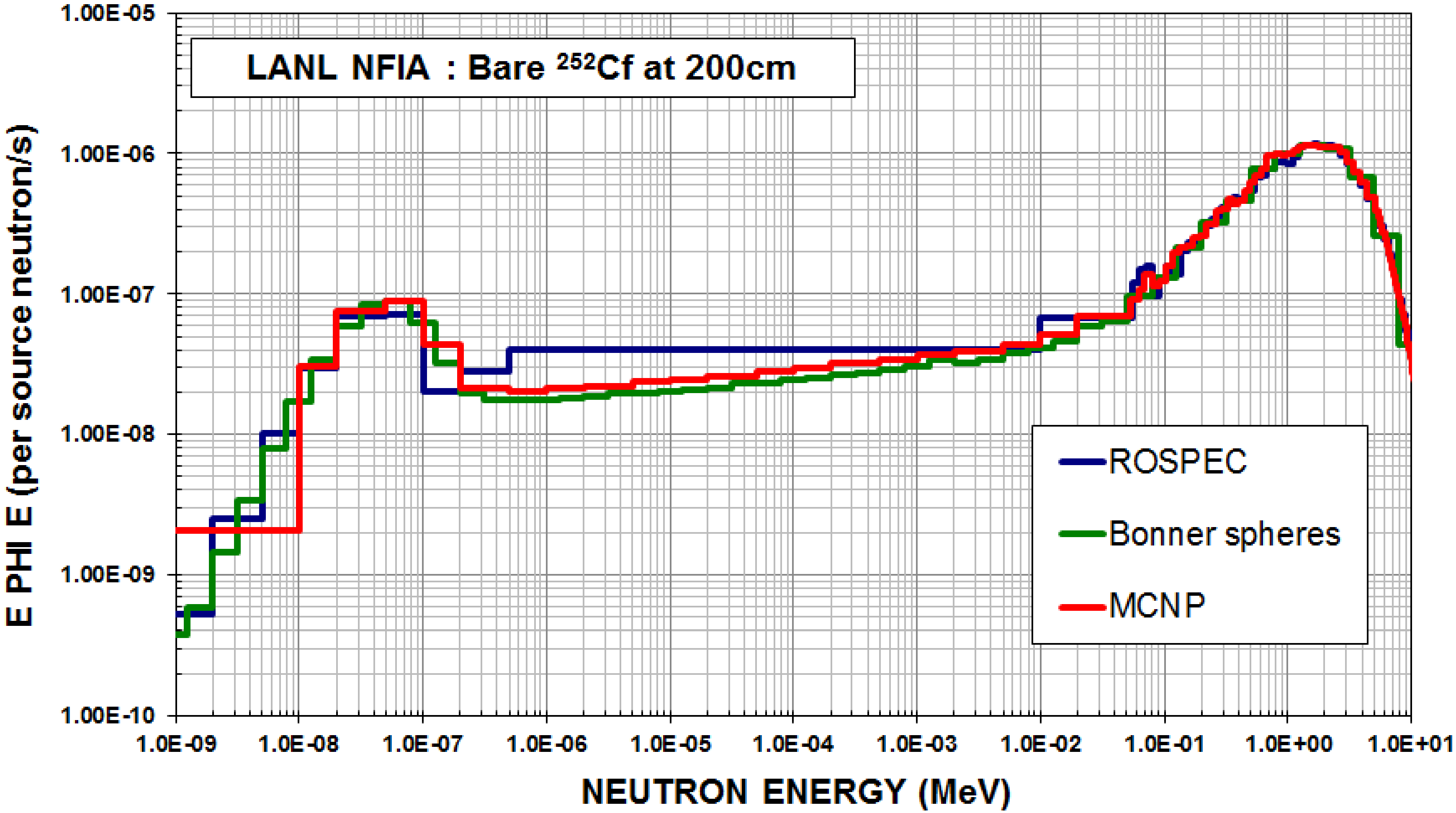
Neutron calibrations at LANL

- **H*(10) uncertainty budget for NFIA range based on uncertainties in:**
  - Source emission rates
  - Source decay corrections
  - Fluence-dose-conversion factors (from ISO 8529)
  - Geometry correction
  - Room return (includes in and out-scatter)
  - Distance between source and instrument

