National Institute of Standards and Technology
U.S. Department of Commerce

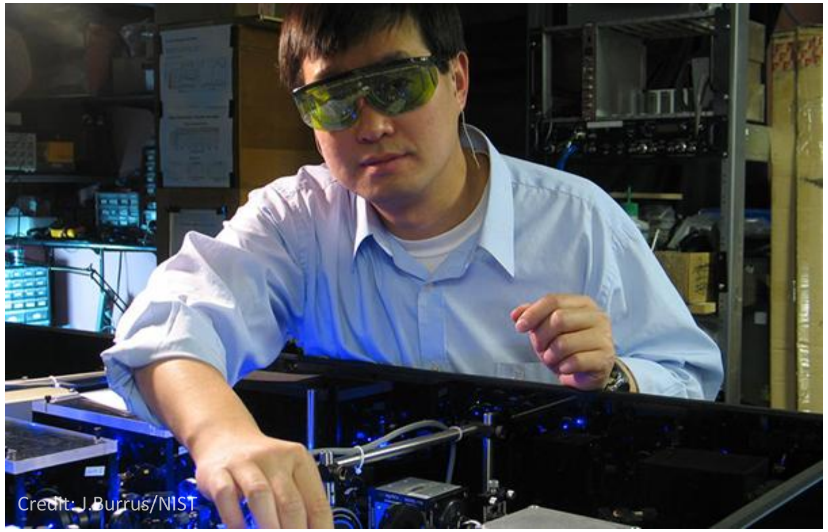
Introduction to NIST

Alan K. Thompson
Chief of the Radiation Physics Division
National Institute of Standards and Technology
alan.thompson@nist.gov

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


©Robert Rathe


Credit: J.Burrus/NIST


©Nicholas McIntosh Photography

NIST Mission

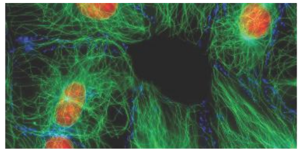
Advanced communications

(https://www.nist.gov/advanced-communications)
NIST promotes the development and deployment of advanced communications technologies by advancing the measurement science underlying wireless technologies.

Artificial intelligence

(https://www.nist.gov/artificial-intelligence)

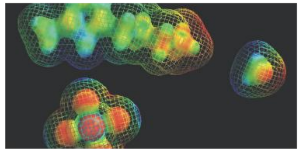
NIST promotes innovation and cultivates trust in the design, development, use and governance of artificial intelligence (AI) technologies and systems in ways that enhance economic security



Bioscience (https://www.nist.gov/bioscience)
NIST provides measurement assurance through the development of quantitative analytical measurement tools to aid industry in the deployment of innovative biotechnologies and advanced biomaterials.

Buildings & Construction

(https://www.nist.gov/buildings-construction)

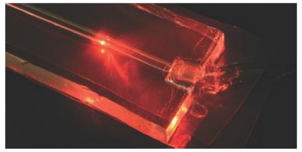


Chemistry (https://www.nist.gov/chemistry)
NIST develops the technology, measurement methods and standards to address the needs of the chemical industry.

Cybersecurity and privacy

(https://www.nist.gov/cybersecurity-and-privacy)

NIST develops cybersecurity and privacy standards, guidelines, best practices, and resources to meet the needs of U.S. industry, federal agencies, and the broader public. Our activities range from

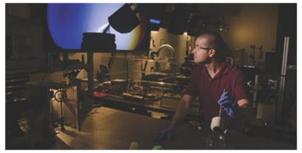


Electronics (https://www.nist.gov/electronics)
NIST provides the standards, develops the instruments and performs the calibrations necessary to keep both the smallest electronic components and the largest power grids running smoothly and safely.

Energy (https://www.nist.gov/energy)
NIST develops testing methods, measurement science and reference materials to ensure the quality of energy-related products and services and ensure fairness in the marketplace.

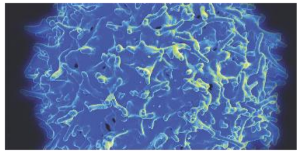
Environment (https://www.nist.gov/environment)
NIST is helping to advance measurements and tools for environmental science.

Fire (https://www.nist.gov/fire)
NIST's fire research develops, verifies and utilizes measurements and predictive methods to quantify the behavior of fire and means to reduce its impact.



Forensic Science (https://www.nist.gov/forensic-

science)
Bringing together experts from the forensic, research, legal and law enforcement communities to strengthen forensic science and create a safer, more just society.



Health (https://www.nist.gov/health)
NIST provides measurement assurance for biomedical stakeholders through the development of measurement tools for medical devices, clinical diagnostics, imaging tools and the characterization of

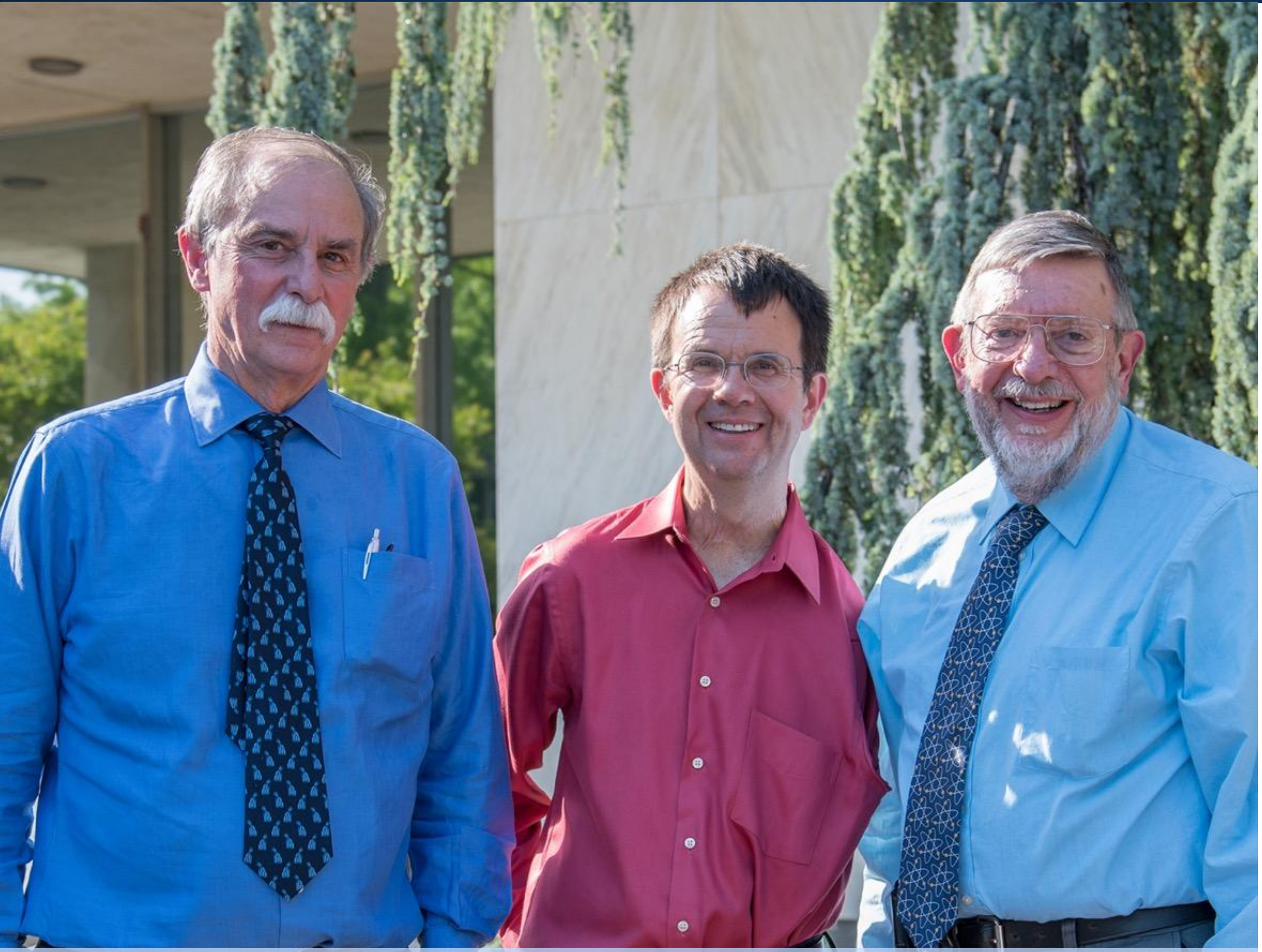
Metrology

The science of measurement and its application. NIST's work in metrology focuses on advancing measurement science to enhance economic security and improve quality of life.

Measurements essential to commerce, trade, and innovation

Federal role established in the U.S. Constitution

NIST's Biggest Strength: Our Reputation



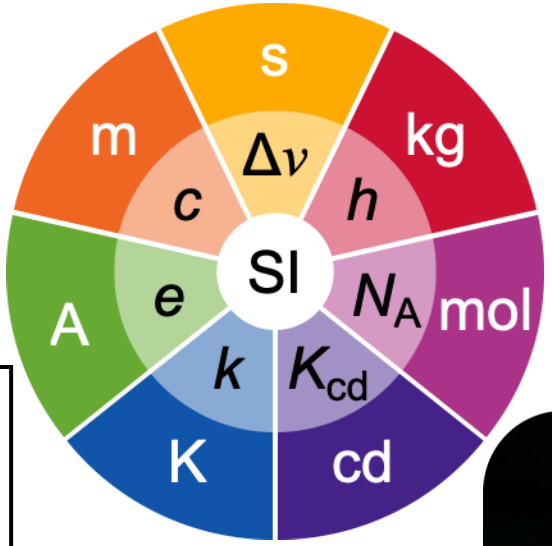
NIST Nobel Laureates David Wineland, Eric Cornell, and Bill Phillips

Credit: NIST

- Technical excellence
- Integrity
- Uncompromising
- Rigorous
- Unbiased
- Industry focused
- Non-regulatory

NIST is the US *National Metrology Institute* (NMI)

The United States Constitution, Article I, section 8 gives Congress the power to:
"fix the standard of weights and measurement."



