Industrial and medical application of nuclear radiation detection

35th Symposium- "Instrumentation resources in Pakistan" February 22, 2025.

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MISSOURI S&T

Founded 1870 | Rolla, Missouri

MISSOURI UNIVERSITY OF SCIENCE AND TECHNOLOGY

ABOUT Missouri S&T

NO. 1
Public University in Missouri for Return on Investment
Georgetown's Center on Education and Workforce, 2022

OVER
7,000
Students
Both on-campus and distance

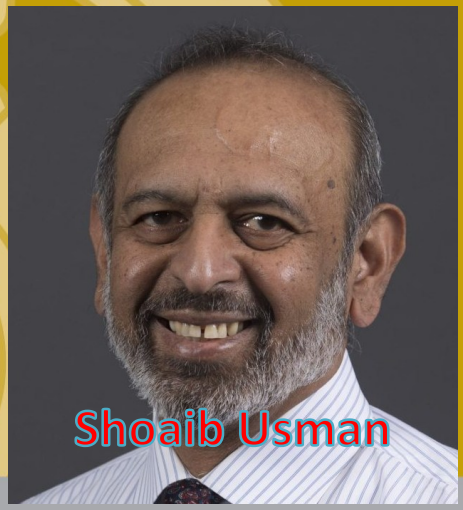
NO. 3
Among Public Universities for Best Career Placement
Princeton Review, 2025

7TH
Best Value College in the United States
SmartAsset, 2022

- **STEM-dominant**
- 6,456 students (2023) most in engineering,
- Known primarily for engineering school
- College of Engineering and Computing (CEC)
  * 18 BS * 21 MS & * 17 PhD programs
- $300 million gift from **June and Fred Kummer** established Kummer College
- Carnegie R1 Doctoral University starting 2025

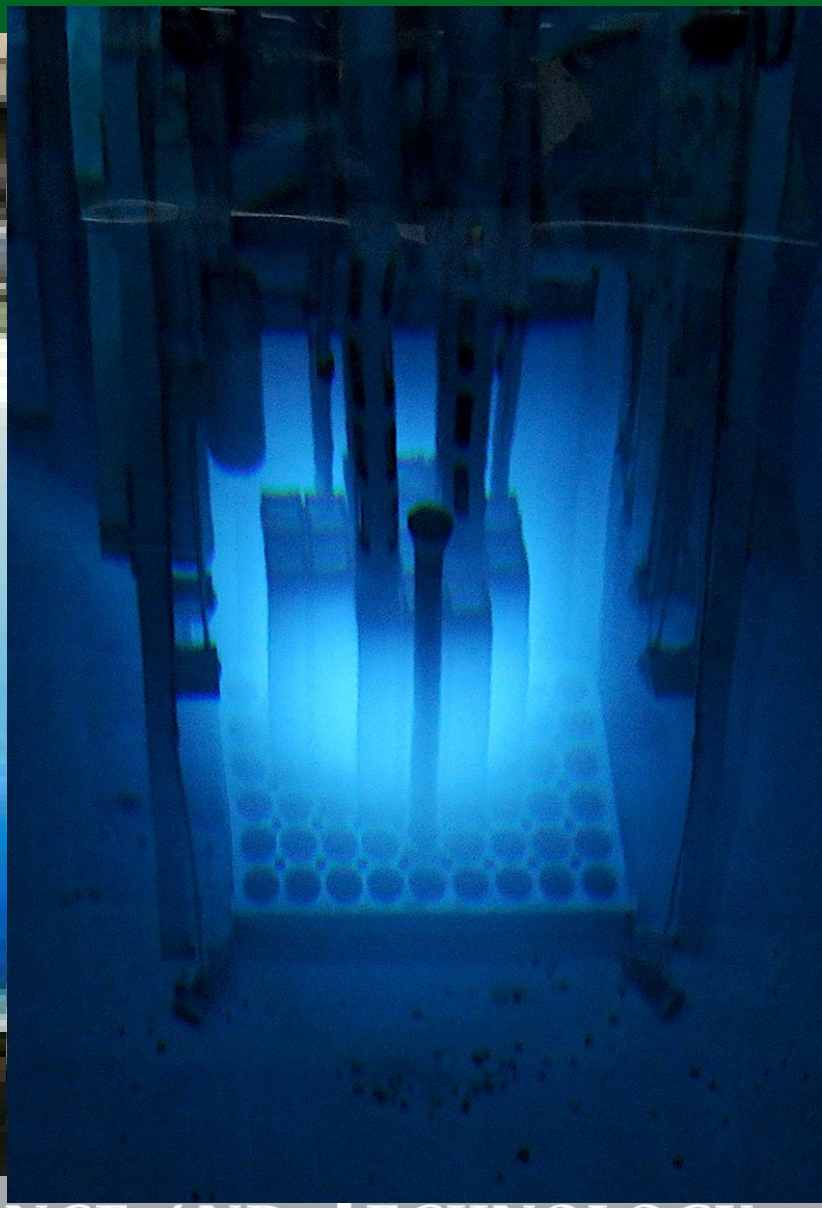
ABOUT NERS @ Missouri S&T

Nuclear Engineering & Radiation Science



MISSOURI UNIVERSITY OF SCIENCE AND TECHNOLOGY

ABOUT MSTR



Content of Presentation

I. My Background

II. Nuclear Instrumentation

III. Medical Applications

IV. Industrial Applications

V. Example Reactor Instrumentation

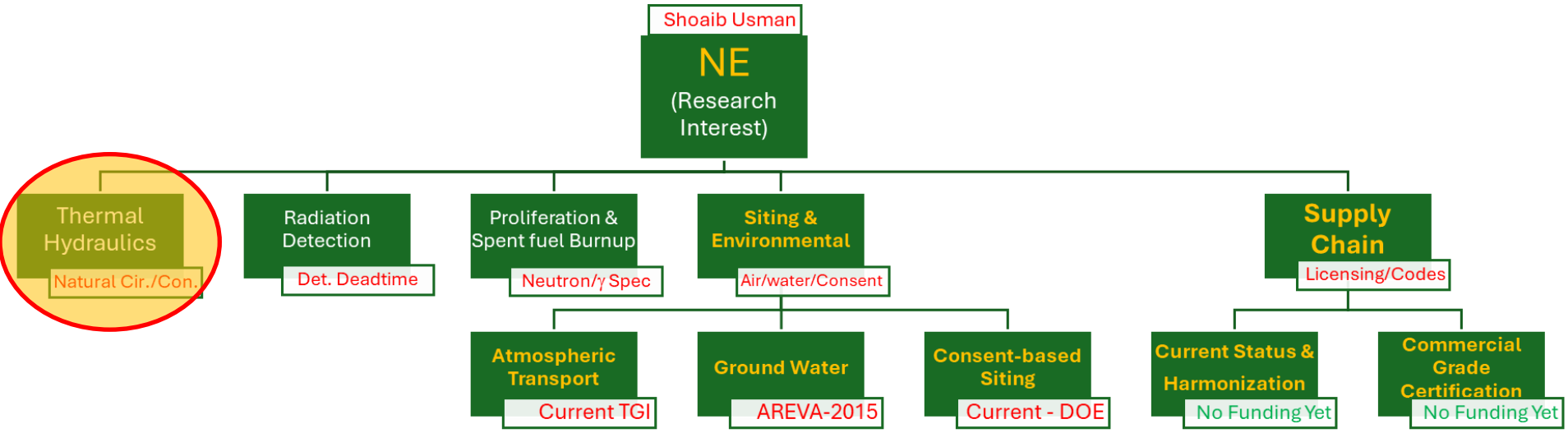
VI. Development Opportunity and Codes

VII. References

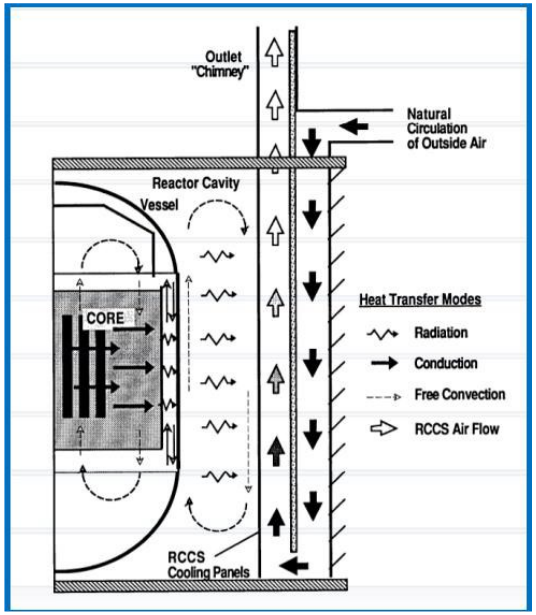
Shoaib Usman (Educational Background)

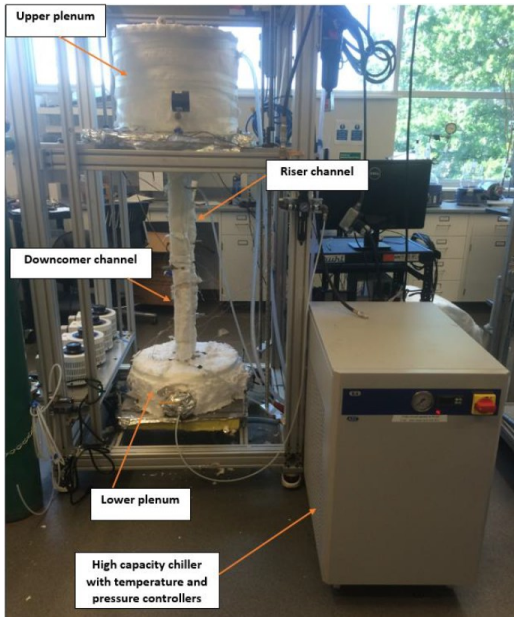
- B.E. N.E.D. University of Engineering & Technology, Mechanical Engineering 1988, Project: Design of a System for Ethylene Production from Naphtha, Advisor: Dr. Syed F. Ali
- M.S. University of Cincinnati, Nuclear Engineering 1993, Thesis: Development of a Phenomenological Model for Predicting CHF Under Low Quality and Subcooled Swirl Flow Conditions, Advisor: Dr. Joel Weisman
- M.S. University of Cincinnati, Health Physics, 1996, Project: Response of Electret Radon Detector to Interference from Ambient Gamma Radiation, Advisor: Dr. Henry B. Spitz
- Ph.D. University of Cincinnati, Nuclear Engineering 1997, Dissertation: On the Spectral Theory of Turbulence and Atmospheric Dispersion, Advisor: Dr. Henry B. Spit

