Los Alamos
NATIONAL LABORATORY

National Criticality Experiments Research Center (NCERC) Capability

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NCERC Futures Workshop

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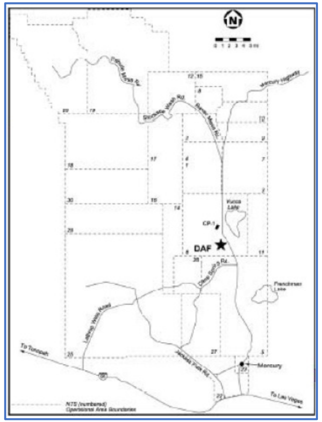
NCERC is our nation's only general-purpose critical experiments facility and is one of only a few that remain operational throughout the world

Location: Device Assembly Facility (DAF) at the Nevada National Security Site (NNSS)

Operated by: Los Alamos National Laboratory

NCERC Mission Statement:

The mission of the National Criticality Experiments Research Center (NCERC) is to conduct experiments and training with critical assemblies and fissionable material at or near criticality in order to explore reactivity phenomena, and to operate the assemblies in the regions from subcritical through delayed critical. One critical assembly, Godiva-IV, is designed to operate above prompt critical.



National Criticality Experiments Research Center

NCERC is our nation's only general-purpose critical experiments facility and is one of only a few that remain operational throughout the world

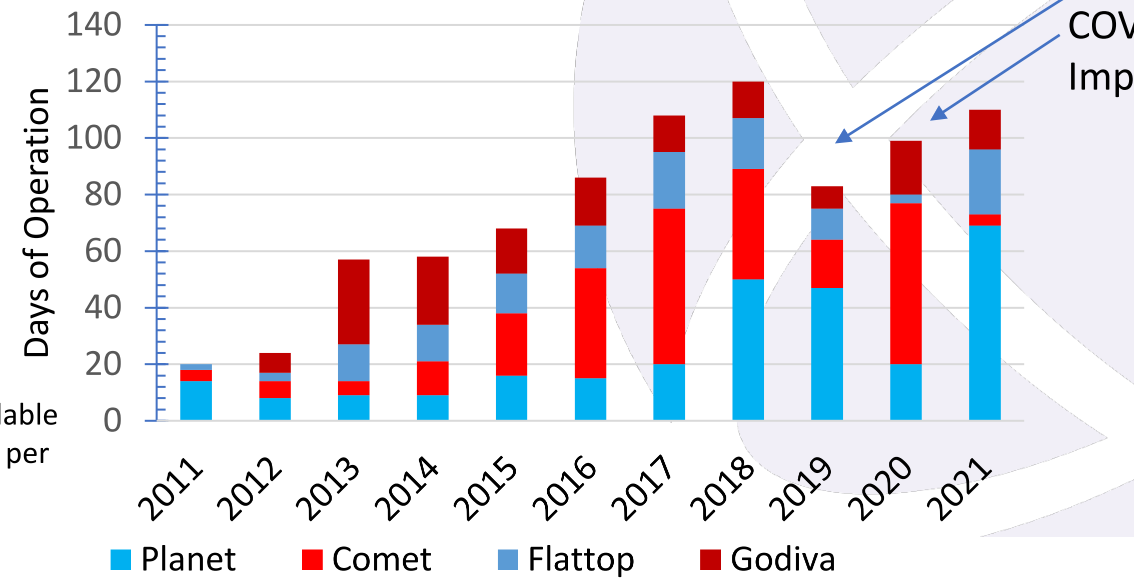
- Large quantities and variety of SNM enable both critical experiments and unique static subcritical experiments.

- **Directly Contributing to Important National and International Missions many of which are represented here today**
- **Recently celebrated 10-year anniversary of operations**

Must Plan and Invest for Enduring Capability and Expanding Missions

If you build it, they will come…

- **NCERC operating pace has steadily increased**
- **Demand for specific machine varies from year to year**
- **Special Issue of Nuclear Science and Engineering (NSE) highlights first decade with 5 papers**



Max ~180 available operating days per year

We need your input…

Identify the challenges and research directions in subcritical and critical experiments

Key questions for each topical area:

- What are our capabilities today?
- What are the gaps that exist?
- What specific capability for NCERC would you propose to fill the gaps in this research area?
- What are the programmatic drivers, federal sponsor mission needs, and how would this fit in programmatic priorities?
- What is the potential impact if solved?

What enhancements of capability benefit the greatest amount of research?

Overview of NCERC Capability

NCERC sustains a Critical Experiment Capability that dates back to the Manhattan Project

- **Early Critical Experiments were essential to:**
  - Basic physics understanding of nuclear chain reactions (criticality)
  - Early weapons designs
  - Safe handing of Special Nuclear Material (SNM)
- **Two criticality fatalities at LANL happened in NEN-2 predecessor organizations**
  - 1945: Daghlian criticality accident at Omega Site
  - 1946: Louis Slotin criticality at TA-18 site
- **1946: Los Alamos Critical Experiments Facility (LACEF) founded at Pajarito Site (TA-18) at LANL** – remote operation of critical experiments
- **1999: Decision made to move LACEF to DAF at NNSS**
- **2004: First nuclear material shipment to the DAF**
- **2011: Critical Operations begin at NCERC**

Capability consists of decades of experience both in science and operations.

Current NCERC Capability

- **Four critical assembly machines in two assembly cell buildings**
- **Two high bay buildings for static subcritical measurements**
- **Extensive inventory of nuclear material**
  - Can be used for critical experiments on the critical assembly machines
  - Or to construct high neutron multiplication, static objects referred to as Radiation Test Objects (RTOs) and Inspection Objects (IOs).

