The Role of the Research Reactor in Nuclear Engineering Education

An Illustration of Research Reactor Utilization in Training & Education

Outline

- Introduction
  - Presenters, Facility and Facility Mission
- University of Wisconsin Nuclear Engineering Curriculum
- Nuclear Engineering Classes Taught at the Research Reactor
  - NE 234
  - NE 427
  - NE 428
- Training at the Research Reactor
- Outreach at the Research Reactor
- Regional Technical Support

Introductions

John Murphy, SRO

- Engineering Physics Instructor
  - InterEgr 160 - Freshman Design
  - NE 231 - Intro Nuclear Engineering
  - NE 412 - Senior Nuclear Design
  - NE 550 - Advanced Reactors
  - NE 565 - Power Plant Technology
- UW Engineering Physics Department Outreach Coordinator

Michelle Blanchard, SRO, PE

- UW Nuclear Reactor Lab Reactor Supervisor
- UW Nuclear Reactor Lab Senior Reactor Operator
- ANS Wisconsin Section Secretary
- UwWIN (Women in Nuclear) Advisor

UW Nuclear Reactor

1 MW TRIGA: Regional Resource

1961 : Initial criticality 10kW

1964: Power level increase to 250kW, original flat-plate fuel

1967: Cooling system installed. Reactor converted to 1000 kW TRIGA with pulsing capability.

1979: Completed conversion to TRIGA FLIP fuel. Last ops 8-19-2009

2009: Conversion to LEU. First critical 9-16-2009. 9-30-2009 loaded to operation core.

Reactor Lab Mission

- University of Wisconsin Nuclear Engineering
  - UW Students: NE427, NE428, NE234
- Training
  - Nuclear Power Plant Operators
  - Fire Fighters – HAZMAT Teams
  - High School Teachers
- Outreach
  - School Children, Boy Scouts, Girl Scouts
- Regional Technical Support
  - Radiation Surveys, Instrument Calibrations and Technical Assistance for Hospitals, Police Departments, Fire Departments and Other Universities and Businesses

Nuclear Engineering Student Curriculum

- The undergraduate nuclear engineering program is divided into two tracks, a power track and a radiation sciences track.
  - Power Track: The power track focuses on power generation applies broad science and engineering knowledge to basic principles of nuclear reactors: nuclear reactor analysis, radiation transport and shielding, heat transfer in nuclear reactor systems, and nuclear reactor design.
  - Radiation Sciences Track: The Radiation Sciences track focuses on the non-power applications of nuclear engineering. It includes courses on biological effects of radiation, radiation detection and instrumentation, shielding of radiation and the safe handling and disposal of radioactive materials.

Core Curriculum

Freshman Year

Fall Semester	Spring Semester
Chemistry I	Statics
Calculus I	Calculus II
Communications	Statistics

Sophomore Year

Fall Semester	Spring Semester
Calculus- Multi Variables	Differential Equations
General Physics	Modern Physics
Dynamics	Thermodynamics
Computing	Mechanics of Materials
Public Speaking	

Core Curriculum

Junior Year

Fall Semester	Spring Semester
Fund. of Nuclear Engr.	Nuclear Reactor Theory
Appl. Math. Analysis	Ionizing Radiation
Intro. to Materials Science	Transport Phenom.
Electrical Circuits	

Senior Year

Fall Semester	Spring Semester
Nuclear Heat Tranport.	Reactor Design
Nuclear Instrum. Lab	**Nuclear Reactor Lab.**
Technical Writing	

Nuclear Engineering Classes Taught at the UW Nuclear Reactor Lab

- NE 234, Reactor Operator Training
  - *NRC Operating License possible*
- NE 427, Nuclear Instrumentation
- NE 428, Nuclear Reactor Lab

Nuclear Engineering Students in the Reactor Lab

NE 234 Reactor Theory

- know the characteristics of moderators and how moderation changes with temperature.
- be able to identify the different components that make up K-effective, and to indicate how changes in temperature, control rod position, fuel burnup, and other parameters will change the value of K-effective.
- be familiar with Xenon and Samarium production and burnout in a reactor core

NE 234 Reactor Theory

- be able to perform subcritical multiplication problems and use inverse count rate ratio plots to predict approach to critical.
- be able to predict how the reactor will respond to changes induced by changes in control materials and the reactor plant system.

NE 234 Radiation Protection

- know the 10 CFR Part 20 limits and requirements
- know how time, distance and shielding influence radiation exposure
- know the characteristics of alpha, beta, gamma, fast and thermal neutron radiations
- be able to employ standard survey methods in the reactor laboratory, including air sampling, water sampling and swipe tests.

NE 234 Radiation Protection

Plant Systems

- Understand and operate:
  - pool water makeup & purification
  - nitrogen-16 diffuser & cooling system
  - sampling systems for pH, conductivity & radioactivity
- Understand the operating principles and operation of:
  - process monitoring
  - radiation monitoring
  - reactor power monitoring,
  - reactor control & safety systems

Plant Systems: Demin and Air Monitoring Cart

NE234 Plant Systems

- Thorough knowledge of reactor core and components
- Knowledge of the construction, safety features, use and purpose of all currently used experimental facilities
- Knowledge of the location of all operating controls and indications.

Procedural Practices

- Knowledge of license and technical specification requirements
- Knowledge of the administrative controls and relationships involved in operation of a nuclear reactor.
- Use of written procedures and instructions to assure compliance with regulations and good practices; including:
  - operating procedures
  - surveillance procedures
  - maintenance procedures
  - emergency procedures

Reactivity Feedback

- Objective
  - Introduce Fuchs-Nordheim model of reactivity feedback
  - Pulse the reactor
  - Verify the validity of the Fuchs-Nordheim model
  - Measure the prompt neutron life time and reactivity coefficient of energy feedback

