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National Nuclear Security Administration

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Nuclear Criticality Safety

Summer Internship 2018

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11 July 2018

NCS Summer Internship

Nuclear Criticality Safety Division

Los Alamos NATIONAL LABORATORY EST. 1943

Educational Development

Weekly Presentations

- Richard P. Feynman
- Theremin Technology
- Cherenkov Radiation
- Lectures on Nuclear Basics

Relevant Classes/Tours

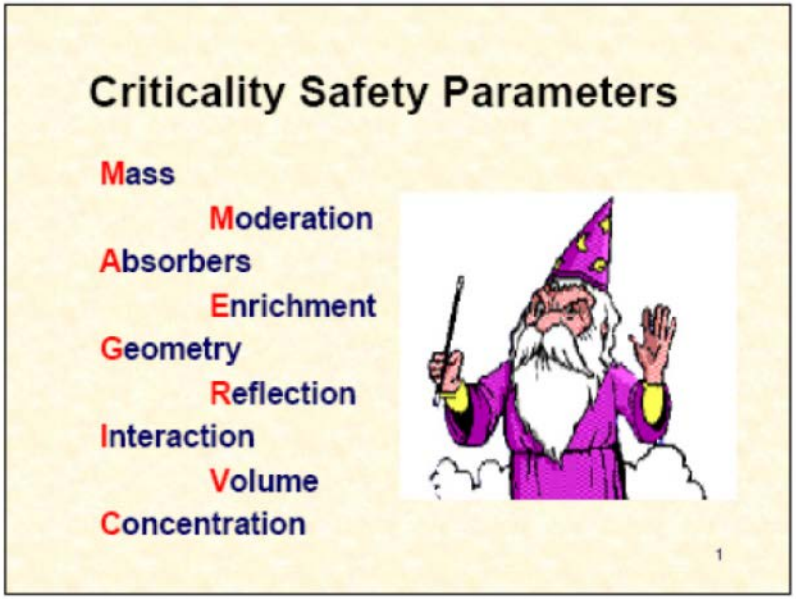
- TA-66 (NDA measurements)
- UNM Short Course
- TA-55 Facility Tour

CRITICALITY SAFETY IS HARD

Bang
Head
Here

Directions:
1. Place kit on FIRM surface.
2. Follow directions in circle of kit.
3. Repeat step 2 as necessary, or until unconscious.
4. If unconscious, cease stress reduction activity.

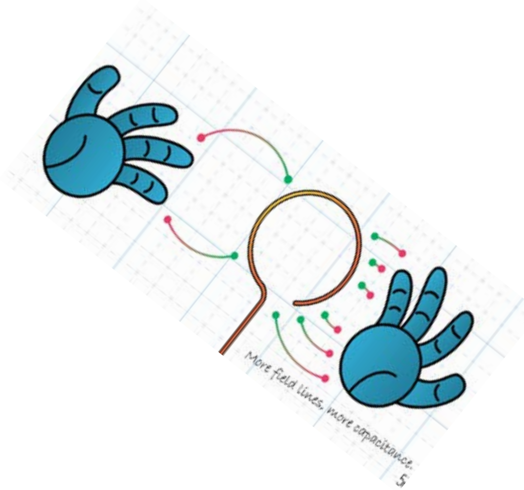
Nuclear Criticality Safety Fundamentals



To maintain conditions as subcritical (prevention of a sustained chain reaction), certain physical parameters of fissionable materials can be controlled.

Theremin Technology

- Theremin is a musical instrument invented by Leon Theremin, Soviet scientist and musician, that utilizes the performer's body as an electrical control; tones are produced by varying movements of the right hand and fingers in the electromagnetic area about a vertical rod at the right of the instrument.
- The simulator device uses Theremin technology to simulate reflection effects on nuclear reactivity.



