Radiation Detection and Measurement

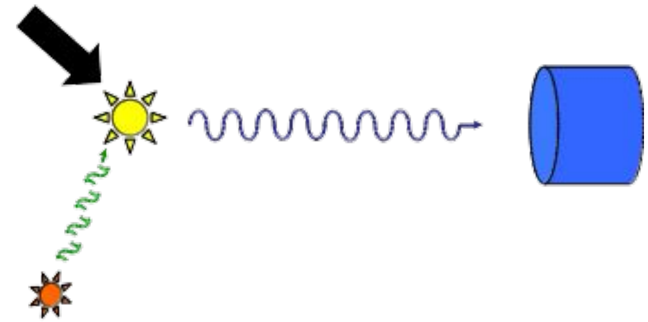
- Comprises instrumentation and methods for the **detection**, **characterization**, and **localization** of emitted radiation and it's sources
  - **Detection** of radiation
    - Is radiation emitting source present or not?
    - Sensitivity, signal-to-background
  - **Characterization** of radiation and emission sources
    - Energy/identification
    - Intensity/quantification
    - Time of arrival
    - Multiplicity
    - Type/charge/mass
    - Polarization
    - ...
  - **Localization** of radiation-emitting sources
    - Directionality (incident flux)
    - Position of origin

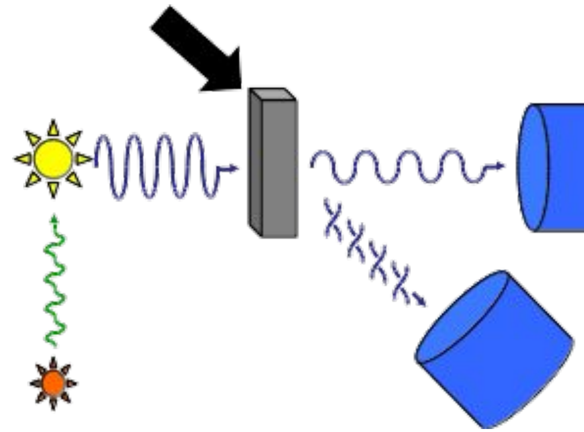
General Properties of Radiation Detectors

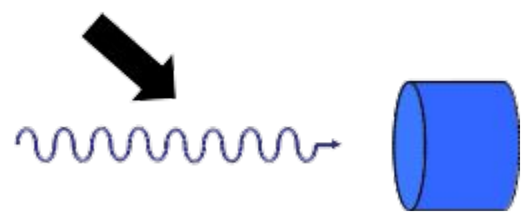
- Properties from physics, materials, geometry, etc.
  - Energy resolution
  - Efficiency
  - Timing Characteristics
    - Time resolution
    - Time-coincidence properties
  - Rate capabilities
    - Pulse-pair resolution, dead-time
    - Throughput
  - Position sensitivity
  - Pulse shape discrimination
- Engineering aspects
  - Relates to specific application
  - Size, weight, reliability, ruggedness, complexity, maintenance requirements, power delivery & consumption
- Cost!

Conceptual Applications of RD&M

- Radiation as an information carrier
  - **Emission** measurements
    - Derive information about object based on the radiation it emits
      - E.g. Gamma-ray spectroscopy, emission tomography (PET, SPECT)
  - Includes **induced emission**
    - Active interrogation
  - **Transmission** & scattering
    - Obtain information about transmission/scattering medium
      - E.g. radiography, CT, small-angle neutron scattering
- Detecting/characterizing the radiation itself
  - CDM searches, neutrinos, HEP