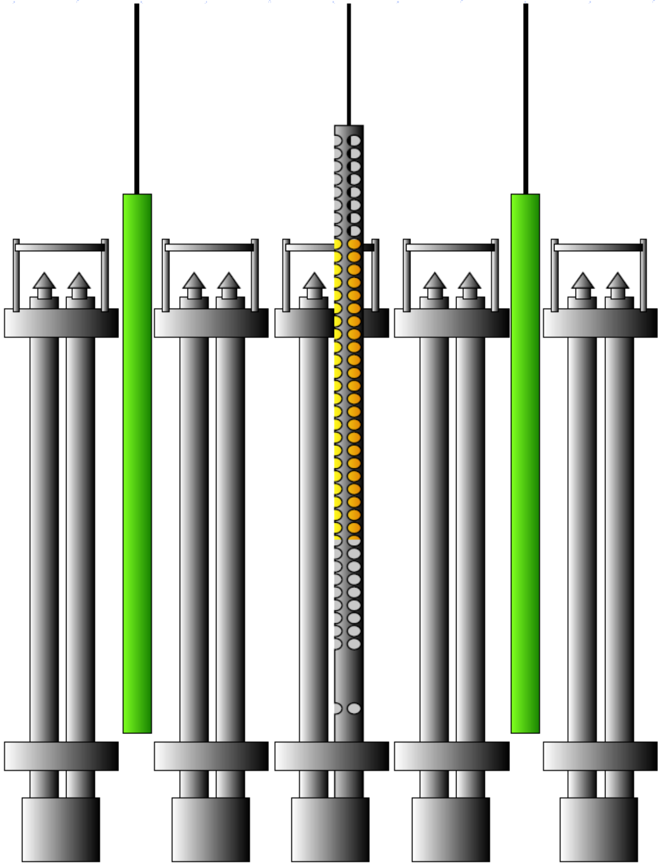
TRIGA Fuel

- TRIGA-FLIP fuel is designed with a large prompt negative temperature coefficient.
- Most of this temperature coefficient is due to the presence of erbium oxide in the fuel
- Erbium has a very large resonance absorption peak at about 0.4 eV
- Most of the moderation in the core is provided by the hydrogen in the zirconium hydride-uranium fuel
- The energy release from fission immediately causes an increase in the motion of the hydrogen which raises the neutron energy enough to cause a significant increase in absorption by the erbium, thus reducing reactivity.

234 Reactor Operations

Students operate the nuclear reactor
(1 hour individual session each week)

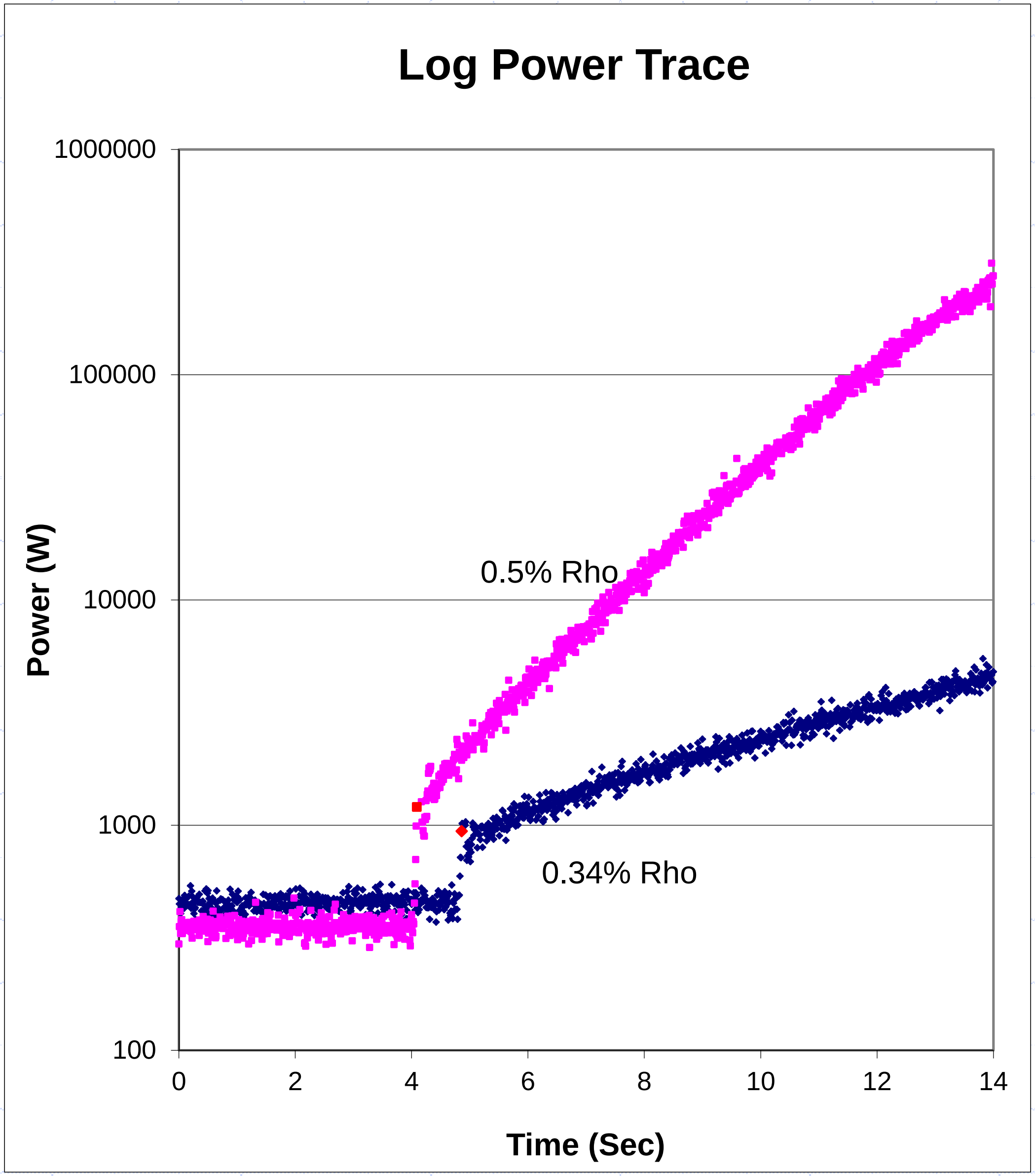
- •Approach to critical
- •Low and intermediate power operations
- •Reactivity measurements
- •Point of "adding heat"
- •Reactor behavior for positive and negative reactivity insertions
- •Prompt critical operation



