NRAD HEU to LEU Conversion

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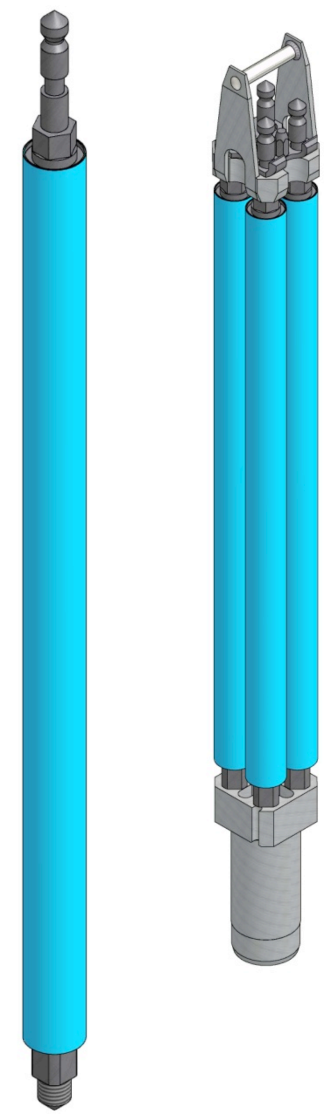
NRAD Background

- Neutron Radiography Reactor (NRAD) TRIGA Mark II reactor.
- Licensed power is 300 kW
  Operating power is 250 kW
- NRAD was created from TRIGA FLIP fuel that came from the Puerto Rico Nuclear Center (PRNC).
- First went critical in 1977.
- The main purpose of this facility is to perform neutron radiography on irradiated fuel and other highly radioactive materials.

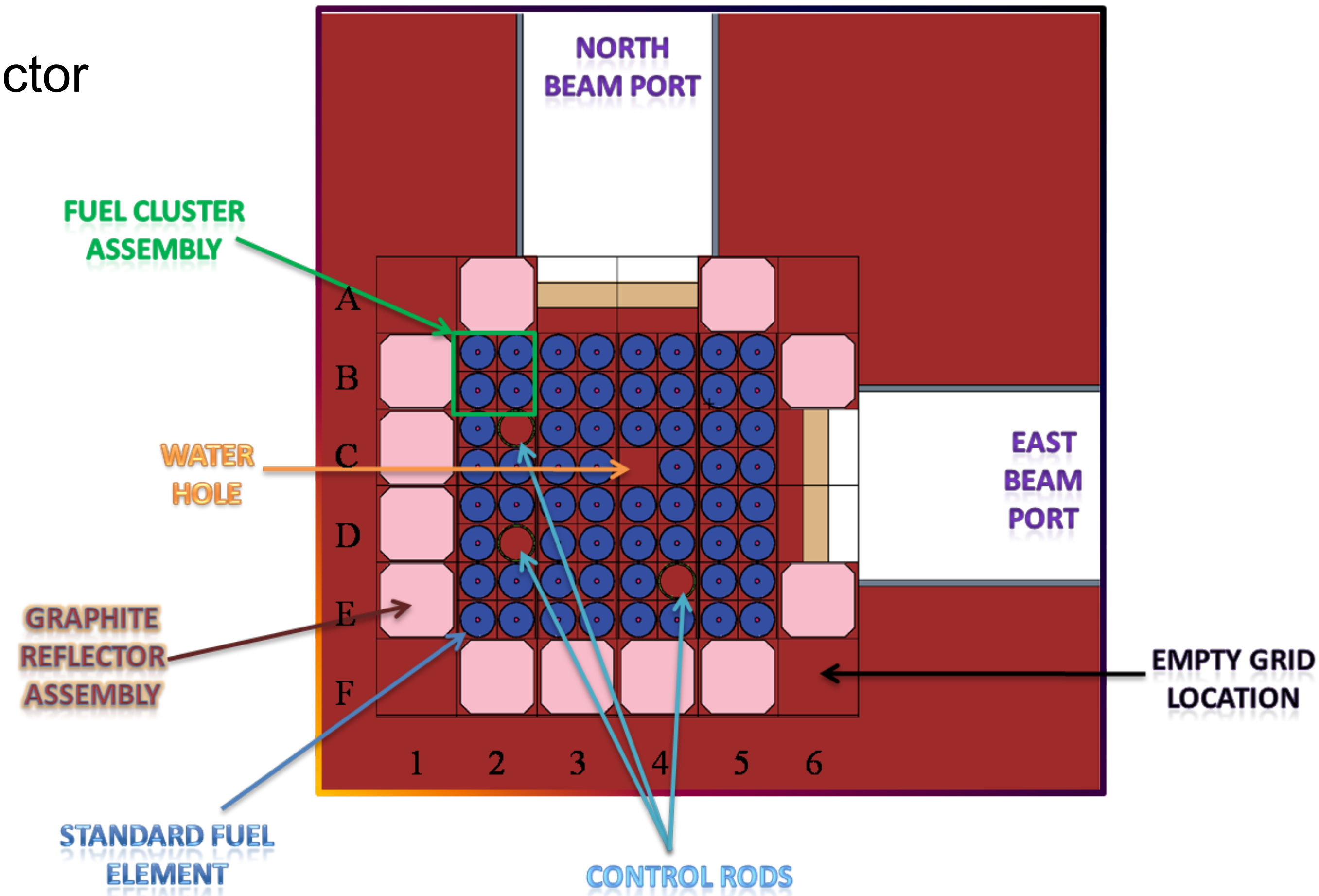
Fuel Description

Design Data	HEU (FLIP) Fuel	LEU (30/20) Fuel
Number of Fuel Rods	60	60
Fuel Type	UZrH-Er	UZrH-Er
Uranium Enrichment %	70	19.75
Uranium Density wt-%	8.42	30
Erbium wt-%	1.48	0.90
Zirconium Rod Outer Diameter, mm	5.715	5.715
Fuel Meat Outer Diameter, mm	34.823	34.823
Fuel Meat Length, mm	381	381
Clad Thickness, mm	0.508	0.508
Clad Material	304 SS	304 SS



