



U.S. Start Up Experience Following Conversion of a TRIGA Fueled Reactor

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Overview

- Introduction
- Facility Description
- Major Milestones
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- Predictions Versus Measurements
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Introduction

The U.S. needed to convert 26 HEU fueled reactors to LEU fuel

- Between 1984 and 2009 -16 were converted
- 4 licenses were terminated and 2 were decommissioned prior to completion of conversion
- 4 facilities remain to be converted once a suitable fuel has been developed and approved for use

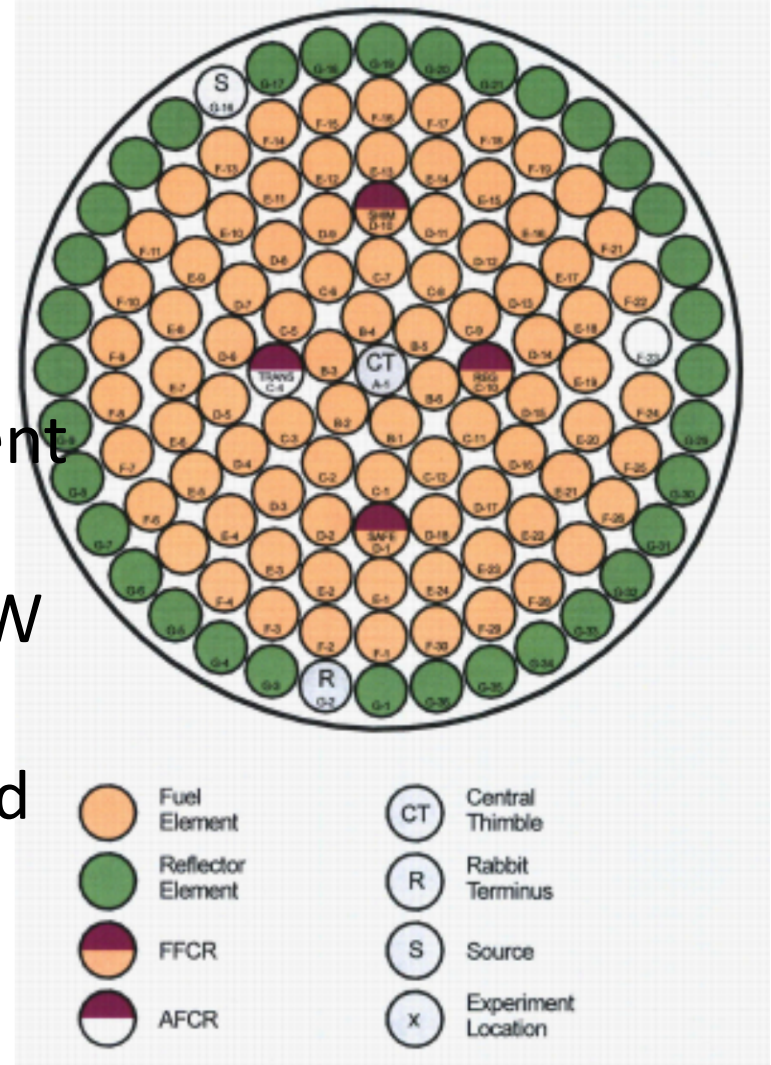
Facility Description

1100 kW TRIGA Facility

- Initial license 1967 at 250 kW
- 1969 increase to 1000 kW
- 1976 Fuel Lifetime Improvement Program (FLIP) fuel
- 2008 Renewed license 1100 kW

- University Owned and Operated

- HEU fuel - TRIGA FLIP
- LEU fuel - TRIGA 20/30



Major Milestones (simplified)



- Conversion Safety Analysis Report (SAR) developed and submitted to the Nuclear Regulatory Commission (NRC)
- LEU receipt procedures developed
- LEU shipped in batches (based on Department of Energy schedule)
- New HEU storage racks built and approved

Major Milestones (continued)