Positive Reactivity Insertions

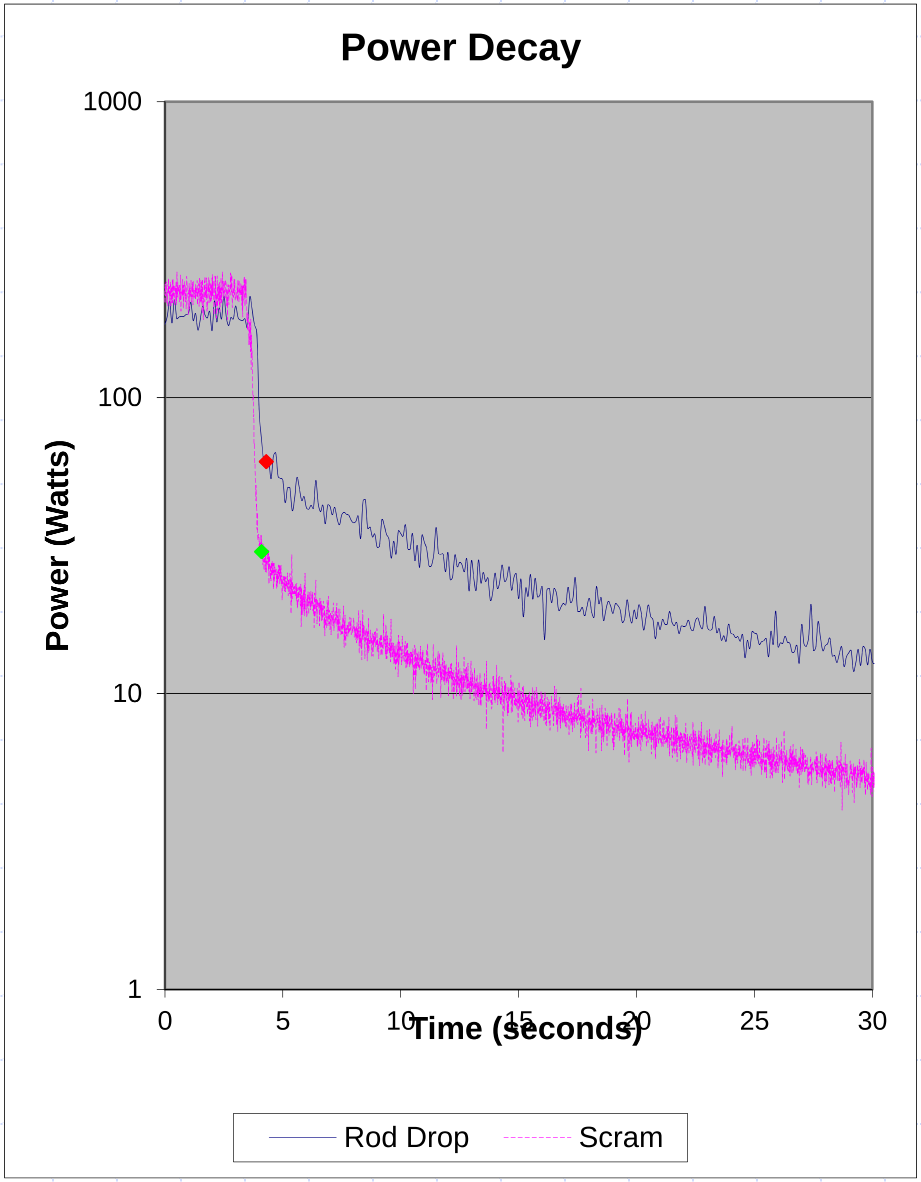
Reactivity related to:

- Prompt jump in power
- Period of power increase



Negative Reactivity Insertions

- Reactivity related to:
  - Prompt drop in power
  - NOT related to period of power decrease



Point of Adding Heat: Negative Reactivity Insertion

time	#1 (in)	#2 (in)	#3 (in)	Reg (in)	Trod (in)	Power Level (kW)	Fuel Temperature (C)	Rho (%) *use integral worth curve
0915	11.59	**0”**	11.59	11.59	11.58	<1 kW	29.2	0
0930	11.59	**4.39**	11.59	11.59	11.58	100	65.7	0.2
0934	11.59	**5.89**	11.59	11.59	11.58	200	96.8	0.42
0938	11.59	**7.76**	11.59	11.59	11.58	400	161.3	0.8
0941	11.59	**9.94**	11.59	11.59	11.58	800	239.2	1.2
0943	11.59	**11.35**	11.59	11.59	11.58	1000	279.8	1.48

NEEP 427: Nuclear Instrumentation Laboratory

- Investigate detector characteristics
  - Gas filled detectors
  - Scintillation detectors
  - Solid state detectors
- Introduce counting statistics & error analysis
- Introduction to Health Physics

