NCS Pipeline UC Berkeley Course Overview

Presented at the
Nuclear Criticality Safety Program's Technical Program Review
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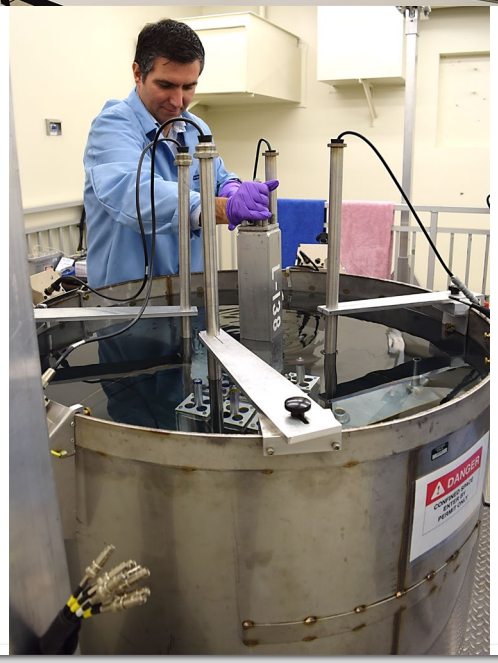
Lawrence Livermore National Laboratory

Course Overview

- The criticality safety divisions at Lawrence Livermore National Laboratory (LLNL) and Los Alamos National Laboratory (LANL), in partnership with Dr. Max Fratoni of UC Berkeley, taught the fourth annual nuclear criticality safety course during the fall 2021 semester at UC Berkeley.

- This course is part of a larger pipeline project designed to stimulate student interest in the field of criticality safety.
  - Teaches the fundamentals of criticality safety
  - Provides hands-on experience with special nuclear material
  - Guest lectures are taught by criticality safety engineers at LLNL and LANL
  - Complete a semester long project to write a criticality safety evaluation



Lecture Topics

Week	Date	Lecture	Instructor
1	8/26	Introduction	Fratoni
2	8/31	Background review	Fratoni
	9/02	Factors in criticality safety: MAGICMERV/MERMAIDS	Fratoni
3	9/07	Criticality safety evaluation: an introduction	LLNL
	9/09	MCNP: Intro	Fratoni
4	9/14	Process description	LANL
	9/16	MCNP: Geometry	Fratoni
5	9/21	Criticality accidents	LANL
	9/23	MCNP: Materials	Fratoni
6	9/28	Criticality accidents	LANL
	9/30	MCNP: Running	Fratoni
7	10/05	Hand calculations: One-group and modified one-group diffusion theory	LLNL
	10/07	MCNP: Output	Fratoni
8	10/12	Evaluation update: process description	
	10/14	Evaluation update: process description	
9	10/19	Criticality safety evaluation: advanced material	LANL
	10/21	MCNP: Tallies	Fratoni
10	10/26	Criticality experiments	LLNL
	10/28	MCNP: Repeated structures	Fratoni
11	11/02	Benchmarks and validation	LLNL
	11/04	Evaluation update: credible process upset con	
12	11/09	Evaluation update: credible process upset con	
	11/11	Veterans Day (no class)	
13	11/16	ANSI/ANS Standards (SD130) DOE 10 CFR 820 and 420.1C	LLNL
	11/18	MCNP: variance reduction	Fratoni
-	11/23	no class	
	11/25	Thanksgiving (no class)	
14	11/30	Fuel facility applications	LANL
	12/02	Discussion	Fratoni
15	12/07	Criticality safety evaluation presentation	
	12/09	Criticality safety evaluation presentation	