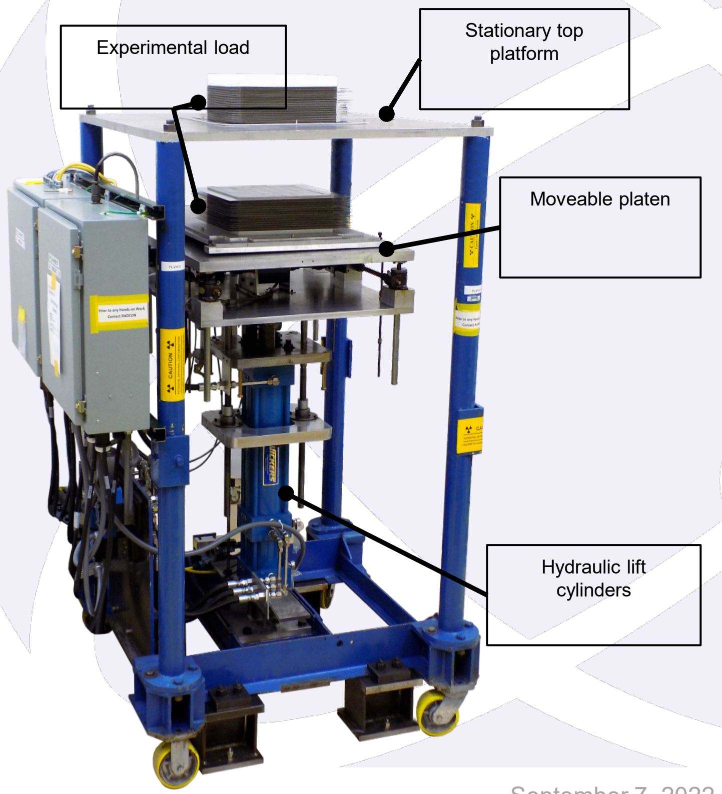
Rocky Flats shells
Metal HEU nesting hemishells

BERP Ball
4.5 kg alpha-phase Pu (94 wt% Pu-239)

Planet

Planet is a general purpose, light-duty vertical-lift assembly designed for flexibility.

- One portion of the experiment on the stationary upper platform
- The other portion installed on the moveable platen
- Lifted remotely with hydraulic cylinders and stepper motor



Comet

Comet is a general purpose, heavy-duty vertical-lift assembly designed for flexibility

- One portion of the experiment on the stationary upper platform
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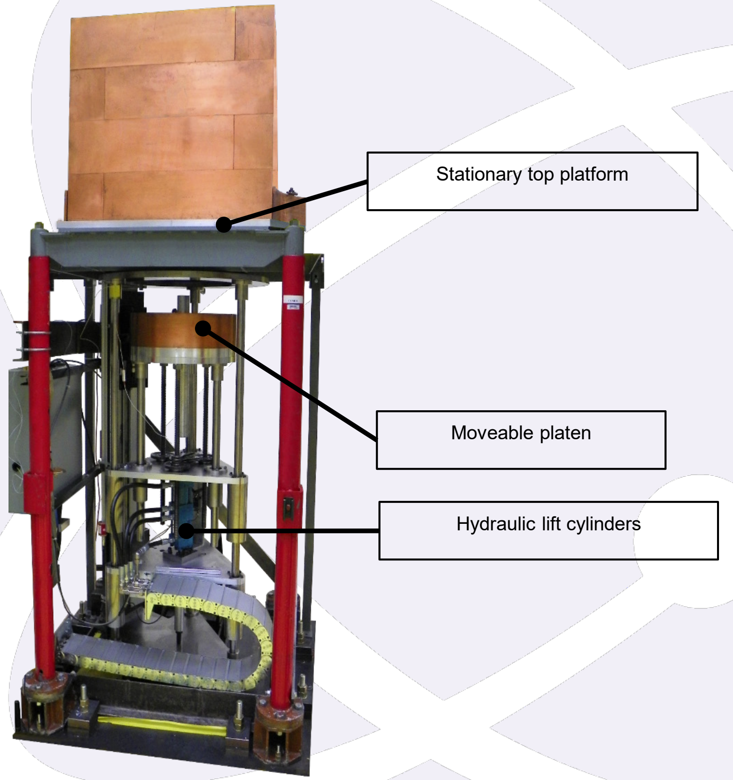
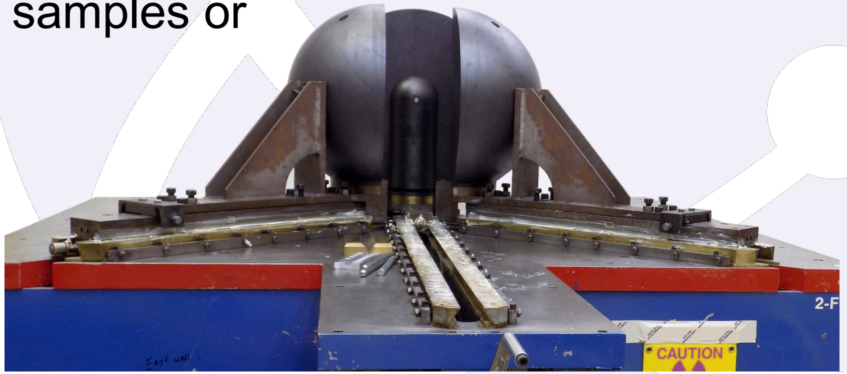


Flat-Top

Flat-Top is a fast spectrum benchmark critical assembly designed to demonstrate fundamentals of reactor physics and used as a general-purpose radiation source.

