LA-UR-18-27870

Approved for public release; distribution is unlimited.

Title: Introduction to Nuclear Criticality Safety and Los Alamos National Lab

Author(s): Meredith, Austin Dean
Bowles, Amanda S.

Intended for: This is a presentation we will use to teaching the first class of a
Criticality Safety Course at various universities.

Issued: 2018-08-17

Disclaimer:

Los Alamos National Laboratory, an affirmative action/equal opportunity employer, is operated by the Los Alamos National Security, LLC for the National Nuclear Security Administration of the U.S. Department of Energy under contract DE-AC52-06NA25396. By approving this article, the publisher recognizes that the U.S. Government retains nonexclusive, royalty-free license to publish or reproduce the published form of this contribution, or to allow others to do so, for U.S. Government purposes. Los Alamos National Laboratory requests that the publisher identify this article as work performed under the auspices of the U.S. Department of Energy. Los Alamos National Laboratory strongly supports academic freedom and a researcher's right to publish; as an institution, however, the Laboratory does not endorse the viewpoint of a publication or guarantee its technical correctness.

Unclassified

Introduction to Nuclear Criticality Safety and Los Alamos National Lab

Austin Meredith and Mandy Bowles
Criticality Safety Analysts at LANL

August 22, 2018

Operated by Los Alamos National Security, LLC for the U.S. Department of Energy's NNSA

Unclassified

Agenda

- **Intro to Criticality Safety**
 - Critical Systems
 - Daghlian Accident
 - Criticality Safety
 - What?
 - How?
- **Nuclear Criticality Safety at LANL**
- **LANL**
 - History
 - Today
- **Los Alamos & Surrounding Areas**

Introduction to Nuclear Criticality Safety

Critical Systems – Fission Chain Reaction

Subcritical, Critical, and Supercritical Systems

- **Neutron Balance:**
 - Production $\leftrightarrow$ Losses (Absorption + Leakage)

- **Effective Multiplication Factor**

$$k_{eff} = \frac{\text{Neutron production rate}}{\text{Neutron loss rate}}$$

- **If $k < 1$, system is subcritical**
 - Production < Losses
 - Fissions per second decreasing
- **If $k = 1$, system is critical**
 - Production = Losses
 - Fissions per second remain constant
- **If $k > 1$, system is supercritical**
 - Production > Losses
 - Fissions per second increasing

Why do we like Critical Systems?

When/why might we *not* want a system to go critical?

Daghlian Accident – 21 August 1945

- **Plutonium core**
 - 2 hemispheres of δ -phase Pu metal
 - 6.5 kg
- **Critical assembly**
 - Hand-stacking 4.4 kg tungsten carbide bricks around core
- **Accident**
 - Experimenter moving final brick over assembly
 - Neutron counters alerted him assembly would be supercritical with addition of final brick
 - Withdrew hand, brick slipped and fell
 - System went superprompt critical
 - Estimated dose of 510 rem from 10^{16} fissions
 - Harry Daghljan died 28 days later

*Harry K. Daghljan, Jr.
Experimenter*

Reenactment of the configuration with about half of the tungsten blocks in place.

Criticality Accidents

- **The release of energy as a result of accidentally producing a self-sustaining or divergent fission chain reaction.**
 - i.e. An unintended nuclear reactor, usually without shielding, coolant, and control
- **Can kill or injure people and damage processing equipment**
- **Cannot readily be mitigated, only prevented**
 - Because an excursion happens too quickly
 - <https://www.youtube.com/watch?v=pa0Fmcv83nw>

What is Criticality Safety?

The art and science of preventing criticality accidents and ensuring that anyone that could be exposed to one makes it home alive at the end of the day.

How is Criticality Safety Typically Practiced?

- **Operations proposes a new process or a change to an existing process**
- **Criticality Safety staff analyze the system**
 - Ensure the entire process remains subcritical under all normal and credible abnormal conditions.
 - Process designs should incorporate sufficient factors of safety to require at least two unlikely, independent, and concurrent changes in process conditions before a criticality accident is possible. (Double Contingency Principle)
- **Criticality Safety staff work with Operations and Engineering staff to develop controls on the process**

Controls

- **Controls are developed to limit process parameters important to criticality safety**

- Mass
- Absorption
- Geometry
- Interaction
- Concentration/Density
- Moderation
- Enrichment
- Reflection
- Volume

- **Engineered Controls > Administrative Controls**
- **Passive Controls > Active Controls**
- **Controls must be easy to implement or people will find work-arounds**

Generic Example

- An operational group wants to be able to move plutonium solution from one storage tank (Tank #1) to another system of storage tanks (Tanks #2).
- How would we ensure that the system remains subcritical?
 - We limit process parameters to ensure all normal and credible abnormal conditions will remain subcritical and satisfy the DCP
 - For Example
 - Limit fissile **Mass**
 - Introduce materials with large **Absorption** cross-section
 - Only use tanks with favorable **Geometry**
 - Increase spacing between tanks to reduce **Interaction**
 - Limit the fissile **Concentration** of the solution
 - Avoid optimal **Moderation**
 - Decrease **Enrichment**
 - Limit **Reflection**
 - Control **Volume** of solution

Nuclear Criticality Safety at LANL

Flow of Requirements

High-Level Legal Requirement: 10 CFR 830, Section 830.204

- *Ensures that operations with fissionable material remain subcritical under all normal and credible abnormal conditions*
 - *Identifies applicable nuclear criticality safety standards*
- *Describes how the program meets applicable nuclear criticality safety standards*

Required by DOE Order 420.1C

Captured in the LANL NCS Program Document, SD-130

(approved by DOE)

Implemented for Each Facility (AP-522)

Criticality Safety Evaluation Documents

A Day in the Life

- **Fissile Operation Maintenance**
- **Operation Observation**
- **New / Updated Operations Analysis**
- **Interaction with Operations**
- **Training (Providing & Receiving)**

Live , Work, Play

Los Alamos National Lab – History

- Located in Northern New Mexico, on the Pajarito Plateau, 35 miles from Santa Fe
- Organized in 1943, during World War II, as part of Manhattan Project
 - Secret site dedicated to design of first nuclear weapons
- After World War II, still designed weapons, but branched out over time, especially after end of Cold War
- Other notable missions have included deep-space exploration projects, non-proliferation efforts, non-nuclear national security, health physics work, etc.

Los Alamos National Lab – Today

- **Currently run by Los Alamos National Security, LLC**
 - In midst of contract transition
- **Employs ~11,700 people**
- **\$2.55 billion annual budget**
- **Center for World-class R&D:**
 - Plutonium Science and Manufacturing
 - Nanotechnologies
 - Energy
 - Isotope Production
 - Neutron Sciences
 - Weapons Research and Design
 - Etc.

Los Alamos National Lab - Today

<https://www.youtube.com/watch?v=fmP-ymRhI9U>

Town of Los Alamos

- History
 - The area was inhabited by Indigenous people and homesteaders, and eventually became home to the Boys' Ranch School, which eventually closed when the U.S. government chose the area for the Manhattan Project during WWII.
- Recreational Rich
 - Hiking & Biking (100 miles of trails)
 - Skiing (9 different Hills or Resorts)
 - 3 National Parks (Bandelier, Valles Caldera, Manhattan Project)
- Family Friendly
 - Great Schools, Safe Neighborhoods
- Climate – Perfect.

Santa Fe and Surrounding Areas

- 60% of Employees Commute
Rio Arriba – 20 Miles (30 Min.)
Santa Fe - 35 miles (40 Min.)
ABQ– 100 Miles (75 Min.)
- Culture Rich Area
 - Art, Opera, Culinary, Markets