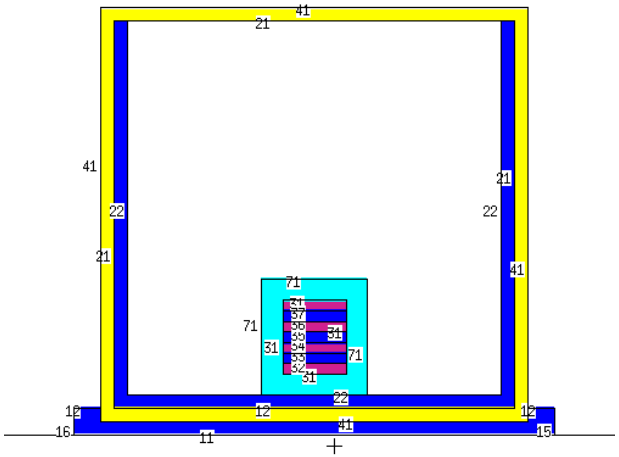
Overview of Projects

- A variety of fictional operations are provided to the students by LLNL and LANL to complete a criticality safety evaluation.
  - Students work in teams of 3 to 4 individuals
  - LLNL and LANL mentor the students by acting as Operators, Engineers, and Subject Matter Experts
  - Students present their evaluations periodically throughout the semester
- Students have the flexibility to approach the criticality safety evaluation how they would like.
  - Hand calculations, handbook data, and/or radiation transport codes
  - Students must determine the normal and credible abnormal conditions to evaluate
  - Controls and agreed upon by the students and Operators (mentors)

LLNL Criticality Safety Evaluation Projects

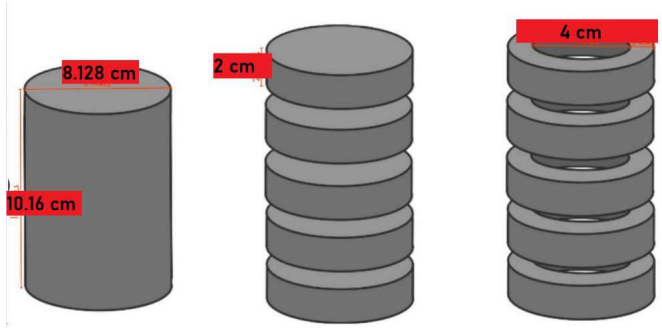
Experiments with Uranium-233 and Shielding

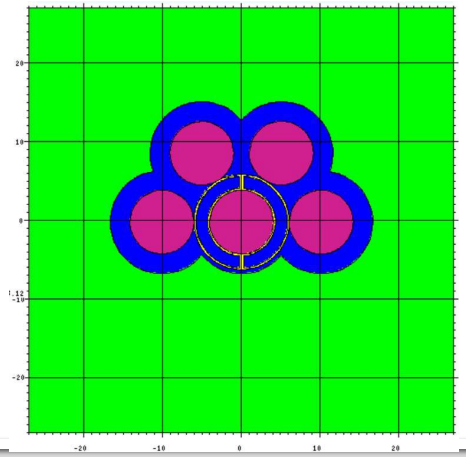
Scientists at LLNL are performing experiments with large quantities of ^{233}U metal, which generates significant radiation exposure to workers, due to the presence of ^{232}U impurities. To reduce worker exposure, scientists want to use varying thicknesses of tantalum, lead, and/or tungsten.



Machining Highly Enriched Uranium Rings

Engineers at LLNL are receiving five 10-kilogram cylinders of highly enriched uranium (93% by weight percent ^{235}U) metal from another laboratory and need to machine each solid cylinder into 5 identical rings for a total of 25 rings.