Range & source	Relative uncertainty (k=2)
NFIA, Bare ^{252}Cf	6.0%
NFIA, D_2O-Cf	9.1%
NFIA, AmBe	9.0%
NWI, AmBe	10.7%

Well within the 10% (k=1) DOE recommendation

Absolute comparison of ROSPEC, Bonner sphere and MCNP-calculated spectra



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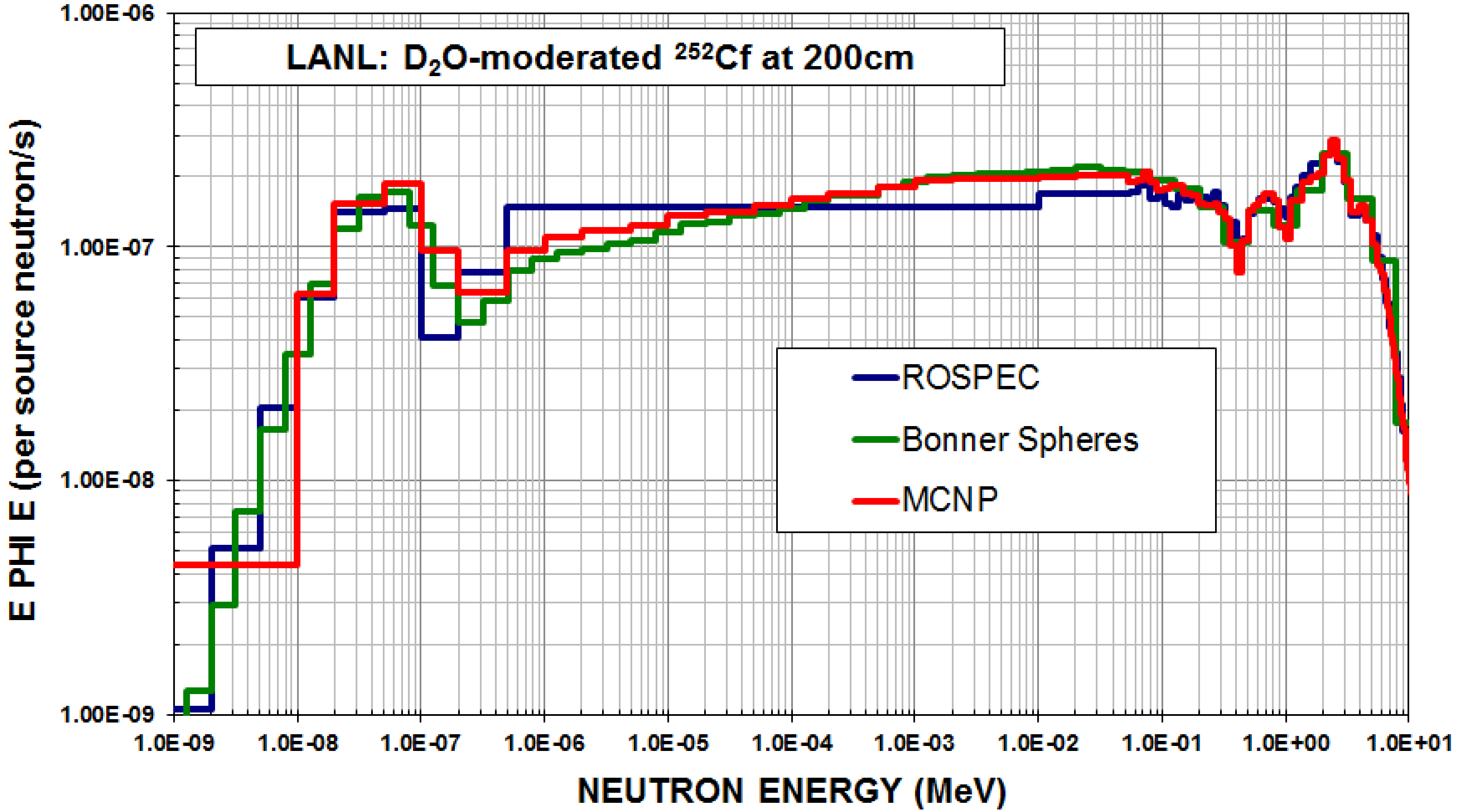