- The physics of the Theremin instrument were adapted in an NCS Reactivity Simulator that is used to simulate added reflection from the human body (e.g. hands)
- As hands are moved closer to the device, the number of simulated clicks increases, representing increased neutron multiplication (reactivity) due to the reflection from the hands

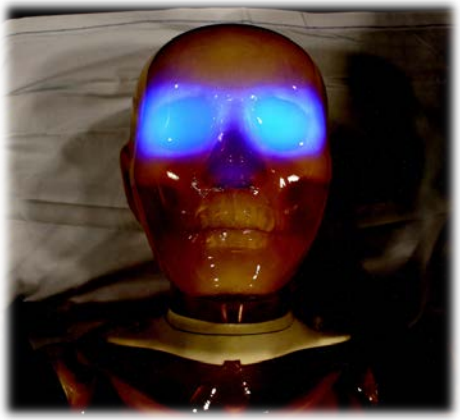
Cherenkov Radiation

- If a particle's speed is higher than speed of light in the medium, radiation is given off
- Electromagnetic radiation gives off when a charged particle passes through an insulator at a speed greater than the speed of light in that medium.
- Amount of light and angle of emission depends on particle velocity
- Cherenkov radiation, when it is intense in a Nuclear Reactor, appears as a weak bluish white glow in the pools of water shielding.
- Although, here at the lab if we were to see this weak blue glow, it would be simultaneous critical.
- The Blue Flash could only be seen for less than a second after reaching criticality, unless in an aqueous setting where you would see the blue light for an increased amount of time.

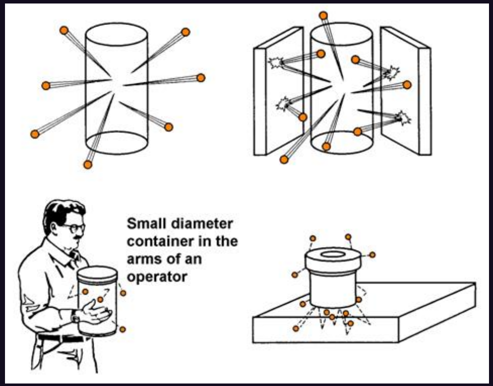
The blue flash is a characteristic of criticality accidents

Caused by Cherenkov radiation propagating through the fluid of the eye

Manifests as a sudden bright blue flash to the affected individual

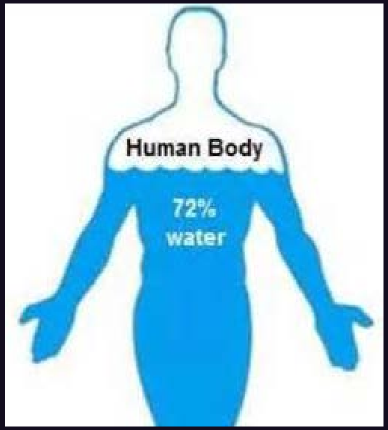


Reflection



Escaping neutrons move away in a straight line until they hit something in their path. When such a collision occurs, the neutrons may be scattered, or reflected, back into fissionable material.

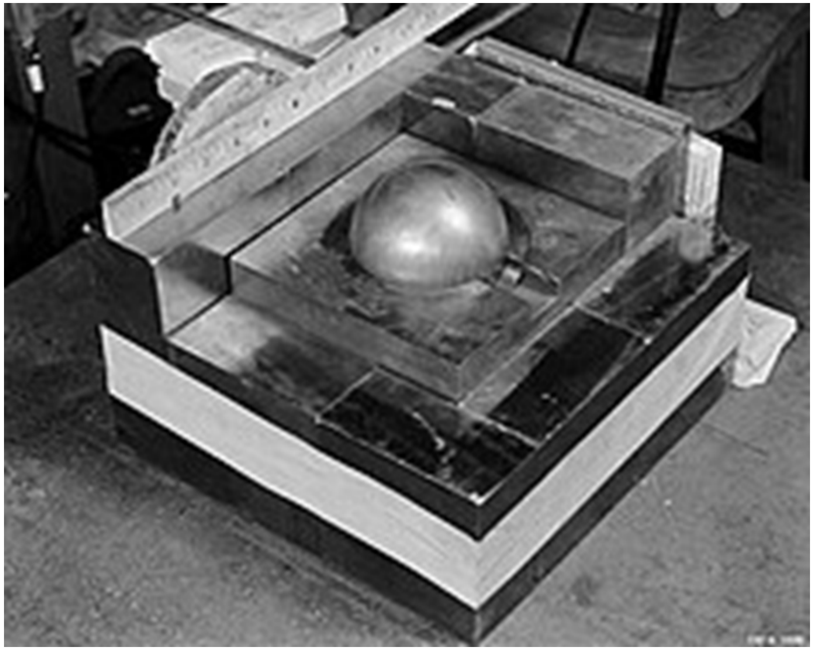
Some examples of effective reflectors include gloveboxes (steel, plastic, glass), concrete walls and floors, radiation shielding, and insulation. Materials that are efficient moderators (chiefly, hydrogenous materials) are also efficient reflectors.