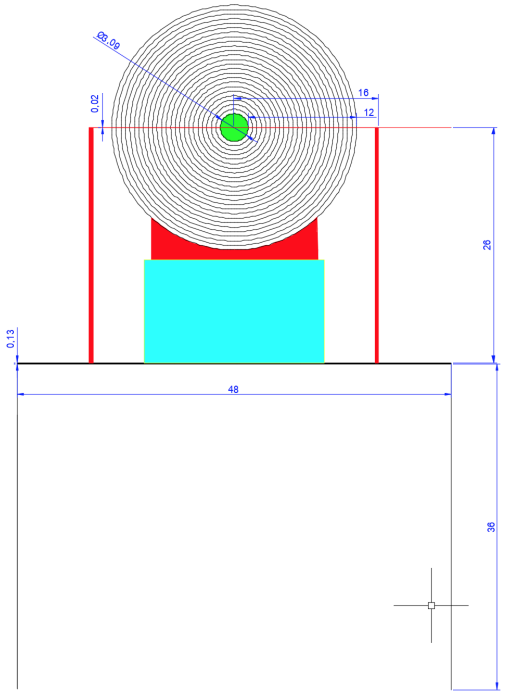




LLNL Criticality Safety Evaluation Projects

Experiments with Plutonium and Depleted Uranium Reflectors

Scientists at LLNL are performing experiments with a 5-kilogram sphere of plutonium (95% ^{239}Pu and 5% ^{240}Pu) metal and would like to place hemishells of depleted uranium around the plutonium sphere.



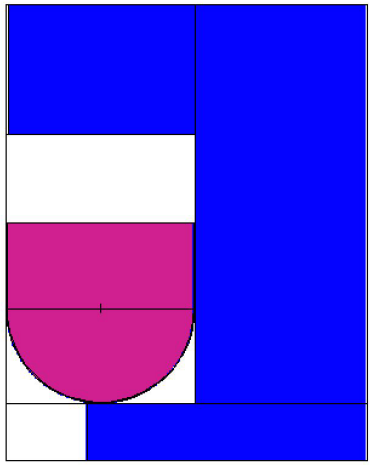
Experiments with Uranium Solution in a Cylindrical Container with Iron Foam

Scientists at LLNL want to perform a series of experiments that involve placing uranium solution (0.711-90% weight-percent ^{235}U) inside either (1) an empty cylindrical container, or (2) a cylindrical container that is completely filled with iron foam.

LLNL Criticality Safety Evaluation Projects

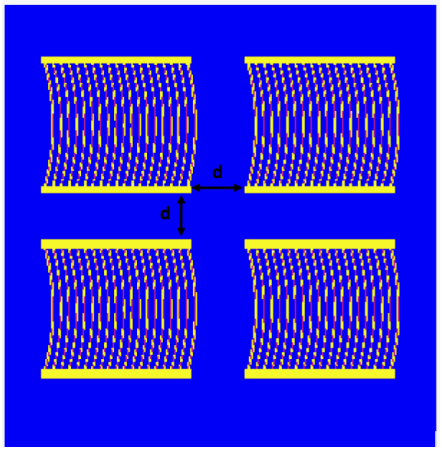
Hobart Model HL120 Mixer

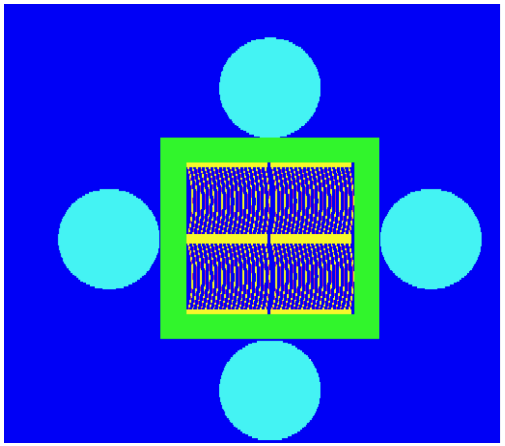
Fissile material handlers at LLNL wants to use a Hobart Model HL120 Mixer to blend plutonium liquid waste with a solidifying mineral.



Inherently Safe Subcritical Assembly (ISSA) Heavy Water Experiment

Scientists at LLNL want to perform experiments with ISSA but replacing the light water with heavy water.



