Aluminum Fuel Cladding Condition at the US Geological Survey TRIGA Reactor

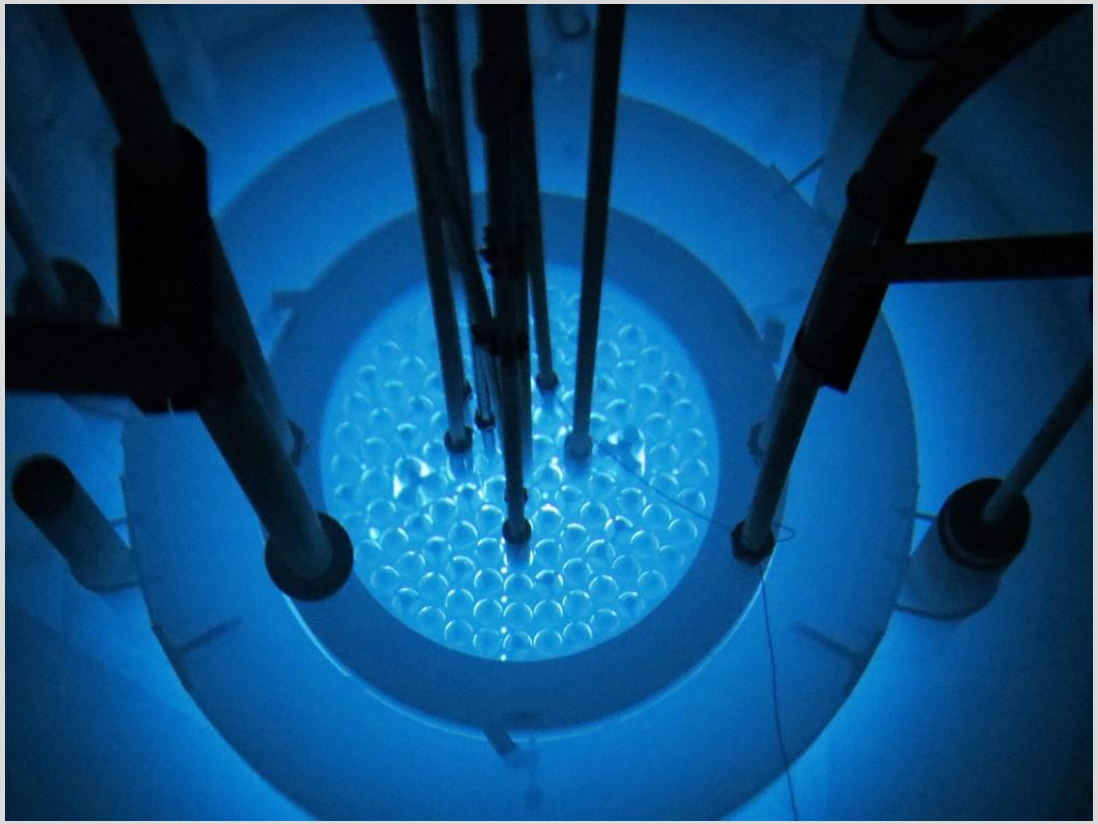
Clayton Manning

Reactor Health Physicist/Senior Reactor Operator

US Department of the Interior – US Geological Survey

US Geological Survey TRIGA Reactor (GSTR)

- 1-MW Mark I TRIGA Reactor
  - Denver Federal Center-Lakewood, CO
- First critical in 1969 to support USGS mission
  - Measure mineral and metal content of rock and soil
  - Perform geochronology on rock samples
  - Expanded into other commercial work in 2000s
- Initial license – only Stainless Steel-clad fuel



USGS
science for a changing world

US Geological Survey TRIGA Reactor (GSTR)

- Not owned by a university, so not eligible for DOE University Fuels Program
- USGS has not typically been able to afford new fuel since 1969
  - Suffered a major Reduction-in-Force in 1990s
  - Original fuel reaching EOL as of 2000s