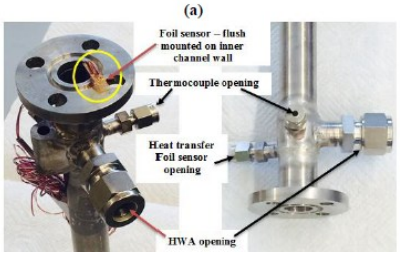
Thermal Hydraulics (Publications J:28, C:25)

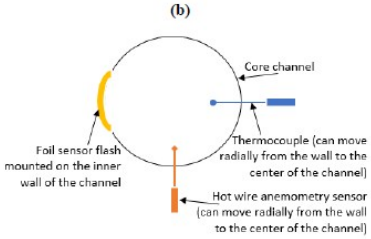


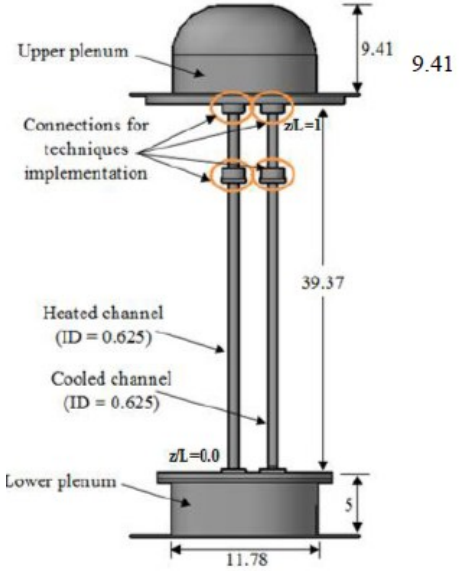
- Critical Heat Flux – Boiling Crisis
- Heat Transfer Enhancement
- Natural Convection
- Natural Circulation
- Passive Reactor Safety
- Multi-physics











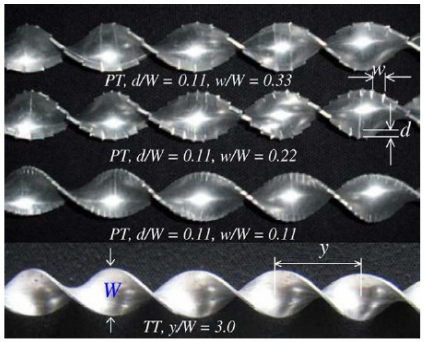


Fig. 1. Geometries of peripherally-cut twisted tapes (PTs) and typical twisted tape

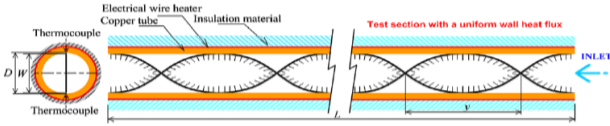


Fig. 2. Test tube with peripherally-cut twisted tape insert.

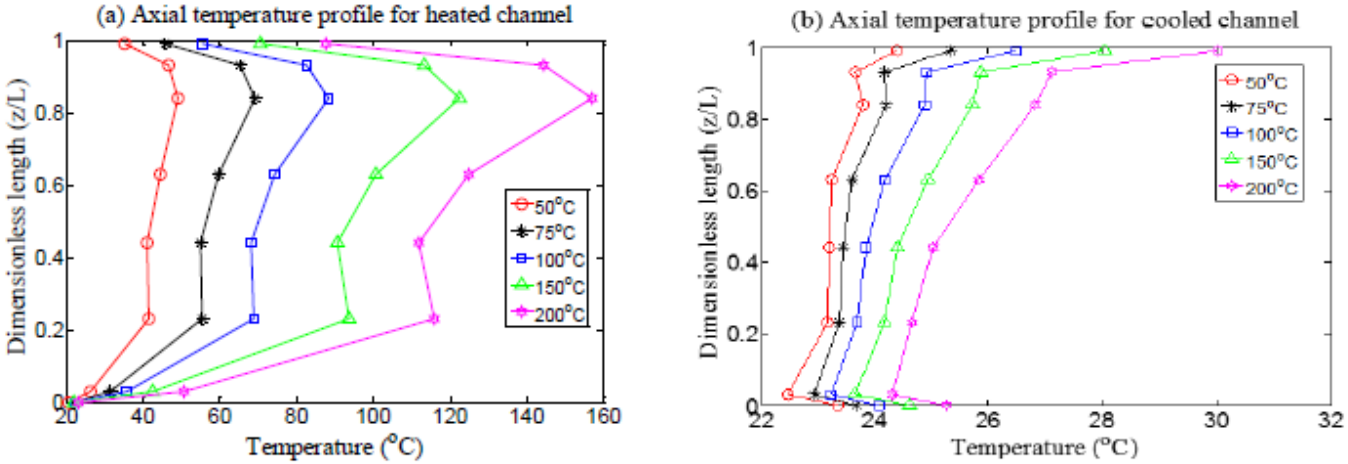
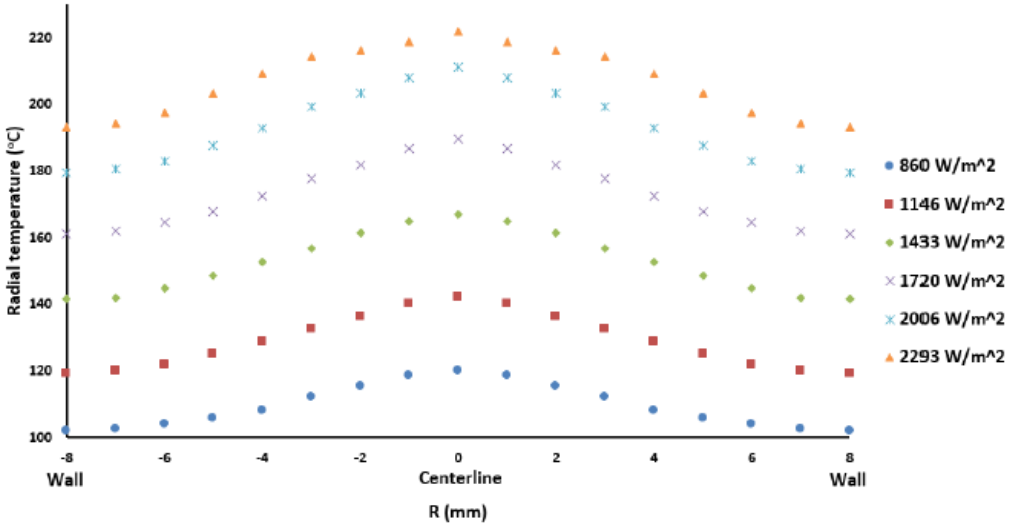
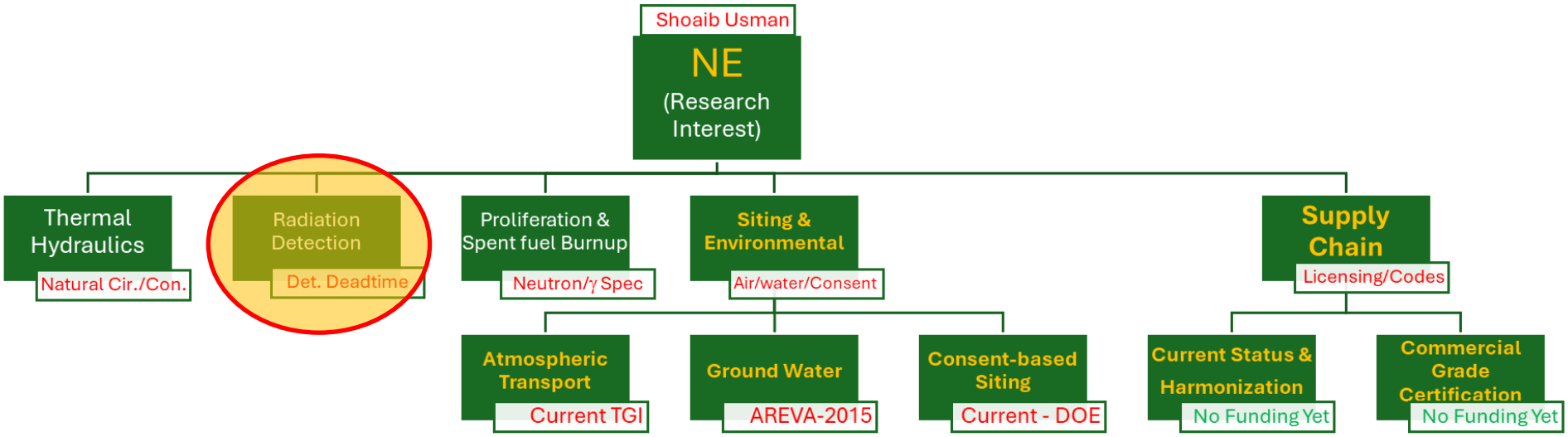


Figure 13: Axial temperature profile obtained for (a) heated channel, (b) cooled channel

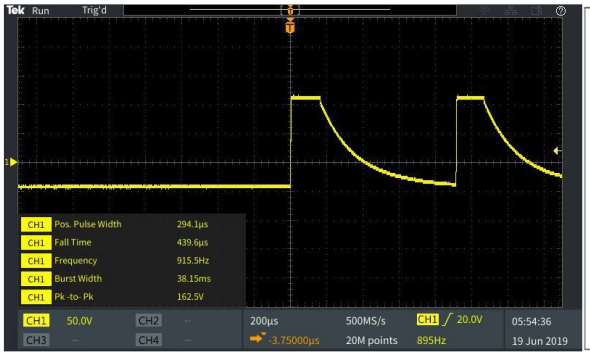


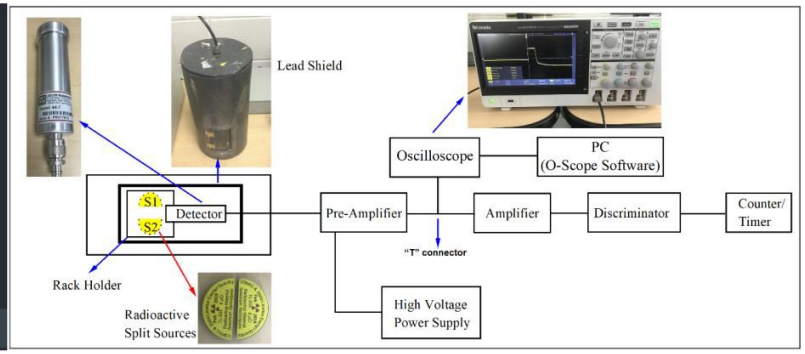
Time to Drain

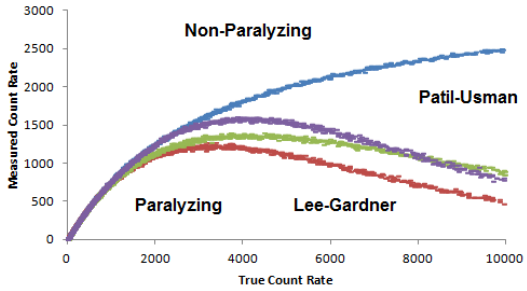
Radiation Detector (Publications J:10, C:10)