Water is a very efficient reflector and requires special consideration because of the numerous ways water can be introduced into a system. For example, a pipe or valve might leak, allowing water to flood an open drum and act as a reflector. There is even enough water in the human body that it can act as a reflector and therefore its effects must be considered.

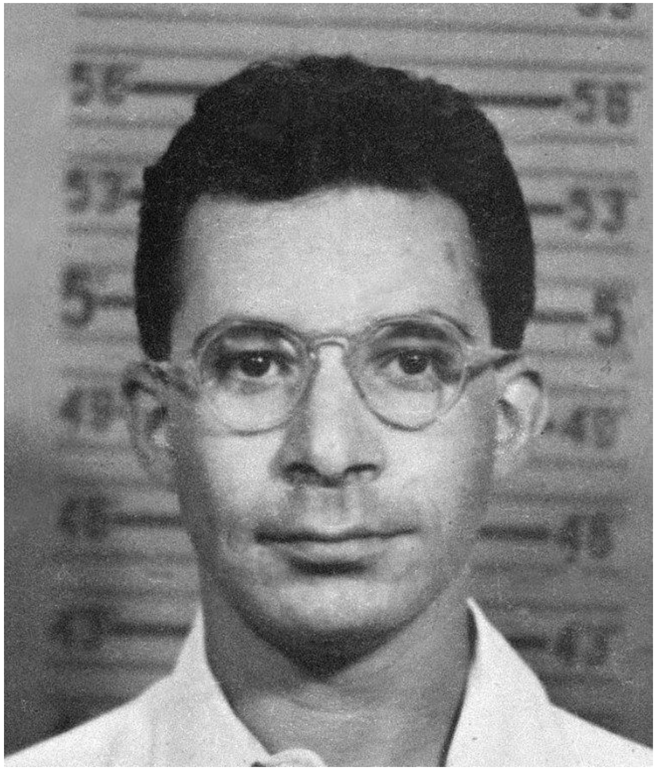
Harry Daghlian Reflection Test (1945)