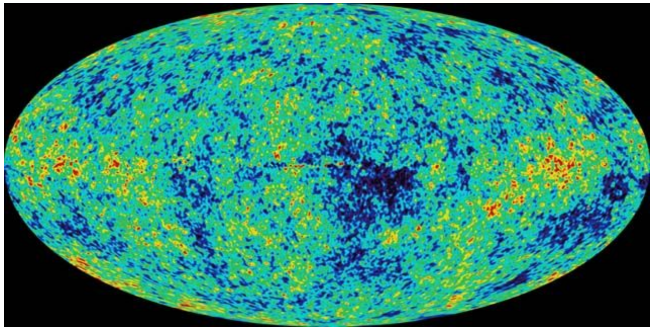


Practical Applications of RD&M

- Medical applications
  - Radiology (X-rays & photons for diagnostics, therapy)
  - Emission tomography (PET, SPECT)
    - Medical diagnostics, pharmaceutical development
  - Dosimetry
- Scientific Applications
  - Archaeology/Geochronology (^{14}C and related dating techniques)
  - Biology, Chemistry, Geology (radiotracer techniques [^{32}P])
  - Physics, astrophysics, cosmology
- Materials science
  - Photon and neutron radiography, other imaging methods (SANS)
    - Defect detection, distribution studies
- Industrial applications
  - Mining (petroleum exploration), well logging
  - Gauges (flow meters, thickness & density gauges)
  - Gamma-ray altimetry

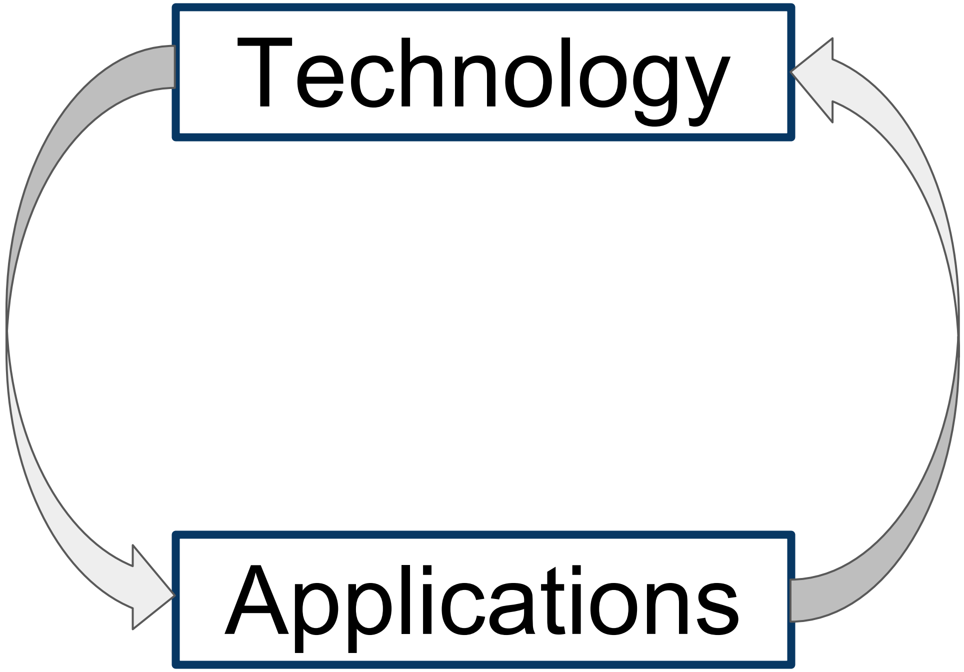
Radiation is Everywhere!

- EM radiation from cosmic microwave background (CMB) is pervasive
  - On old CRT TV's with analog receivers, ~1% of the static on the screen could be attributed to the CMB
- In this course, we'll focus on **ionizing radiation**
  - Directly & indirectly ionizing
  - Energy scale: ~10 eV to ~10 MeV
- Primarily focus on radiation originating in the atomic nucleus and related processes
  - Radioactivity!



http://cosmology.berkeley.edu/Education/CosmologyEssays/The_Cosmic_Microwave_Background.html

Model for Technological Progress



Example: Discovery of X-Rays

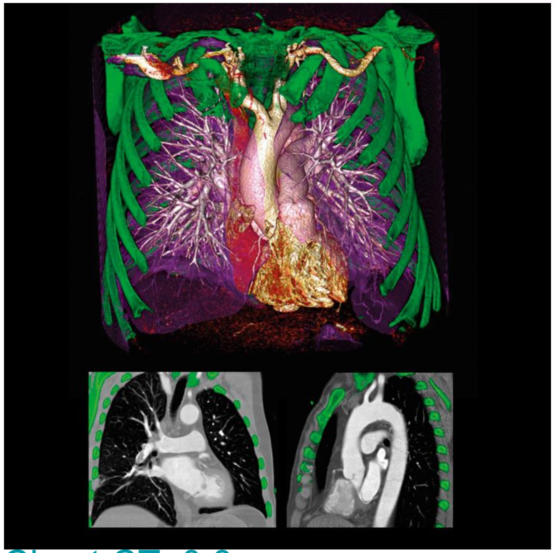
- November 8th, 1895: Wilhelm Roentgen discovers X-rays
- November 22nd, 1895: First radiographic X-ray
  - Of his wife Anna-Bertha's hand
- First publication of X-radiation
  - "On a new type of radiation", Dec. 28th 1895
- Immediately realized potential for medical applications
  - By Jan. 1896 - preliminary investigations for diagnostic images
  - Mid 1896 - applied for imaging kidney stones, broken bones, etc
- Unfortunately, dose effects not discovered until later

Taken **2 weeks** after the discovery of x-rays!