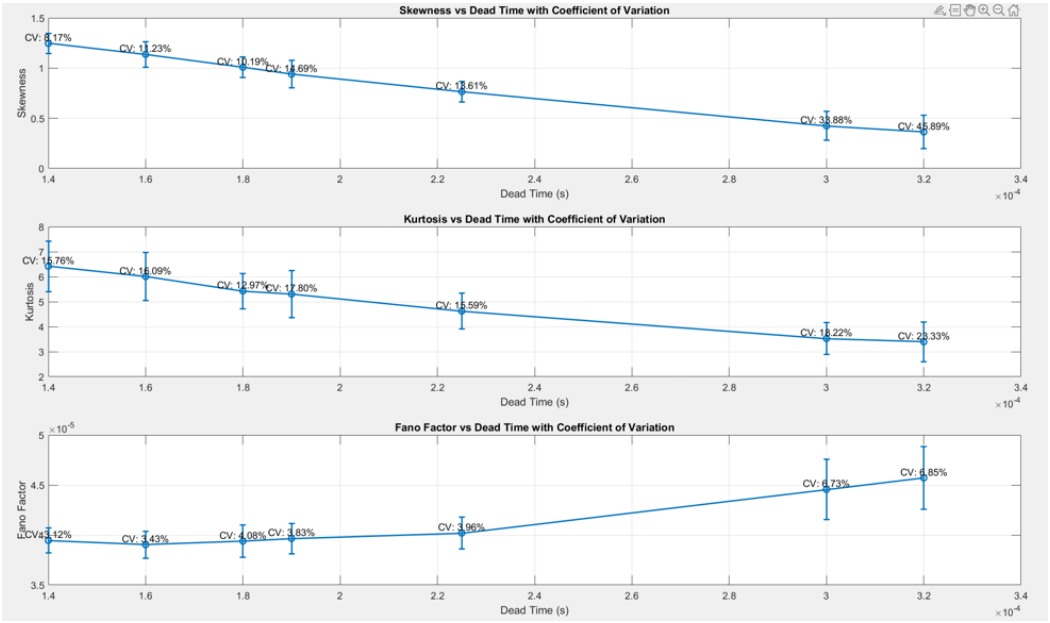


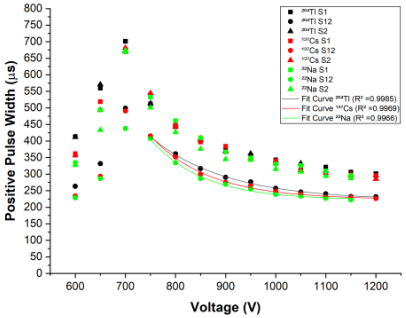
- Detector Deadtime and Spectral Convolution

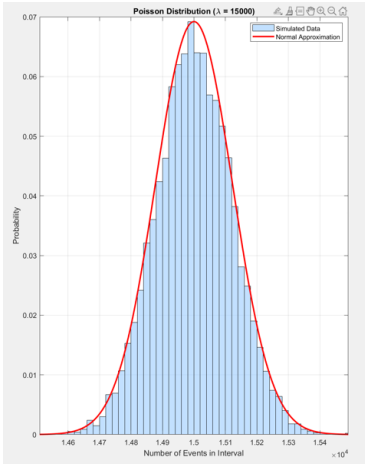


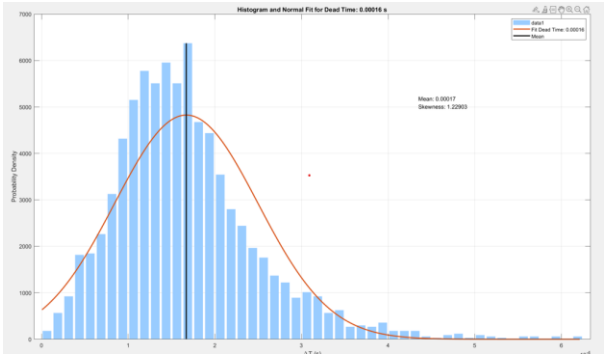




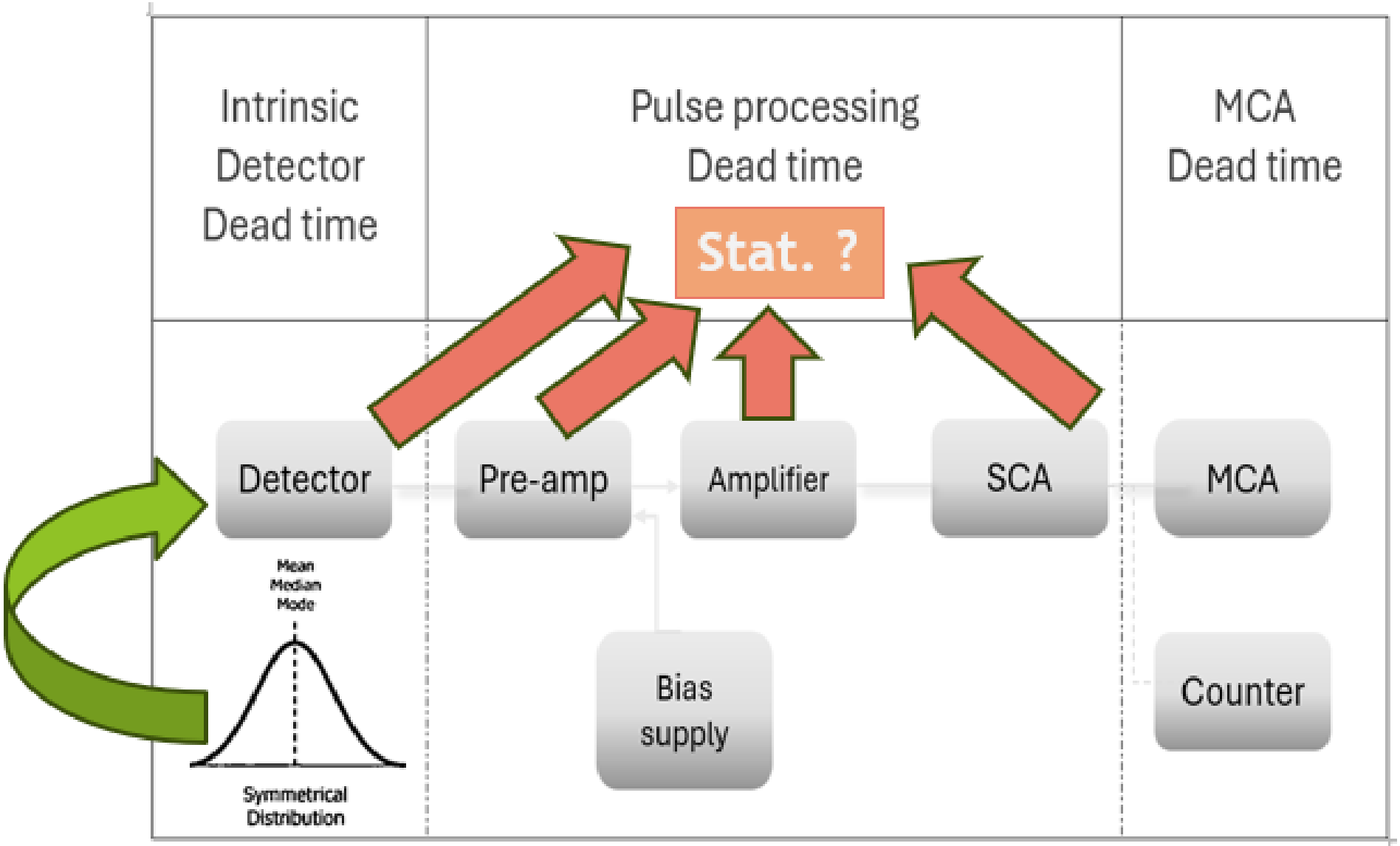




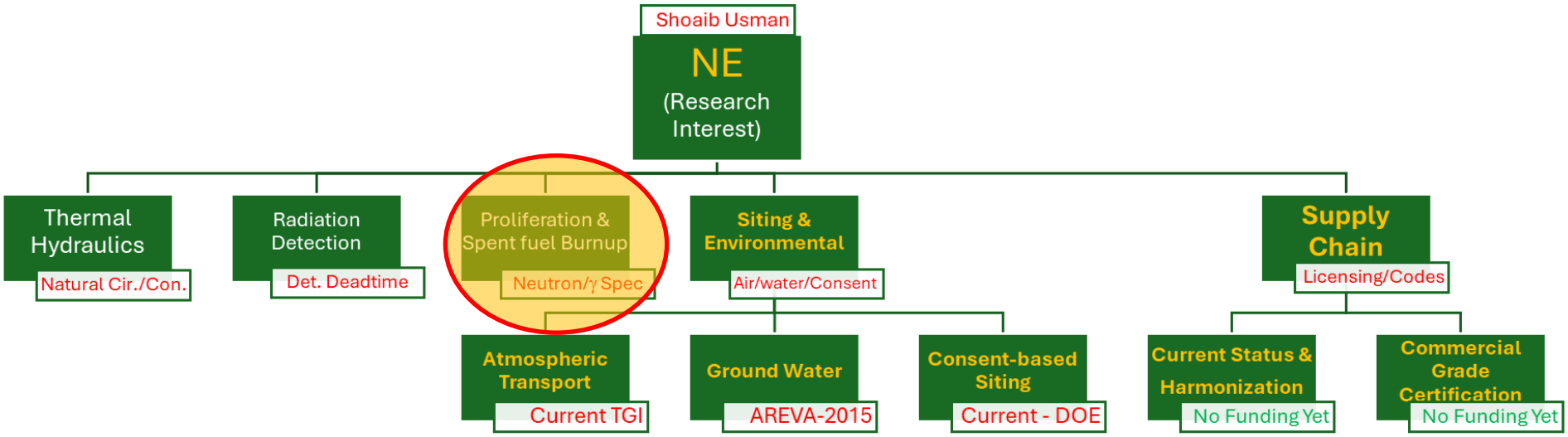




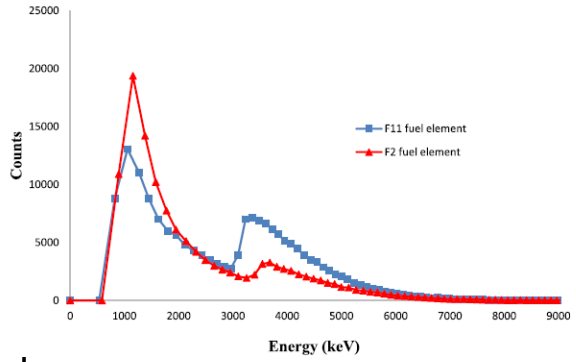
- Detector Deadtime and Poisson Statistics Distortion