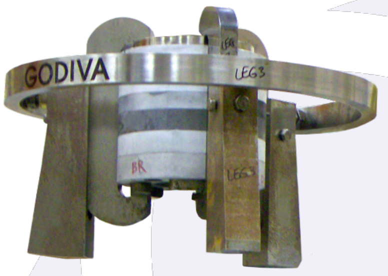
- A spherical, 1,000-kilogram natural uranium reflector
- Three natural uranium control rods
- HEU or Pu core
- Glory hole through the center for fuel, samples or detectors



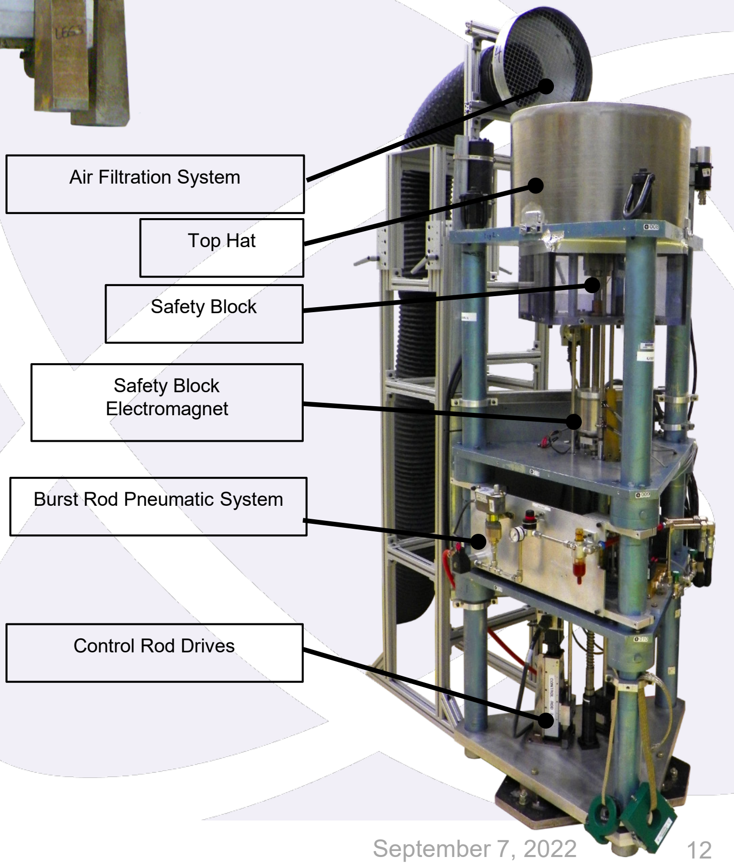
Godiva IV

Fast burst critical assembly

- 65 kg HEU(93%)
- 1.5% molybdenum alloy for strength
- Cylindrical
  7-inch diameter (17.8 cm),
  6-inch tall (15.2 cm)
- Six stationary stacked rings
- One moveable safety block
- Two mechanically driven control rods
- One pneumatically driven burst rod
- Core without safety block or control rods
  - Multiplication ~10, k_{eff} ~ 0.9



Godiva HEU Core underneath the Top Hat



Godiva IV Stats

- Burst 'size' noted by temperature rise near center of core.

Temperature Rise	70 °C	150 °C	250 °C
Reactivity	$1.04	$1.07	$1.10
Initial Period	30 µsec	18 µsec	11 µsec
FWHM	100 µsec	55 µsec	33 µsec
# fissions	1 E 16	2 E 16	4 E 16

For 70 °C burst

In glory hole
Fluence 1.5E14 n/cm^2

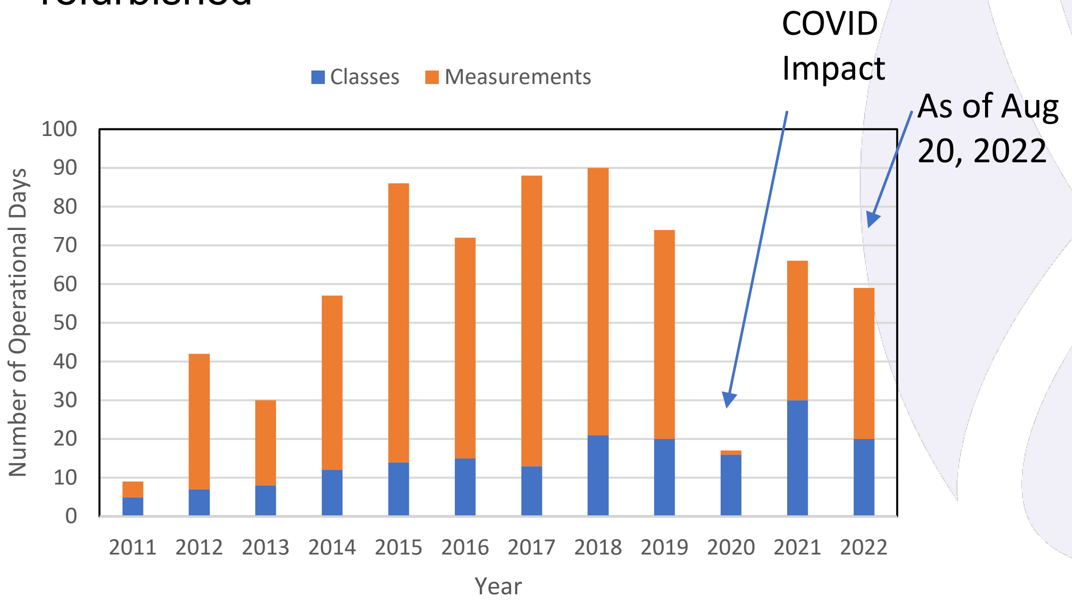
On Top Hat
Fluence ~5E12 n/cm^2
Dose ~12 Gray