Neutron calibrations at DOE facilities

- **LANL RP-SVS Group has characterized the following DOE neutron calibration ranges using spectrometers and MCNP modeling**

- **Various facility designs (cubic, circular, hexagonal) but all low-scattering environments**

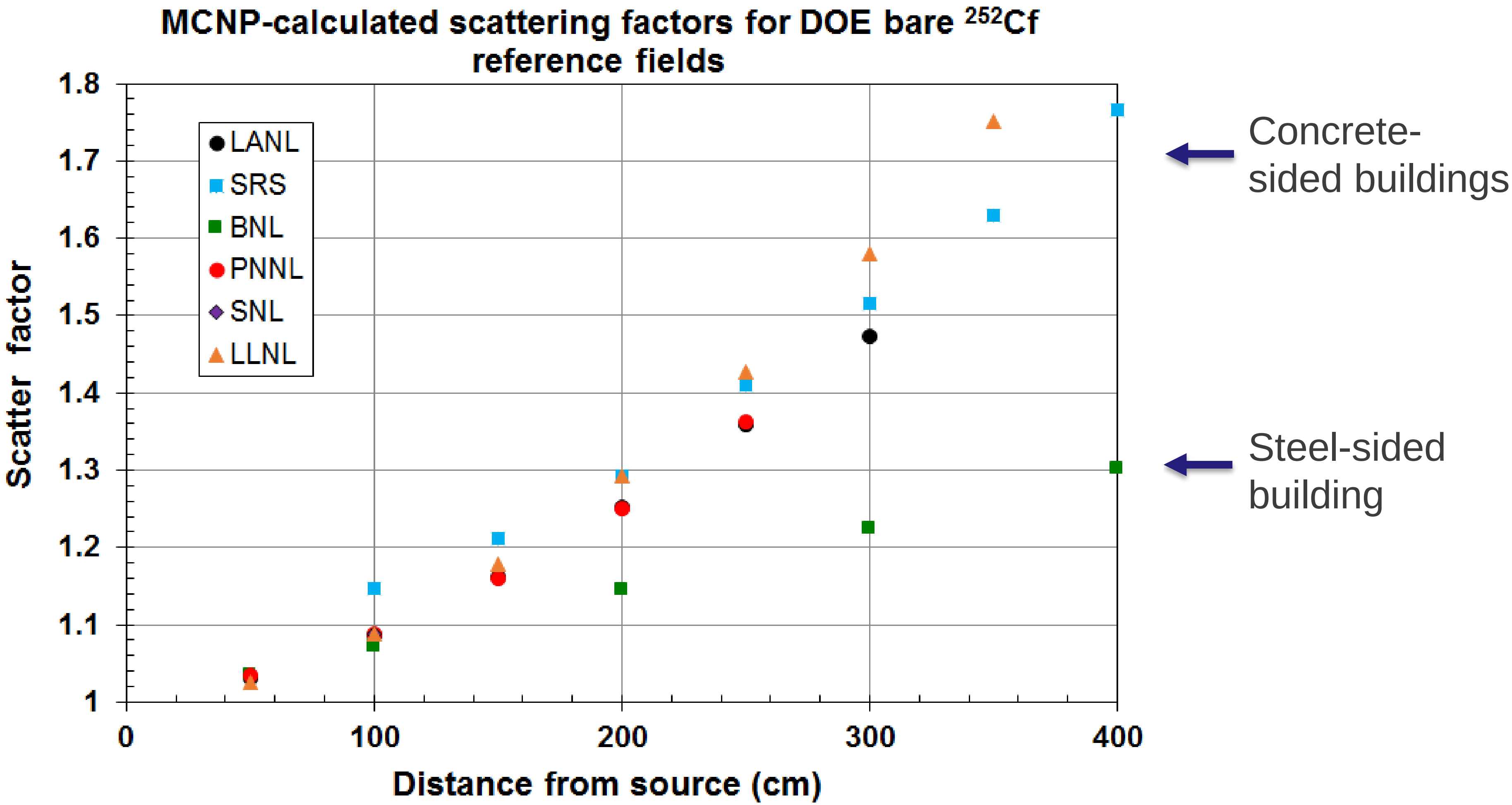
DOE site	date	Bare ^{252}Cf	D_2O-^{252}Cf	AmBe	PuBe	PuF_4
BNL	2/2003	✓	✓		✓	
PNNL	3/2003	✓	✓			
SNL	2/2004	✓			✓	
SRNL	3/2005	✓	✓			✓
LLNL	3/2008	✓	✓			
ORNL	3/2017	✓	✓		✓	
LANL		✓	✓	✓		