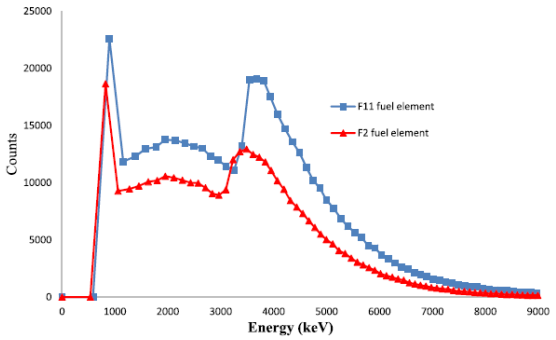


Proliferation & Spent fuel Burnup (Publications J:8, C:7)



- Delayed Gamma Spectroscopy
  - Prompt Neutron Analysis
- Delayed Neutron Spectroscopy





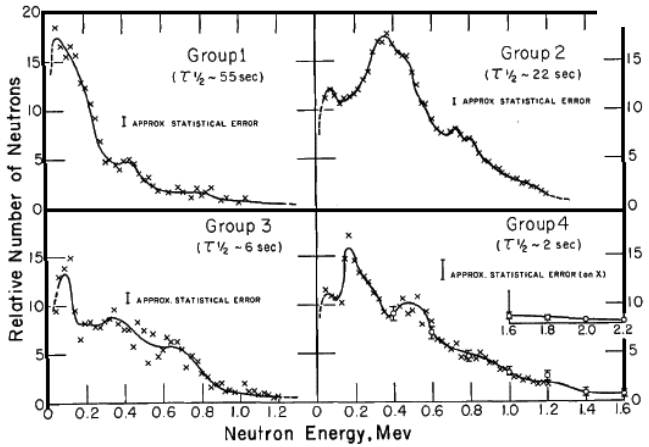
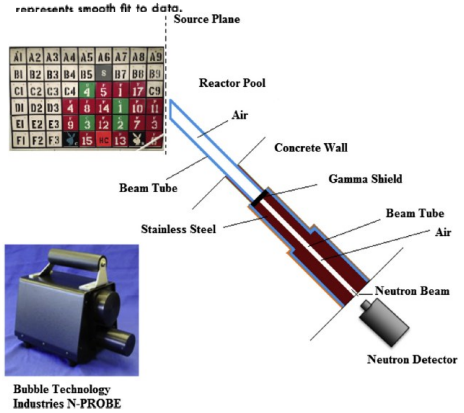
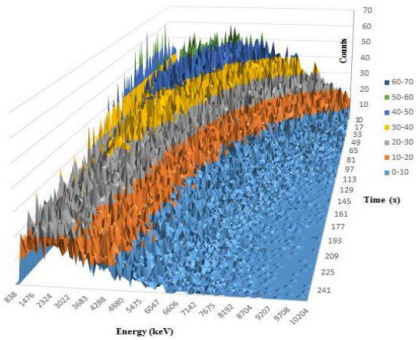


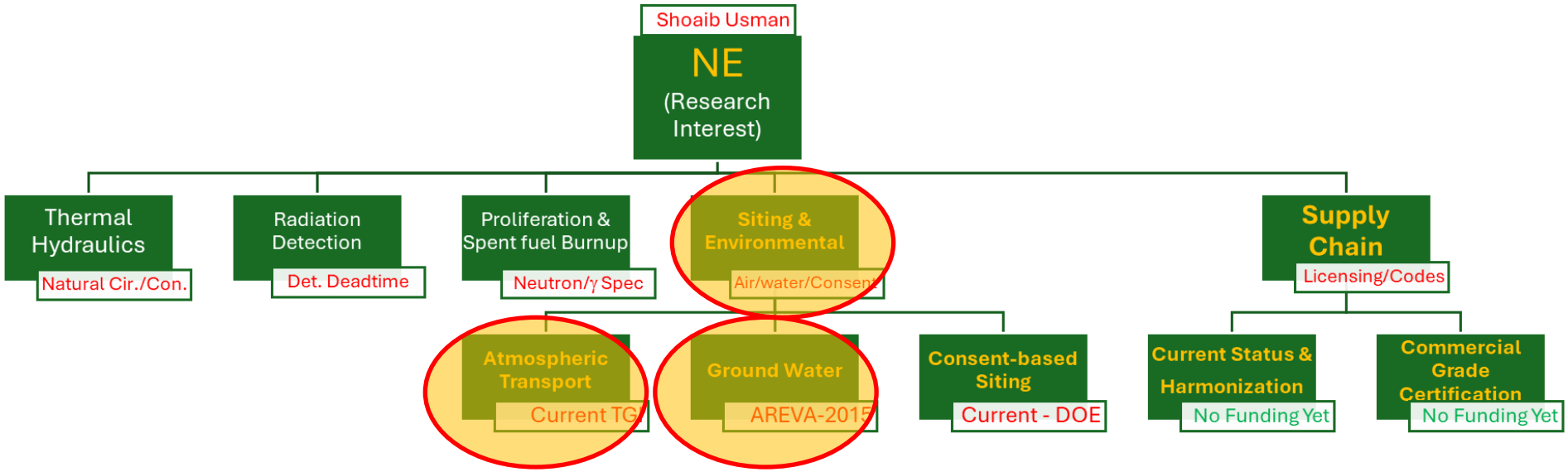
Fig. 4–5. Measured delayed-neutron group spectra. (x) denotes He^3 spectrometer data of Batchelor and Hyder [22] analyzed into individual group spectra using Keepin-Wimett data [2]. (⊡) denotes cloud chamber data of Bonner, Bame, and Evans [21]. Solid line represents smooth fit to data.

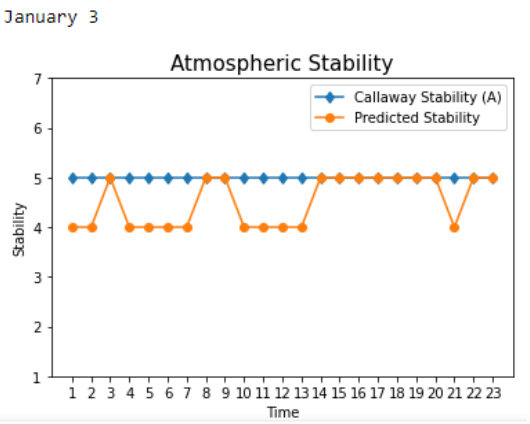


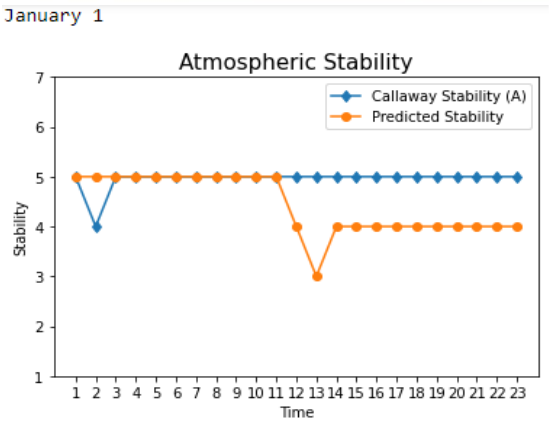
Bubble Technology Industries N-PROBE

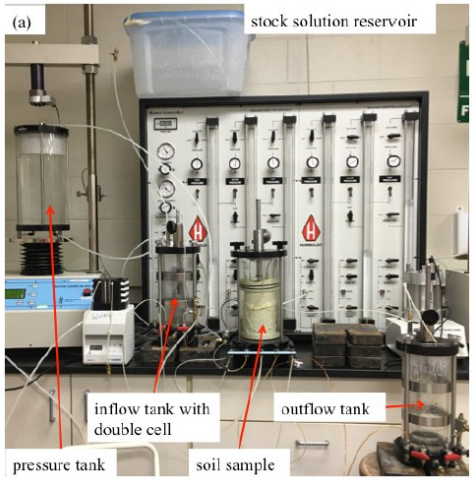


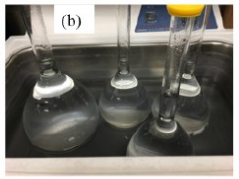
Siting and Environmental Issues (Publications J3:, C:5)

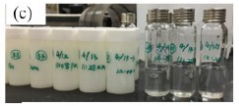












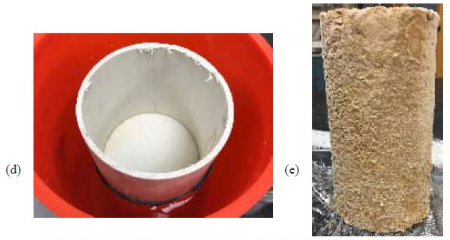


Figure 2. Flow through column for coefficient of retardation measurement setup.

energies

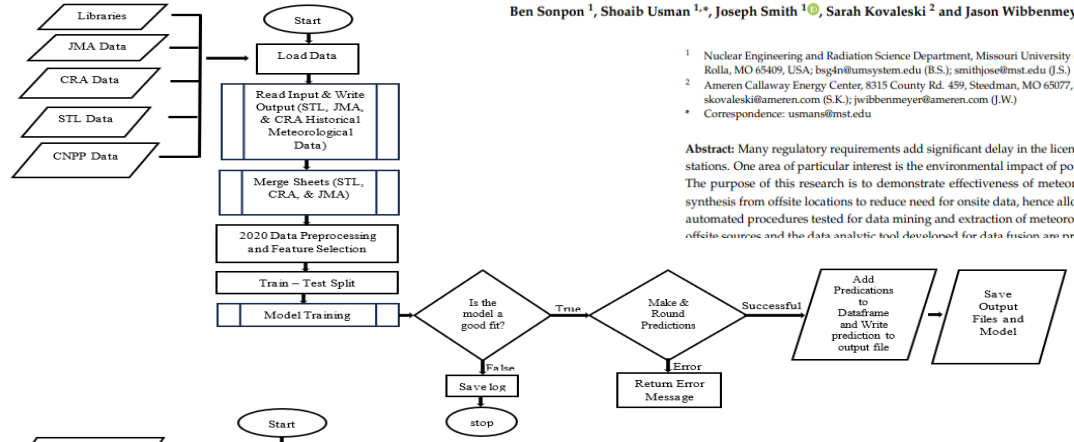
Article

Meteorological Data Mining and Synthesis for Supplementing On-Site Data for Regulatory Compliance