At 2 meters
Dose ~2 Gray

At 4 meters
Dose ~1 Gray

Static subcritical measurements and experiments

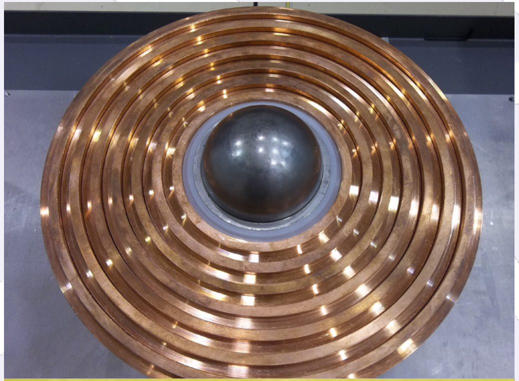
- High neutron multiplication, static objects referred to as Radiation Test Objects (RTOs) and Inspection Objects (IOs).
- Started in 2005…while critical assembly machines were being refurbished

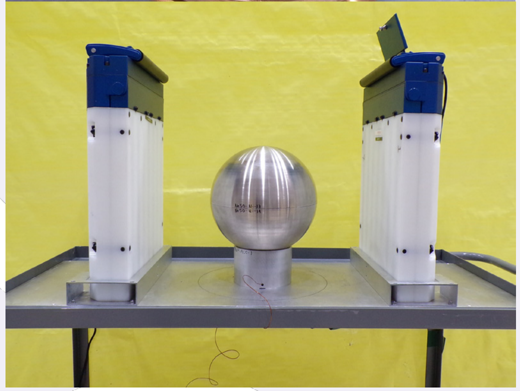


Subcritical measurements are performed in high-bays.

Radiation Test Objects (RTOs) and Inspection Objects (IOs)

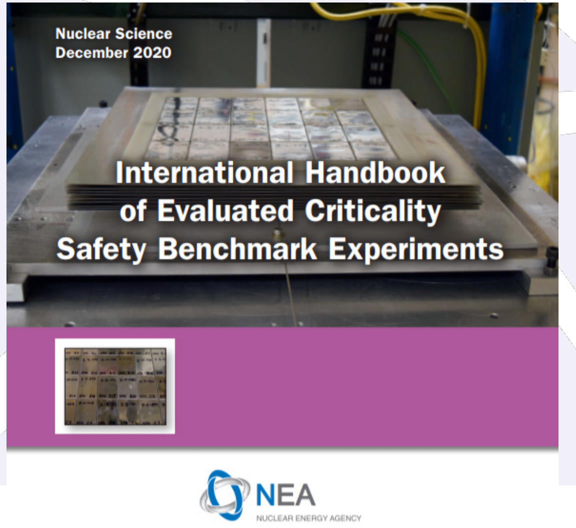
- **What is an RTO/IO**
  - Involves one or more pieces of nuclear material
  - Often includes reflection from various non-nuclear material
  - Built by hand
  - Criticality safety evaluations are written for each RTO/IO to ensure subcriticality during normal and credible upset conditions
  - Primary purpose is for radiation detector testing: neutron multiplicity, gamma spectroscopy, gamma imaging
  - Often paired with X-ray imaging and/or neutron generators
- **During the first ten years of NCERC, RTO/IO capabilities have greatly improved**
  - New criticality safety evaluations allow greater flexibility to meet user needs
  - Growing set of non-nuclear material
  - Improvement in detection equipment available at NCERC

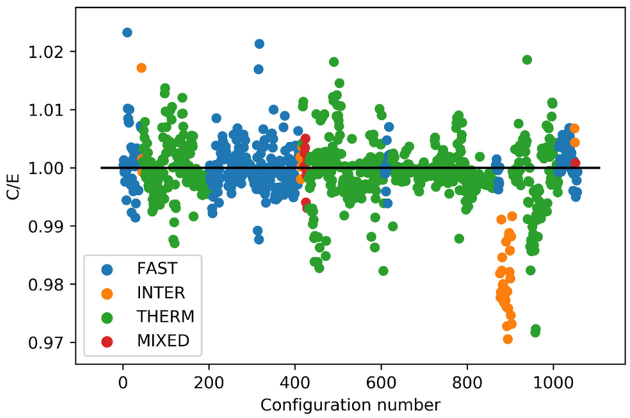




Benchmarks are the goal of many NCERC Experiments

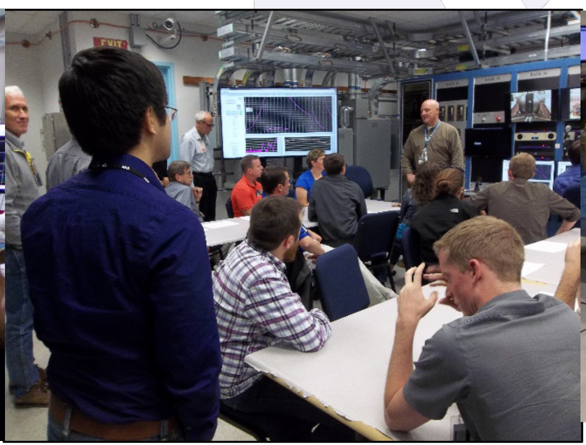
- For many integral experiments, a benchmark evaluation is the end goal
- ANSI/ANS-8.1: “Where applicable data are available, subcritical limits shall be established on bases derived from experiments…”
- Criticality safety evaluations utilize predictive simulations
  - Relies on codes to be correct and for nuclear data to be accurate
- Critical and subcritical experiments are extremely useful for validation
- The International Criticality Safety Benchmark Evaluation Project (ICSBEP) contains well characterized experiments
  - All uncertainties are evaluated
  - Bias and uncertainties of model simplifications provided