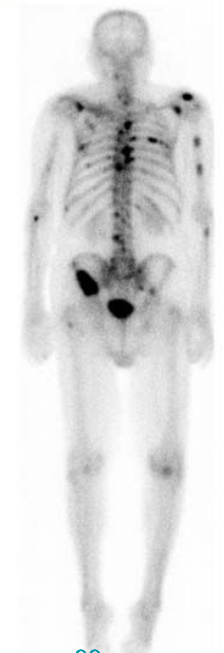
Presented mid-January, 1896

A Century Later…

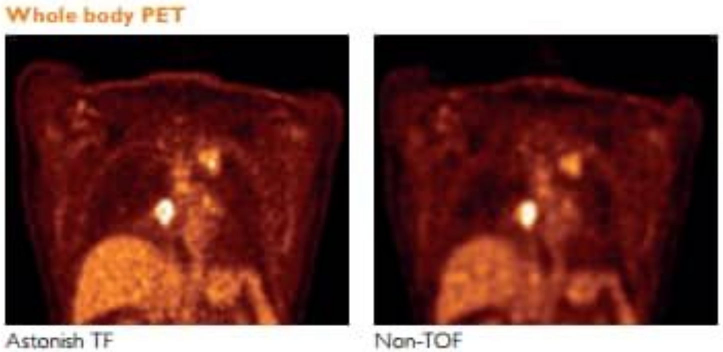
- ~$34 Billion per annum global market
- Radiographic anatomical imaging
  - Computed tomography
    - Dual-beam (attenuation corr.)
    - Cone-beam (time & dose min.)
- Emission tomography for metabolic imaging
  - PET
    - Superior time resolution (LYSO) →Time-of-flight PET
  - SPECT
    - Detector position resolution impacts resolution
- Current limitations beyond instrumentation
  - Patient motion →**data fusion**
  - Gated collection, motion correction



Chest CT, 0.3 mm resolution



SPECT bone scan w/ ^{99m}Tc - multiple metastases

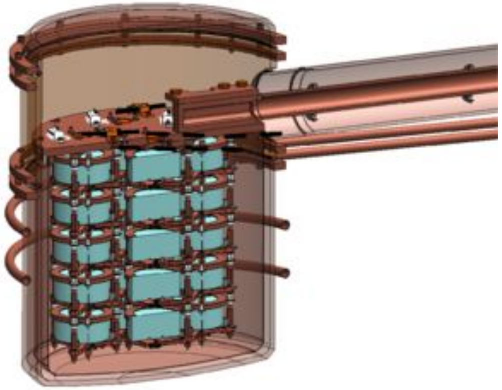


Improved image resolution from TOF-PET

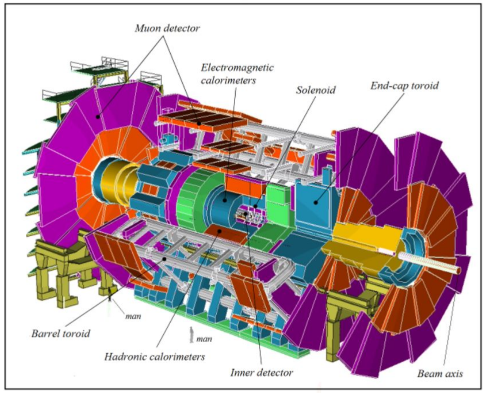
RD&M in Fundamental Science

- Atomic [100 eV - 100 keV] and nuclear [1 keV - 20 MeV] physics
    - e.g. GRETINA & AGATA
- Particle physics (HEP)
    - e.g. ATLAS, CMS
- Rare event searches
    - CDM, 0νββ decay
        - Super CDMS, Edelweiss, LeGEND, LuXe/LZ, etc.
- Astrophysics
    - e.g. Planetary exploration, X-ray and Gamma-ray astronomy