- Thus, most of the fuel on hand has been original 1969 vintage, or acquired as “lightly-used” second-hand fuel
  - Michigan State University TRIGA Reactor (1989)
  - Veteran’s Administration – AJ Blotcky Reactor Facility (2002)
  - INTEC – Idaho National lab (2017)
  - VTT Technical Research Centre of Finland (2021)

AJ Blotcky Reactor Facility
Omaha, NE

USGS
science for a changing world

AJ Blotcky Reactor Facility
Omaha, NE

- Opened in 1959
  - 20 kW Mark-I Reactor
  - Pace of research had slowed significantly as of the early 2000s
- September 11, 2001 terrorist attacks
  - Generated security concerns amongst VA and congressional leaders
  - Coupled with the slowing pace of research, led to decision to shut down reactor
  - Strong motivation to remove fuel from facility
- GSTR in need of fuel (as always)
  - Agreed to take all the fuel despite not being licensed to use aluminum-clad fuel (yet)

Aluminum Fuel at GSTR

- Fuel was inspected at VA and shipped to Denver in 2003
  - No major abnormalities noted

- License amendment received to operate with fuel in 2006
  - Only in outer two rings (F & G)
  - Some fuel placed in core right away, but other fuel was only placed in core later (~2011)
  - For the first 5 years, inspect 20% of in-core Al-clad fuel annually
    - After 5 years, returned to 60-month/100% cycle

Fuel Inspections at GSTR

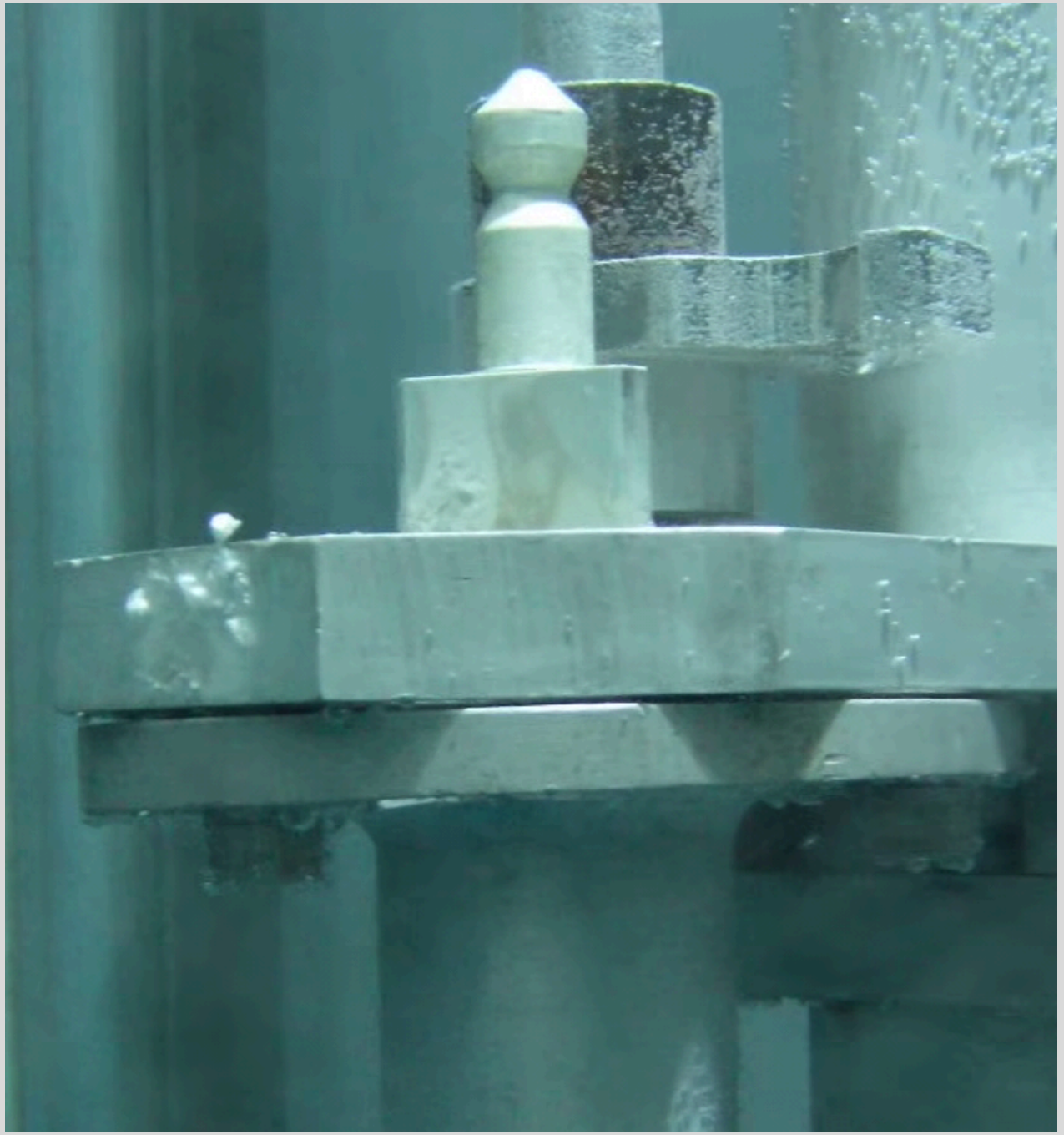
- Historically, GSTR fuel inspections only involved a cursory examination through the water's surface
  - Did not include serial number visual verification
  - 2018 inspection averaged ~2-3 minutes per fuel element, *including* measurements
  - Written notes on visual inspections were often not particularly detailed