Our Criticality Safety Courses provide a ‘hands-on’ experience that make concepts memorable

- **NCSP Two-Week Hands-On Criticality Safety Courses**
  - Focus on DOE Criticality Safety Engineers, Officers, and Managers
  - First week is classroom training; second week is hands-on demos and experiments
- **Plutonium Facility (PF-4) Classes** – focus on Operators and Process Supervisors
- **Nuclear Emergency Support Team Classes**

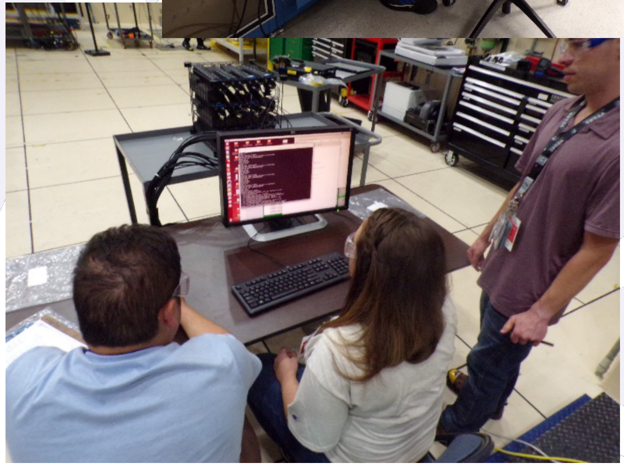


Our courses support criticality safety, operations and nuclear emergency response across DOE and DoD complex

Leveraging NCERC to Fill the Pipeline

- **NA-22 funded University Consortia**
  - Provide collaborations between University research groups and Laboratory technical staff members
  - Provide unique opportunity for SNM detection system testing at NCERC on subcritical RTOs (Plutonium, Highly Enriched Uranium, Neptunium)

Training Next Generation session led by Geoff Fairchild

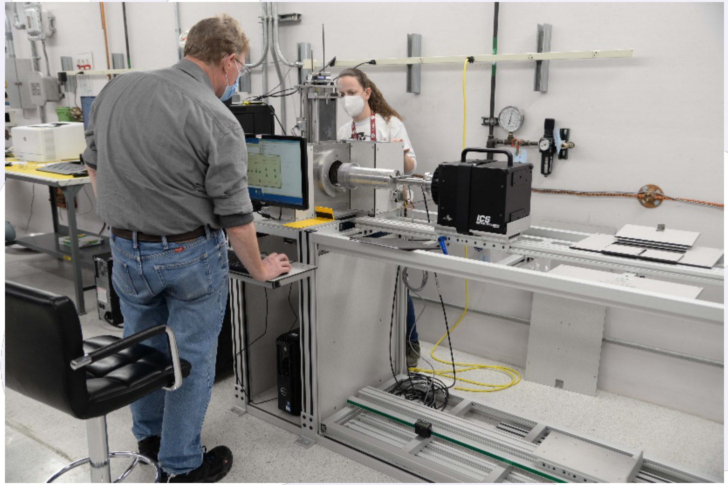


NCERC Count Room Capabilities

The ability to count samples immediately after irradiation provides nuclear data on short-lived isotopes.

- **Automated sample changer to count fission and activation foils**
- **Access to tunnel connecting to Godiva building**
- **NA-22 Infrastructure Upgrade Funding in FY21-22**
  - HPGe detectors with Mobius Coolers
  - Kolga shields
  - Rabbit System Development
  - Harshaw TLD Reader
  - High precision scale
  - Moveable source cabinets

Capabilities relevant to Forensics and more



◄ Todd Bredeweg (C-NR) and Lauren Overbay (NEN-2) set up sample changer in new location.

Safety Basis

- **Defines the overall operating envelope of a nuclear facility**
- **Current Constraints**
  - Solution/Powder experiments are not authorized
  - Material at Risk [MAR] Limits
    - General purpose assemblies limited to 150kg PuE [^{239}Pu Equivalent] metal, 45kg PuE non-metal solid
  - Excess reactivity limits
    - General purpose assemblies limited to 80 cents of excess reactivity
    - Flattop limited to 80 cents excess reactivity for the HEU core and 50 cents excess reactivity for the Pu core
    - Godiva limited to a maximum excess reactivity *insertion* of $1.15
  - Critical Assembly Machines
    - Limited to Planet, Comet, Flattop, and Godiva-IV

Selected Highlights over the past 10 years

- Many good examples of moving from mission need to experiment execution quickly
- Increased capability with each new experiment
- Improved skills, knowledge, detectors, equipment, analysis techniques

2011-2012 First Critical* on Planet, Comet, Flattop, Godiva

* at NCERC

June 2011

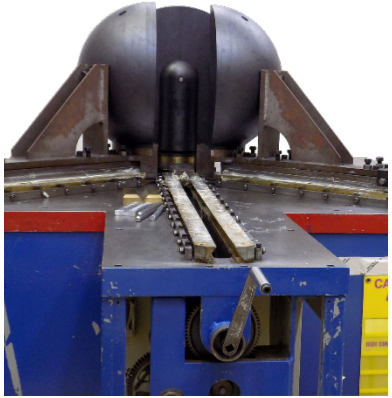
Planet

Taken critical with the Class Foils experiment. Used to mimic a solution to show students the effect of moderation on critical mass.