Three Main Activities of Metrology

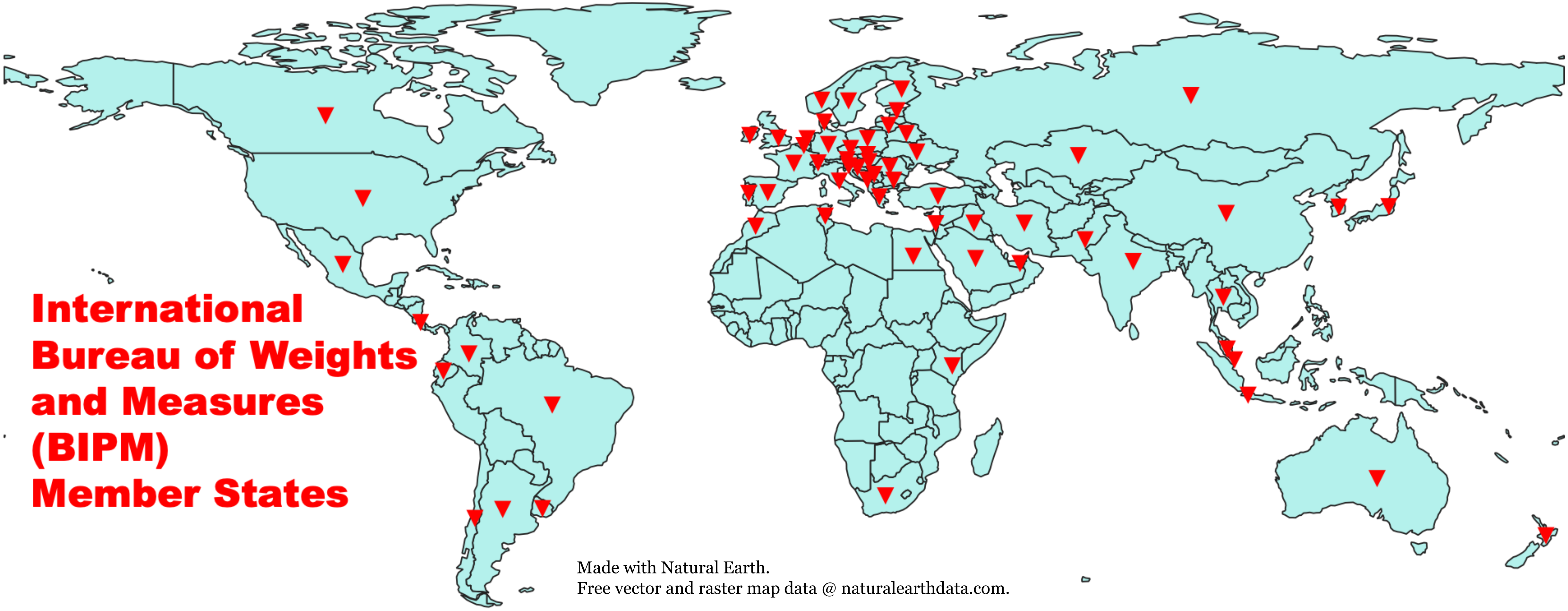
- *Definition* of units (SI)
- *Realization* of the units
- *Dissemination* (traceability) of the units

NIST *Measurement Services* are the direct way we disseminate the SI

- Calibrations
- Standard Reference Materials (SRM)
- Standard Reference Data (SRD)
- Office of Weights and Measures (OWM)
- Standard Reference Instruments (SRI)

  (Calibrations + SRM)

NIST is the US National Metrology Institute



Unique NIST Products and Services

454 ton (Million-Pound) Deadweight Machine

Credit: NIST

1,100 Standard Reference Material (SRM) products

100+ Standard Reference Data (SRD) products

550 measurement services

Every year:

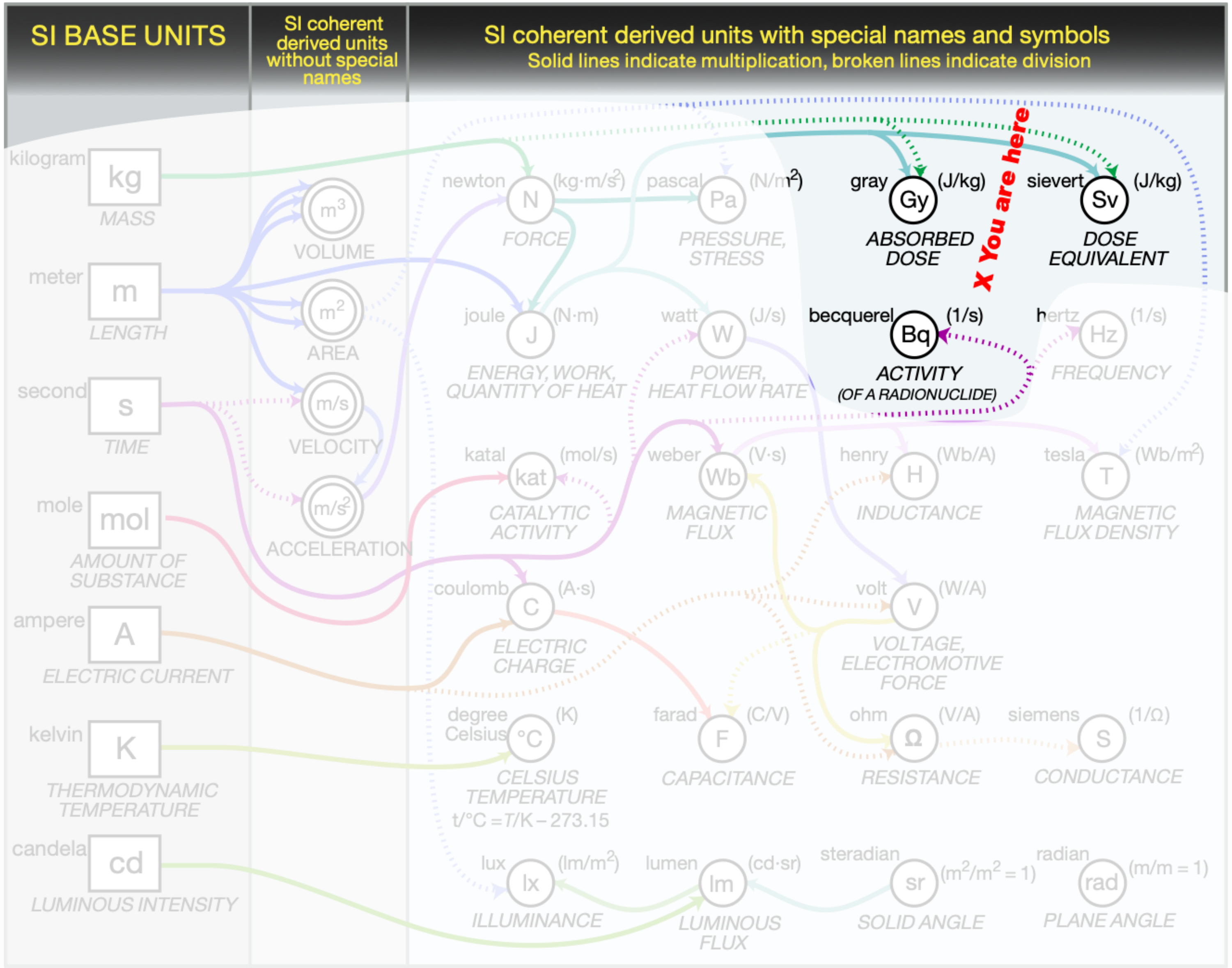
32,000 SRM units sold

13,000 calibrations and tests

650 accreditations of testing and calibrations laboratories

20,000 SRD products downloaded or purchased

NIST is the USA's National Metrology Institute




Calibrations
Sievert
Fundamental
Symmetries
Brachytherapy
Dose
SRD
Weapons
Cancer Therapy
Gamma
Fuel Cells
X-ray Imaging
Tracers
Materials
Gray
RADIOACTIVITY
Alpha
Device Sterilization
Low-level radioactivity
QIS
RADIATION
Bq
Neutron
Food
Safety
Nuclear Medicine
Beta
Nuclear Power
SRM
Mammography
Homeland Security
Radiography
Air Kerma

Radiation Physics Division

https://www.nist.gov/pml/radiation-physics

Physical Measurement Laboratory

RADIATION PHYSICS DIVISION

The Division develops, maintains and disseminates the national measurement standards for ionizing radiation and radioactivity, and methods and models to address related applications.

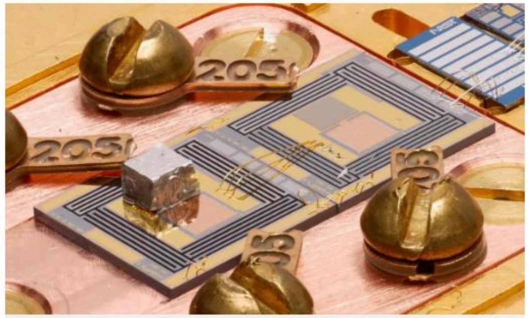
NIST Store

Calibrations

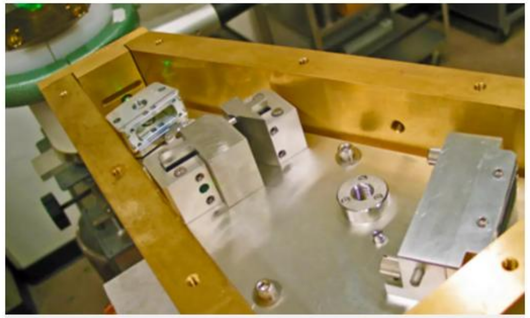
Ionizing Radiation

- Dosimetry for High-Dose Applications
- Neutron Sources, Dosimetry
- Radioactivity
- Sealed Gamma-Ray or Beta-Particle Sources
- X-Rays, Gamma-Rays, Electrons

On the Road to a Neutron Microscope: First Light for World-Class Neutron Imaging Facility



True Becquerel - A New Paradigm for 21st Century Radioactivity Measurements



NIST Calibrates Quartz Crystals for Fusion Device

Radiation Physics Division

Division Chief:
Alan K. Thompson

Deputy Division Chief:
Lizbeth Laureano-Perez

Dosimetry:
Michael Mitch

10 Federal Staff

- Realize and disseminate the gray (Gy)
- Absorbed dose / dose standards / kerma for: external-beam therapy, Brachytherapy, diagnostic radiology, radiation protection, and radiation processing
- Photon and charged-particle data center
- Research in remote sensing, nano-sensor development, radiation resistance of materials, DNA dosimetry, nuclear event response

Neutron Physics:
H. Pieter Mumm

14(3) Federal Staff

- Precision Neutron Metrology
- Fundamental Neutron Physics
- Neutron Dosimetry & Calibrations
- Imaging and Interferometry
- Neutron Polarizers
- Nuclear Security

Radioactivity:
Brian Zimmerman

17 Federal Staff

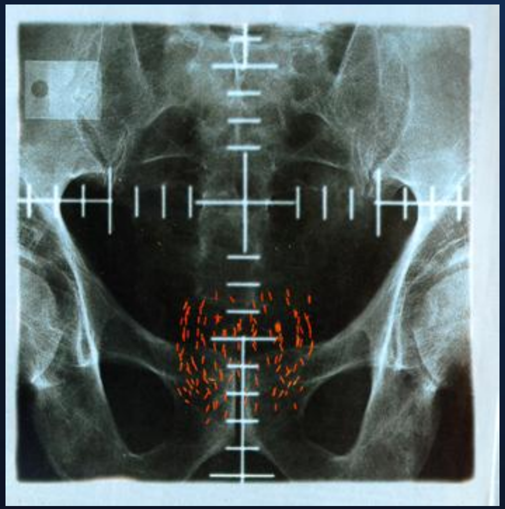
- Realize and disseminate the bequerel (Bq)
- Radioactivity Metrology
- Nuclear Security
- Medical Applications
- SRM / Cal / Proficiency / MAP

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.