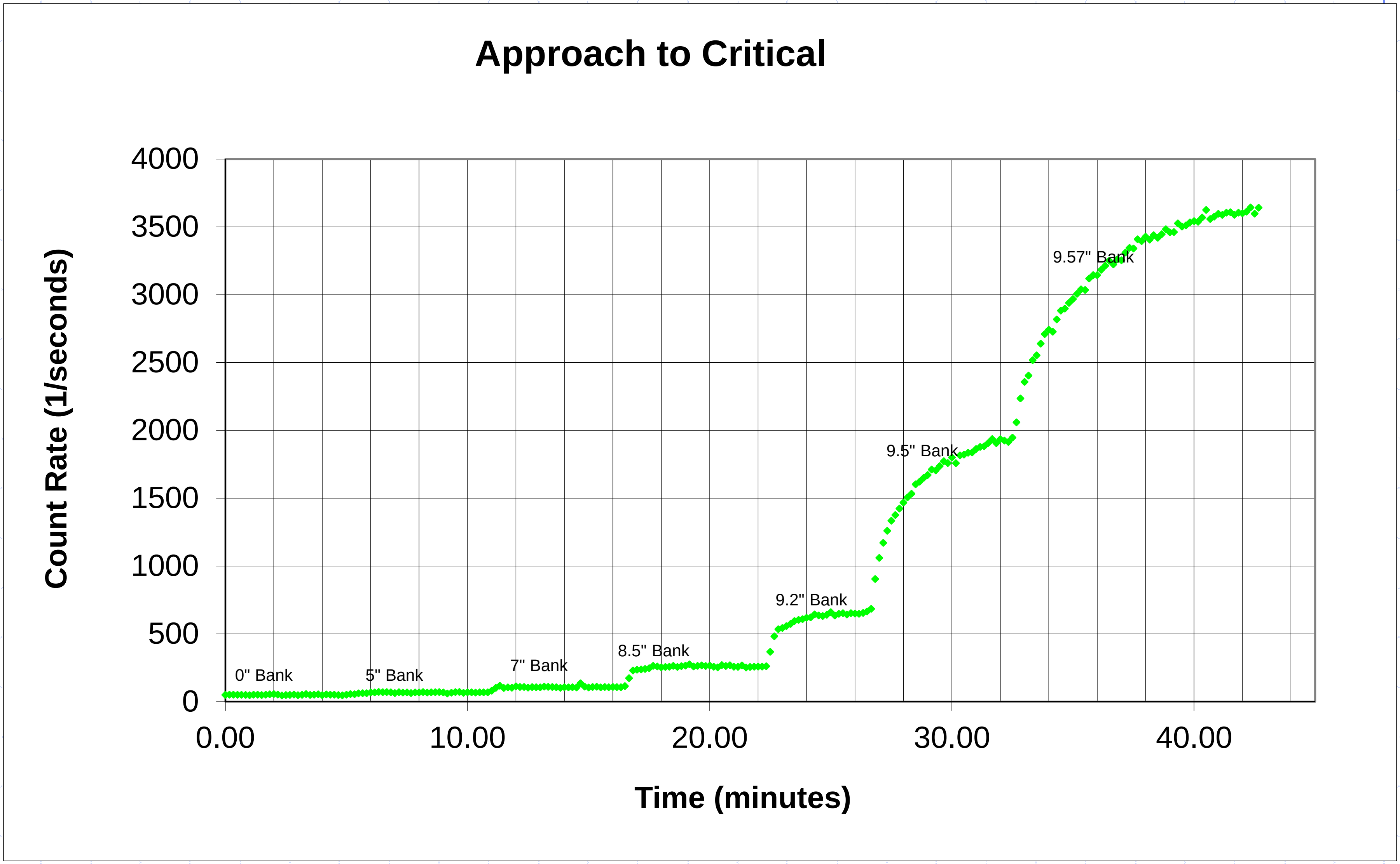
NEEP 428: Reactor Laboratory

- Investigate reactor theory in a laboratory setting
- Demonstrate practical applications of measurements
  - Critical Experiment
  - Control Element Calibration
  - Reactor Pulsing
  - Fast Neutron Flux Measurement
  - Diffusion Length of Thermal Neutrons
  - Resonance Absorption

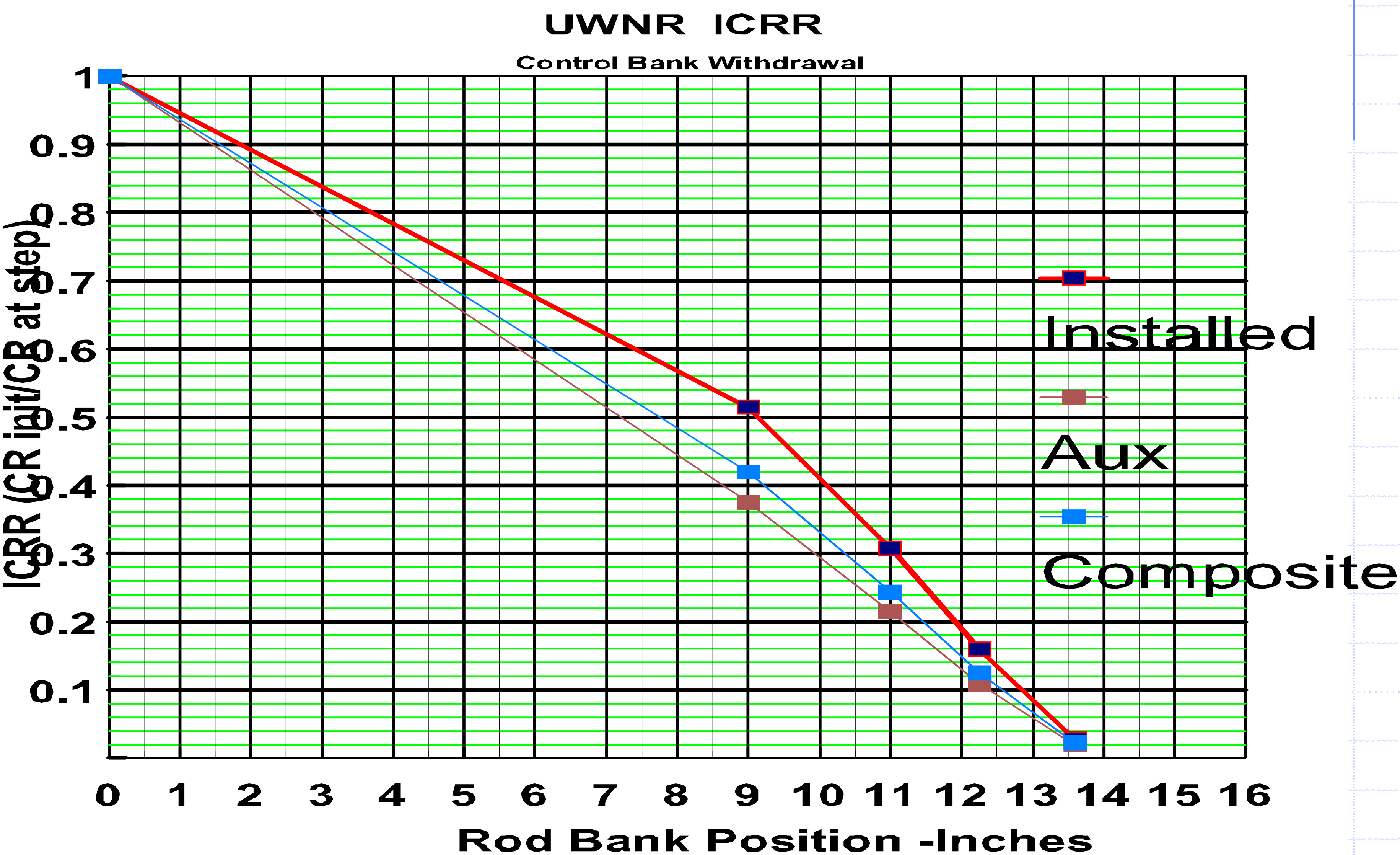
428: Critical Experiment

- Objectives
  - Introduction to nuclear safety and procedures
  - Define neutron multiplication and derive a relationship to predict criticality
  - Investigate sensitivity in relationship

Subcritical Multiplication During Approach to Critical



Inverse Multiplication “1/M” Prediction of Critical Configuration



428: Reactivity Measurements

- Objectives
  - Discuss delayed neutron precursors
  - Observe effects of prompt and delayed neutrons on reactor behavior
  - Relate reactor period to reactivity through Inhour equation

$$\rho = \frac{l}{k_{eff} \cdot \tau} + \sum_i \frac{\beta_i}{1 + \lambda_i \cdot \tau}$$

  - Perform a control element reactivity calibration
  - Measure shutdown margin (prompt drop)