August 2011

Comet

Critical with the Zeus experiment. Zeus was designed with a copper reflector for intermediate energy spectrum experiments.



November 2011

Flattop

Included alignment of safety blocks. First critical with the HEU core. The Pu core was later taken critical in 2016.

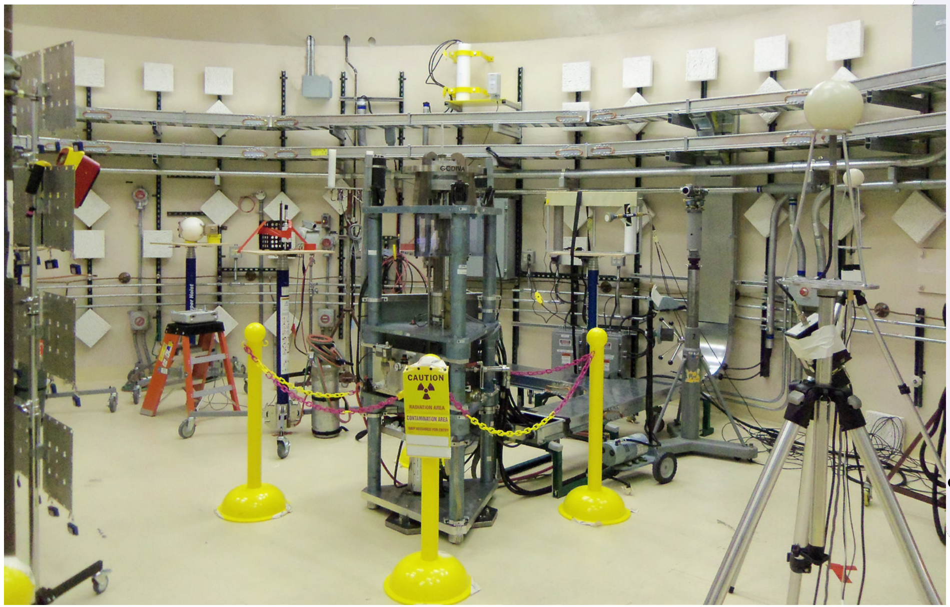
October 2012

Godiva IV

Fuel assembled under criticality safety evaluation. Delayed critical operations performed in 2012, burst operations began the following year.

and NCSP Criticality Safety Classes begin at NCERC

2013-2014 First Godiva Burst + 37 more



- **NCSP supports needs related to criticality accidents including**
  - International dosimetry intercomparisons with focus on nuclear accident dosimeters
  - Criticality alarm testing for current Y-12 systems, new systems for the Uranium Processing Facility (UPF) and systems developed by the UK Atomic Weapons Establishment (AWE)
- **Short Lived Fission Product Yield Measurements**
  - ^{235}U in 2014, ^{238}U, ^{239}Pu, ^{237}Np, ^{233}U in later years

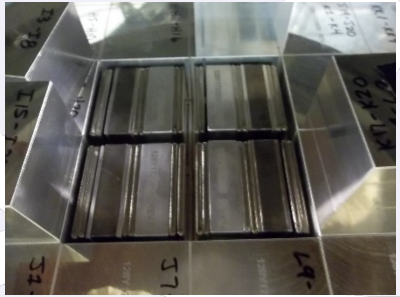
2015-2016 Japan Atomic Energy Agency Collaboration

- **US government priority to re-patriate SNM from non-nuclear weapons states**
  - Japan agreed to send fast-critical assembly SNM back to US
  - Had ongoing needs for nuclear data, particularly lead void reactivity worth

JAEA Researchers observe Comet loading

- **JAEA collaboration for Lead Void Measurements on Comet**
  - Lead void data important to accident analysis for JAEA transmutation facility
  - Nuclear data on lead extremely useful for international criticality safety community; common shield material but scarce integral experiments
  - 4 experiments: HEU, LEU, ^{239}Pu, ^{239}Pu+^{240}Pu
  - Published in International Criticality Safety Benchmark Evaluation Project (ICSBEP) Handbook.

Lead and Al spacers with Pu ZPPR plates



2016 Neutron Diagnosed Subcritical Experiments (NDSE) at NNSS

- In 2016, NCERC began providing high-mass SNM inspection objects for diagnostic development
- Supports the NNSA Stockpile Stewardship mission
- Multiple measurement campaigns in the following five years

Expanded IO capabilities and ability to perform operations outside of facility.

Inspection Object placement at Area 11 Test Stand at NNSS in front of DPF

2017-2018 Kilopower Reactor Using Sterling Technology (KRUSTY)

- **KRUSTY collaboration with NASA and NCSP**
  - Successfully demonstrated a deep space reactor concept which was the first new US fission reactor design for space application in decades
  - Validated beryllium nuclear data important to criticality safety
  - Safety Basis changes were successfully implemented
  - Demonstrated reactor safety (self-regulation/fault tolerance) in 28-hour high-power run at 800 ºC
  - Published in International Criticality Safety Benchmark Evaluation Project (ICSBEP) Handbook

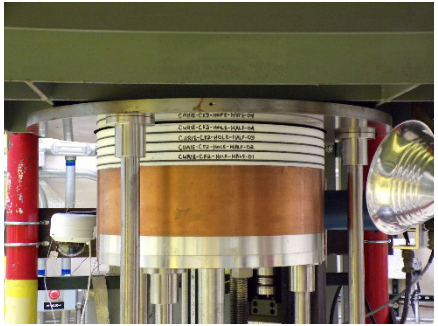
KRUSTY collaboration with NASA and NCSP

Demonstrated a new capability for NCERC in terms of reactor power, high temperatures, extended operation

2019-2020 NCSP Integral Experiments on Comet

A continuous focus of NCSP is to provide integral experiment data for criticality safety community.