Ben Sonpon [1], Shoaib Usman [1,*], Joseph Smith [1], Sarah Kovaleski [2] and Jason Wibbenmeyer [2]

[1] Nuclear Engineering and Radiation Science Department, Missouri University of Science and Technology, Rolla, MO 65409, USA; bsg4n@umsystem.edu (B.S.); smithjose@mst.edu (J.S.)
[2] Ameren Callaway Energy Center, 8315 County Rd. 459, Steedman, MO 65077, USA; skovaleski@ameren.com (S.K.); jwibbenmeyer@ameren.com (J.W.)
* Correspondence: usmans@mst.edu

Abstract: Many regulatory requirements add significant delay in the licensing of new nuclear power stations. One area of particular interest is the environmental impact of potential atmospheric release. The purpose of this research is to demonstrate effectiveness of meteorological data mining and synthesis from offsite locations to reduce need for onsite data, hence allowing rapid automated procedures tested for data mining and extraction of meteorological data offsite sources and the data analytic tool developed for data fusion are presented her



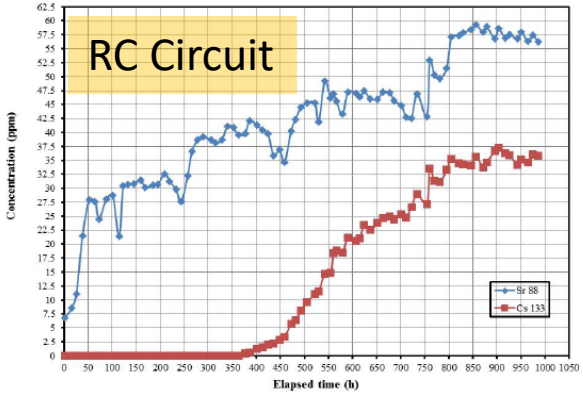
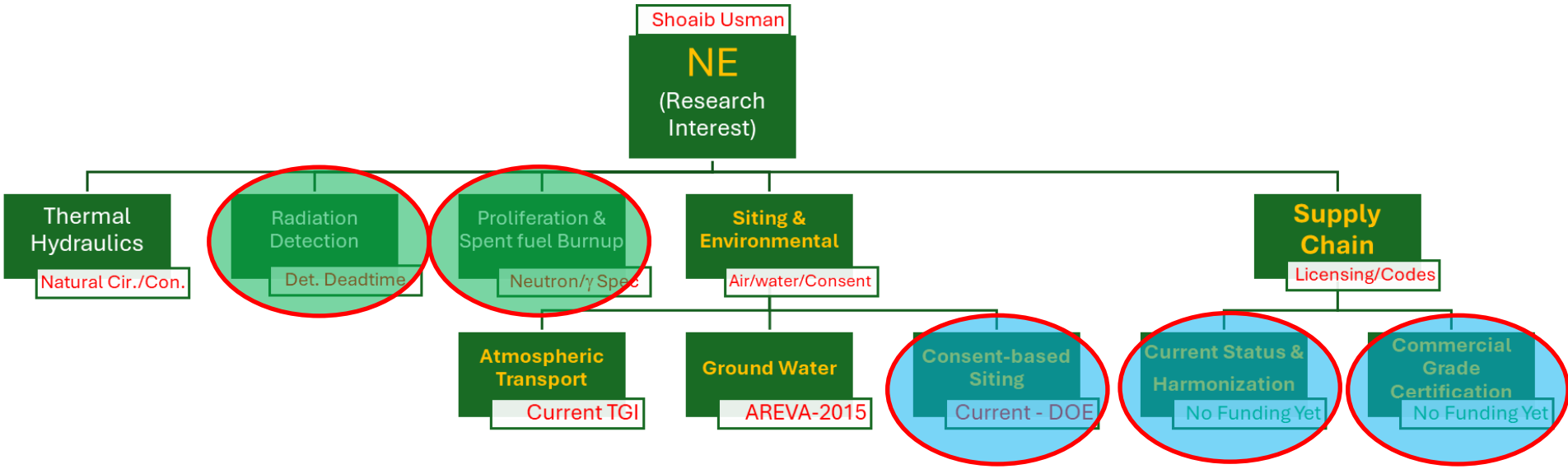
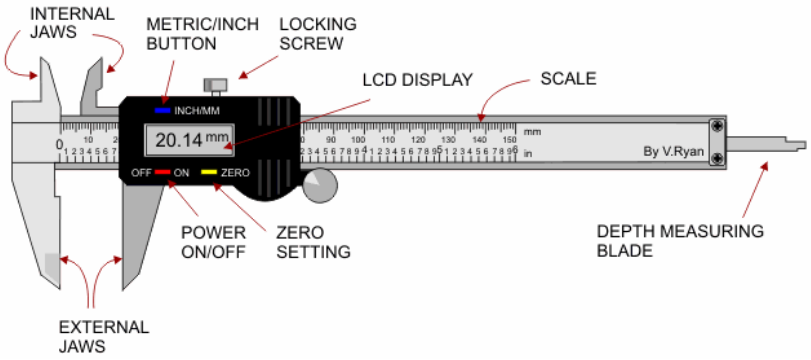


Figure 6. Time response of Sr and Cs concentration past Energy Valley site soil – Experiment # 3.



- The material presented here is **NOT NEW** but a summary of my radiation Measurement and spectroscopy teaching and research

Length Measurements Tools



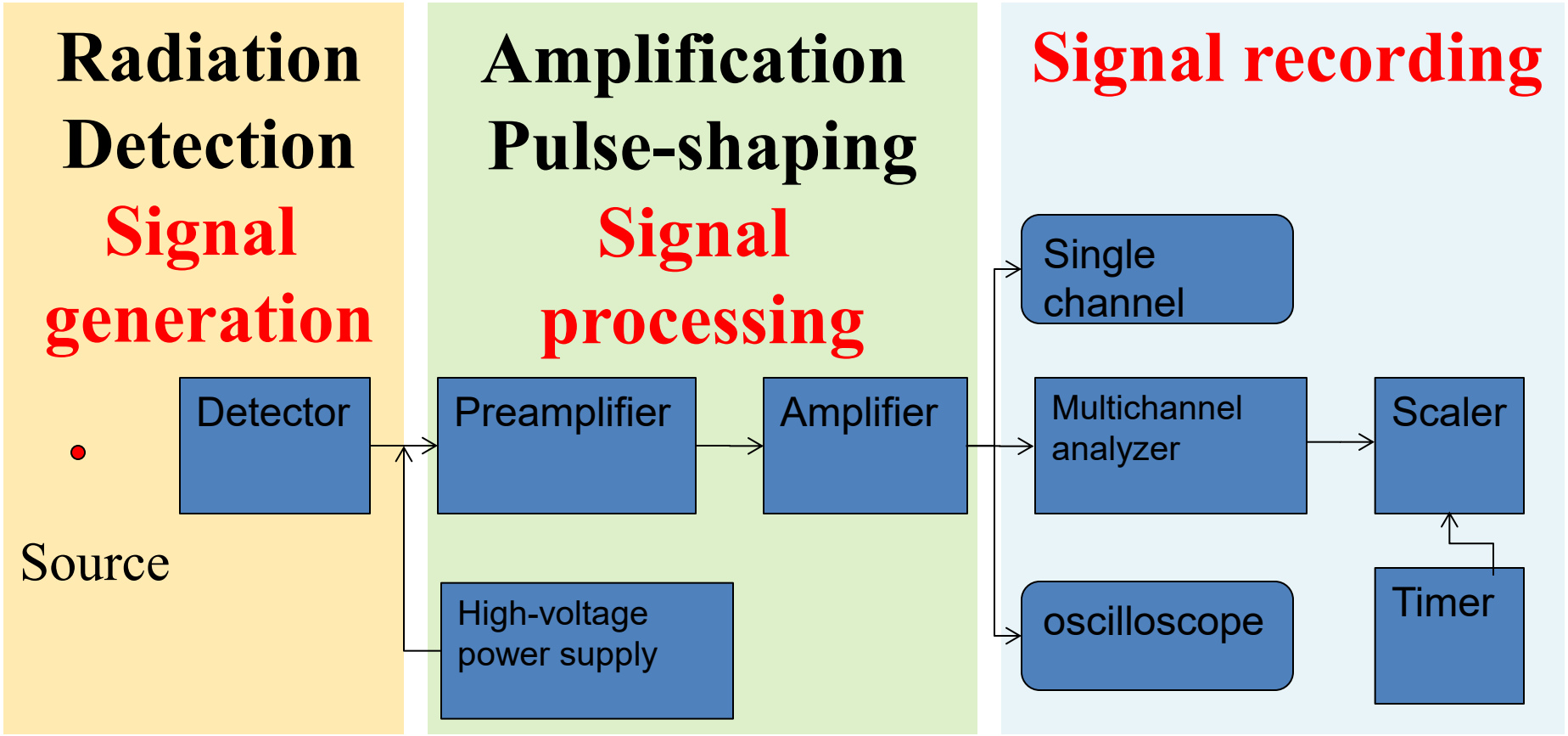
Length Measurements Tools

Measured by vernier-caliper,
marked with a chalk,
cut with an axe

https://www.gardeningknowhow.com/garden-how-to/info/what-do-marks-on-trees-mean.htm

https://www.pond5.com/stock-footage/item/106614508-half-cut-tree-trunk-forest?dd_referrer=https%3A%2F%2Fwww.google.com%2F