Core Description

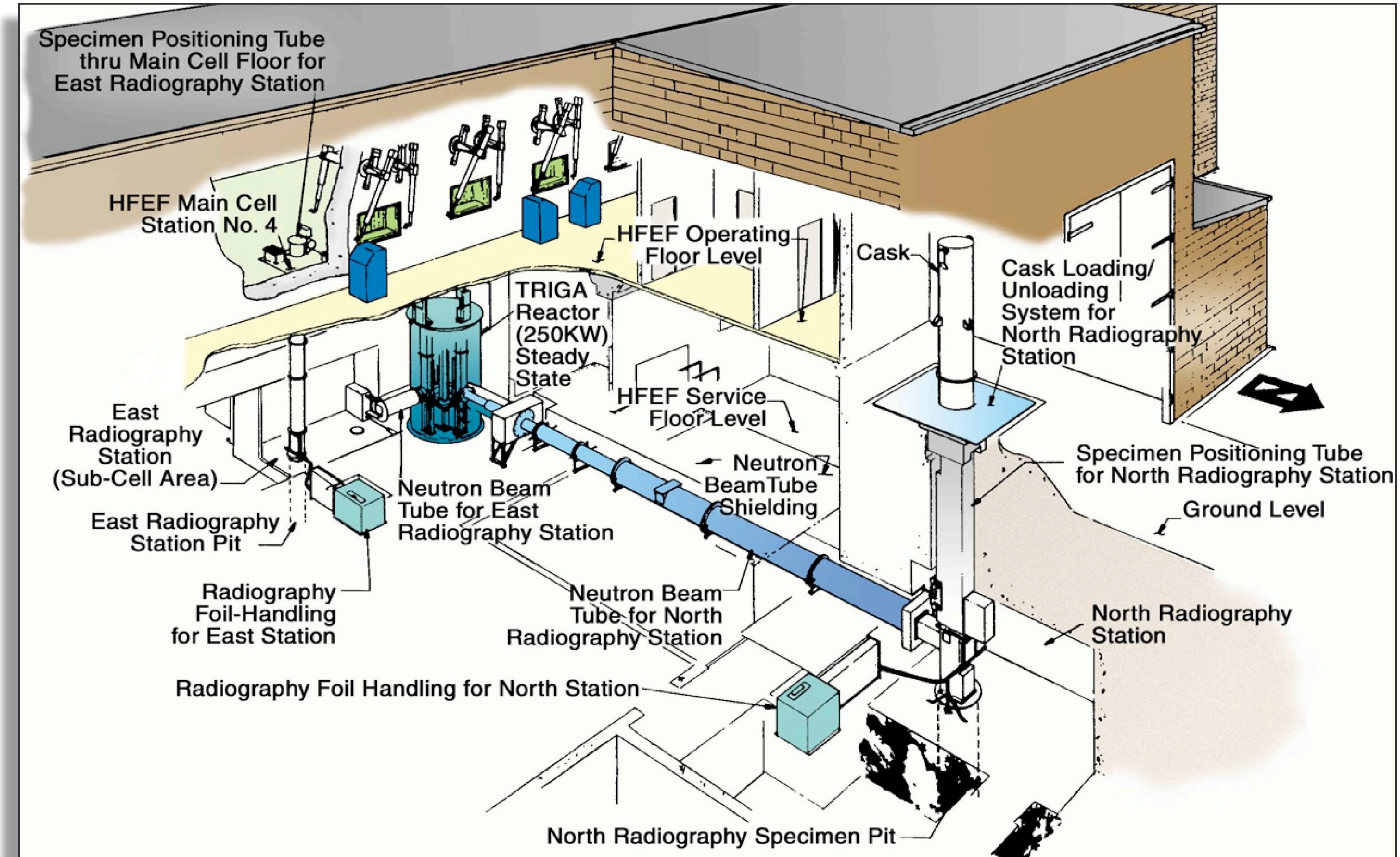
- 60 standard TRIGA fuel elements
- 12 Graphite Reflector Blocks
- 3 Control Rods
- 1 Water Hole



Facility Description

- The reactor room is located beneath the Hot Fuel Examination Facility (HFEF) main cell.
- 2 Beam Lines provide radiography capabilities.
- East Beam line intersects a tube that extends up into the hot cell where objects can be lowered into the beam.
- Objects can be lowered into the north beam line from a truck lock capable of handling casks and larger materials.
- A water hole provides in-core irradiation capability.
- Open grid positions at the northwest and southwest corners are also used for experiment irradiations.

NRAD Layout



Specimen Positioning Tube
thru Main Cell Floor for
East Radiography Station
HFEF Main Cell
Station No. 4
HFEF Operating
Floor Level
Cask
Cask Loading/
Unloading
System for
North Radiography
Station
TRIGA
Reactor
(250KW)
Steady
State
HFEF Service
Floor Level
East
Radiography
Station
(Sub-Cell Area)
Neutron
BeamTube
Shielding
Specimen Positioning Tube
for North Radiography Station
Ground Level
Neutron Beam
Tube for East
Radiography Station
East Radiography
Station Pit
Radiography
Foil-Handling
for East Station
Neutron Beam
Tube for North
Radiography Station
North Radiography
Station
Radiography Foil Handling for North Station
North Radiography Specimen Pit

Plan to Remove HEU Fuel

- Step 1 – Place the NRAD cask in the tank and move a fuel cluster into the cask.
- Step 2 – Remove cask from tank, bag cask to the hot cell, lift fuel cluster from the cask and place it in a storage basket.
- Step 3 – Move storage baskets from the decon cell to the main cell.
- Step 4 – Inspect fuel elements in the main cell and transfer elements to NAC baskets.

Refurbishing the NRAD Cask

- The NRAD cask was last used in 1977 to load the core with HEU fuel
- Both a dimensional inspection and weld inspection were performed
- A new lid was designed with a removable plug in the top.
- The cask was surveyed and fixed contamination levels were recorded.