- Starting in 2023, inspections started to include serial number verification and more detailed visual inspection
  - The old "binoculars through the water surface" method would no longer be sufficient

2023 Fuel Inspection

- Early-run aluminum fuel (approx. SN 1-1000) has notoriously obscure serial number placement

- Do you see the Serial Number?



USGS
science for a changing world

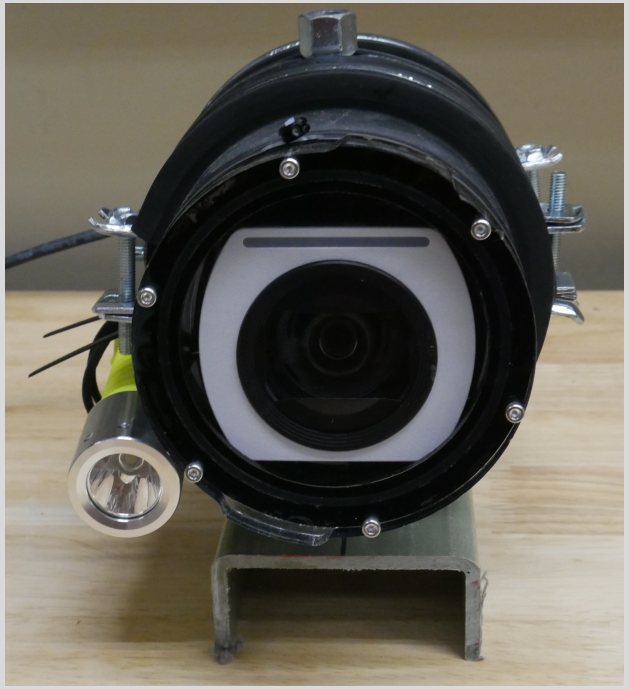
2023 Fuel Inspection

- Serial Number 853

- Underwater camera system utilized
  - Serial Number ID
  - Visual Inspection

USGS
science for a changing world

Underwater Camera System



- 4K video camera in underwater robotics enclosure
  - ~$3000 in parts
- Diving flashlight
- Ethernet communication powered via PoE
- Remotely operated optical/digital zoom
- Fantastic video quality

2023 Fuel Inspection Results

- With the much-improved visual inspection methods, much more detailed views of the fuel were available

- The results on the VA aluminum fuel were… unexpected

2023 Fuel Inspection Results

USGS
science for a changing world

What are we looking at?