General Principle of Radiation Measurements



General Principle of Radiation Measurements

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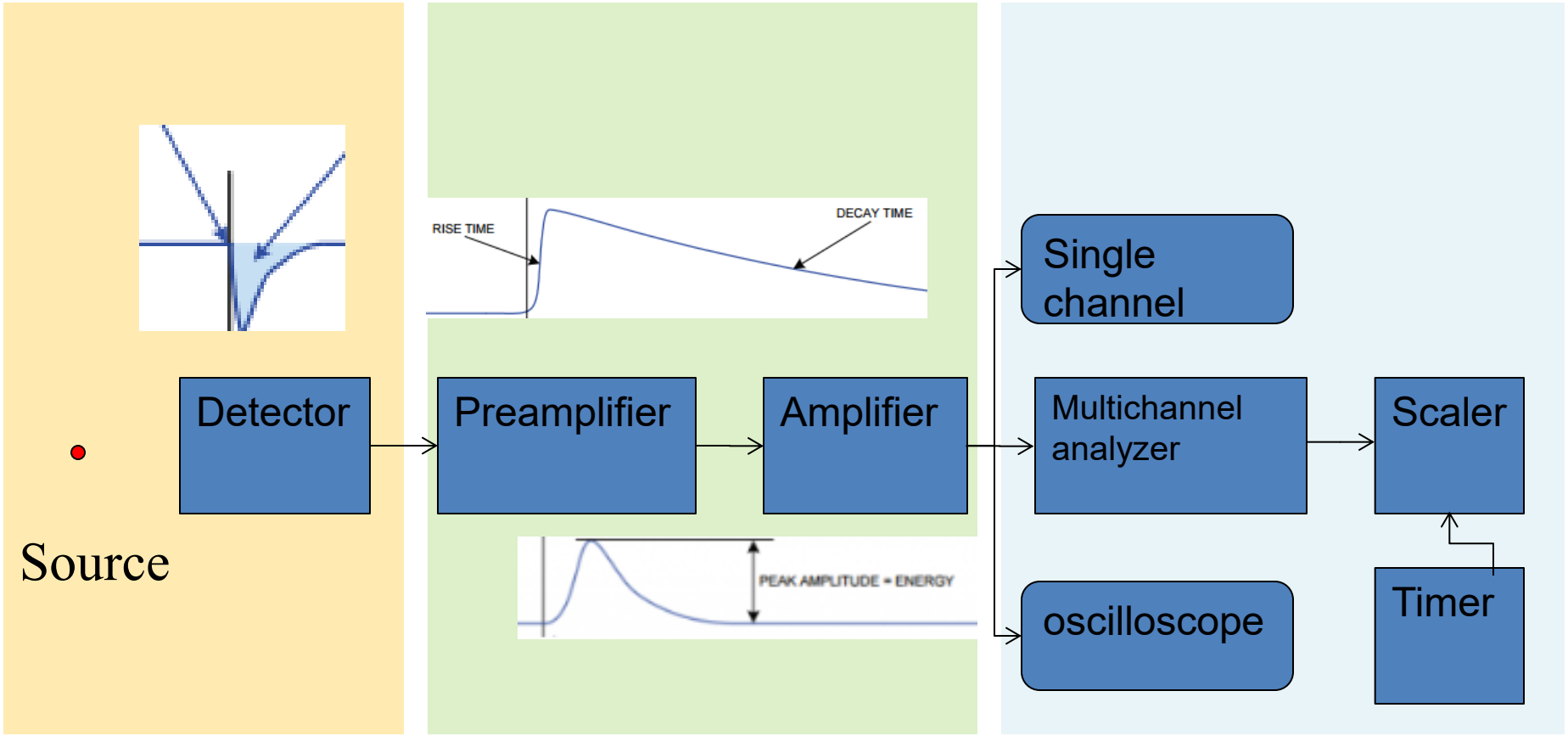
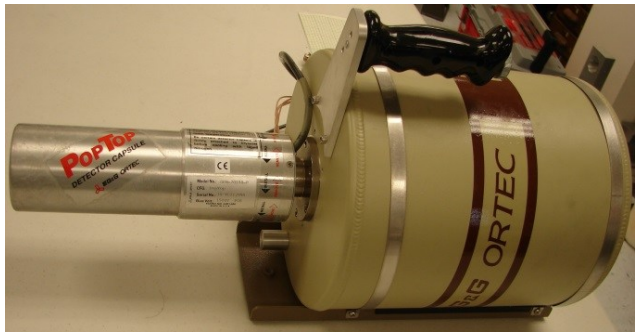
Source

General Principle of Radiation Measurements



https://physicsopenlab.org/2016/04/21/pmt-pulse-processing/

Radiation Measurements Tools



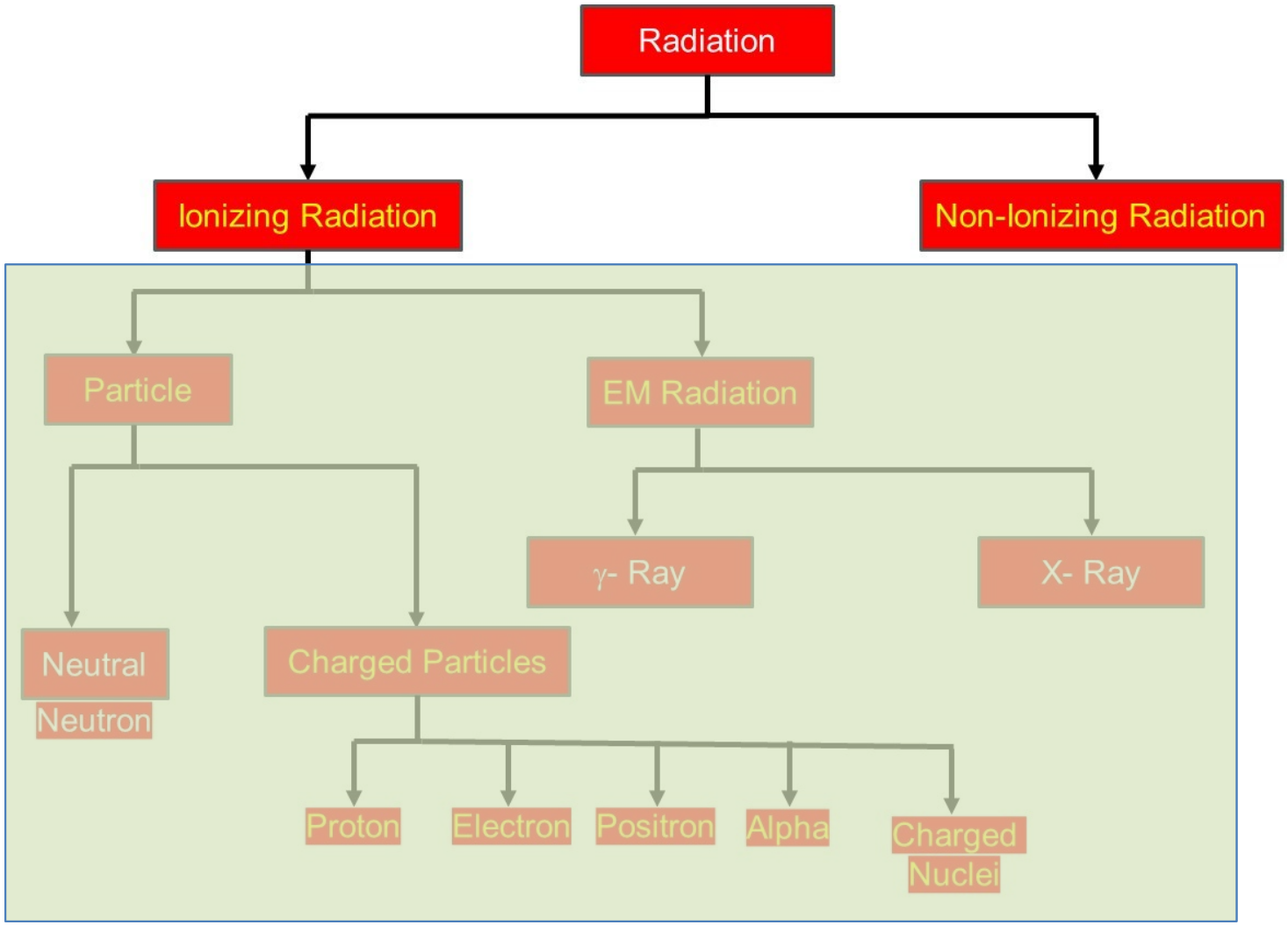
Radiation Detection Measurements & Spectroscopy

- Detection: Only interested in presence of radiation above level.
- Measurement: Interested in the intensity of radiation.
- Spectroscopy: Interested in type & energy distribution of radiation.

Mode of Detector Operation

- Current Mode: Only presence or intensity of radiation.
- Pulse Mode: Intensity and energy distribution of radiation.
- Mean Sq. Voltage Mode: Direct Dose measurement etc.