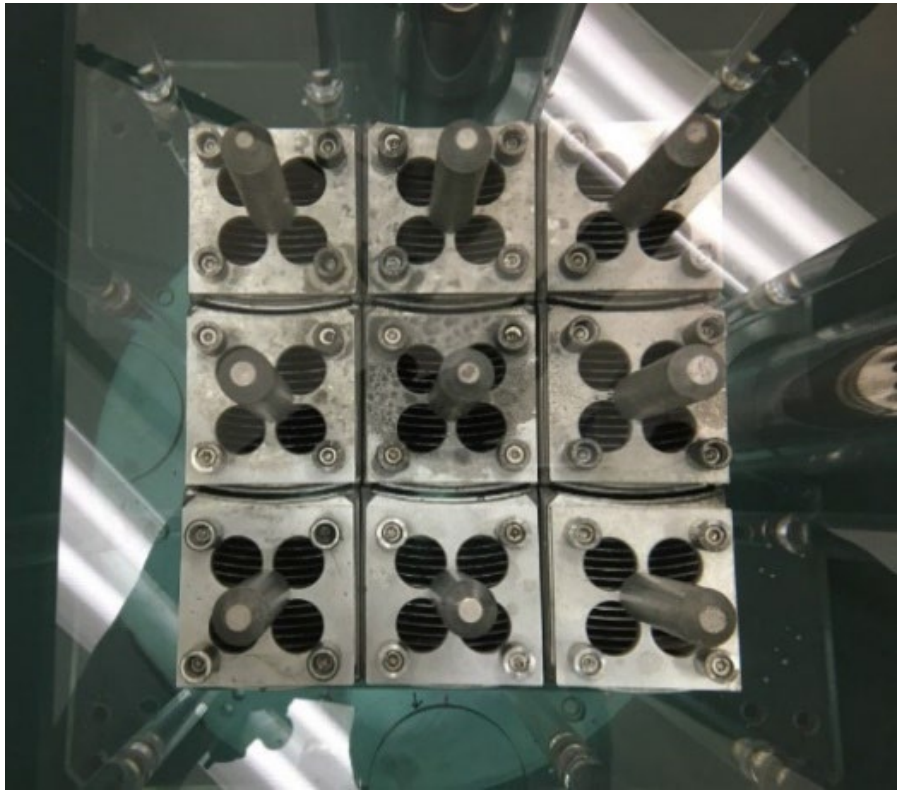


Hands-on Learning with ISSA

- Two days out of the semester, students visit LLNL to perform subcritical measurements with LLNL's Inherently Safe Subcritical Assembly (ISSA).
- ISSA is a safe and simple system making it ideal as a training resource.
- ISSA provides hands-on experimental training to illustrate criticality safety and reactor physics.

ISSA Training Facility

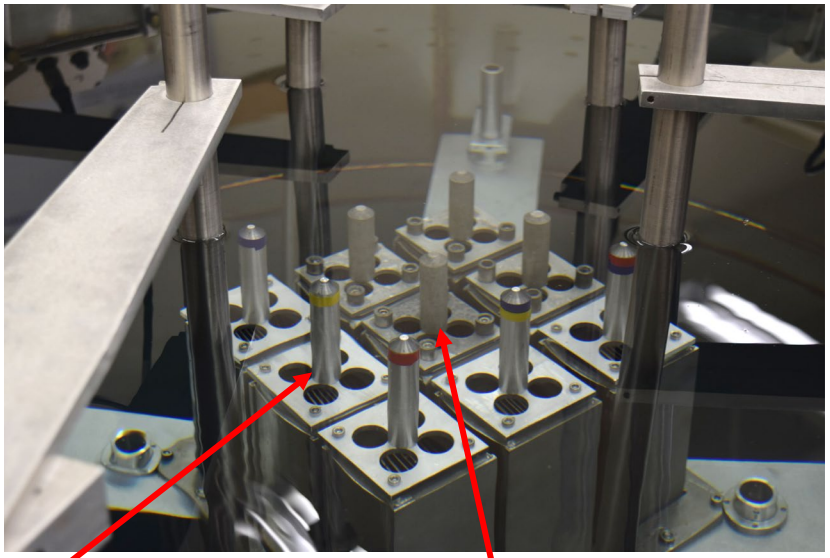
- ISSA consist of 9 repurposed nuclear fuel assemblies from the Omega West Reactor manufactured by the Naval Nuclear Fuel Division of Babcock & Wilcox.
  - Each assembly consists of highly enriched uranium dispersed in a matrix of aluminum and fully clad in pure aluminum
  - Assemblies were cut by LLNL to 2-feet in length for ease of handling
- Under the supervision of qualified criticality safety engineers, students are able to handle the fuel assemblies.
- Students use the ISSA handbook to perform experiments demonstrating the effects mass, spacing, reflection, and moderation have on neutron multiplication.