$$1\ \mathrm{Gy} \equiv 1\ \mathrm{J} / \mathrm{kg}$$

Medical Physics

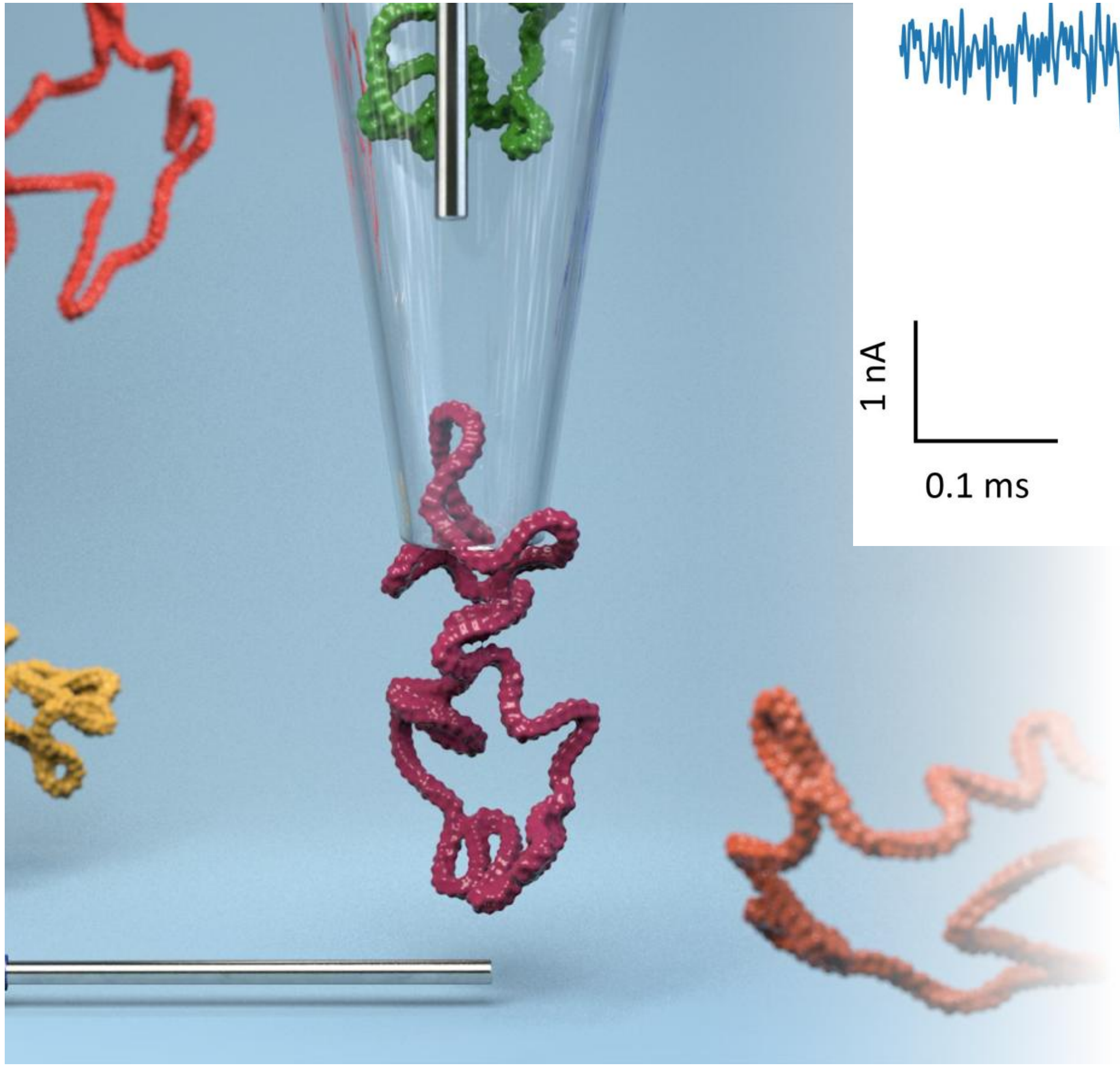


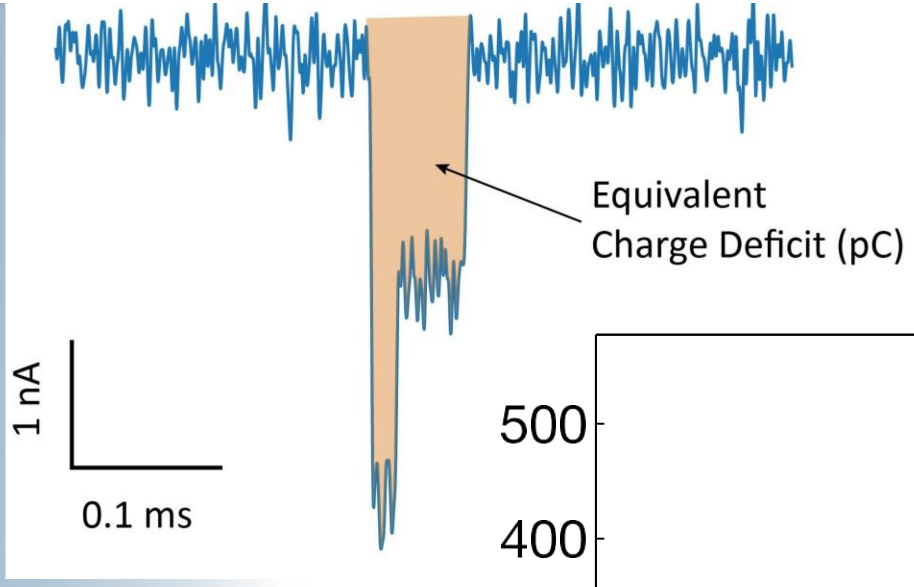
Radiation Protection

Radiation Processing

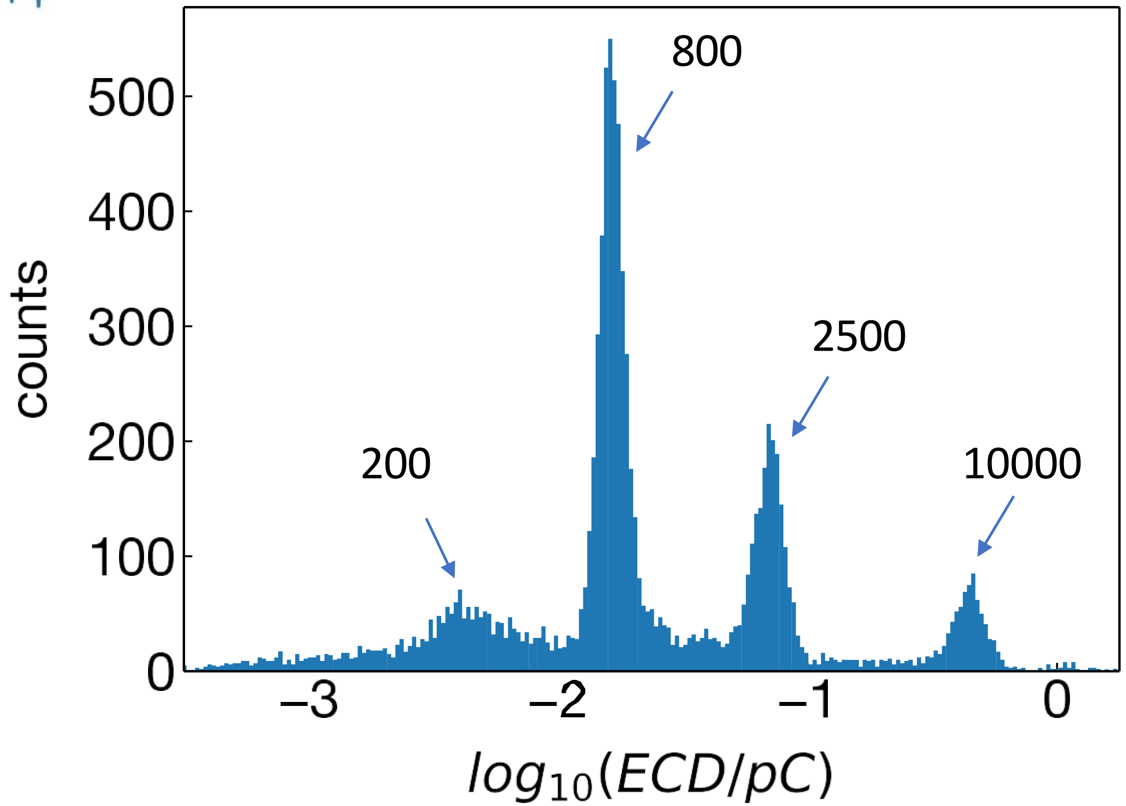
Homeland Security

Extracting molecular size from ionic current

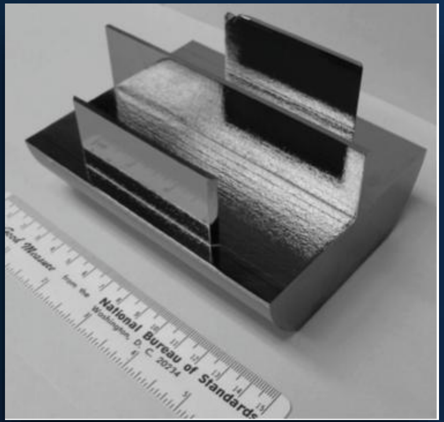




Integrated charge give length of a molecule ***translocating pore***

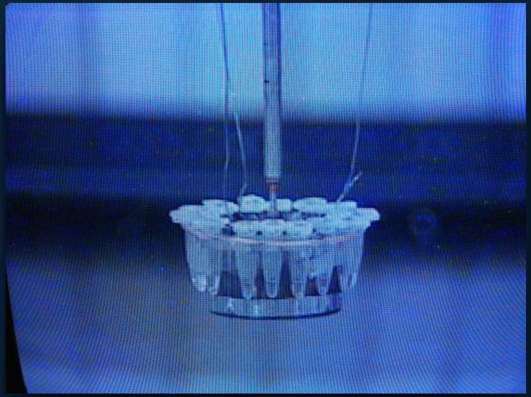


Neutron Physics Group



Neutron interferometry

Calibrations and Metrology:
- Neutron source calibrations
- Neutron meter calibrations
- High dose irradiations
- Absolute neutron fluence
- Standard cross sections



High dose irradiation of DNA samples

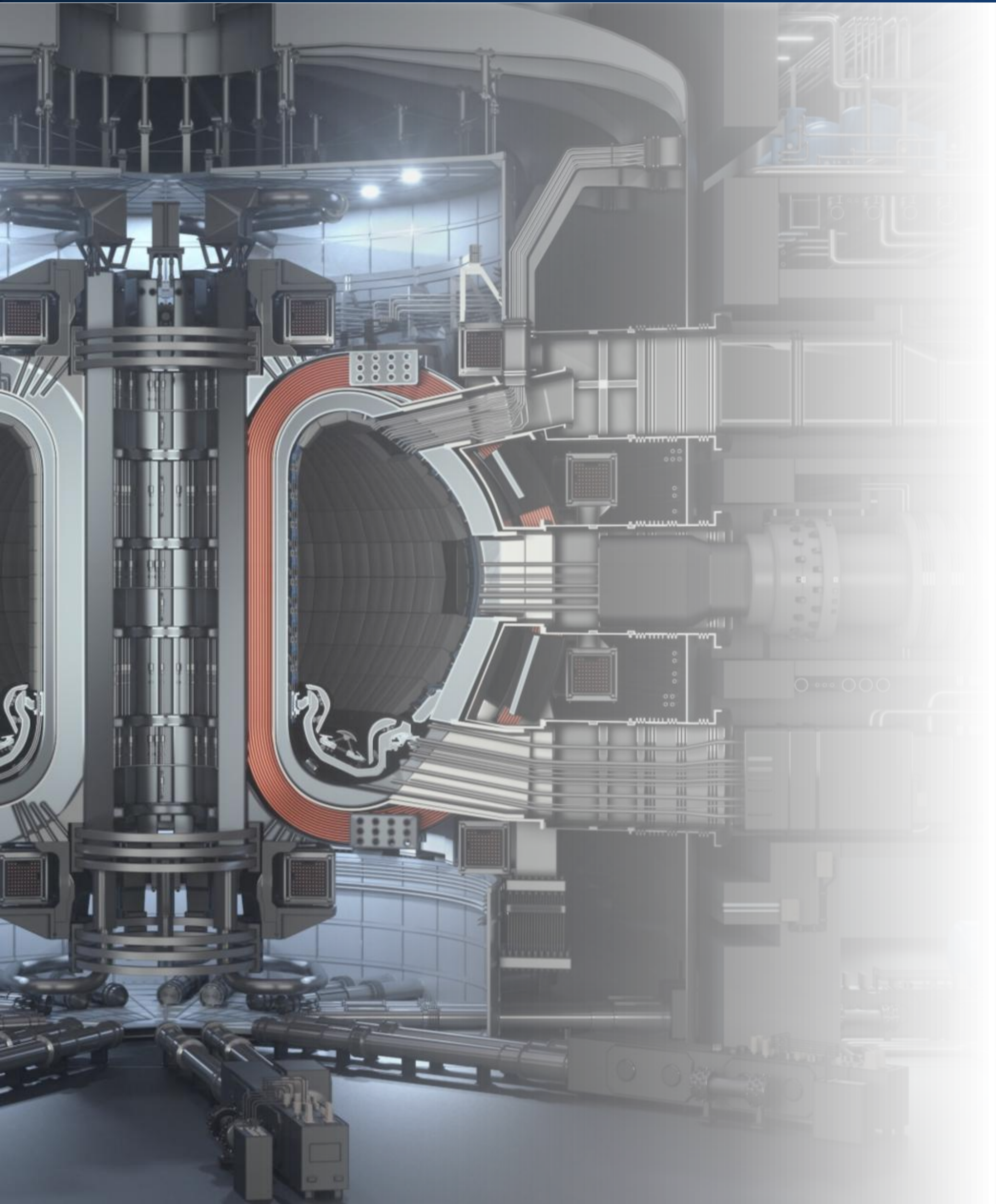
Basic Physics Research:
- Fundamental neutron physics
- Neutron interferometry
- Reactor neutrinos