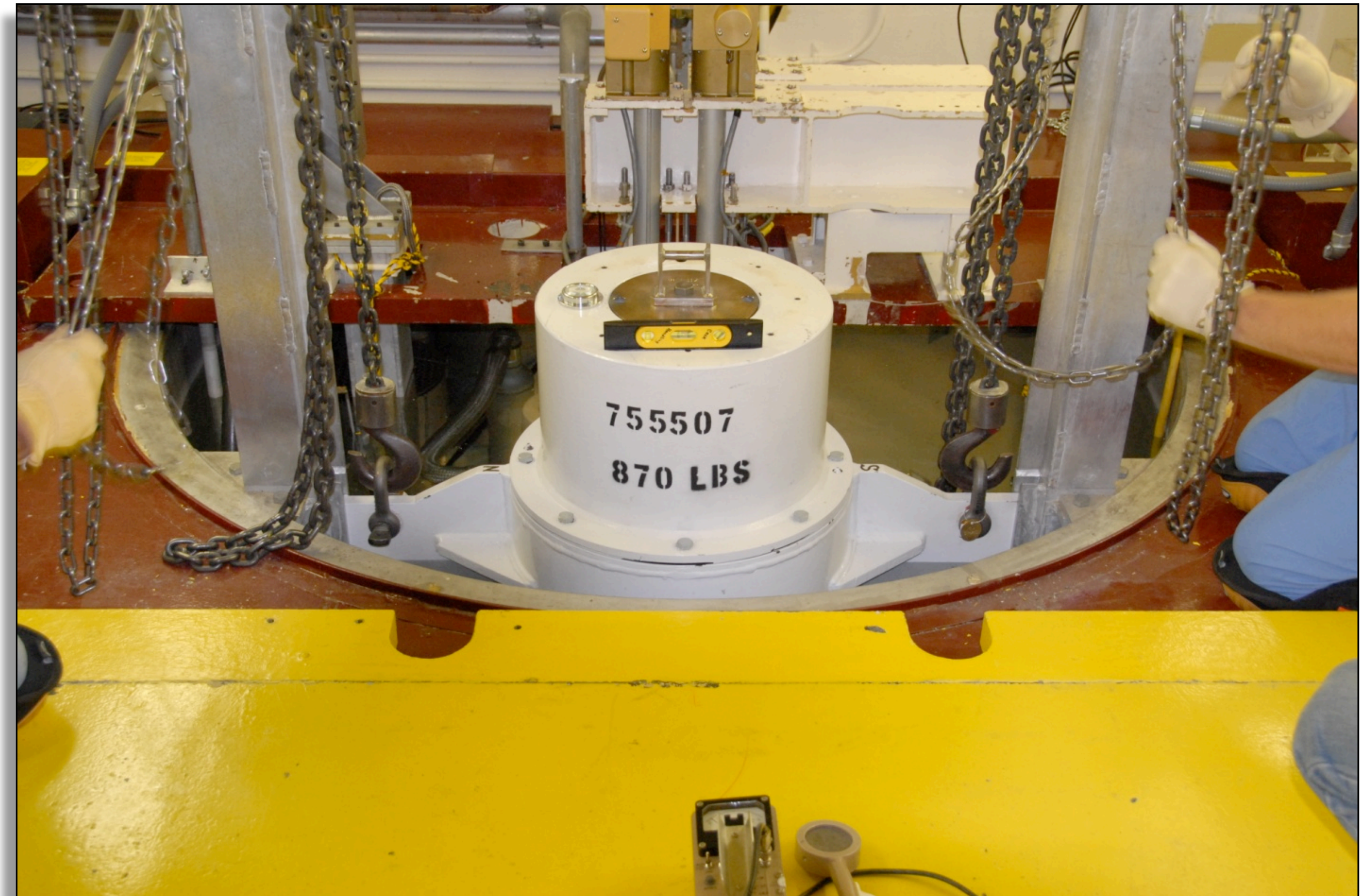
NRAD Cask After Being Removed From Storage

Cask Handling System

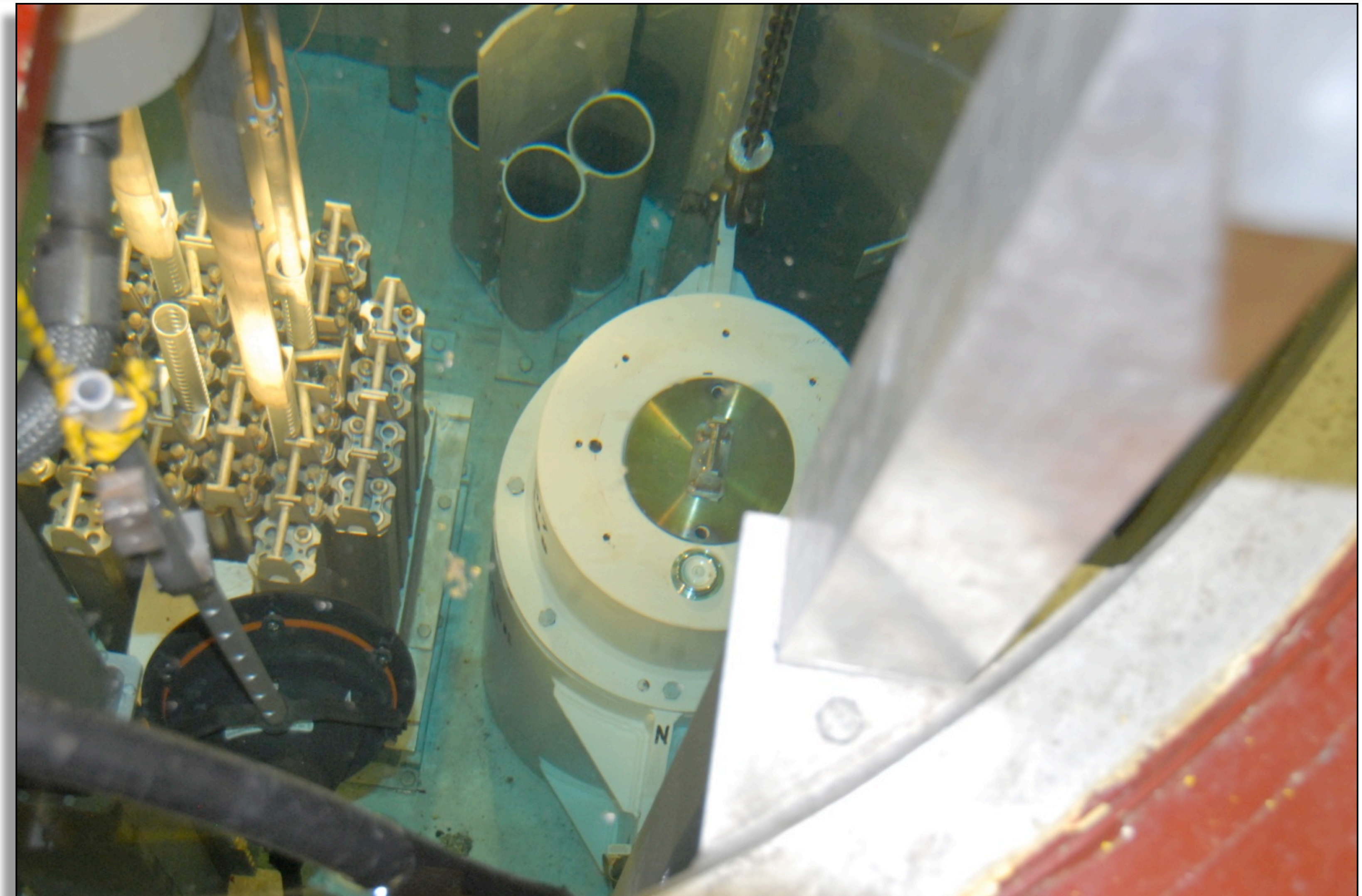
- I Beams or Monorails
- 2 Ton Trolley Hoists
- Guide Rails

- This system was maintained into the mid 80's when it was placed in storage
- The necessary analysis, inspections, load tests and maintenance were all performed to make this system operational again.