- Top 1/3 of element looks rather nondescript
- “Flaky” transition zone to a darker layer near graphite/fuel interface
- Shadows seem to indicate that the different zones have different depths

USGS
science for a changing world

What are we looking at?

- Middle of element tends to have a “speckled” pattern to it
- Some of this pattern appears to have tiny little bumps or texture to it

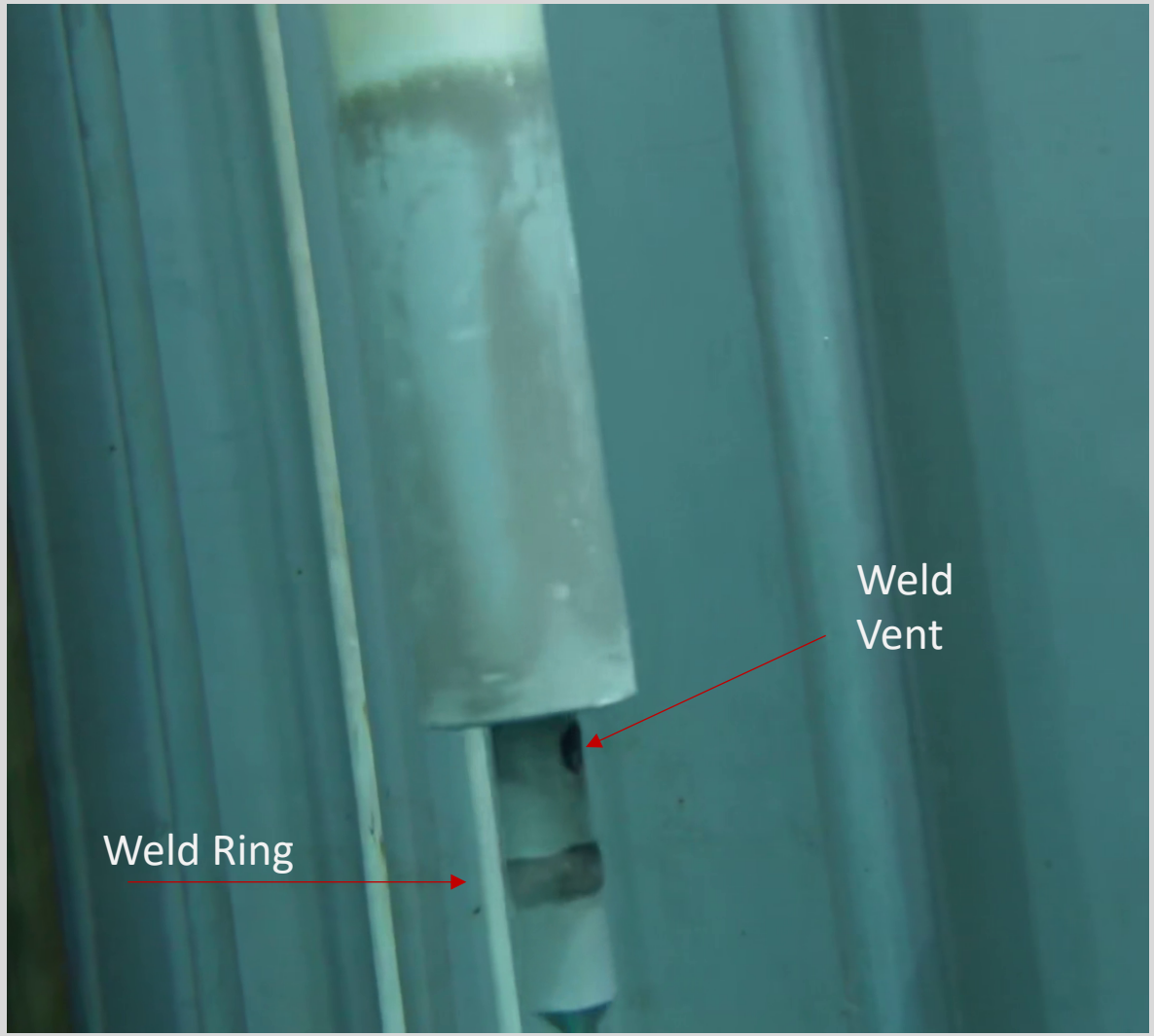
USGS
science for a changing world

What are we looking at?

- Similar flaky layer near bottom graphite/fuel transition zone
- Lower graphite section much darker than upper section

What are we looking at?

- Bottom weld appears compressed
- Thick weld ring around bottom pin
- Large dark “dot” is a weld vent that was welded shut at end of manufacturing



USGS
science for a changing world

2023 Fuel Inspection Results

- None of the fuel exhibited the “flaky” or speckled features upon inspection at VA reactor
- All VA fuel has been operated in the GSTR to some degree since receipt
  - No “Control Group”
- Insufficiently detailed fuel inspection methods and records to retrospectively track progress of degradation from 2006-2023

Possible Mechanisms

- Affects entire bulk of oxide layer of fuel section
- Temperature/heat?
  - GSTR: 1000 kW (pulsing!) vs VA: 20 kW (non-pulsing)
  - Significantly higher heat production despite restriction to F&G rings
  - Oxide spallation can occur if oxide layer builds up excessively under high temperature conditions
    - Growth/spallation cycles
- Not many other users of Al-clad TRIGA fuel that share our operational envelope

Possible Mechanisms

- Chemical?
  - 2014 - ~10 mL of bromine-containing compound leaked from sample container into reactor pool water
  - No pitting corrosion identified on Al-clad fuel
  - This effect is not seen on any other aluminum core or tank surfaces
    - Unlikely to be due *solely* from chemical attack

- Coupled chemical/temperature mechanism?
  - Chemical attack initiates oxide growth