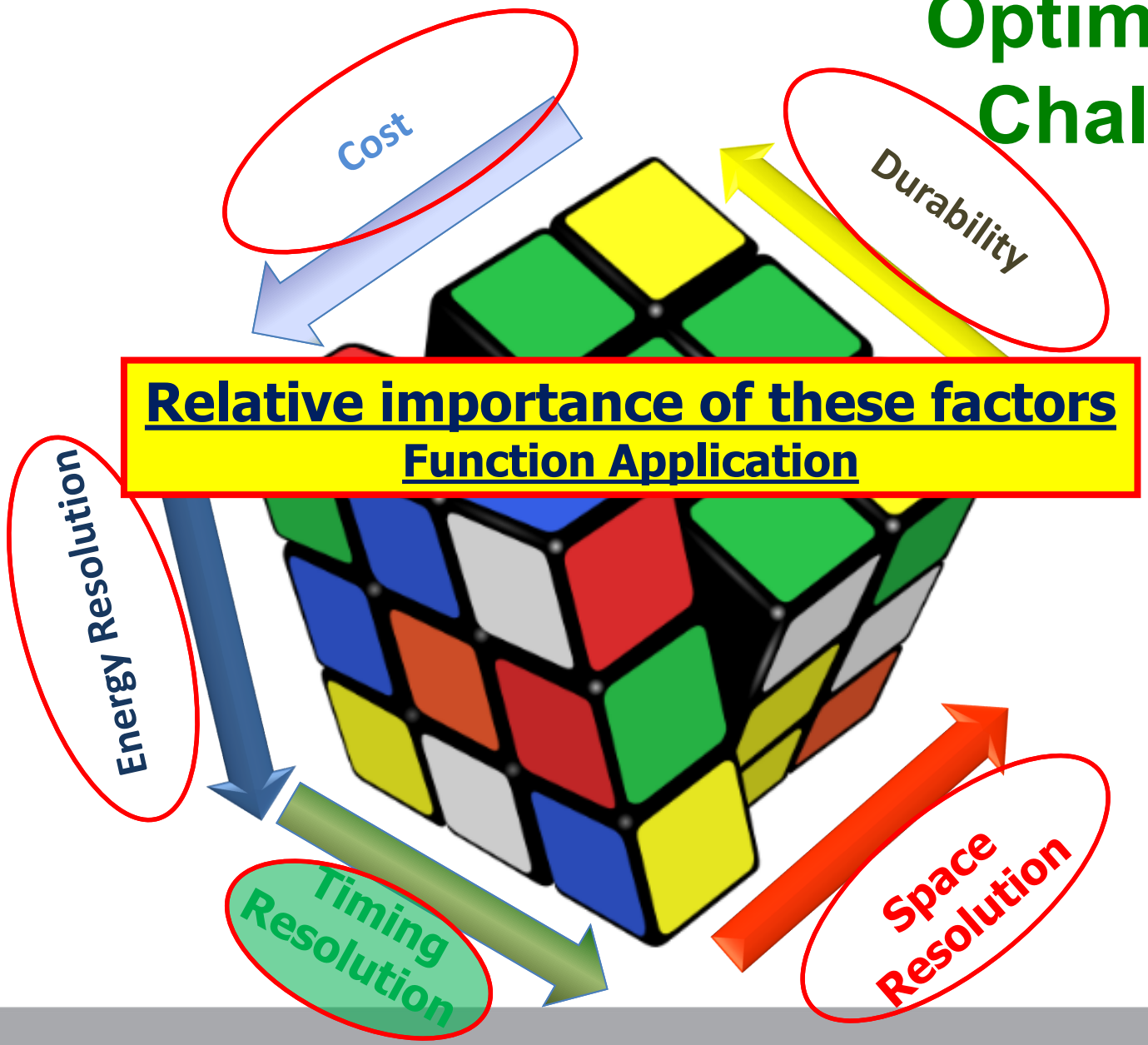
Radiation Measurements Tools



Radiation Detection Desired Features

- **Resolution**:
  - Space: Location of the radiation source.
  - Space: Spatial detail of the target/shield.
  - Energy: Being able to unfold the energy distribution of the source.
  - Timing: Being able to see pulses separately.
- **Type of Radiation**:
  - Ability: Responsive of different types of radiation?
  - Differentiation: Ability to separate one type of radiation from the other?
- **Cost**:
  - Based on the features above cost will change.
- **Durability**:
  - Maintenance cost and life expectancy.
- **Size**:
  - Space availability for the detector.

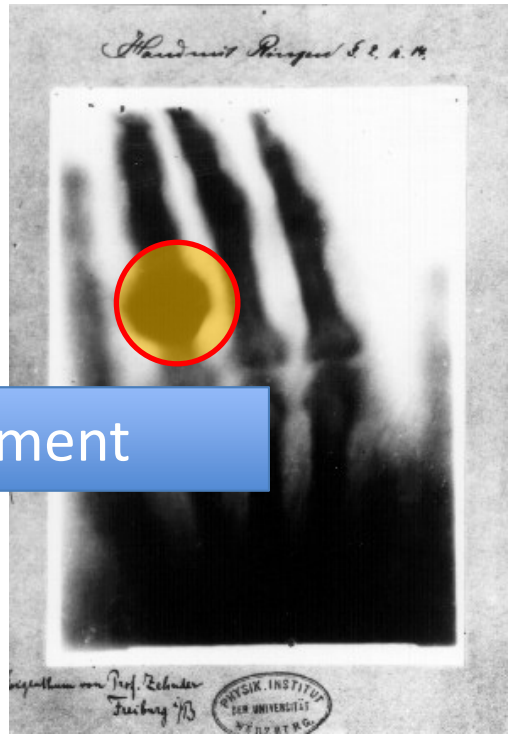
Optimization Challenge



Radiation for Medical Diagnosis

https://www.sooryadiagnostics.com/xray

https://www.nibib.nih.gov/science-education/science-topics/nuclear-medicine

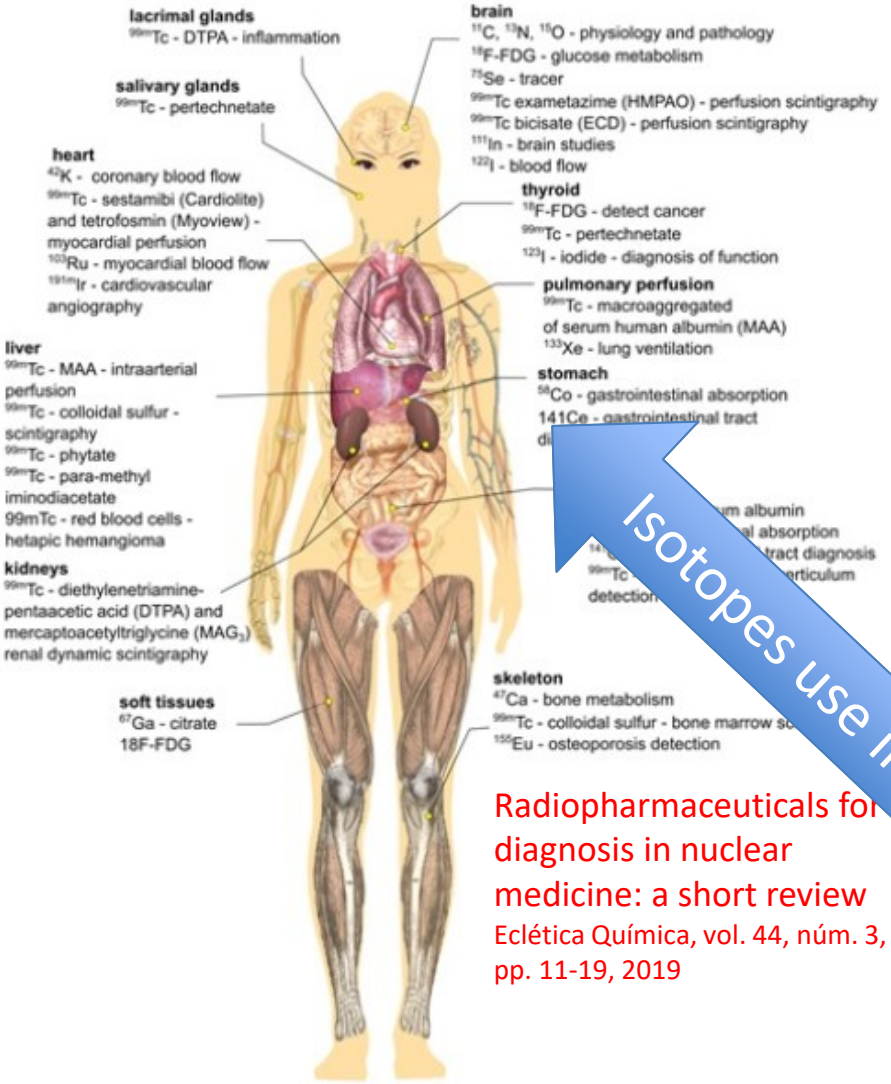


Soorya Diagnostics LLP
Lighting your way to better health

National Institute of Biomedical Imaging and Bioengineering (NIBIB)

Hand mit Ringen (Hand with Rings): print of Wilhelm Röntgen's first "medical" X-ray, of his wife's hand, taken on 22 December 1895 and presented to Ludwig Zehnder of the Physik Institut, University of Freiburg, on 1 January 1896

Radiation Measurements Tools



Radiopharmaceuticals for diagnosis in nuclear medicine: a short review
Eclética Química, vol. 44, núm. 3, pp. 11-19, 2019

Isotopes use in diagnosis

Radiation in Healthcare: Imaging Procedures: CDC
https://www.cdc.gov/radiation-health/features/imaging-procedures.html

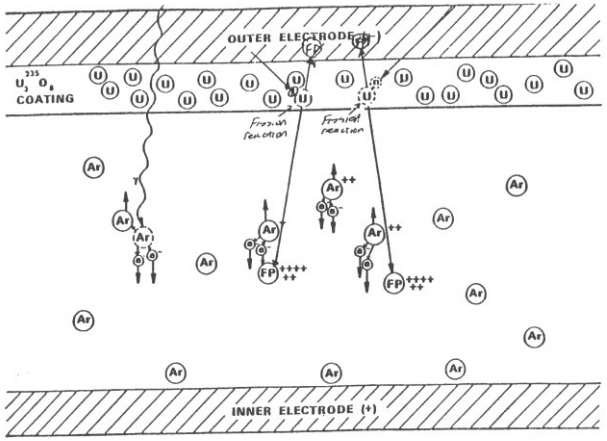
- Source-Detector Geometry:
  - External Source & Detector.
    - X-Ray Image
    - CT-Scan
  - Internal Source & Internal Detector.
    - PET Scan
    - Injected into patients.
    - Many choices

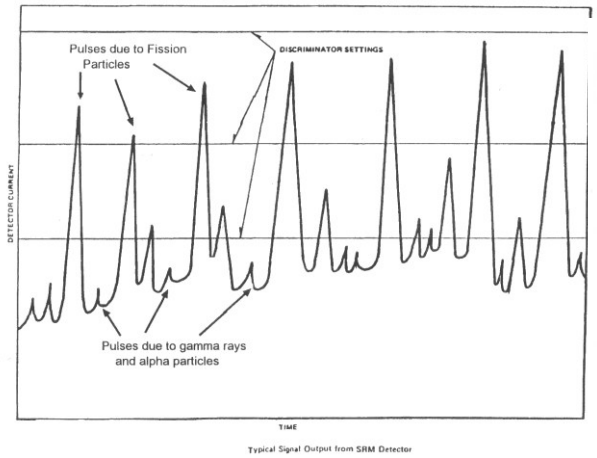
Radiation Detection for Industrial Application

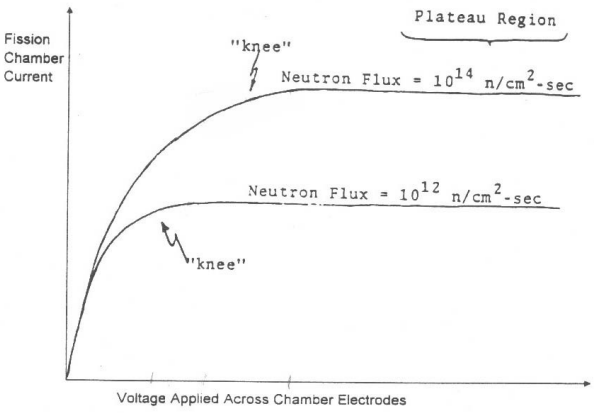
- Oil and Gas Exploration:
  - Well Logging – Natural gamma emissions.
  - Active Interrogation – use of neutron sources.
  - Bulk Density and Neutron Porosity Measurements
- Civil/Construction Engineering:
  - Moisture/Density Devices.
  - Rebar Inspection.
- Mechanical Engineering:
  - Weld Inspection.
  - Structural steel.
  - Corrosion.
- Manufacturing:
  - Metal Thickness.
  - Coating Thickness.
  - Aircraft Inspection.
- Chemical Engineering:
  - Chemical Reactor column scanning.
  - specific gravity
- Fire Safety:
  - Smoke Detector.
- Cargo Inspection:
  - Custom and Arms Control.
  - Airport Security.