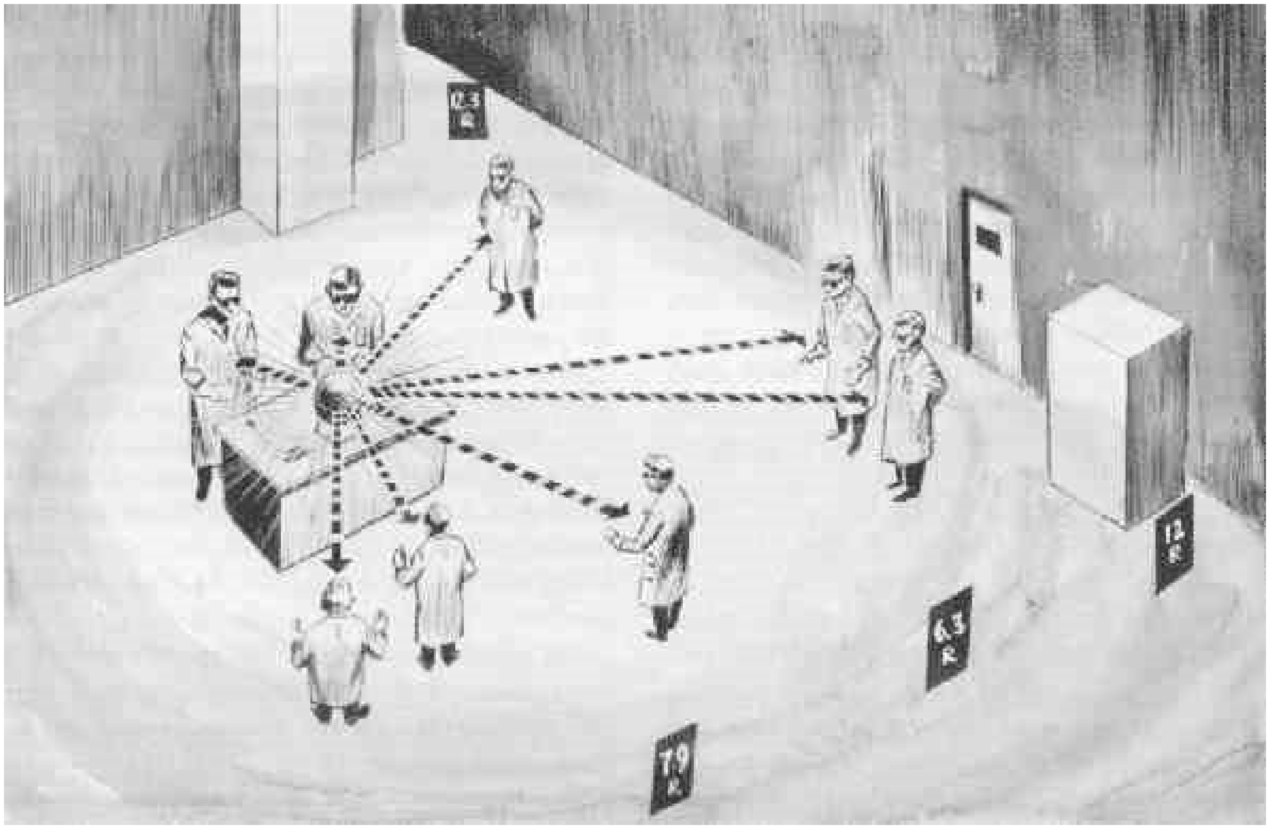
- Scientist Harry Daghlian suffered fatal radiation poisoning
- 6.2 kilogram plutonium sphere
- Brick acted as a neutron reflector, bringing the mass to criticality.
- First known criticality accident causing a fatality



Louis Slotin Accident of 1946

- Same 6.2 kilogram plutonium sphere involved with the Daghlian Accident
- Surrounded the plutonium sphere with two 9-inch diameter hemispherical cups of beryllium
- “Blue Flash”
- Received fatal dose of radioactivity

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6.3
7.9

Simulator for Criticality Safety Training

- Criticality safety is included as part of training for fissile material handlers (FMHs) at LANL. In order to provide additional insight into the neutronics involved with handling fissionable material, the NCSD, with the assistance from LANL's Technology Applications team, has developed a reactivity simulator. The simulator is a tungsten ball, similar in size to a sphere of ^{239}Pu with a k_{eff} of 0.99966
- The nuclear reactivity simulator provides an audio, visual, and tactile tool that familiarizes FMH workers with nuclear reactivity in a safe environment

Reactivity Simulator sphere. Increase in signal (clicks) mimics the increase in reactivity due to reflection from hands and body.

As Los Alamos National Laboratory continues to hire fissile material handlers (FMH), it is essential to train these workers and to show them how handling fissile material effects reactivity

Reactivity Simulator cans (right). Increase in signal mimics the increase in reactivity due to interaction between the cans.

Simulator for Criticality Safety Training

Theremin technology simulates effect on reactivity from handling fissile material using the person's body as an electrical control

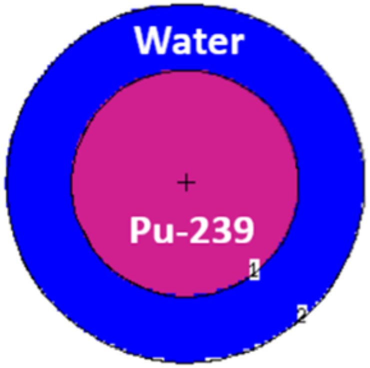
Current reactivity simulators are designed to simulate the reflection and interaction parameters

9.91 kg tungsten ball represents fissile material

Clicking sounds increase as operator moves closer to tungsten ball or as the cans move close together

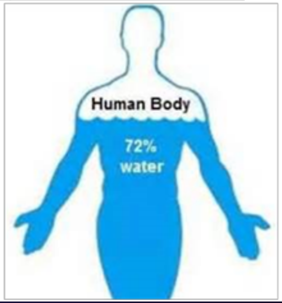
Reactivity Simulator Calculation and Modeling (Sphere)

Plutonium-239 sphere modeled with Monte Carlo N-Particle (MCNP) code. Region 1 (magenta) is plutonium-239 and region 2 (blue) is water.