- CURIE designed to be sensitive to the Unresolved Resonance Region in uranium
- TEX-HEU designed by LLNL to provide baseline configurations across energy spectra.



CURIE: Uranium and Teflon to test unresolved resonance region.

Both evaluated and published in International Criticality Safety Benchmark Evaluation Project (ICSBEP) Handbook.

TEX-HEU: Uranium and poly, Hafnium added in next experiment.

Talk in Nuclear Data Section

2021 Chlorine Worth Study

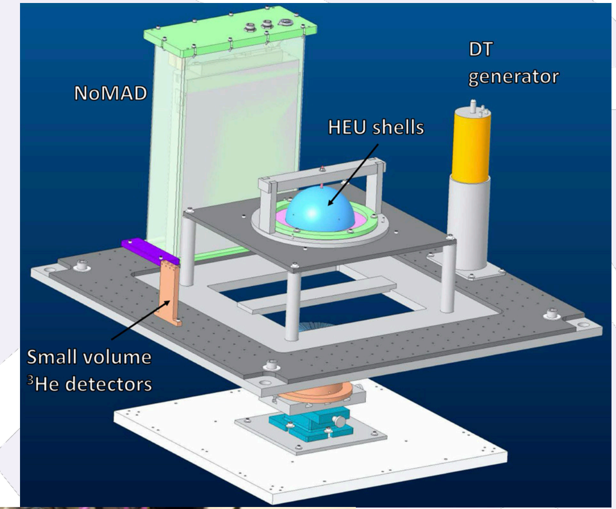
- Aqueous chloride operations at the LANL Plutonium Facility (PF-4) serve the crucial role of recovering plutonium from various processes
  - Such recovery is necessary for the pit manufacturing mission to succeed
- Chlorine Worth Study: experiment to validate the negative reactivity worth of chlorine–chlorine absorbs neutrons
- Crediting chlorine as a neutron absorber can allow criticality safety limits to be safely raised and increase process throughput
- Pu ZPPR plates, poly, and PVC (contains chlorine)

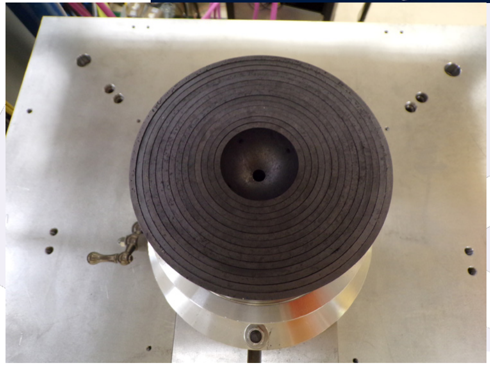
Talk in Nuclear Data Session

2021 Measurement of Uranium Critical and Subcritical (MUSIC)

- **Ten configurations constructed from Rocky Flats Shells**
  - Nesting hemispherical HEU shells
- **Spanning from deeply subcritical to critical**
- **Valuable for nuclear data validation—pure HEU system**
- **Induced fission driven by:**
  - Intrinsic source, Cf-252, DT generator
- **Detectors**
  - NoMAD Instrument with15 He-3 detectors
  - Array of 4 small volume He-3 detectors
  - Array of 8 EJ-309 detectors
  - Array of 12 trans-stilbene detectors

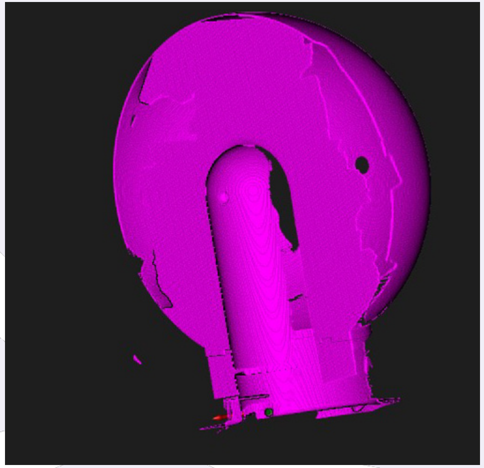
Detector capabilities can be applied to future experiments





2022 Flat-Top Measurements

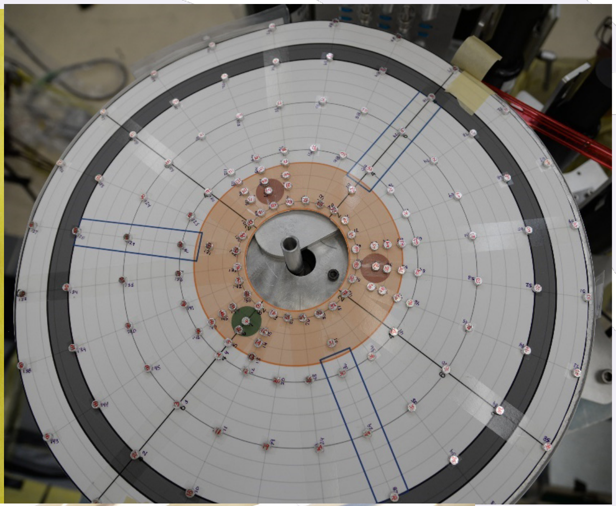
- An effort to update the Flattop Benchmark from early 90’s showed that overall experimental uncertainty could be decreased by improved dimensional and mass measurements
- Coordinate measurement machine (CMM) was used to reduce uncertainty in key dimensions
- Pycnometer used to measure volume of smaller components
- Multiple scales for measuring mass of components ranging from small glory hole pieces to pedestal and core pieces.