Applied Research/Services:
- Neutron imaging
- Polarized He-3 spin filters
- Neutron detection/spectroscopy

Neutron lifetime

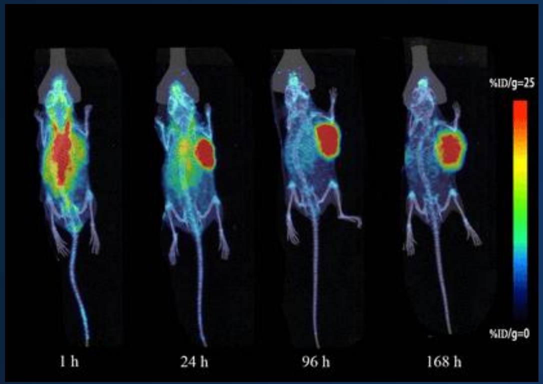
Neutron microscopy

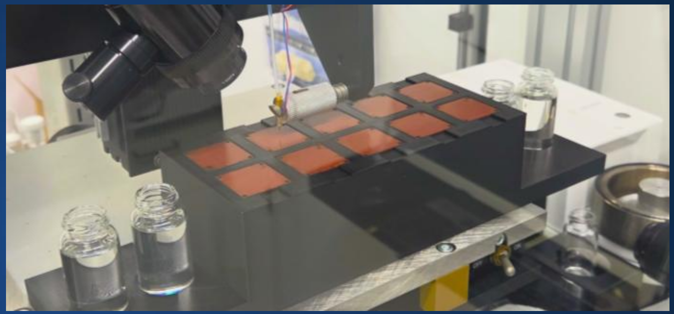
Metrology to Support Fusion Power



- There are numerous urgent metrology needs
  - ISO is considering the creation of a new standards subcommittee for fusion
- Measurement needs
  - Higher-energy (14 MeV) neutrons
    - Fluence rate
    - Radiation protection
  - Pulsed production
  - *Extremely high* production rate
  - Materials degradation (cross sections)
  - Measurements in high magnetic fields
  - X-ray diagnostics
  - Legal metrology for tritium?
  - Radioactive waste products
  - Tritium production
- There are needs to be addressed throughout the Division, and beyond.
- The neutron physics group is leading the effort to find resources, based on
  - Ongoing collaborative work with startup fusion companies
  - Past work with ITER

Radioactivity Group





Medical Applications
STRS + industry

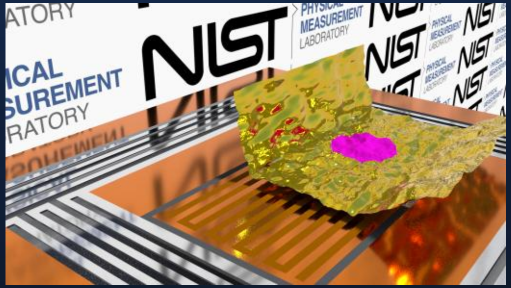
Mass Spectrometry

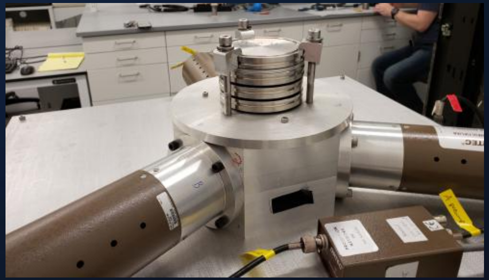
Nuclear Security
DHS, DNDO, DOE

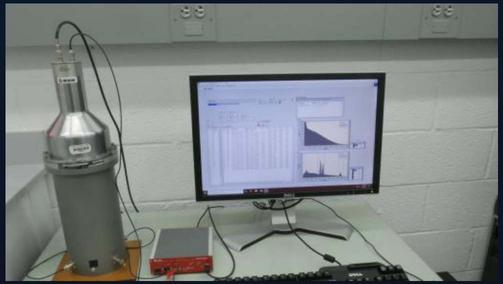
SRMs and Calibrations
Calibrations, SRM sales and devel, STRS

Proficiency Testing, Measurement Assurance
NRIP, DOE, NRMAP, STRS

Basic Metrology
(Primary, Secondary Standards, Nuclear Data)
STRS, IMS, Cal-SD, SRM Devel

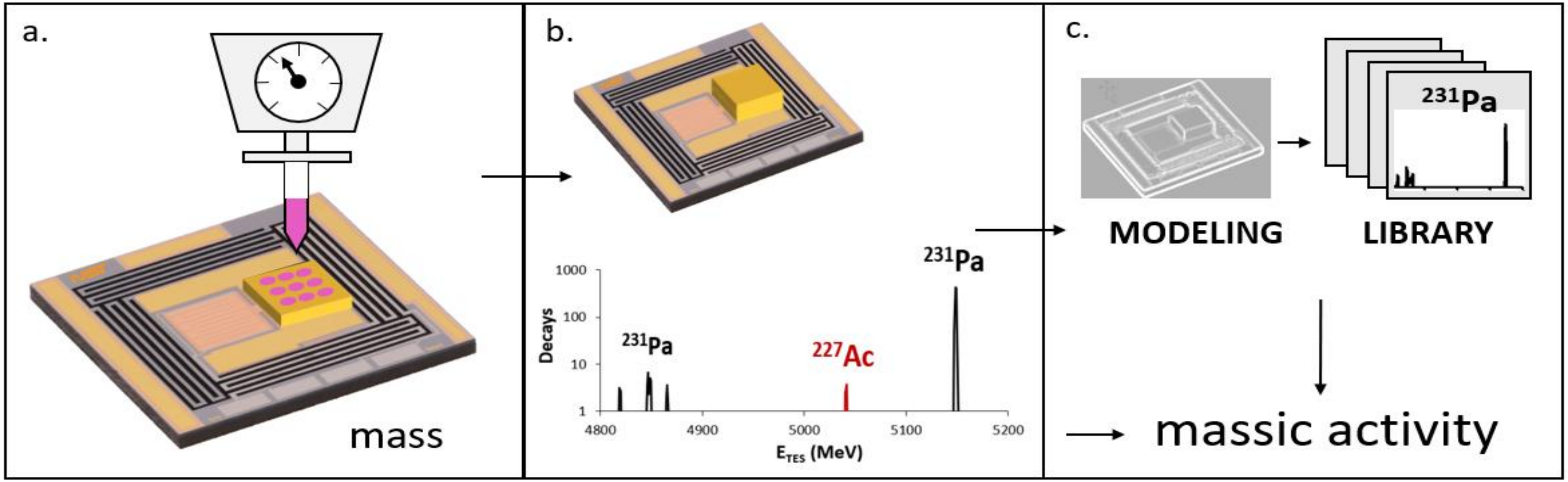






Decay Energy Spectrometry (DES): massic activity of multiple nuclides

Leverage NIST-made quantum sensors for exquisite energy resolution



Quantify source mass

Measure decay energy spectrum

Output list of nuclides with activities (and uncertainties)

TRUE Bq

[J. Res. NIST **126** 126048 (2021)](#)

[Metrologia **62** 045005 (2025)](#)

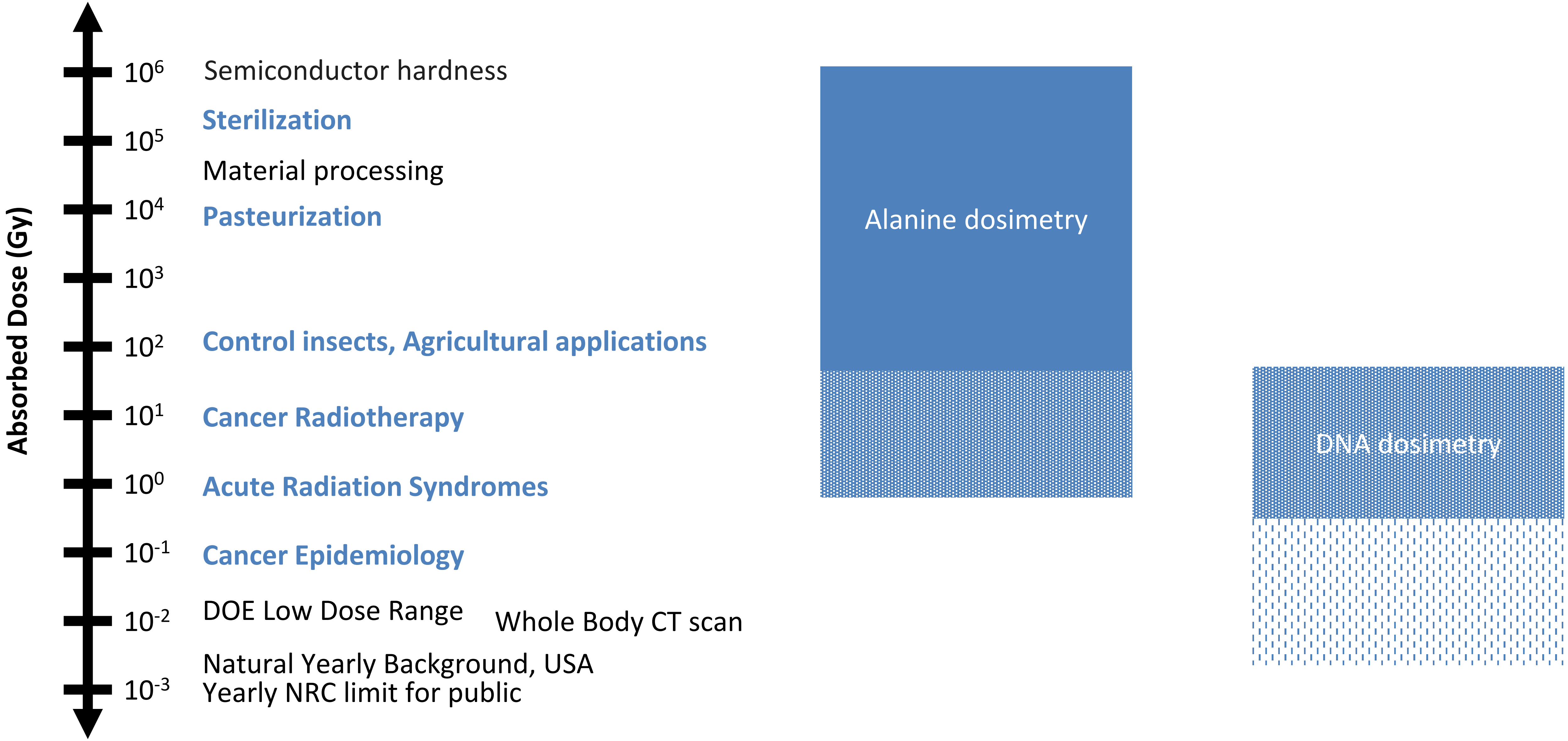
NIST@CIRMS

We are here, and we support CIRMS, so we can learn from our stakeholders to plan for the future.