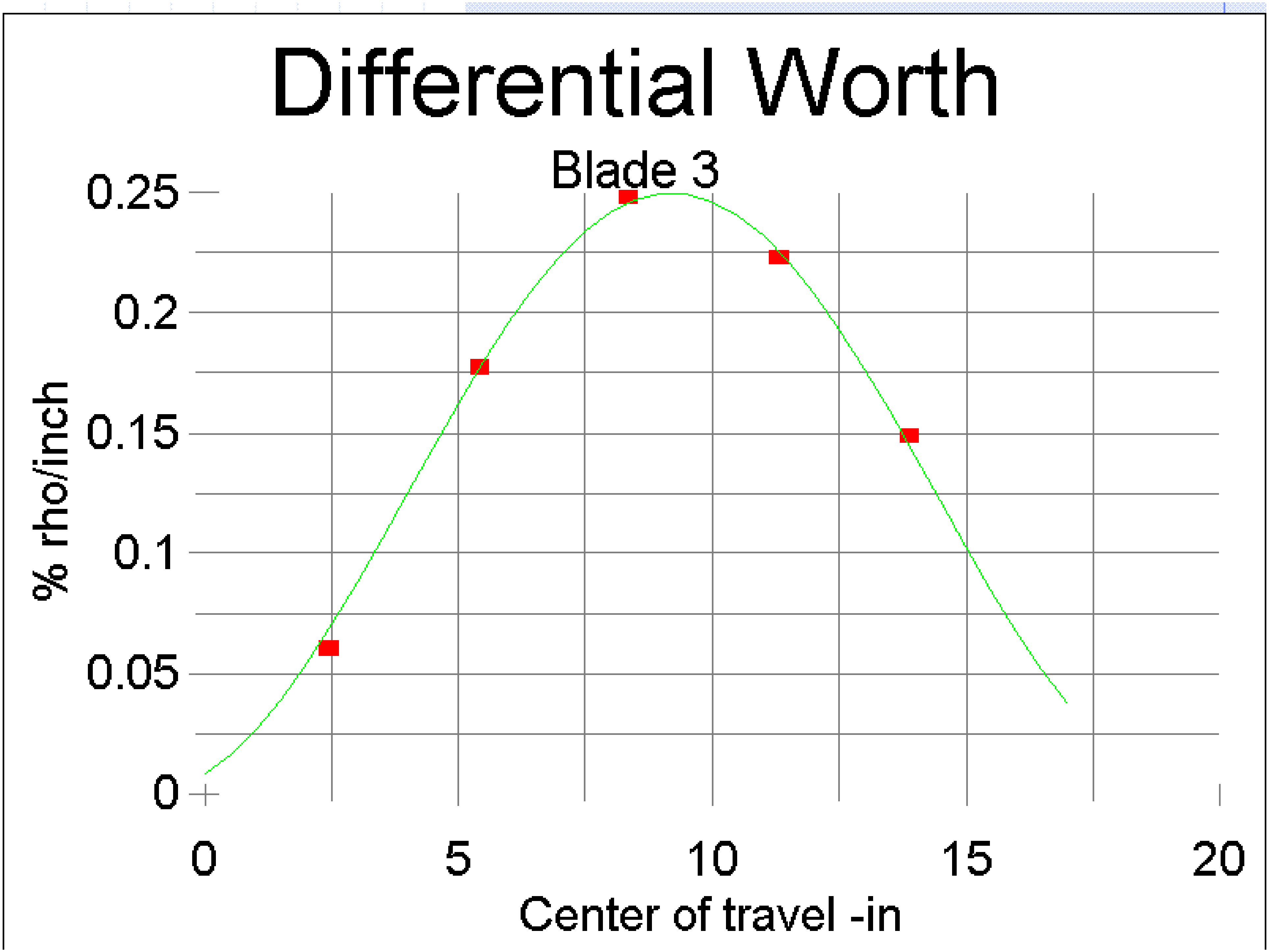
Control Element Calibration

- Make reactor exactly critical at ~ 1W with source removed
- Withdraw control element to approximate a step change in reactivity
- Wait for stable asymptotic reactor period
- Measure reactor power doubling time

Control Element Calibration

- Relate power doubling time to period
- Use Inhour equation to determine reactivity inserted during rod pull
- Determine $\dfrac{\Delta\rho}{\Delta h}$
- Plot $\dfrac{\Delta\rho}{\Delta h}$ vs h for differential worth curve
- Integrate to build integral worth curve

$$\rho = \int_0^H \frac{d\rho}{dh} dh$$


Differential Worth
Blade 3
% rho/inch
0.25
0.2
0.15
0.1
0.05
0
0
5
10
15
20
Center of travel -in

428 Prompt Critical Operation:

Reactivity Insertion Greater than Delayed Neutron Fraction

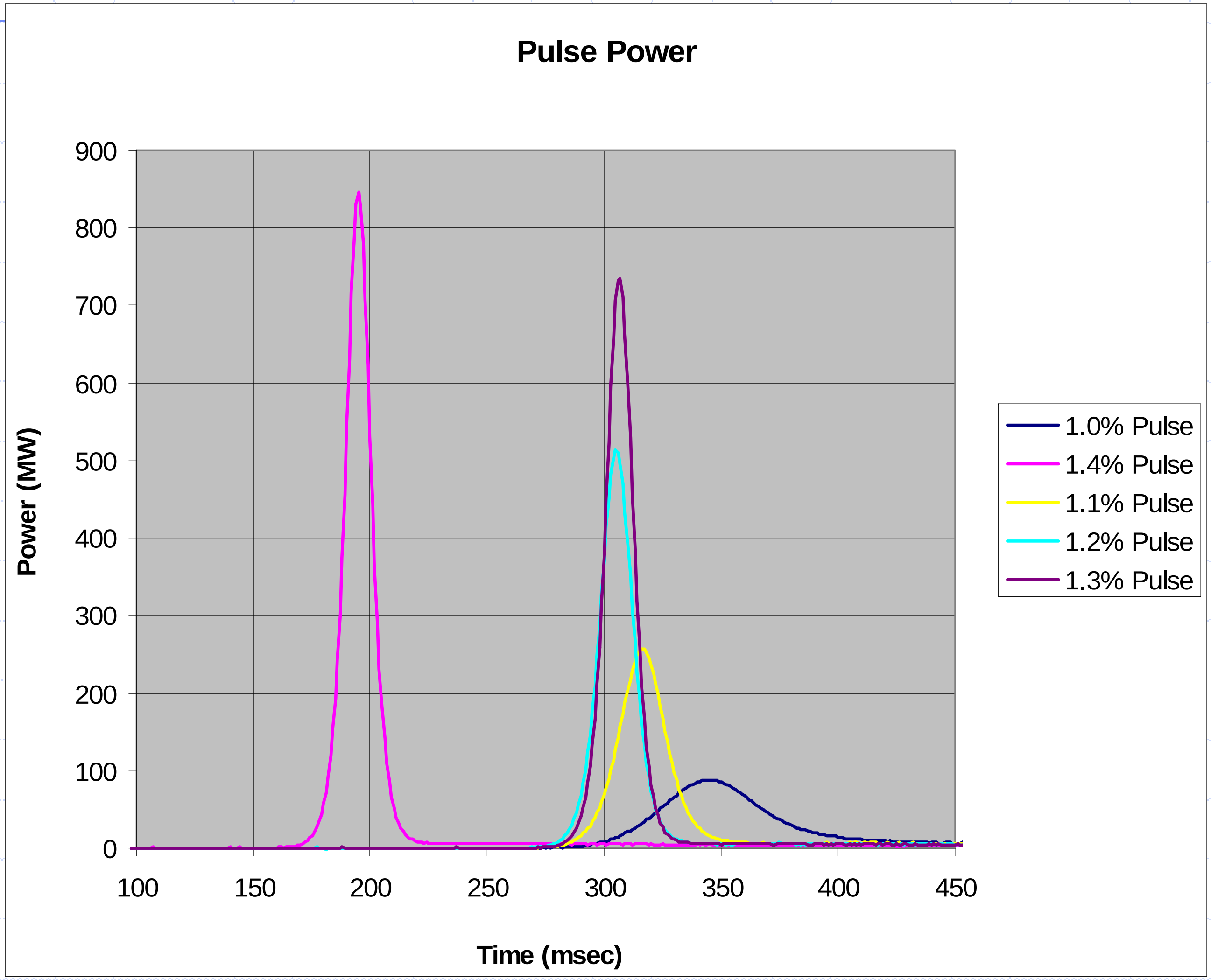
- Assumptions
  - Adiabatic approximation
  - Absence of delayed neutrons
- Kinetics Equations
- Evaluation yields several relationships that describe power rise
- Analysis of pulse validates the model