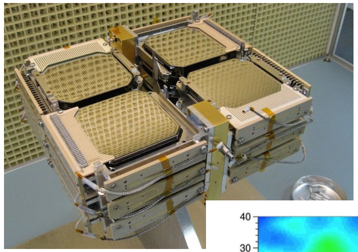
GRETINA (10/30 detectors) - Nuclear structure, rare isotopes

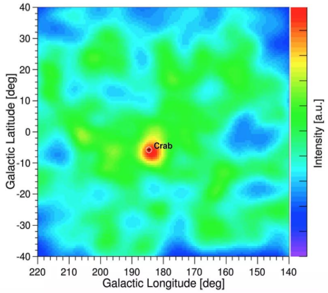


Majorana Demonstrator - 0νββ search with PPC HPGe



ATLAS Detector @ LHC





COSI & Compton image of Crab Nebula

Incredible Opportunities in RD&M

Technology

- Advancements in hardware & software
  - Modern HW & methods (DSP), detector technologies
  - Data fusion: enhance RD&M using contextual information
- Drive down costs →improve accessibility
  - Survey meter: ~$500 for 1920's tech!

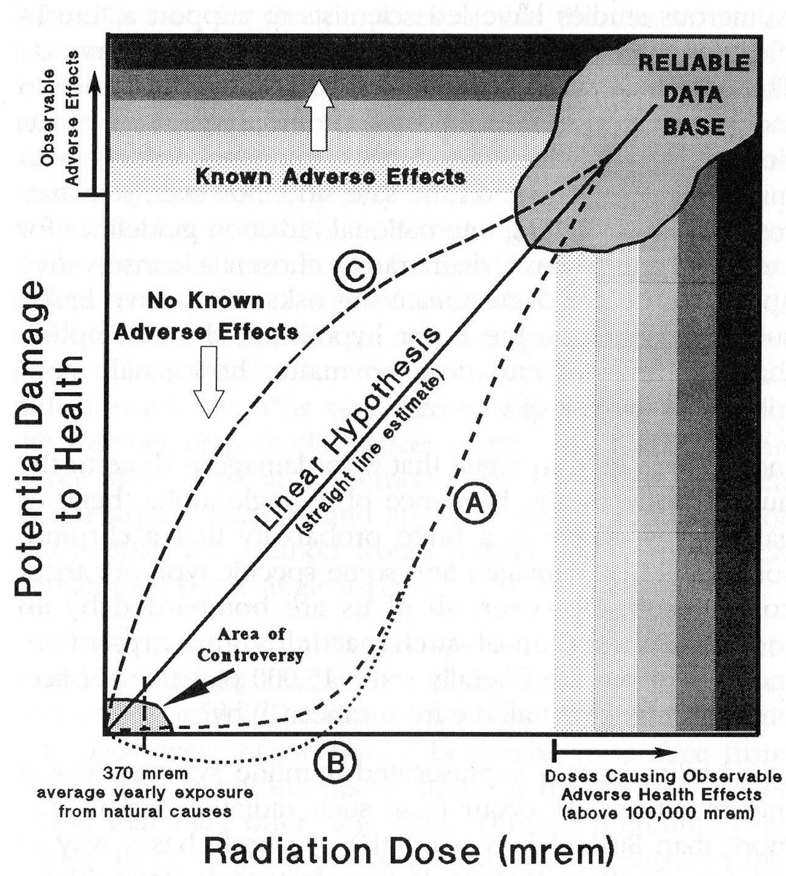
E.g. H3D - Creating interest in spectroscopic gamma-ray imagers for applications in nuclear power plants

Applications

- Emerging real-world applications
  - Nuclear contamination remediation
    - From Hanford to Fukushima
- Nuclear security and safeguards

Example: Radiation Dose Effects

- Linear No-Threshold model
  - We have no idea what the effects of low-dose & low-dose rate (e.g. natural background) are
    - LNT: harmful
    - Hormesis: beneficial
- Difficult to study: no reliable, large-scale data for low-dose radiation
  - Essentially an instrumentation problem
    - Too expensive to deploy existing instrumentation to collect this data
- Reliable, scalable dosimetry instrumentation would have a huge impact on our ability to resolve this question



[Alan E. Waltar "America the Powerless"]