  - Temperature/heat profile commences the spallation cycle

Corrective Actions

- Since:
  - The cladding on the Al-clad fuel has apparent material loss in the fuel section,
  - GSTR does not have the capability to quantify the thickness of cladding remaining, and
  - The root cause remains indeterminate:
- All Al-clad fuel has been removed from service
  - In accordance with Technical Specifications, and good operating sense
- All fuel in GSTR possession is being inspected with camera system to assess status
  - Still in progress

Current Status

- GSTR remains shut down until all fuel has been inspected
- Estimated fuel reserve has dropped by ~10-15 years
  - All lightly-used on hand, no fresh elements
- Drafting license amendment to use stainless steel-clad fuel from VTT TRIGA (Finland)
  - Fuel situation critical without these elements

Future Work

- Evaluate whether aluminum-clad fuel received from VTT is susceptible to same degradation
  - Newer series of fuel
  - “Pulsing” aluminum fuel vs “Non-Pulsing” aluminum fuel from VA
- Continue to investigate root cause of degradation
- Quantify integrity of current VA aluminum cladding
- Establish an aging management system/program
  - Deficiencies in both assessment and mitigation of aging degradation

Lessons Learned

- Ensure visual inspection methods are of sufficient quality to identify issues
  - Likely involves going well above and beyond minimum technical specification requirements

- A high-quality underwater imaging system at reasonable cost is available with current technology and some creativity
  - High-resolution images and video are far superior for cataloging fuel inspection records than binoculars and hand-written descriptions.
    - Storage space is cheap; might as well use it!

Thank You For Time!

- Contact Information:

  - Clayton Manning, USGS TRIGA Reactor Health Physicist/ Senior Reactor Operator
  - cmanning@usgs.gov – 303-236-1466

USGS
science for a changing world