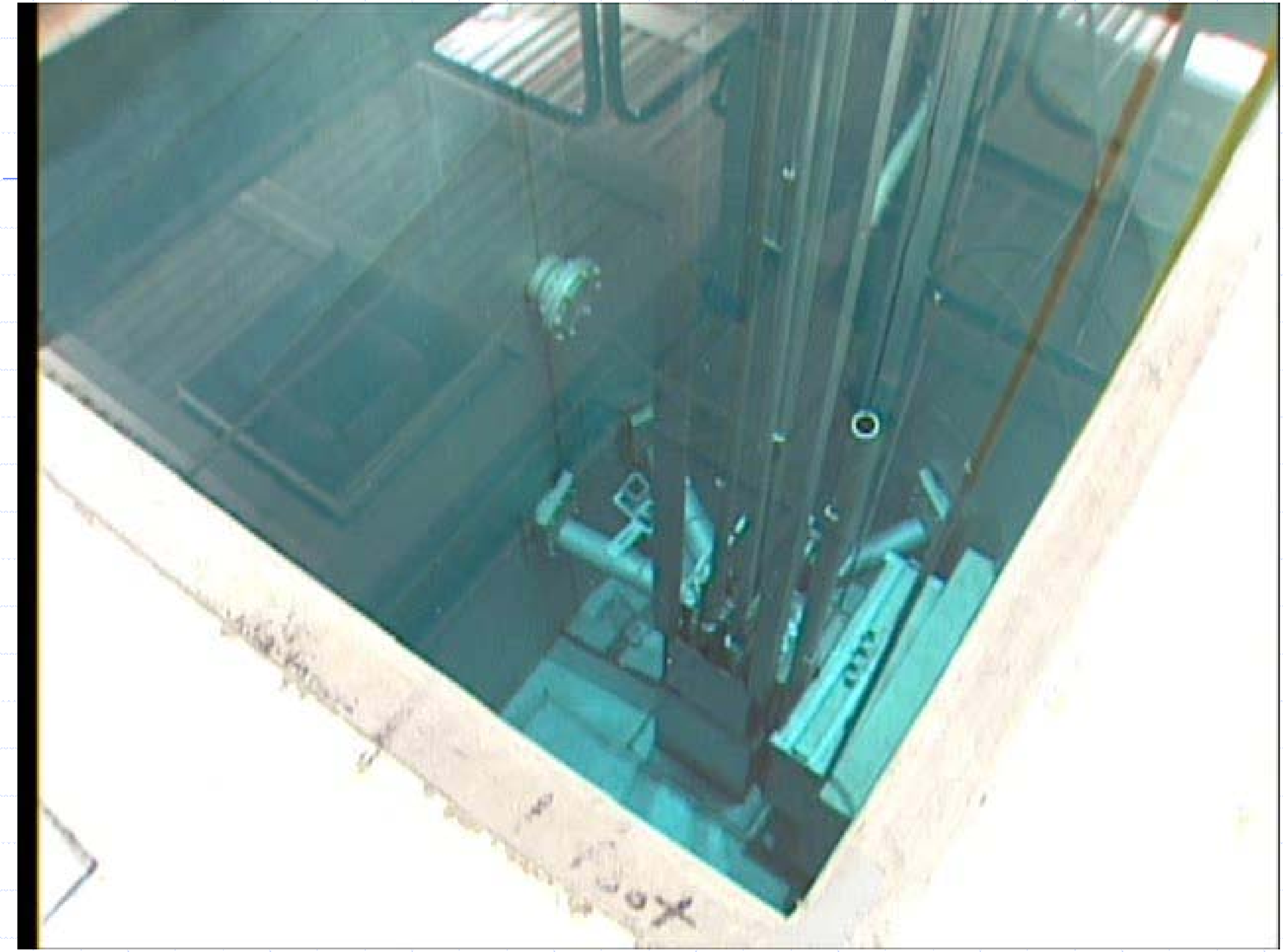
428 Prompt Critical Operation:

Reactivity Insertion Greater than Delayed Neutron Fraction

	Pulse 1	Pulse 2	Pulse 3	Pulse 4	Pulse 5
rho (%)	1	1.1	1.2	1.3	1.396
rho	0.01	0.011	0.012	0.013	0.01396
rho-pr (%)	0.3	0.4	0.5	0.6	0.696
T (Celcius)	198	216	233	252	267
FWHM (ms)	39.42	22.26	16.59	13.60	12.30
FWTM (ms)	94.95	46.76	34.48	28.40	25.80
Period (ms)	10.58	6.22	4.79	4.10	3.83
Integrated Power (MJ)	2.64	5.02	6.53	8.38	10.17
Peak Power (MW)	111	284	506	746	942