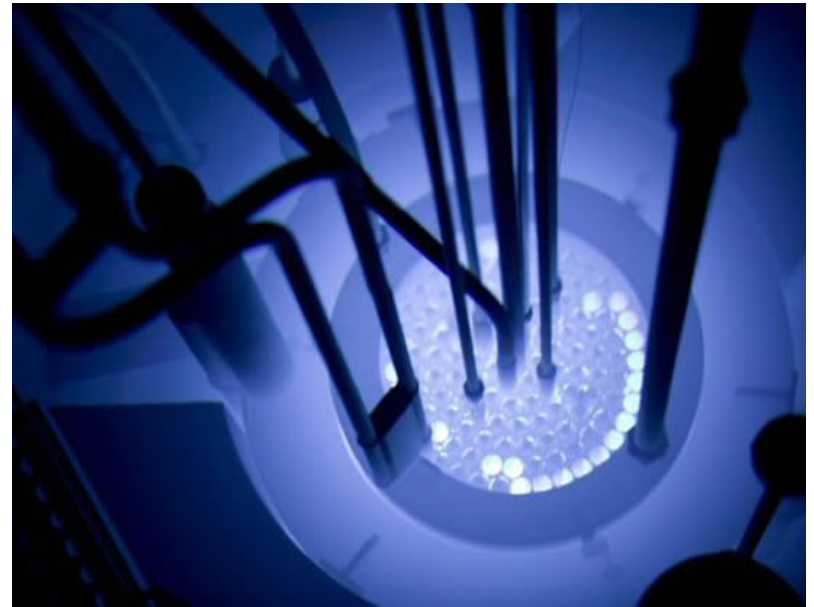
- HEU offload process developed and approved
- NRC issues conversion order
- HEU is removed from core and placed in storage racks

Major Milestones (continued)

- Removed old Al clad reflectors
- Obtain new fuel inspection tool
- Certify bridge crane for refueling operations
- Obtain new control rod connectors and extension rods
- Receive new stainless steel clad reflectors
- Ready to begin initial loading per startup plan

Reactor Core Parameters

- Items modelled and then measured
 - Number of fuel elements to achieve criticality ($1/M$)
 - Thermal power level
 - Integrated control rod worth
 - Parameters unique to a TRIGA core



Reactor Core Parameters (continued)

- Loading of fuel elements
 - Verify administrative controls
 - Install a neutron source
 - Install control rods
 - Partially load fuel based on criticality predictions
 - Use $1/M$ plot to predict criticality
 - Reduce batch size as criticality is approached

Reactor Core Parameters (continued)