Dry Run of Defueling Plan

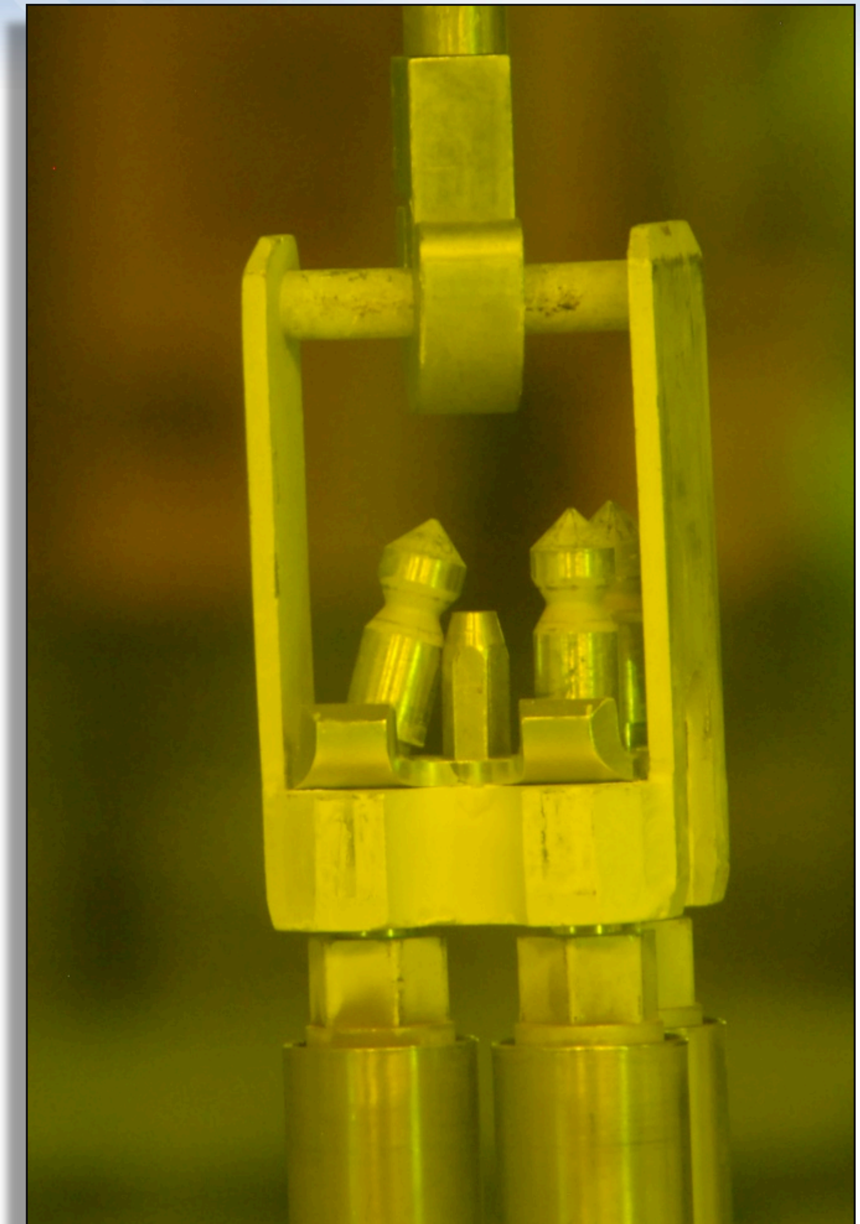


Dry Run Continued

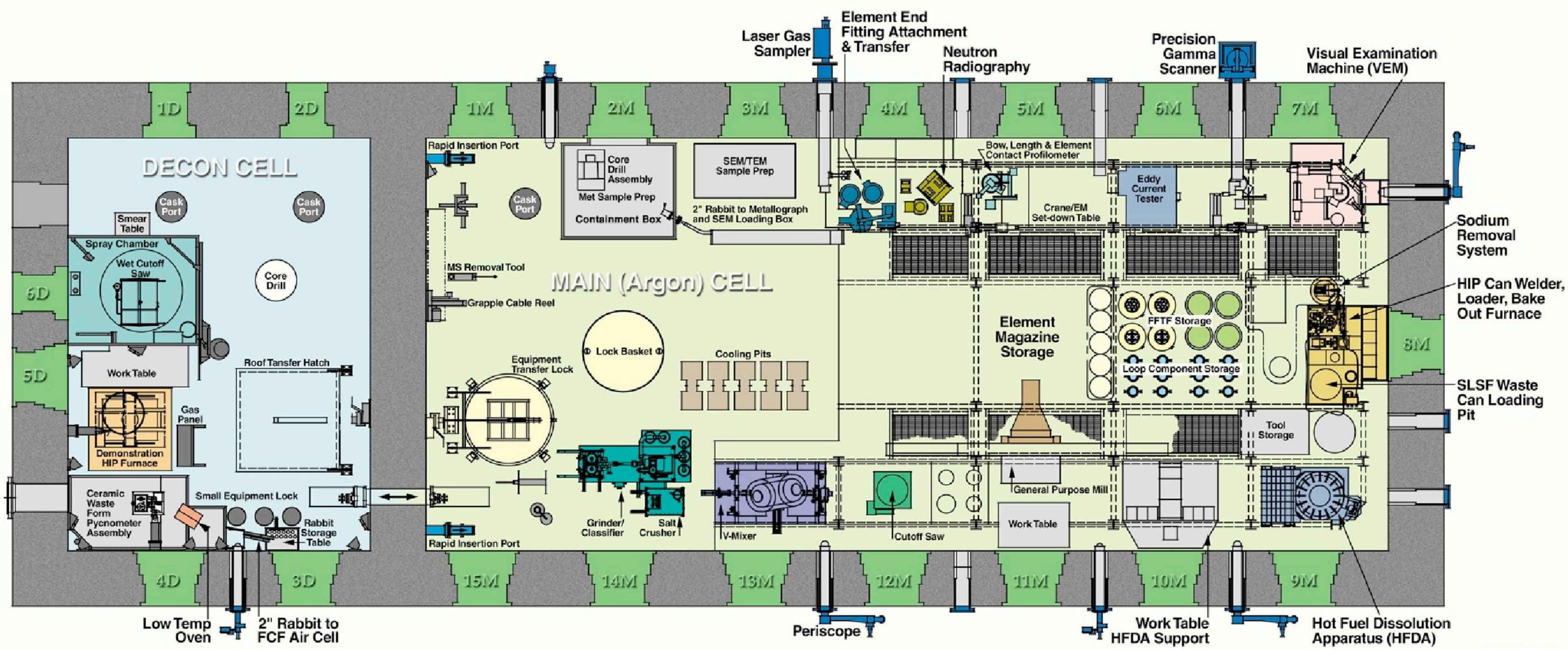


Lifting Fuel Into Decon Cell

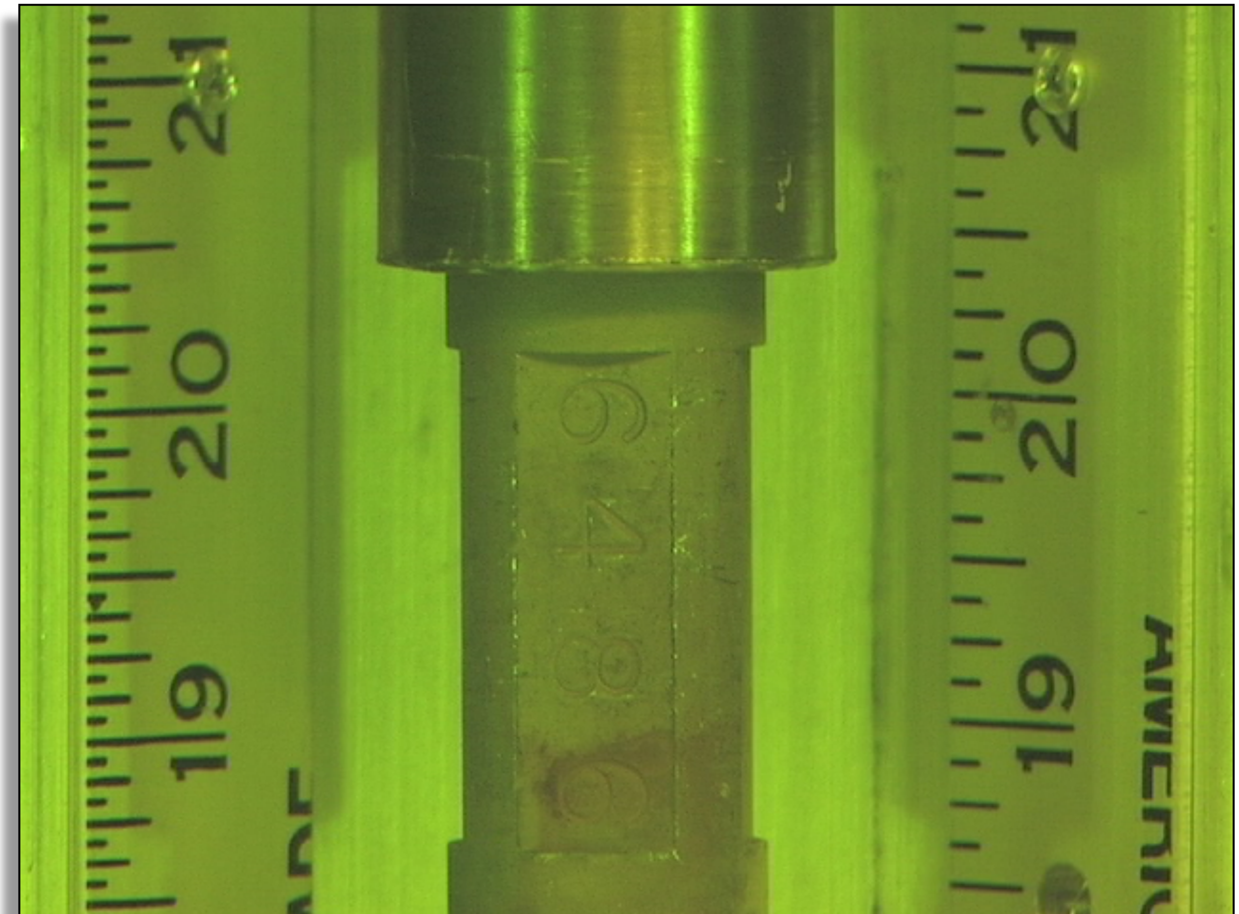
Bent Fuel Pintle

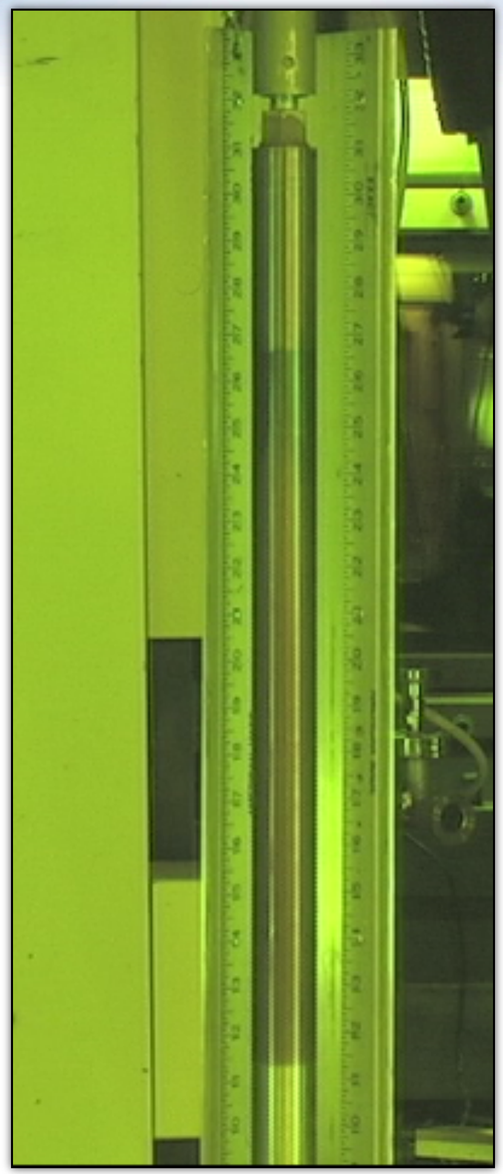


Moving Storage Baskets From the Decon Cell to the Main Cell

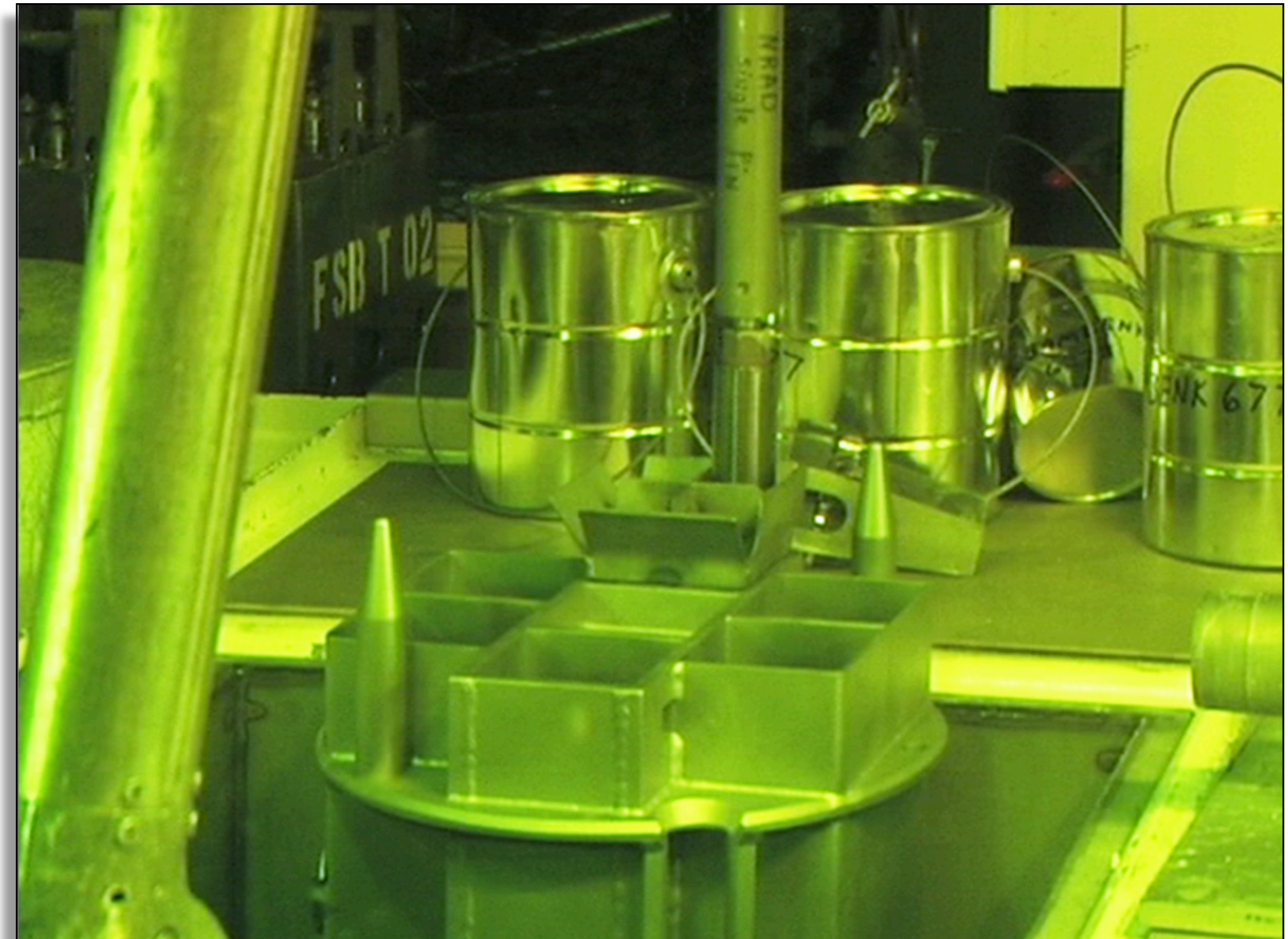


HEU Fuel Inspection





HEU Placed in NAC Baskets

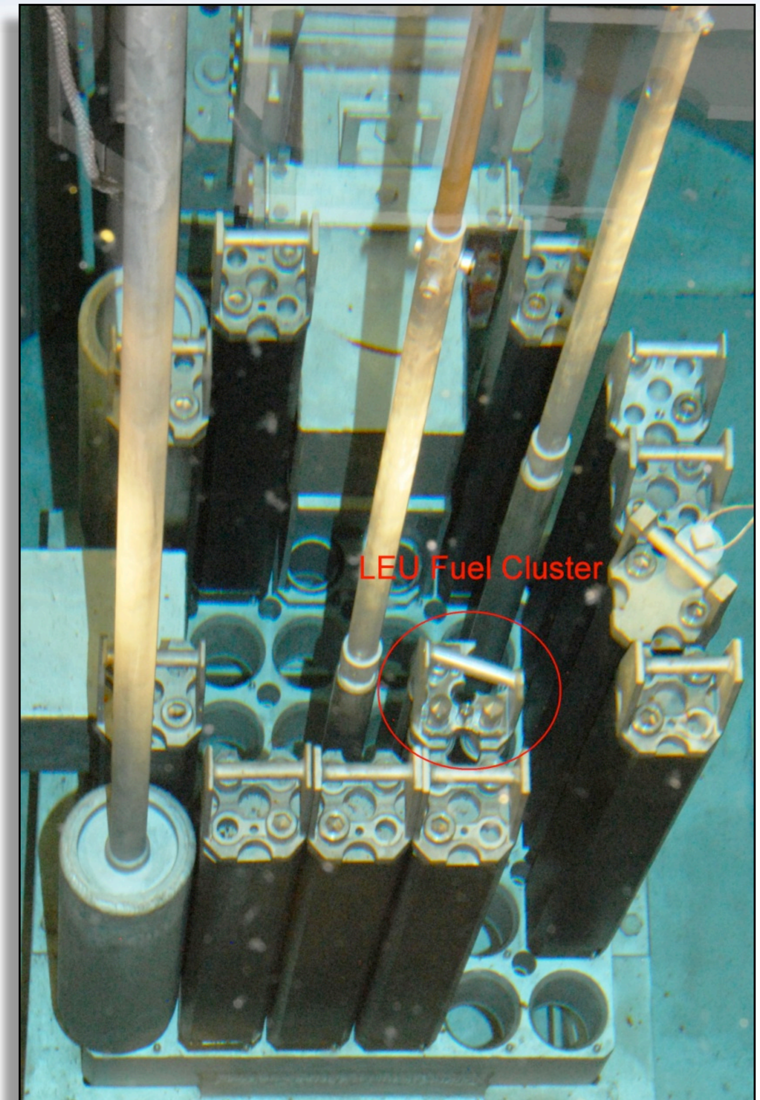


Receiving LEU

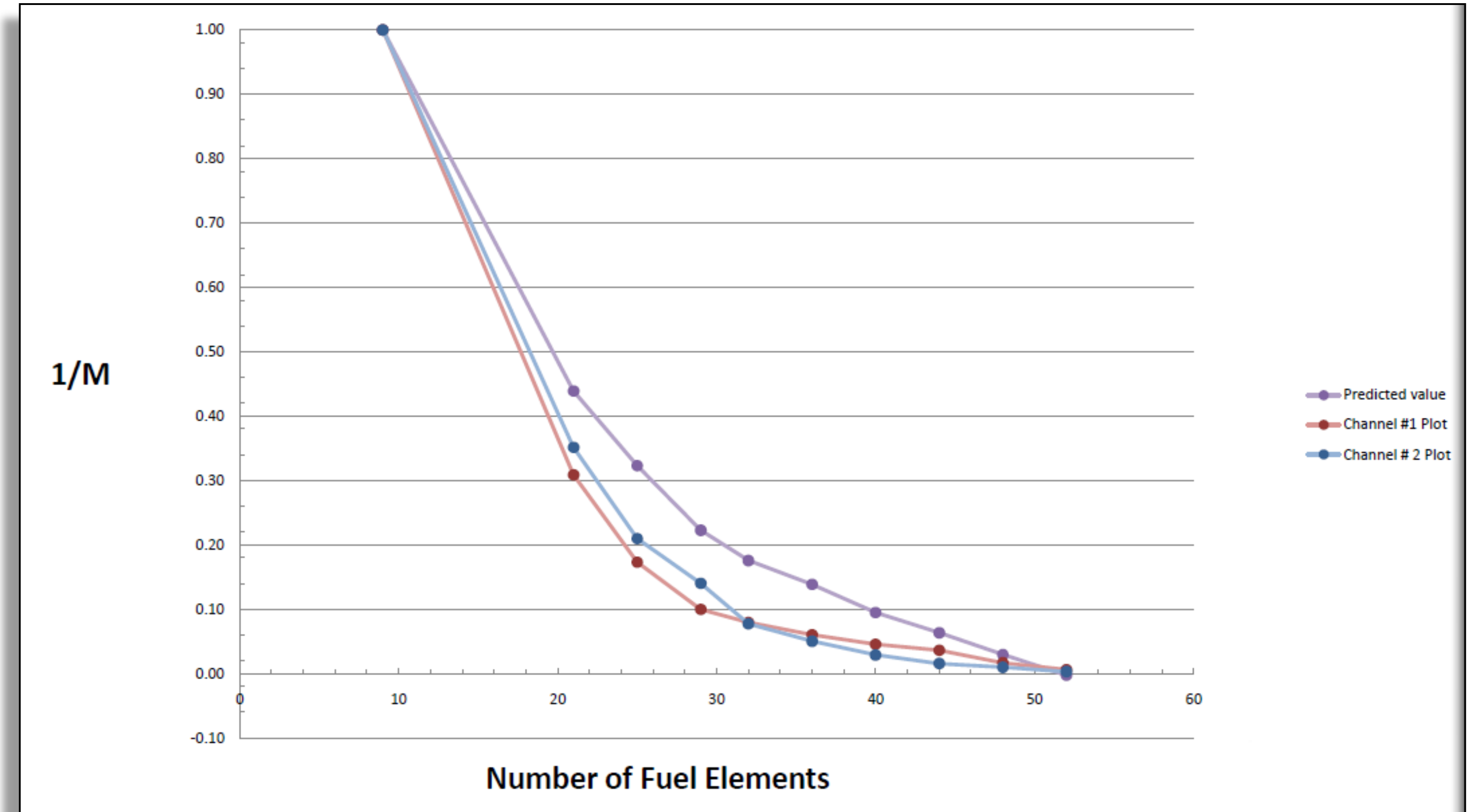
Inspection of LEU Elements

Refueling With LEU

- 3 Element clusters were added to the core first
- All 3 control rods were then installed and checked for operability