Pulse Traces





Training: HAZMAT Emergency Response

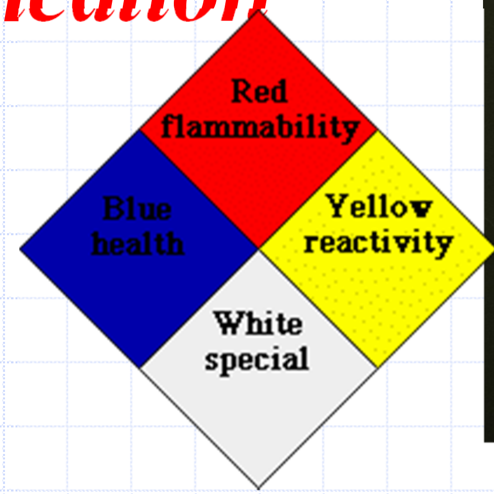
Radiological Monitoring

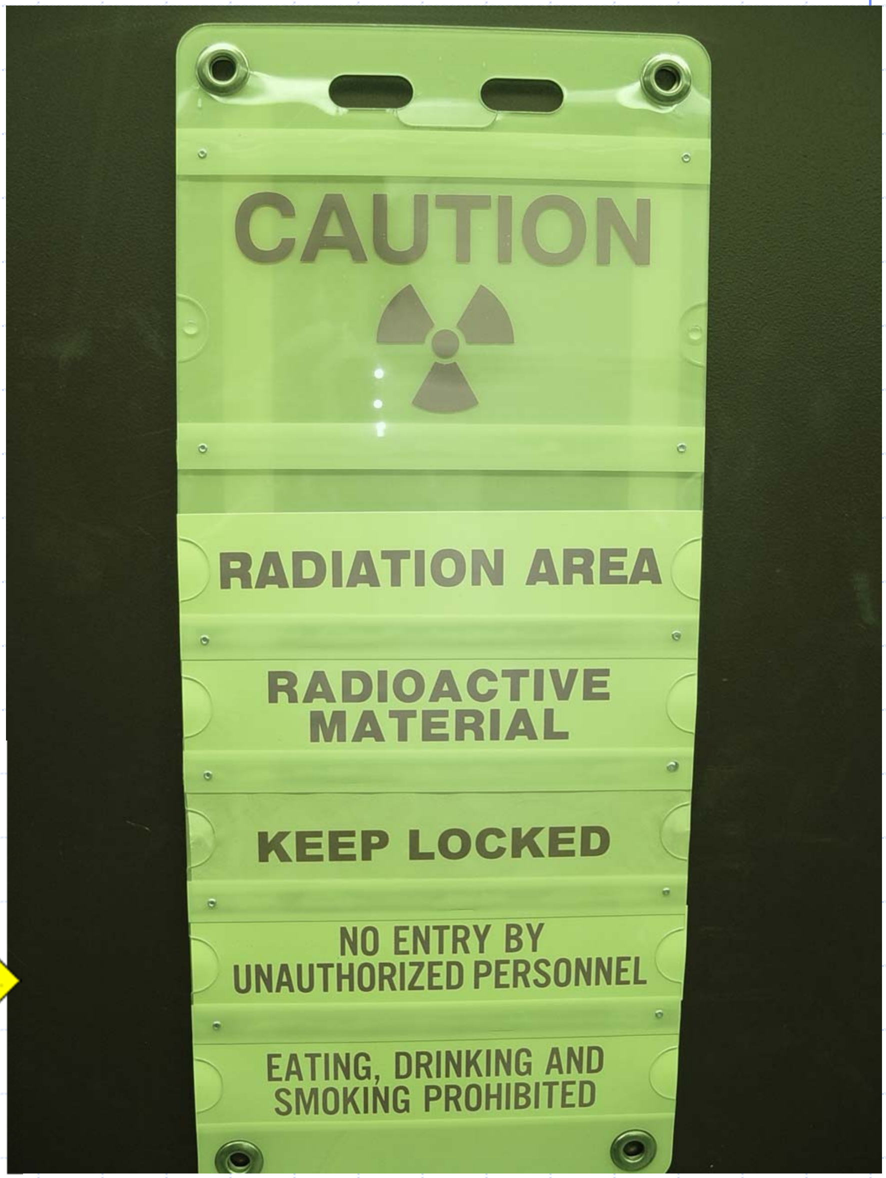
1. **Identify** situation as involving potential radiological hazard: hazard communication

- 2. Assess the hazard: **Measure** radiation levels; hazard communication/support

- 3. **Interpret** the result

Identify situation as involving potential radiological hazard: ***hazard communication***





Assess the hazard: **Measure** the radiation level

Using a radiation detector:

Check for damage

Check for current calibration

Check the battery

Turn it on

Use a checksource

Interpret Results

- Occupational limits and Stay times are desiged to limit your **total dose**. (mRem or Rem)
- Radiation detectors generally measure Dose rate (mRem/hr). Some will also provide total dose (must remember to use reset)
- However, the assumption should always be *AS LOW AS REASONABLY ACHIEVEABLE*. This is ALARA. It's good practice

Training: Nuclear Power Plant Operators

Outreach

- Visitors range from elementary and secondary school to senior citizen groups (Ages 8 – 80)