Approach-to-Critical Experiments

- Students work with 9 all aluminum “mock” fuel assemblies and 9 HEU “live” fuel assemblies to perform approach-to-critical experiments.
- Students perform 1/M curves to predict the different critical configuration for ISSA.

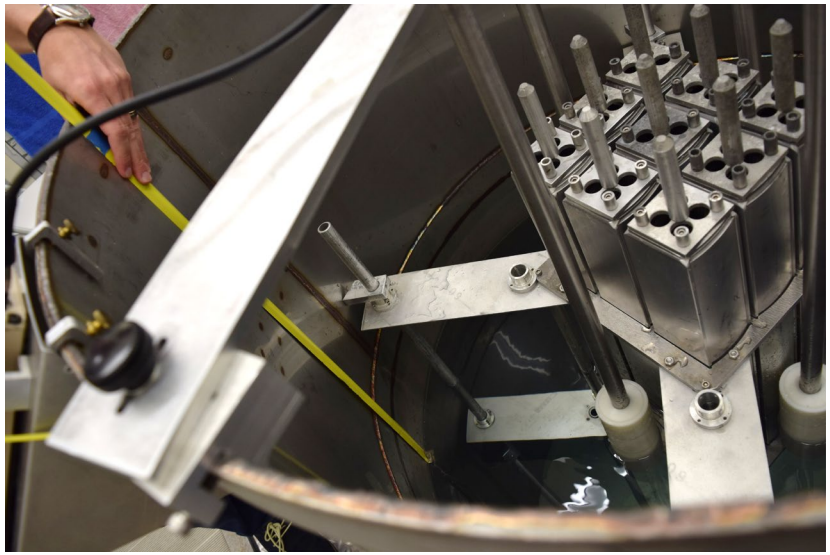
Approach by Number of Assemblies With and Without a Source



Aluminum “mock” fuel

HEU “live” fuel

Approach by Water Height



Capabilities of ISSA

- In addition to ISSA being used as part of the UC Berkely Pipeline course, it has a variety of other training and R&D applications including:
  - Gamma-ray and neutron detector training and criticality safety training to DoD, FBI, and DOE/NNSA inter-laboratory teams that respond to nuclear and radiological incidents
  - ISSA serves as a high-quality source of fission neutrons to design, develop, and test radiation detection systems
  - Training course with the Naval Nuclear Laboratory on neutron noise techniques commonly applied in various domains of nuclear engineering
  - R&D experiments to investigate neutron cross sections, the physics of fission chain reactions, diffusion and Fermi age theory, neutron kinetics equation, and the statistics of fission chain reactions


ISSA
Inherently Safe Subcritical Assembly
L-132
DANGER
CONFINED SPACE
ENTER BY
PERMIT ONLY
SPANCO 1

Acknowledgements

- This work was funded by the United States Department of Energy's Nuclear Criticality Safety Program (NA-511).
- The class was a joint effort by Lawrence Livermore National Laboratory and Los Alamos National Laboratory in partnership with Dr. Max Fratoni at UC Berkeley.
- The Responsible Individuals for ISSA operations who coordinate the use of ISSA for this course.

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