- The remaining elements were added one cluster (4 elements) at a time.



Approach to Critical



- The critical point calculated from the measured values was 53.6 elements

Critical Core

- The estimated critical point was 52 ±4 elements.
- NRAD went critical at 56 elements (15 clusters).
- With the final cluster installed the core had 60 elements (16 clusters).

	HEU Core	LEU Core
Number of Elements	60	60
Cold Critical Excess Reactivity	$1.55	$1.19
Excess Reactivity at 250 kW	$.93	$.17

Defining "Acceptable" Performance for LEU Core

The GTRI Convert Program defines the parameters for conversion as follows:

- New fuel will not significantly impact the reactor's performance and mission – typically this is defined as within 10% of the original HEU core reactivity

- No major modifications to the reactor are required

- No significant increase in operational costs

Past conversions defined "acceptable" as within 10% of the original HEU core reactivity. Although NRAD is a DOE reactor, the same measure is being applied to the NRAD conversion. The measured NRAD LEU reactivity is currently 23% lower than the HEU and warrants corrective action. This currently does not significantly impact radiography; however it may impact future in core irradiation experiments.

NRAD Today

- Radiography is currently being performed at NRAD with no decrease in image quality and no increase in exposure time.
- The reactor is operational, but the low excess reactivity would likely prevent the reactor from being run for more than 2.5 consecutive days because of Xenon poisoning.
- The NRAD LEU conversion project is working to add 4 fuel elements and 4 graphite elements to the NRAD core. The added fuel and reflector will increase the excess reactivity and resolve the Xenon poisoning issues.
  - The additional fuel elements have already been procured.
  - Analysis and wording in the safety basis are being revised to allow more than 60 elements to be inserted in the core.