Configuration	Radius [cm]	Pu-239 Mass [kg]	k_eff	Standard Deviation
Bare Pu-239 Sphere #1	4.925	9.91	0.99966	0.00057
Water-Reflected Pu-239 Sphere	4.925	9.91	1.09002	0.00069

Water is a very efficient reflector and is used when modeling to simulate the human body when handling nuclear material.

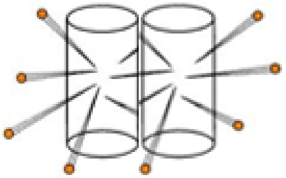


Reactivity Simulator Calculation and Modeling (Cans)

Cans with plutonium-239 ingots modeled with MCNP code. Region 1 (turquoise) is air and region 2 (magenta) is plutonium-239.

Configuration	Radius [cm]	Height [cm]	Pu-239 Mass [kg]	k_eff	Standard Deviation
Can with 3 Pu-239 Ingots	4.4075	8.76	7.10	0.99995	0.00021
Two Cans each with 3 Pu-239 Ingots	4.4075	8.76	2 X 7.10	1.09894	0.00024

The cans modeled are as close as possible to show the effects of interaction with fissile material



Teaching Simulator for Operators Based on Siberian Criticality Accident (1978)

A teaching simulator based on the Siberian Chemical Combine criticality accident of 1978 has been developed. The simulator is designed to teach criticality safety in a setting familiar to operators at the LANL plutonium facility. This accident demonstrates several parameter that have an impact on criticality safety.

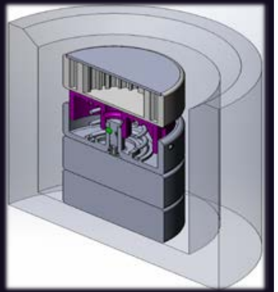
- A mock glove box has been assembled
- Contains appropriate steel can and mock plutonium pucks
- Fourth puck is ejected when added just as occurred in the original accident
- Light system will simulate the “blue flash” from the accident

Simulator Design

Simulator consists of:

the mock glovebox, a repurposed bead blasting box

Two solid plastic mock plutonium pucks

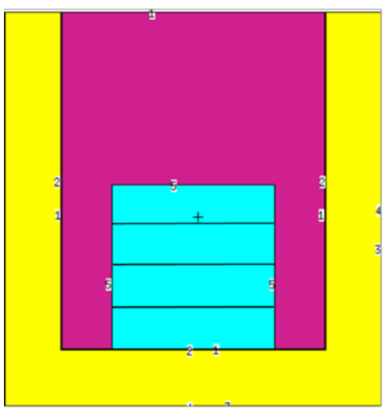


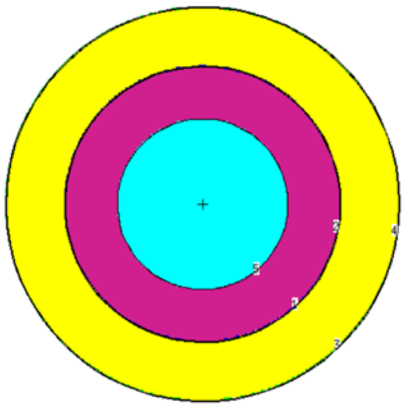
One spring loaded launching puck

A light weight final puck that the operator inserts to simulate the accident conditions

Once inserted the puck is launched from the can and the accompanying blue flash triggered.