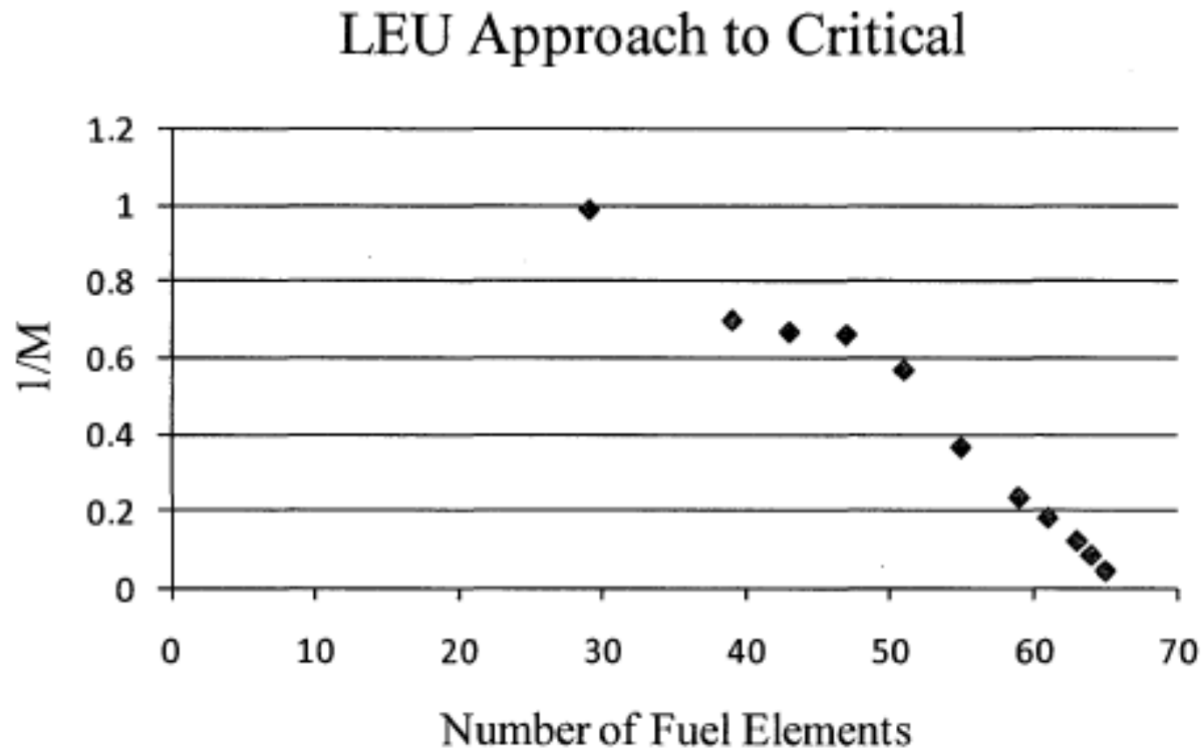


Figure 15, LEU 1/M Plot

Reactor Core Parameters (continued)

Thermal Power

- First hold point at 50% power or 200°C indicated fuel temperature
- Subsequent hold points
 - Instrumentation adjustment
 - Flux wire measurements
 - Heat balance to determine thermal power

Reactor Core Parameters (continued)

Control Rod Calibrations

- Period method not possible with limited excess
- Alternate method developed for calibration

– Rod drop
$$\rho = \frac{-P_0(\Lambda^* + 1/\lambda)}{\int_{t_0}^{\infty} P(\tau) d\tau} \quad (1)$$

where

ρ = reactivity (dollars)

P_0 = reactor power prior to the rod drop

$\Lambda^* = l / k\beta_{eff} = 3.06E-03$ for the LEU beginning of life core

λ = one group delayed neutron precursor decay constant = 0.079 sec⁻¹

t_0 = time at which the test rod is fully inserted

Reactor Core Parameters (continued)

Rod Drop Method

- Prepare recorder and stabilize power
- Start recorder and drop rod from fully withdrawn position
- Evaluate data:
 - t_0 time of initial power decrease and integrate to +300 seconds
 - Generate best estimate compared to predicted worth

Predicted Versus Measured

Elements to go critical

- Predicted number of LEU fuel elements: 69
- Actual number of LEU fuel elements: 66
- Within acceptance criteria of 60 – 70 for criticality
- Number needed for critical with HEU fuel: 65
- Most likely cause(s):
 - Loading pattern biased with low erbium elements in the center, but modelled as uniform
 - Fabrication average of erbium was 1.07 versus 1.10 in model

Predicted Versus Measured (continued)

Thermal properties of the fuel and transient responses (parameters unique to TRIGA fuel)

- Pulsing reactor included prompt temperature reactivity feedback measurements
- Peak power level versus prompt reactivity
- Temperature increase versus reactivity
- Total energy versus prompt insertion

Predicted Versus Measured (continued)

General Observations

- Reactor physics measurements – overall good agreement
- Initial LEU core loading – criticality predictions with 1/M plot were accurate, as well as the 69 element prediction
- Reactivity in the primary coolant decreased as activated materials decayed and purification system removed particles
- Pulse test results – graphs showed strong linearity and correlation. Mean lifetime and delay fraction measurements agreed well with predictions

Lessons Learned

Licensee Observations

- Take advantage of experience from others performing the same or similar task
- Experienced project manager helps to ensure safe execution
- Walk-through and dry-runs are highly beneficial
- Take time to perform repetitive tasks carefully, initial duration may be long, but will improve as the project progresses
- Small durable camera can be an invaluable tool

Reference Information

- Oregon State University restart plan is publically available on the NRC website with the following accession numbers
 - Startup report ML091110188
 - Redacted: Conversion SAR ML080420546
 - License renewal safety evaluation report ML082540035