Observations

- Remote handling systems should have clutches, shear pins, or some type of operator feedback to prevent damaging equipment.
  - The use of heavy equipment such as cranes or electrical manipulators increases the need for force limiting devices.
  - Working blind or in limited sight conditions also increases the need for force limiters or some type of operator feedback.

- Bringing old equipment back to operational status can be time consuming and costly. The complexity of a system might be the determining factor when trying to decide between designing a new system and restoring an old one.
  - The NRAD cask was definitely worth reusing.
  - It may have been quicker and less expensive to replace portions of the cask handling system.

Observations

- Computer models are an excellent tool for predicting reactor behavior, but their limits need to be understood. Models are not perfect, they are approximations. Actual values achieved empirically are needed to validate models and to fine tune reactors.
  - When starting or restarting a reactor adjustments to fuel and reflector quantities and locations should be expected.

- Safety Basis documents and analysis should be written to allow the widest possible range of options.
  - Requirements such as a 60 fuel element limit may be better written as an excess reactivity limit.
  - Brands and model numbers of equipment should be avoided. These details are better left to other documents such as System Design Descriptions which can be easily updated.

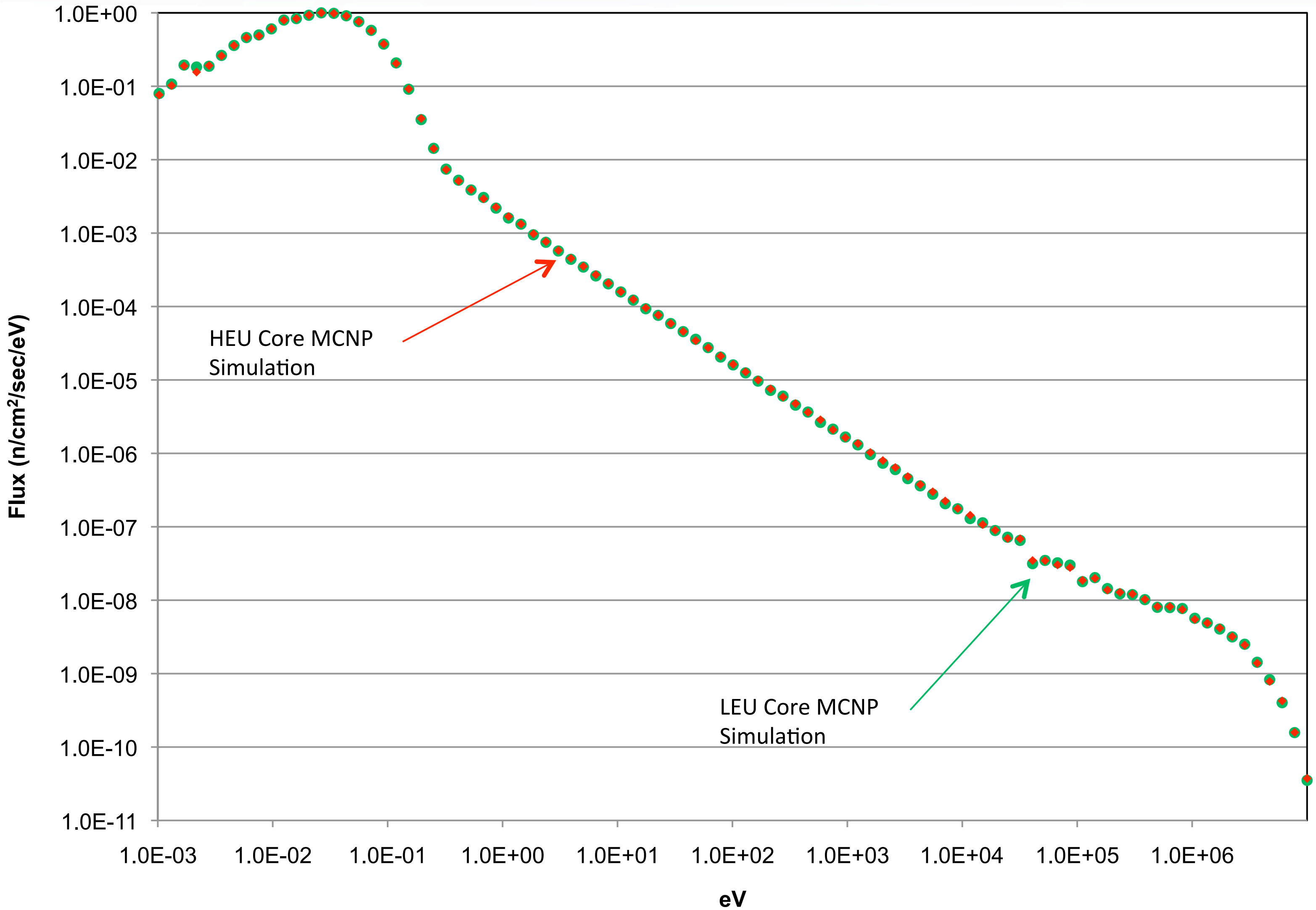
- Reports and analysis for TRIGA fuel should be collected and made available so different facilities can reference the same documents.

Questions?

Foil Irradiation Results

- Radiography beam characterization can be quantified in terms of the “cadmium ratio”
- The cadmium ratio represents the neutron activation of a bare foil compared to a cadmium covered foil
- The ratio is a spectral indicator because the cadmium effectively removes only thermal neutrons
- Cadmium Ratio Result With Gold Foils
  - 1.99 with the HEU core
  - 1.81 with the LEU core
- Cadmium Ratio Results With Indium Foils
  - 2.98 with the HEU core
  - 2.98 with the LEU core

Neutron Energy Spectrum Comparison



Conclusion

- The energy spectrum on the NRAD neutron beam plays a key role in radiograph quality
- MCNP simulation of the NRAD HEU core and NRAD LEU core indicate that the neutron energy spectrum is essentially identical for the two cores
- Foil irradiation results (indium in particular) using the NRAD HEU core and the NRAD LEU core indicate that the neutron energy spectrum for the two cores is essentially identical
- The ability for NRAD to produce high quality neutron radiographs has not been impacted by the conversion of the core from HEU to LEU