Questions?

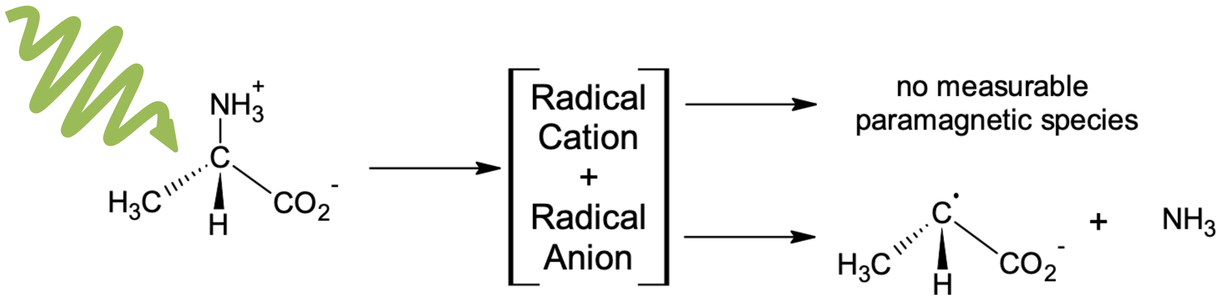
Questions?

Radiation applications and measurements

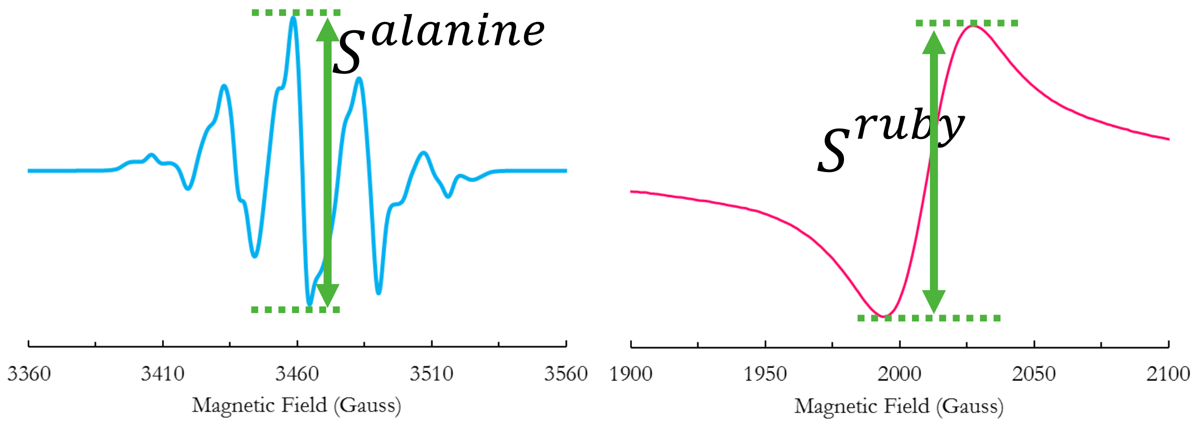


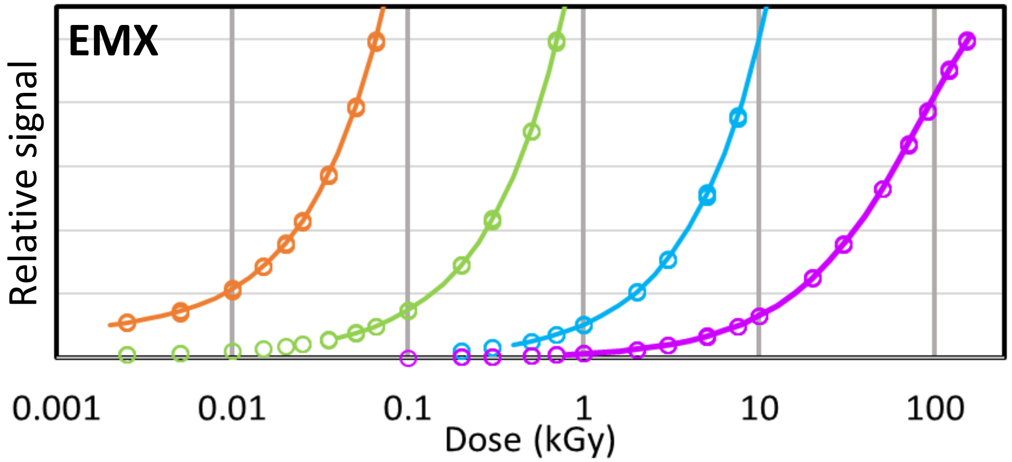
Alanine dosimetry system

NIST established an alanine-Electron Paramagnetic Resonance (EPR) spectroscopy dosimetry calibration service in the 1990s.



The alanine-derived radical anion undergoes deamination producing a free-radical center that is exceptionally stable.[1]



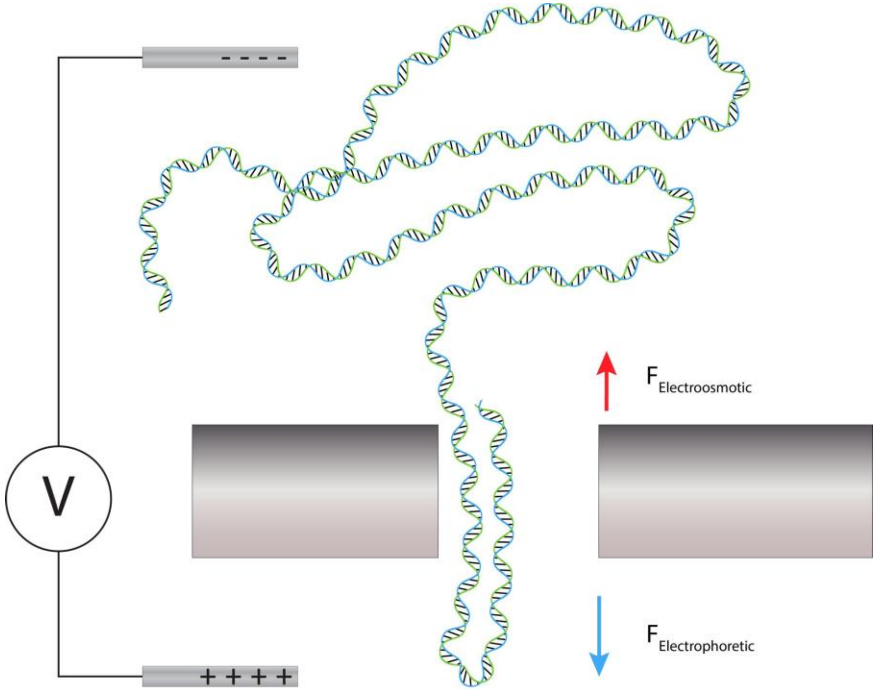


Nichiporov et al., *Appl Radiat Isotopes* **1995,** *46* (12), 1355-1362.

Today’s talk: biological dosimetry

Emergency Response Dosimetry System

DNA as a living dosimeter



Alanine dosimetry

- High accuracy/precision
- Can be put in materials and shaped
- Commercially available
- Relatively insensitive to environmental influences
  - Time, Temperature, Humidity
  - Light, Energy/Quality, Dose rate
- Long lifetime
  - avg decay, few % / y
  - archival
- Broad dose range
  - 1 Gy to 200 kGy
- Tissue equivalent
- No readout treatment required
- ASTM/ISO standard

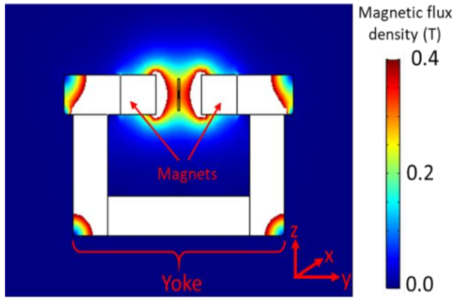
Alanine dosimeter pellets and EPR setup

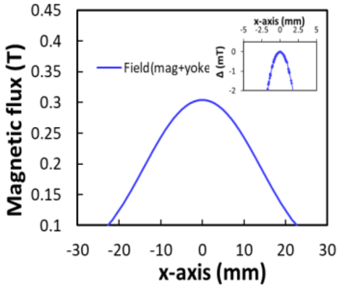
Calibration Customers:

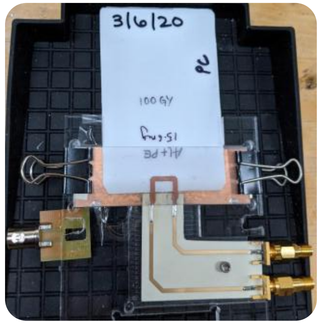
- Medical Device Manufacturers
- Materials Processors
- Aerospace
- Food Processors
- Private-Industry & University Researchers

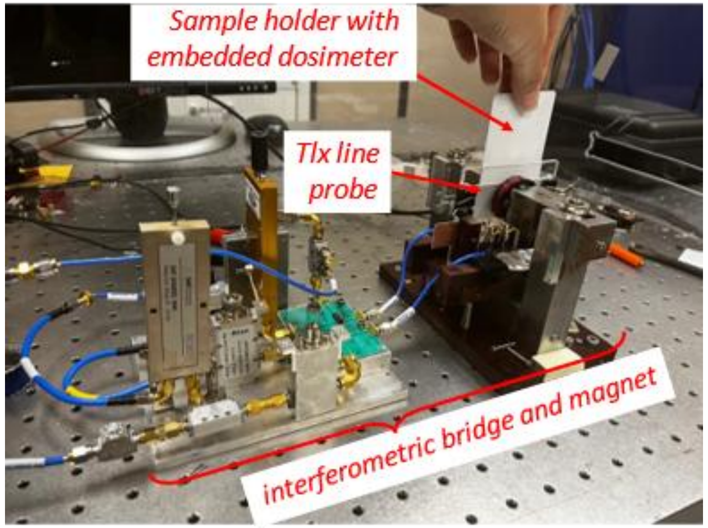
Emergency Response Dosimetry System (ERDS)

- Development of ERDS was carried out under a CRADA with NIST and Global Resonance Technologies (GRT)
- Funding for the development of ERDS was received from the US Department of Defense
    - Small Business Innovation Research (SBIR) Grants
    - Other Transaction Agreement (OTA)
    - Foreign Comparative Testing Program

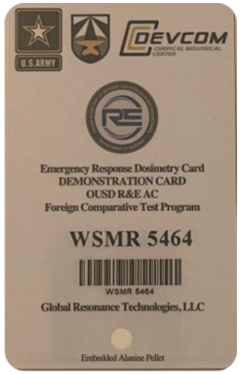


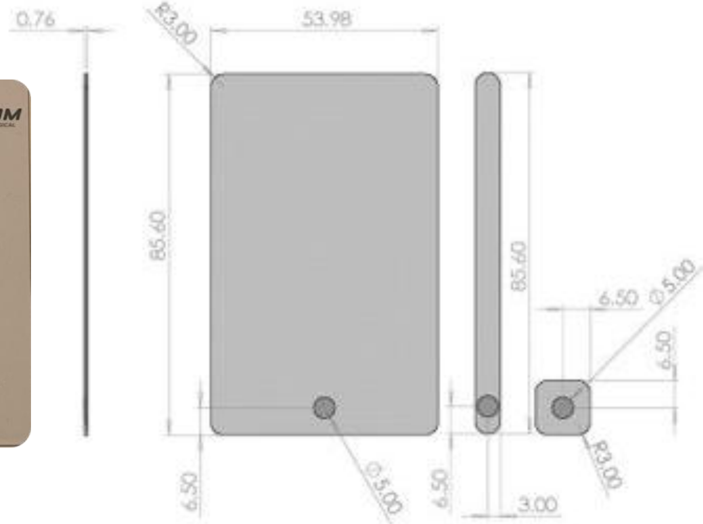






Dosimeter embedded card





Experimental setup showing the magnet, the non-resonant interferometric bridge, transmission line probe, and sample holder with dosimeter