Measurement capabilities that can be applied to future experiments

2022 Godiva IV Reproducibility and Characterization

- Supports ORNL-designed Shielding Benchmark using Godiva as the source.
- Activation foils/wires and dosimetry used to determine reproducibility of Godiva bursts.
- Applies LANL, Sandia and PNNL expertise.
- Activation monitors counted in NCERC Count Room and shipped to Sandia and PNNL.
- Burst detection system improvements with more sensitive scintillator materials.
- Preparation for radiation field characterization by Sandia next year.



Activation foil counting capability benefits future experiments

The Next 10 years and beyond…

The Next 10 years: Ongoing work

- **Continue directly contributing to important national and international missions**
  - Experiments for nuclear data needs
- **Continue to leverage NCERC for pipeline development**
- **Investing in Infrastructure**
  - Control Room Upgrade (NA-50 Capability Based Investments funded)
- **Investing in Science**
  - EUCLID project includes experiment optimization, nuclear data adjustment/validation, and analytical methods
  - Space & Small Modular Reactors (SMRs)--Hypatia, Deimos, DRACO

The Next 10 years: New directions…

Potential Capability Enhancements

- Duplicate Current Assemblies to increase capacity
- Design New Critical Assemblies
- Build Small Modular Reactor Test Beds
- Re-assemble Previous Burst Machines
- …
- What benefits your research?

New Actinide Critical Assemblies

Actinide critical assemblies first discussed as early as 2015.

NA-50 Capital Project requests for both MSTS and LANL have been in place for several years.

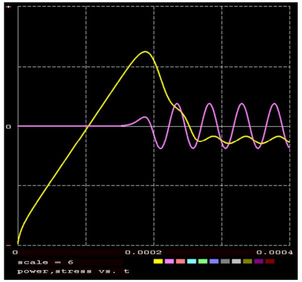
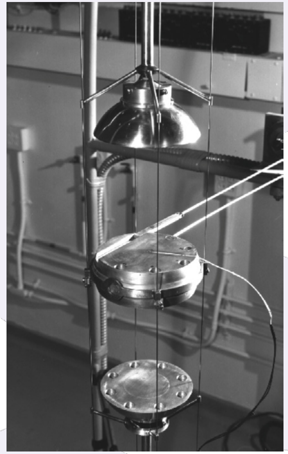


Figure 2 Dynamic simulation of a $1.25 prompt burst.

- **Np burst assembly**
  - The bare critical mass of ^{237}Np has never been measured.
  - A prompt critical burst in a Np system is predicted to be sharper than in a uranium system. Valuable for component survivability testing.



- **New Jezebel**
  - Plutonium metal bare critical assembly
  - Performance of a new bare plutonium critical mass experiment will reduce the experimental uncertainties from Jezebel (the canonical Plutonium benchmark).

Small Modular Reactors

<u>Background:</u> The next generation of civilian nuclear technologies—especially small modular reactors (SMRs), microreactors, and space reactors—are currently being developed.

<u>Objective:</u> A national nuclear testbed for unique problems at the intersection of national security, criticality safety, and nuclear energy.

<u>Problem:</u> Existing infrastructure is not adequate to support both enduring missions and this emergent mission space.

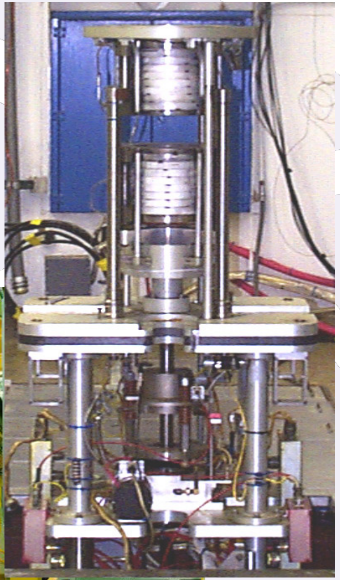
- **General Purpose Testing on Comet**
  - Largest lift capacity, flexible, choice for many modular reactor concepts
- **Specific Design Testing – Zero to Low Power Testing before deployment**
  - DoD, DOE-NE, NASA, Westinghouse, etc.

More discussion in Reactors Session

Additional Possibilities

- **Sandia Pulse Reactor (SPR-IIIM)**
  - The primary mission of the facility was to meet high neutron fluency or pulsed high dose requirements in the testing of electronic subsystems and components.
  - Operated at Sandia from 1975-2000, then 2005-2006 for W-76 Life Extension Program and to generate data for QASPR. >10,000 operations
  - The fuel was then sent to the NNSS and is staged in DAF.
- **Horizontal Split Table**
  - ZPPR fuel was originally used on a split table
  - Honeycomb split table operated at TA-18
  - Can support larger experiments
  - NCSP exploring uses

Talk in Criticality Safety Session



We need <u>your</u> input…

Now that you have heard about the existing capabilities of NCERC,

Some highlights from the first 10 years of operation,

And a few ideas to get you thinking

- ***What enhancements of capability would benefit your research?***
  New assemblies, buildings, new fuels, equipment, safety basis changes.
  Where are similar needs in different application areas

Acknowledgements

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NCSP
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LDRD