Nuclear Reactor Instrumentation - Fission Chamber

Fission chambers has walls lined with a thin coating of uranium (fissile) allowing neutrons cause fission. One of the fission fragments entering the chamber cause gas ionization. Fission chambers can be operated in either pulse mode or current mode. **Gamma Discrimination.**







Interaction → Ionization

Gamma Discrimination

Current Mode Flux

Nuclear Reactor Instrumentation - BF3 Proportional Counter

The BF_3 proportional counter is where neutron interaction produces charged particles with K.E. and hence electrical signal.

$$ {}^{1}_{0}n + {}^{10}_{5}B \rightarrow {}^{11}_{5}B \rightarrow {}^{7}_{3}Li + {}^{4}_{2}\alpha + \text{Q (Energy)} $$

The Boron captures a neutron, then decays to Lithium plus an alpha particle (plus energy).

These charged particles cause ionization of the gas inside the detector chamber. These ions are counted and provide an indication of the number of neutrons present.

Gammas can also cause ionization of the gas and a subsequent current.

Nuclear Reactor Instrumentation

Excore Nuclear Instrumentation

- Monitor neutron flux outside the reactor vessel during all modes of operations.
- Initiate alarms and control signals during reactor operation
- Provide necessary overpower trip protection during reactor operation
- Provide the ability to assess the effect of reactivity changes in a shutdown reactor following an accident

Instrumentation associated with each channel is located in control room. The detectors themselves are housed in instrument wells that surround the reactor vessel.

Nuclear Reactor Instrumentation

Excore Nuclear Instrumentation

The channels of nuclear instrumentation are:

Source Range Monitors

Intermediate Range Monitors

Power Range Monitors

Wide Range Monitors

Nuclear Reactor Instrumentation - Source Range

Source Range Monitors

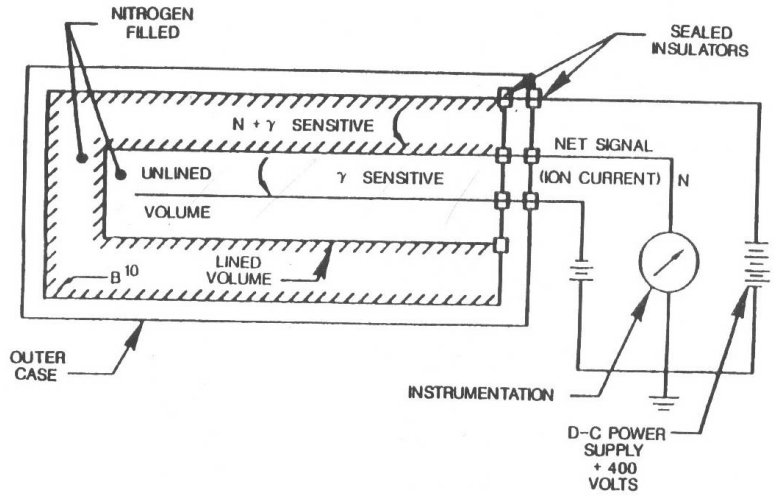
- Detectors - BF3 proportional counters detecting both neutrons and gammas.
- Fission Chamber also a Choice
- Utilize Pulse Height Discriminator to block the smaller gamma pulses
- Preamplifier - Located as close to detector as possible (minimize signal degradation) and amplifies the signal x 100
- Pulse Amplifier - Amplifies the preamp signal and discriminates against gamma pulses
- Initiate alarms and control signals during reactor operation
- Provide necessary overpower trip protection during reactor operation
- Provide the ability to assess the effect of reactivity changes in a shutdown reactor following an accident

Return to Excore Instrumentation

Nuclear Reactor Instrumentation - Intermediate Range

Intermediate Range Monitors

- Moderate neutron flux, pulse mode operation is not possible.
- Gamma high enough that it cannot be ignored.
- Detectors - Compensated Ion Chambers
- Two chamber detector that detects both neutron and gamma radiation. Two separate voltages applied.



COMPENSATED ION CHAMBER

Return to Excore Instrumentation

Nuclear Reactor Instrumentation - Power Range

Power Range Monitors

- High neutron flux, pulse mode operation is not possible.
- Gamma background not significant can be ignored.
- Detectors - Uncompensated Ion Chambers
- Four detector channels, each consisting of an upper and lower detector. Single chamber detector that detects both neutron and gamma radiation.
- Current signal proportional to power generated in upper or lower half of core.

- High Voltage power supply - 800 VDC

- Ammeters - display current signal

Return to Excore Instrumentation

Nuclear Reactor Instrumentation - Wide Range Monitors

Power Range Calibration

Power is measured using the four power range detector channels.

Detectors measure neutron flux and are calibrated in percent power.

Calibration is accomplished by performing a heat balance across the steam generators. The heat balance is used as a more accurate measure of actual core thermal power.

At stable conditions, feedwater flow rates and temperature measurements are taken.

If the difference between the heat balance and the nuclear instrumentation calculated power is greater than 1%, the gain on the power range instrumentation is adjusted.

Return to Excore Instrumentation

Nuclear Reactor Instrumentation - Wide Range Monitors

Wide Range Backup Instrument Channels

Detectors - Fission Chambers

Each detector assembly contains two fission chambers allowing it to operate over twelve decades of neutron flux.

Both chambers used for source range display while only one needed for power range.

Detectors operate in two modes: pulse and MSV (at higher power levels).

Wide Range amplifier Amplifies signal from fission chamber

Pulse height discriminator blocks smaller puses (alphas and gammas)

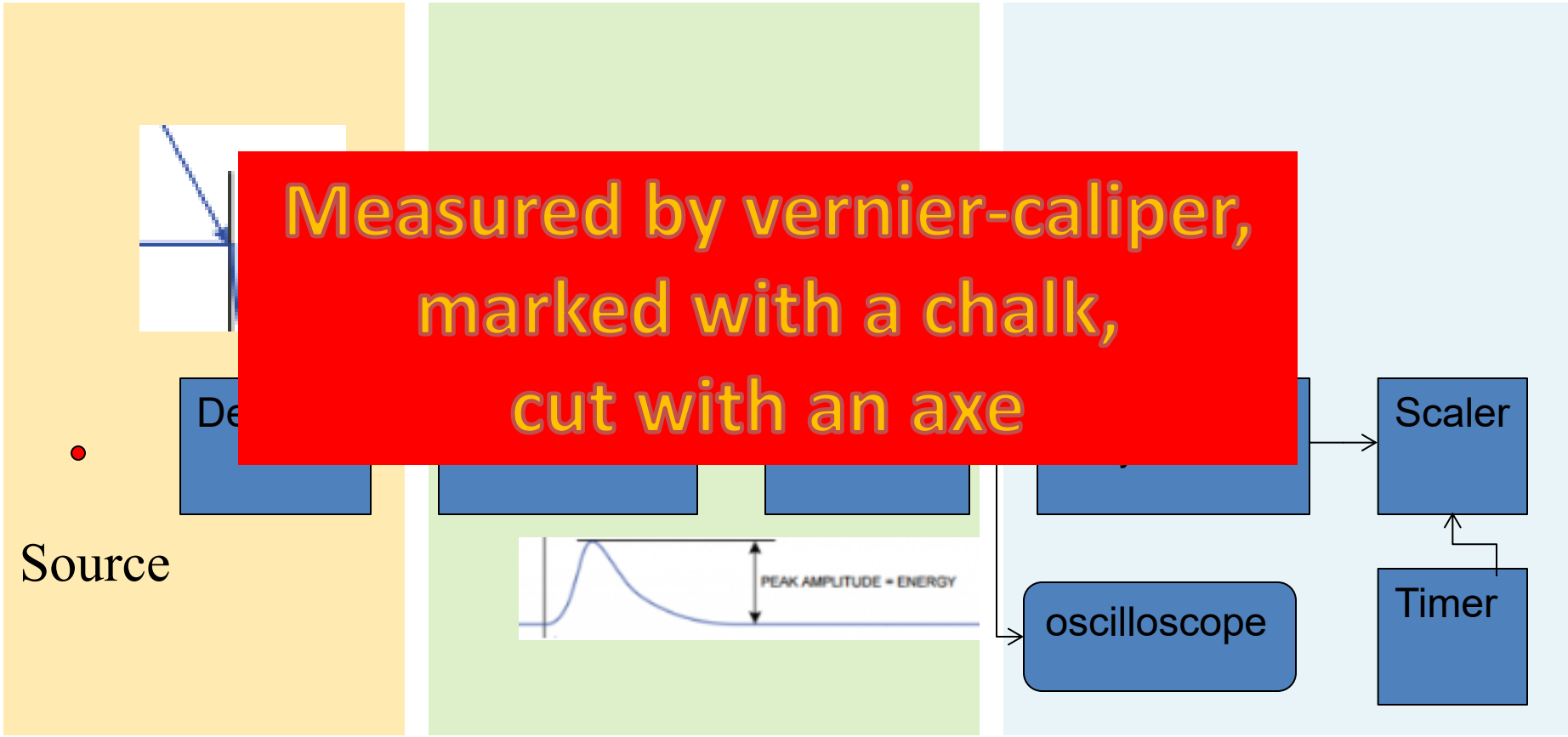
Optical Isolator

Splits signal to drive two signal processors

Isolates signal between amp and signal processor so that failure in one signal processor will not affect the other.

Return to Excore Instrumentation

General Principle of Radiation Measurements



https://physicsopenlab.org/2016/04/21/pmt-pulse-processing/

Nuclear is a Highly Regulated Industry!

- In order to satisfy the regulatory requirements the manufacturers have to follow some set of standards and codes. For example; IEEE , ASME Codes
- NRC is the regulatory authority in the USA.
- Long list of Standards Development Organizations NRC has listed and recognizes as important for nuclear industry and would be involved with supply chain for SMR industry.

Year 2024 Memories

7th International Conference on Nuclear and Renewable Energy Resources
October 27-30, 2024
Key Note Speaker

Nuclear Power Plant Licensing Class Tour April 16, 2024
Wolf Creek visit

Consent-Based Public Engagement Meeting
Chicago History Musuem
August 24, 2024

Year 2024 Memories

Nuclear Power Plant Licensing Class Tour April 30, 2024
Clinton NPP visit

Ben Sonpon Commencement December 13, 2024
Rolla, MO

Technical Meeting on Developing a Sustainable Nuclear Supply Chain for Near Deployment Reactors 18th Ed. Dec. 10-12, 2024
Vienna, Austria

Seminar Presentation at
Istanbul Technical University,
Energy Research Institute and ITU TRIGA Mark-II
November 1, 2024

Year 2024 Memories

Yusra Husna Shoaib
Born (Jan. 23, 2024)