*J.P. Campbell, et al., Anal. Chem., 87, 4910 (2015), *P.R. Shrestha, et al., Anal. Chem., 91, 11108 (2019)

ERDS continued

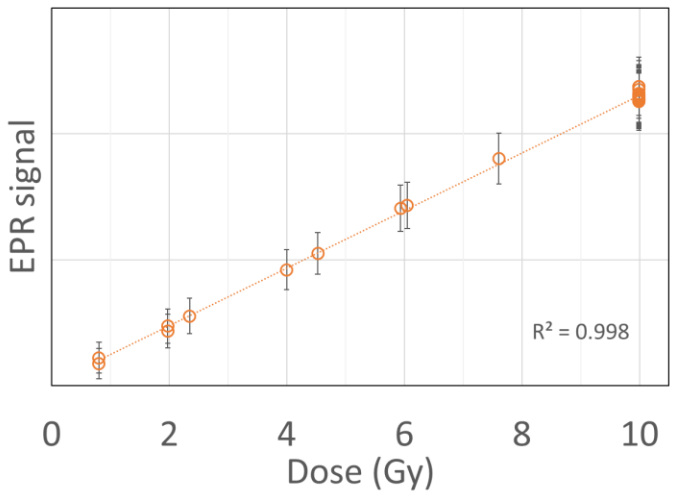
Sensitivity goal of combined neutron and gamma irradiation is 2 ± 0.5 Gy

Current times by dose and material (SN=3)

2 Gy sensitivity in 100 seconds with Lithium Formate

7.5 Gy sensitivity in 100 seconds with alanine

Current lab-grade commercial system at NIST:



- 0.8 Gy to 10 Gy irradiations
- 65 mg alanine pellets
- 15 min collection
- 5 % error bars shown

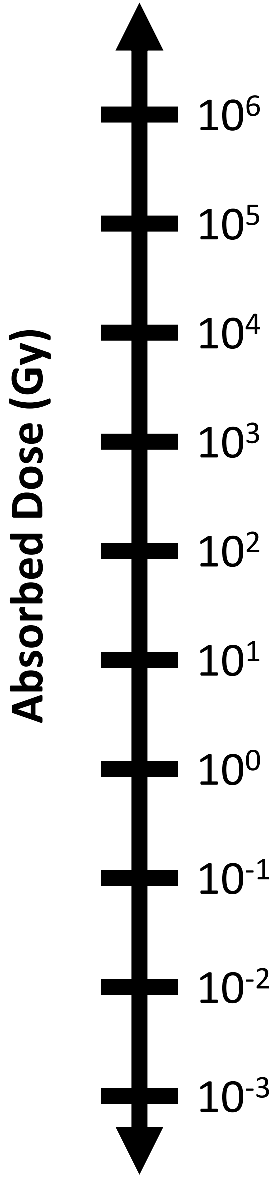
Calibration Customers:

- Medical Device Manufacturers
- Materials Processors
- Aerospace
- Food Processors
- Private-Industry & University Researchers

+

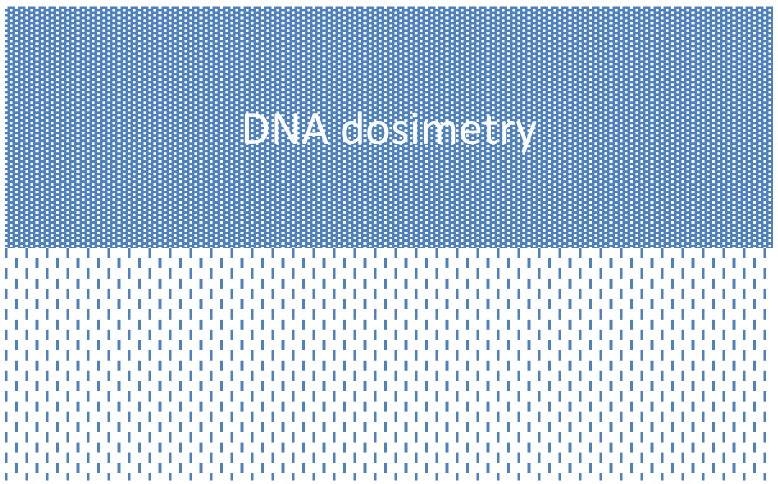
- Radiotherapy/medical applications
- Dosimetry for emergency responders

Physical dosimetry vs biological dosimetry

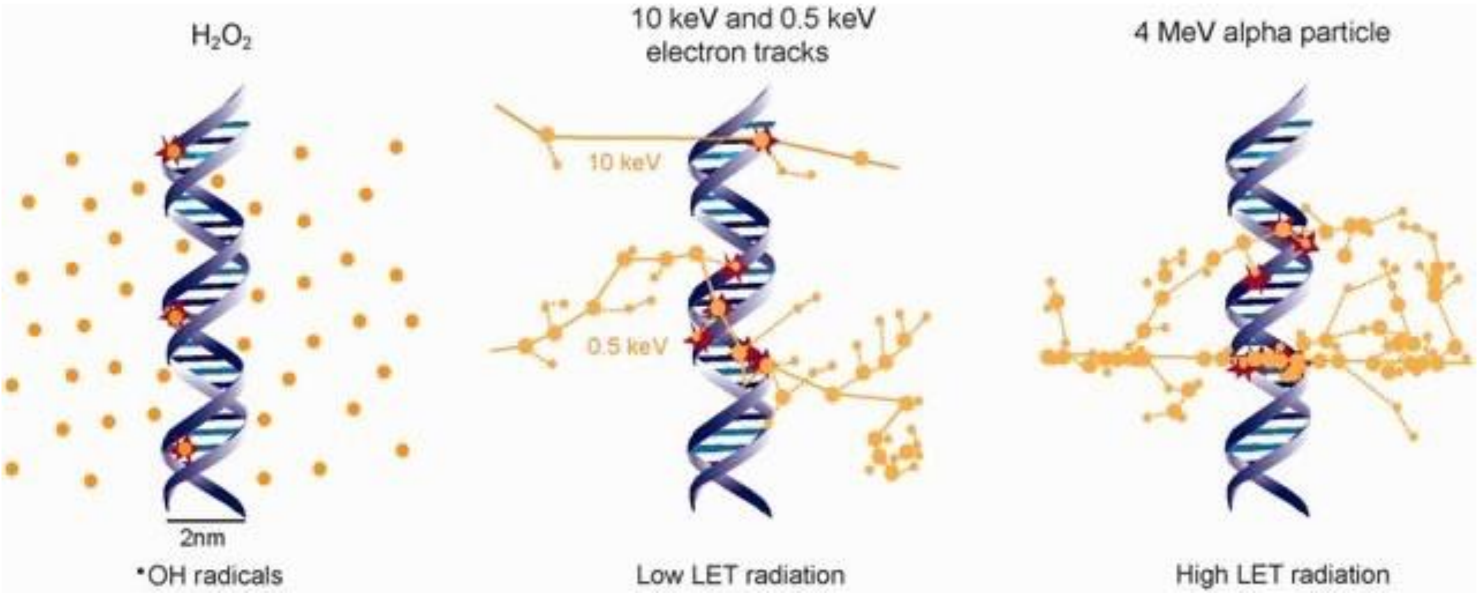


- Physical dosimetry is a measure of the amount of energy absorbed by a substance
- Small known corrections for different types of radiation

- Biological dosimetry is a measure of the response or effects of a biological system to radiation
- Biological systems may repair themselves
- Large differences among organs.
- Large difference among types of radiation.



Why DNA?



Radiation damage to DNA results in

- oxidative base damages
- single-strand breaks (SSBs)
- double-strand breaks (DSBs)

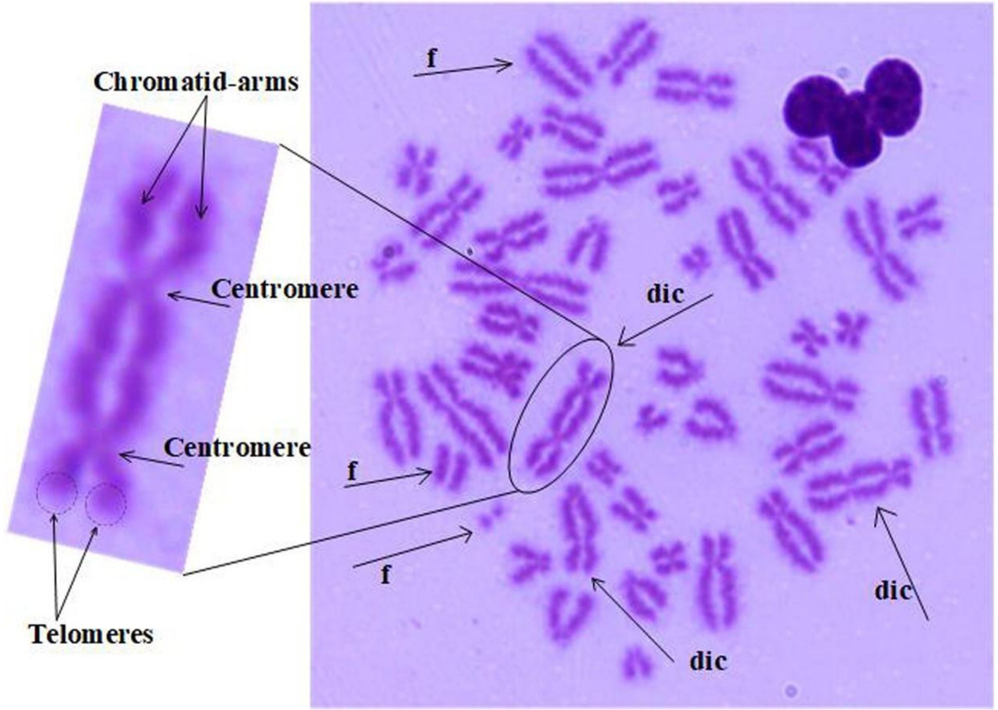
which are highly linked to cell survival.

A. Schipler, G. Iliakis, DNA double-strand–break complexity levels and their possible contributions to the probability for error-prone processing and repair pathway choice. *Nucleic Acids Research*. **41**, 7589–7605 (2013).