Siberian Criticality Accident Calculations





MCNP: Calculating Siberian accident				
Number of pucks	k_eff	stdev	Fissile Mass	Cylinder Height
3	0.96185	0.00055	8.01 kg	6.63 cm
4	1.04434	0.00059	10.68 kg	8.84 cm

Renderings of the MCNP calculations

Blue corresponds to plutonium, magenta air, yellow the steel jacketed cadmium lined polyethylene can

MCNP calculations were performed in support of the simulator design for both the final super critical assembly and the sub critical three puck assembly

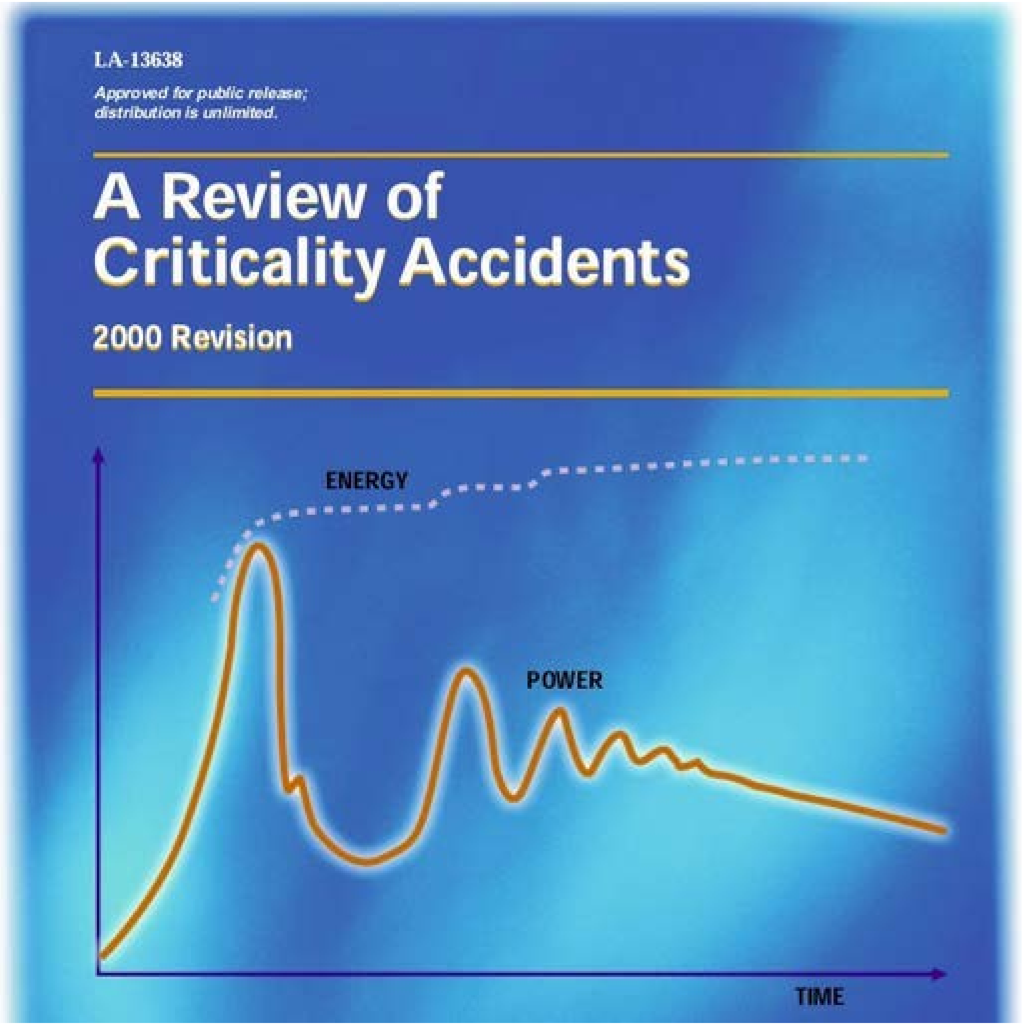
The pucks were stored in cadmium lines steel cans

The reported criticality values for the four puck system reflects the instantaneous criticality following the pucks insertion

As is displayed above the addition of the fourth puck was enough to send the system critical and cause the criticality accident

Future Projects

- Fissile solution simulator
- Waste operations support simulator
- Historical criticality accidents simulations




Questions?