ISO8529 neutron calibration methods

- **None of the various ISO8529 approaches have been adopted (except at NIST) in US**
  - Rightly or wrongly perceived as too difficult to apply
  - In addition, each method has limitations making them less attractive to use
  - Also, the low-scatter calibration facilities at DOE National Labs mitigate the influence of room return and air in and out-scatter on instrument calibrations
  - E.g. calibrating WENDI at LANL gave following calibration factors as a function of distance (bare ^{252}Cf source):

Distance (cm)	cpm per µSv/h	Relative to 100cm
50	28.95 ± 0.06	1.021
100	28.35 ± 0.12	1.000
150	27.96 ± 0.17	0.986
200	28.12 ± 0.22	0.992
250	28.14 ± 0.27	0.993

Neutron calibrations at DOE facilities



Vendor calibrations

- **Vendors typically rely on a secondary transfer instrument sent to NIST for calibration**
  - But their calibration facilities are much smaller than NIST or DOE National Labs
  - Therefore a greater need to consider ISO8529 techniques
    - But don't have the expertise and/or inclination to invoke

- **Often have accreditation through other organizations (e.g. NVLAP)**
  - Some (most ?) may not be aware of ISO8529

- **ANSI N323AB-2013 gives the following guidance on the uncertainty (k=2) associated with a neutron reference field:**
  - <100 µSv or <100 µSv/h ± 30% of conventionally true value
  - >100 µSv or >100 µSv/h ± 20% of conventionally true value

Neutron dosimetry at DOE facilities

- **Only passive dosimeters (TLDs, track etch) used for official dose-of-record purposes**
  - Lucite phantoms (40x40x15cm) used to mount dosimeters in reference fields
  - Each Lab independently manages their external dosimetry program
  - EPDs only used for real-time monitoring e.g. hot jobs

- **External dosimetry program accredited through DOELAP (Lab Accreditation Program)**
  - Every three years, a combination of:
    - Performance testing of neutron dosimeter
      - Dosimeters irradiated at PNNL then read by DOE Lab
      - Bare Cf and D_2O-Cf techniques only
    - On site visits and inspections

Alternatives to ^{252}Cf

- **Heavy reliance on ^{252}Cf for calibration purposes**
  - Future availability in question
  - Price becoming prohibitive
  - No obvious replacement in the emission range required (~10^9 n/s)
    - – DHS considering use of ^{244}Cm sources for performance testing purposes
  - DT generator-based source recently proposed by PNNL (Health Physics, 113, 183, 2017)
    - – Drawbacks include maintenance, limited tube lifetime, ^{3}H build-up, and an external means of accurately monitoring neutron output is required

Summary

- **DOE neutron instrument/dosimeter calibration based on the ICRP-74/ICRU-57 limiting and operational quantities**

- **Neutron free-field calibrations at DOE National Labs based on low-scatter facilities**
  - NIST–traceable reference fields
  - Characterized using a combination of MCNP and spectral measurements
  - Calibration methods outlined in ISO8529 not followed (or needed)

- **Future availability/affordability of ^{252}Cf a concern**