Measuring gross DNA damage

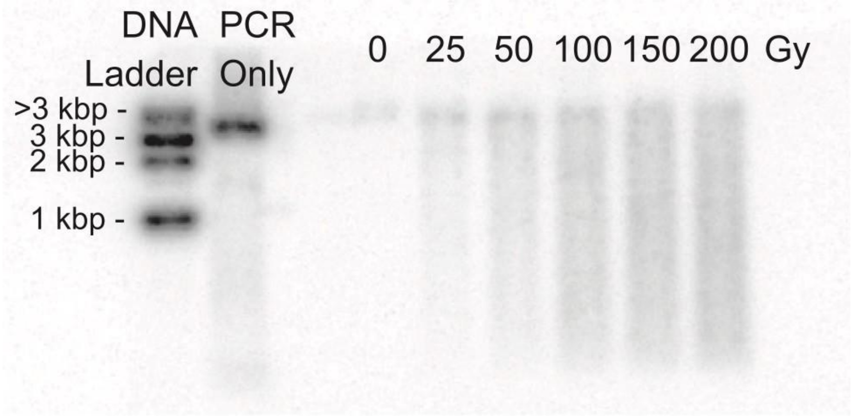
Chromosome aberrations and cell death

- Detected after doses as low as 0.1 Gy.
- Reflect both the initial damage and the repair/misrepair
- Dose of 0.5 – 2 Gy ➔ <*m*> = 1 /cell



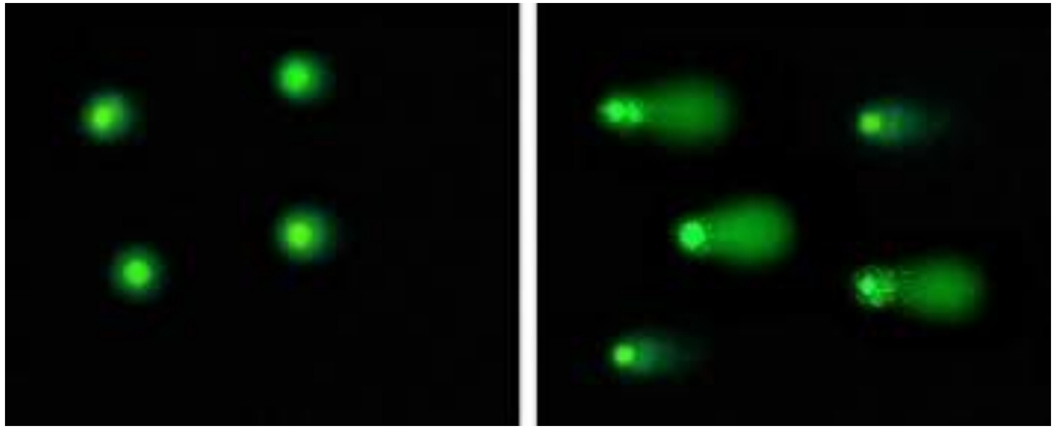
X. Shen, Y. Qi, T. Ma, Z. Zhou, A dicentric chromosome identification method based on clustering and watershed algorithm. *Sci Rep*. **9**, 2285 (2019)
Adapted from: https://ocw.mit.edu/courses/22-55j-principles-of-radiation-interactions-fall-2004

Electrophoretic separation is *almost* quantitative



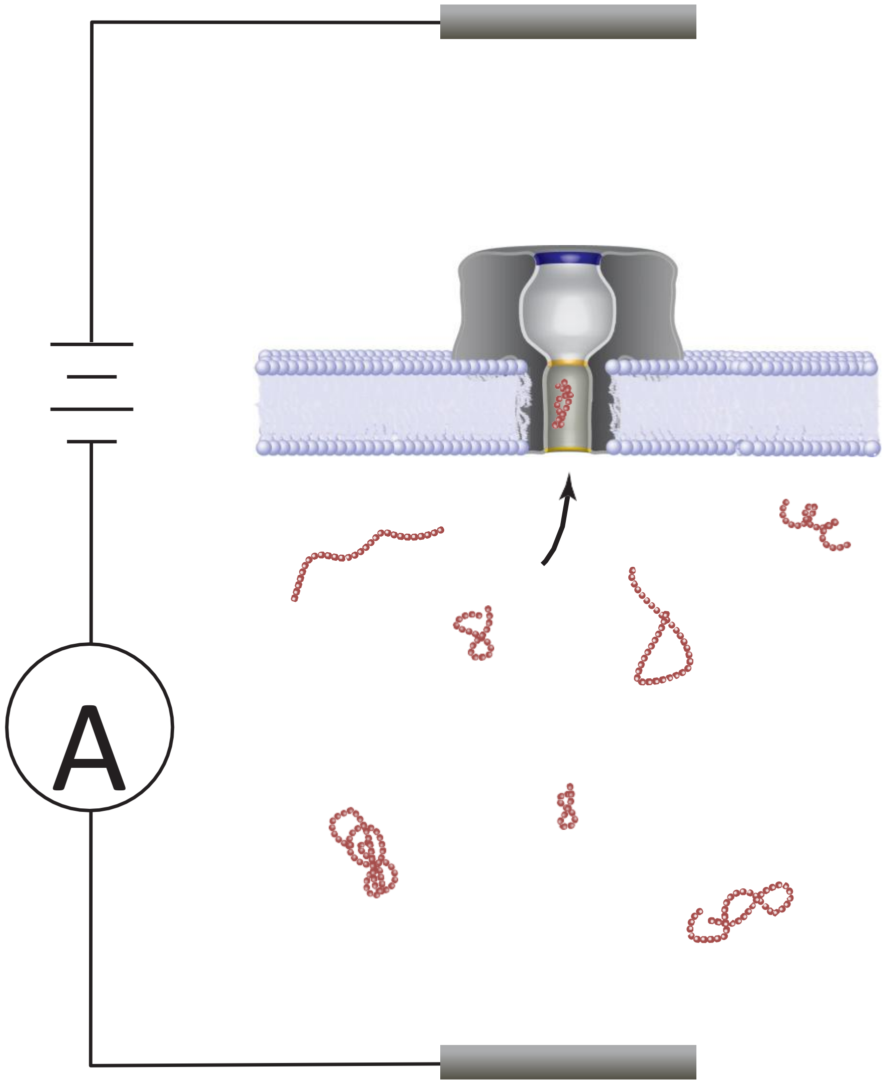
M. Obeidat, et al. *Medical Physics*. **45**, 3460–3465 (2018).

The comet assay provides a single cell assessment.

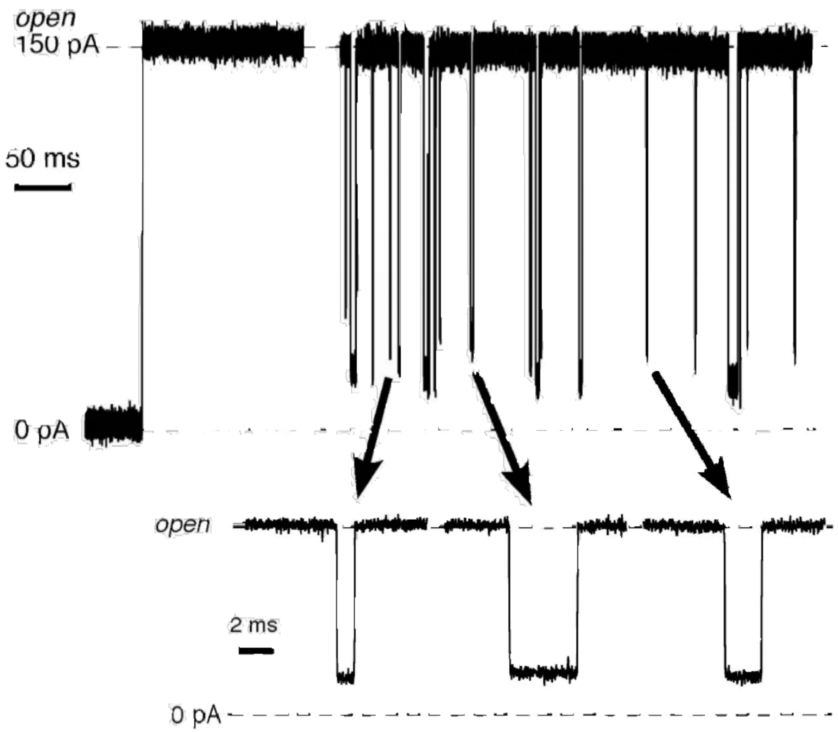


https://www.cellbiolabs.com/comet-assay-kits-96-well Ostling, O., and Johanson, K. J. (1984). *Biophys. Res. Commun.* 123, 291–298.

Resistive pulses with porin cavity nanopores



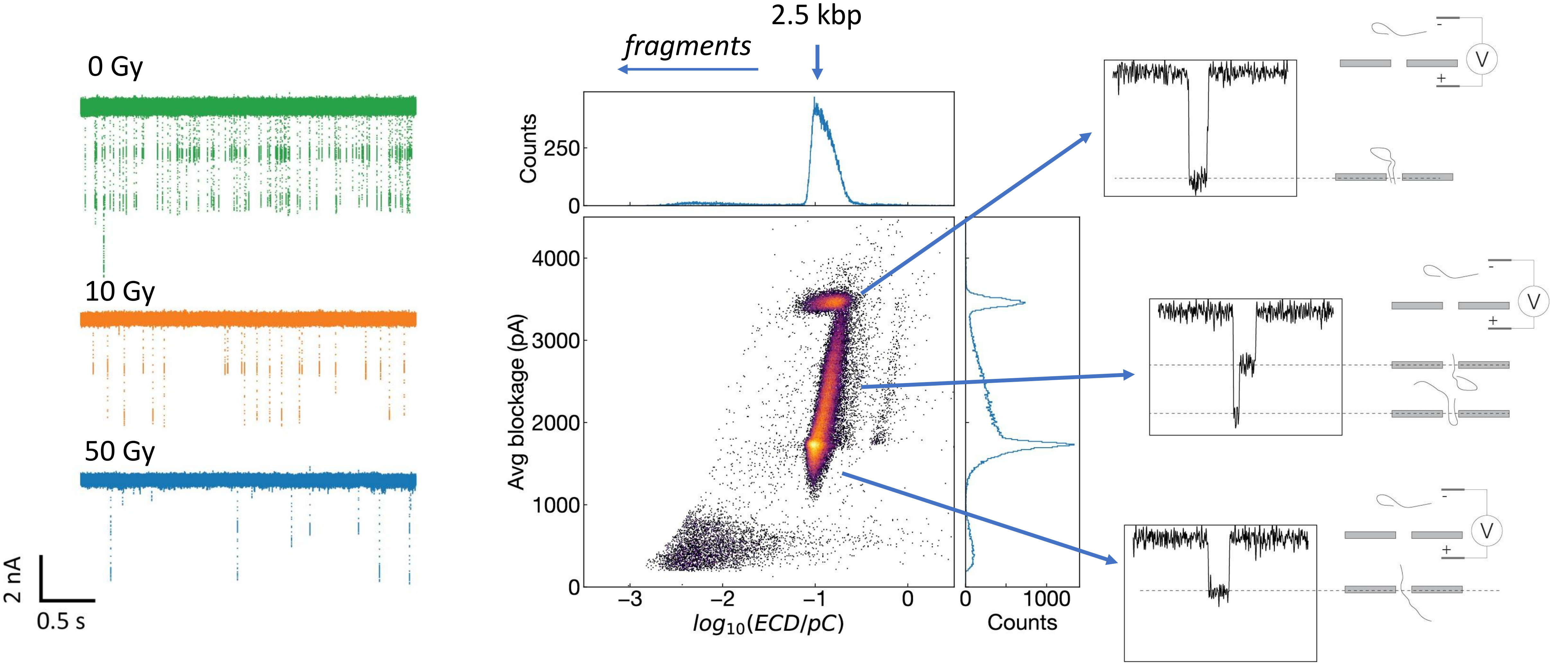
- Volume in the *attoliter* to *yoctoliter range* the size of a molecule
- Ionic current measured from externally applied voltage
- *As molecules partition in to the cavity the current is interrupted*



Robertson, Rodrigues, Stanford, Rubinson, Krasilnikov & Kasianowicz. (2007) *Proc. Natl. Acad. Sci. USA* **104**, 8207.