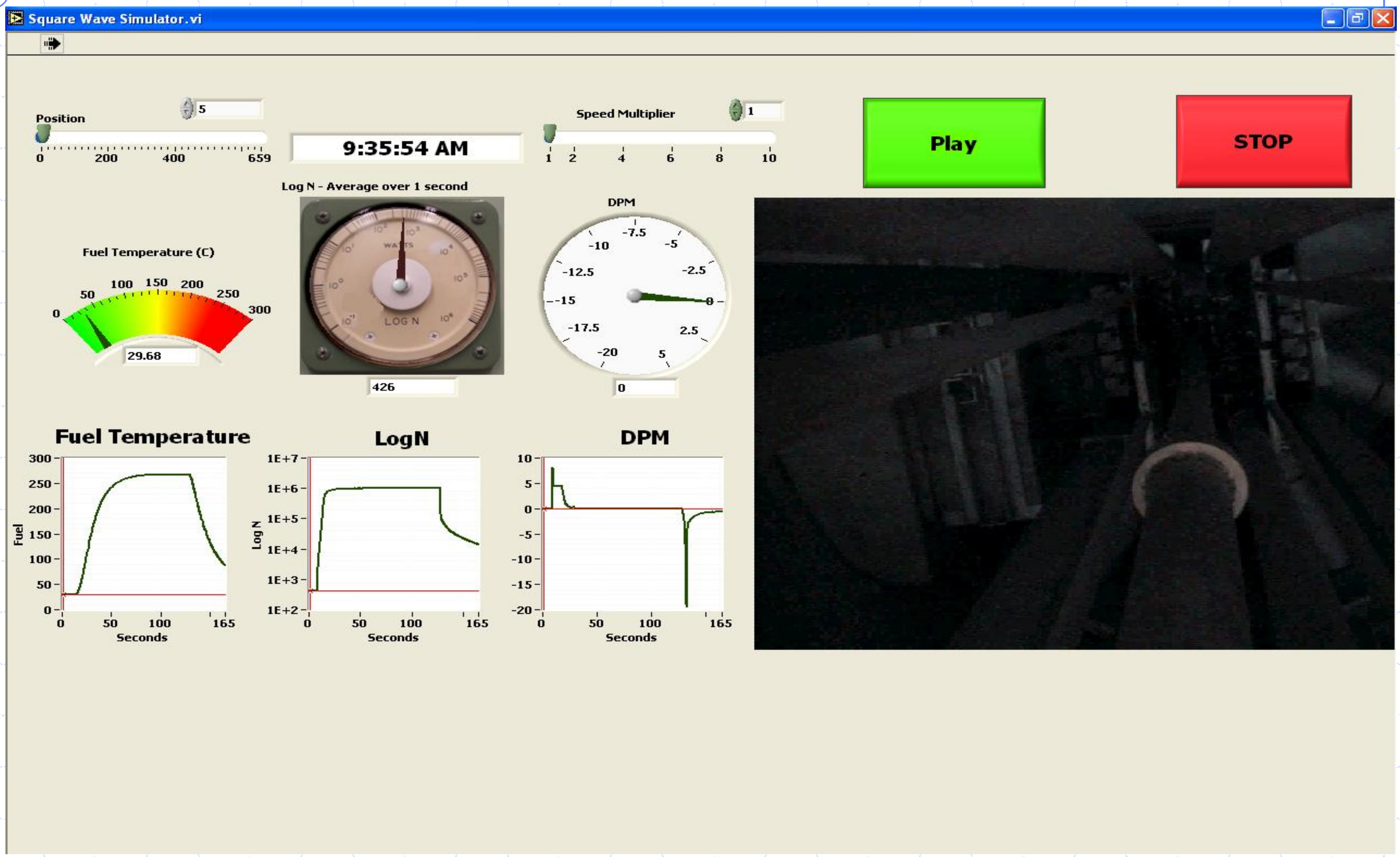
- Goals:
  - Describe sources and applications of nuclear energy
  - Describe how a nuclear reactor works
  - Tour our reactor
  - Answer questions and dispel myths

Outreach: Girl Scouts and Boy Scouts

Outreach: Distance Education Capabilities

- National Instruments LabVIEW data acquisition system
  - Camera input
  - Startup channel count rate
  - Reactor power level
  - Fuel temperaure
- Adobe connect
  - Cameras
  - Communication

Screen Shot: Square Wave



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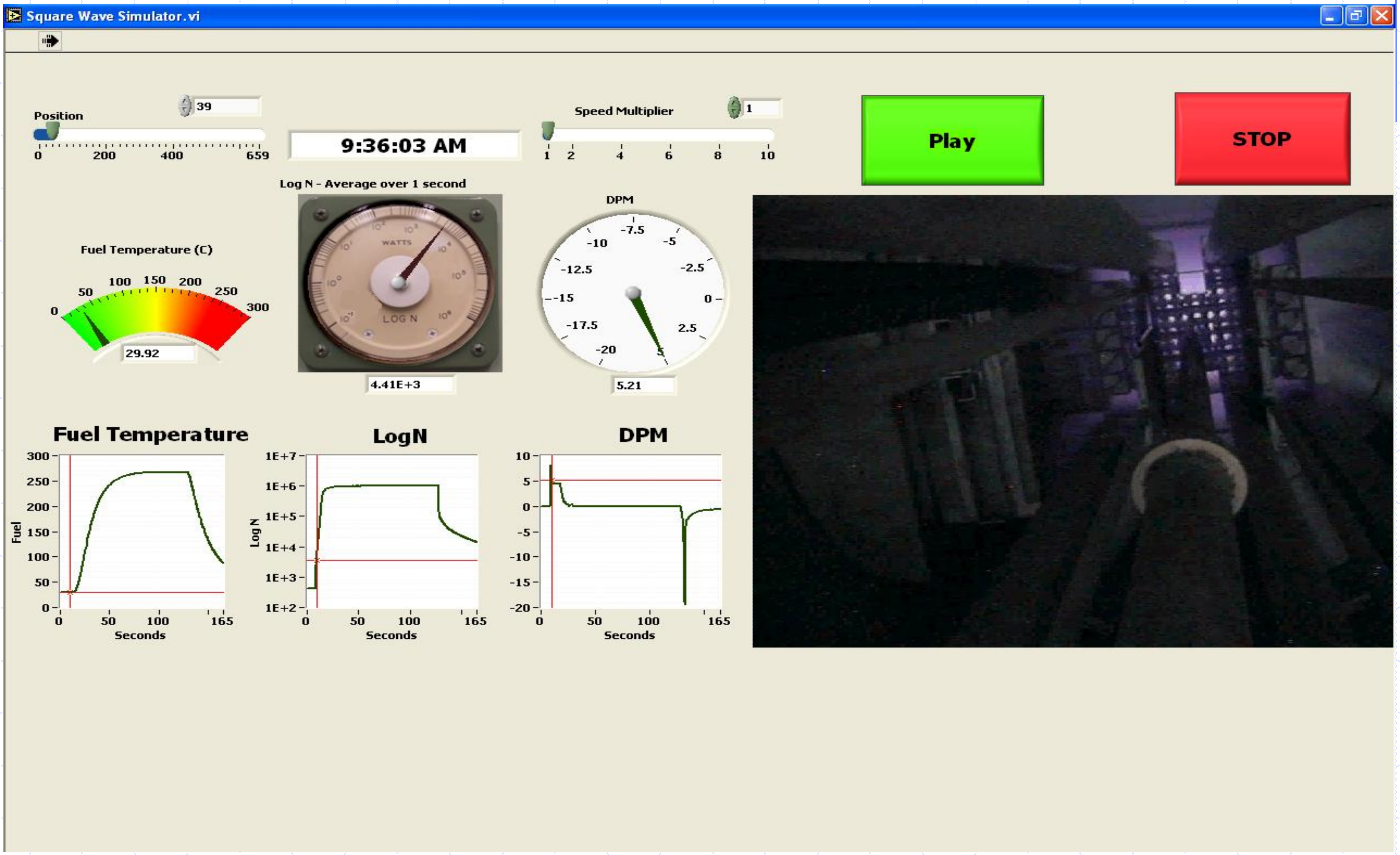

Screen Shot: Square Wave

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Outreach: Regional Technical Support

- Radiation Surveys
- Instrument Calibrations
- Emergency Planning