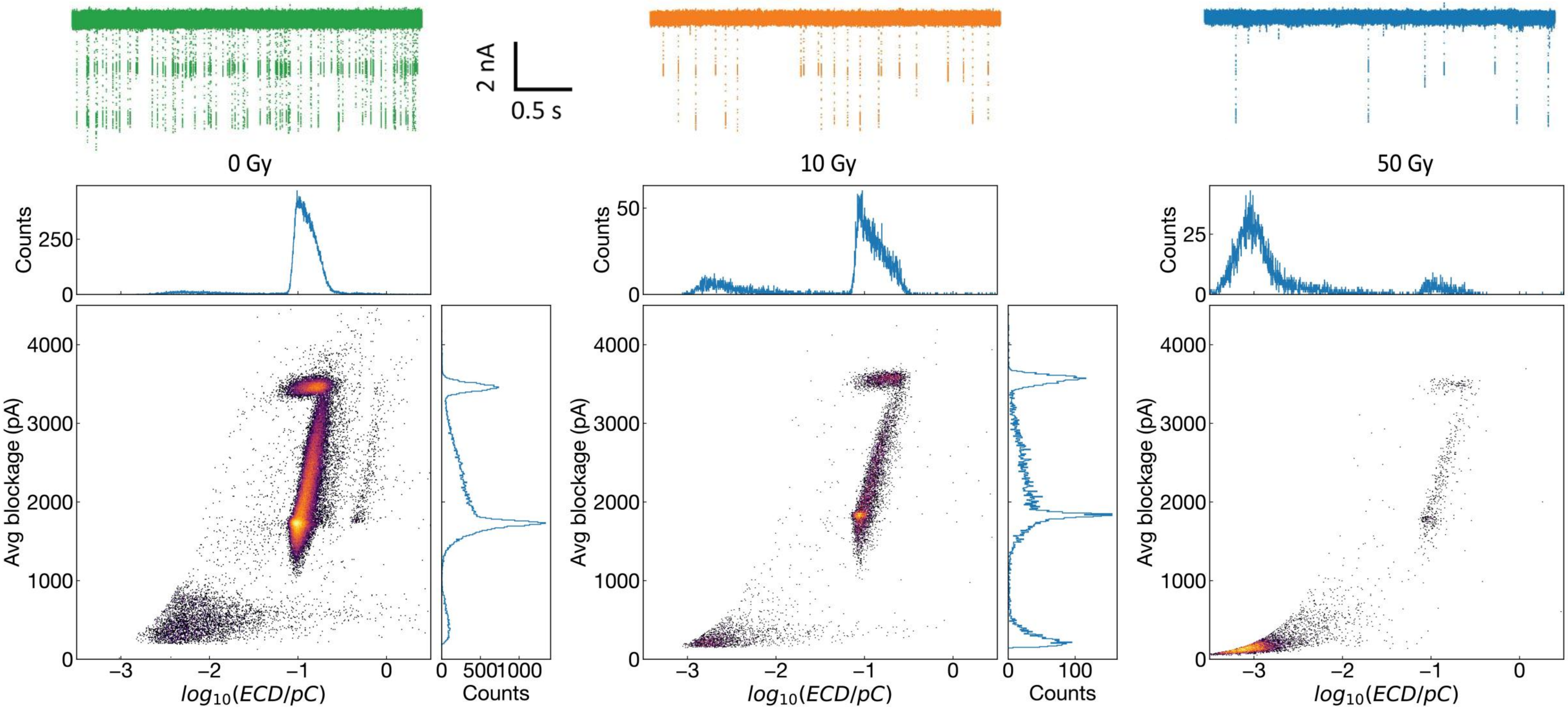
Radiation-induced fragmentation of DNA

2.5 kbp DNA irradiated with ^{60}Co gamma-rays

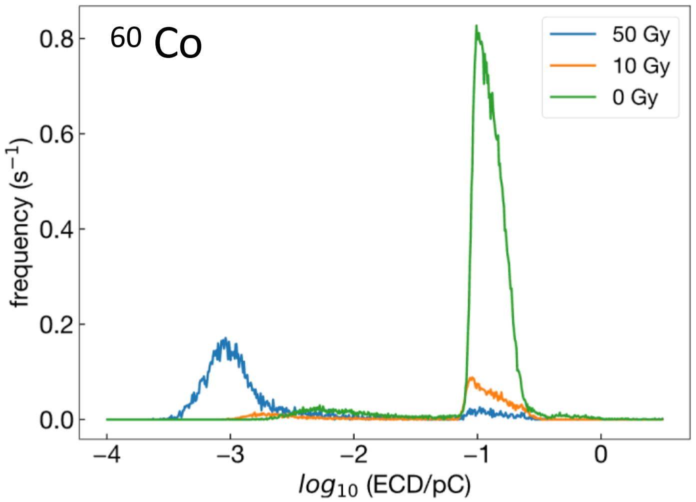


Radiation-induced fragmentation of DNA

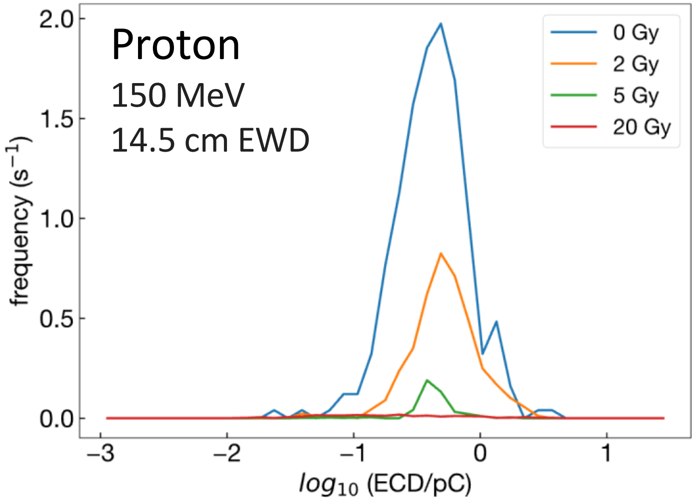
2.5 kbp DNA irradiated with ^{60}Co gamma-rays



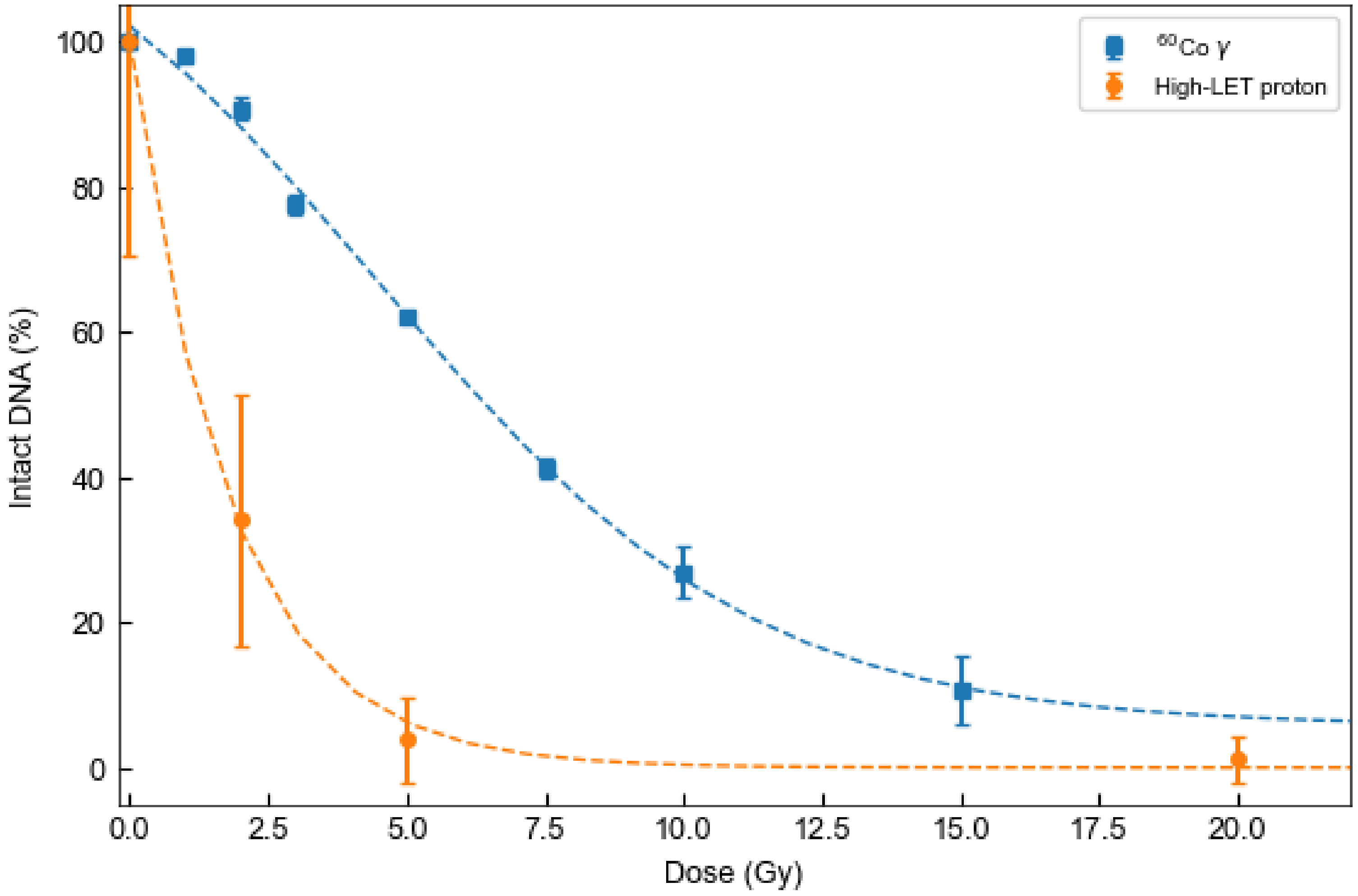
Proton vs γ



60 Co
50 Gy
10 Gy
0 Gy
frequency (s^{-1})
log_{10} (ECD/pC)



Proton
150 MeV
14.5 cm EWD
0 Gy
2 Gy
5 Gy
20 Gy
frequency (s^{-1})
log_{10} (ECD/pC)



^{60}Co γ
High-LET proton
Intact DNA (%)
Dose (Gy)

Future Directions

NIST

Alanine dosimetry

- Building prototype of ERDS reader.
- Characterizing alanine batch.
- Radiation processing applications
  - Partnering with facilities to tailer dosimeters and reader.
- Emergency response
  - Optimizing readings to lower doses (1 Gy to 10 Gy)

DNA biodosimetry

- Characterize DNA fragmentation with radiation from other sources (e^- beam, x-ray, γ-ray, proton, neutron, alpha particles)
- Single-base damage assay increases sensitivity and lowers the measurable range to <100 mGy
- ssDNA is more flexible than dsDNA
- Use different DNA with more folds

Acknowledgements (past and present)

Robert Gougelet, M.D.
Founder and President, GRT
Advanced Electronics Group, NIST
RGougelet@GlobalResonanceTechnologies.com

Ian Speers, MPH, CPH, MedLog
Director, Public Health Emergency Response Innovation
Ispeers@GlobalResonanceTechnologies.com

GlobalResonanceTechnologies.com

Pragya R. Shrestha, Kin P. Cheung, Jason P. Campbell

Ileana M. Pazos
Joseph Robertson
Michael Lamontagne
Shannon Newell
Ron Tosh
Michael Zwolak
Zeeshan Ahmed
Miral Dizdaroglu
Melis Kant
Greta Babakhanova

Adam Hall (Wake Forrest)
Sara Abu Jalboush (Wake Forrest)

Vincent Tabard-Cossa (U. Ottawa)
Kyle Briggs (Northern Nanopore)
Mathew Waugh (Northern Nanopore)

Jerimy Polf (H3D, inc/ M3D, Inc.)