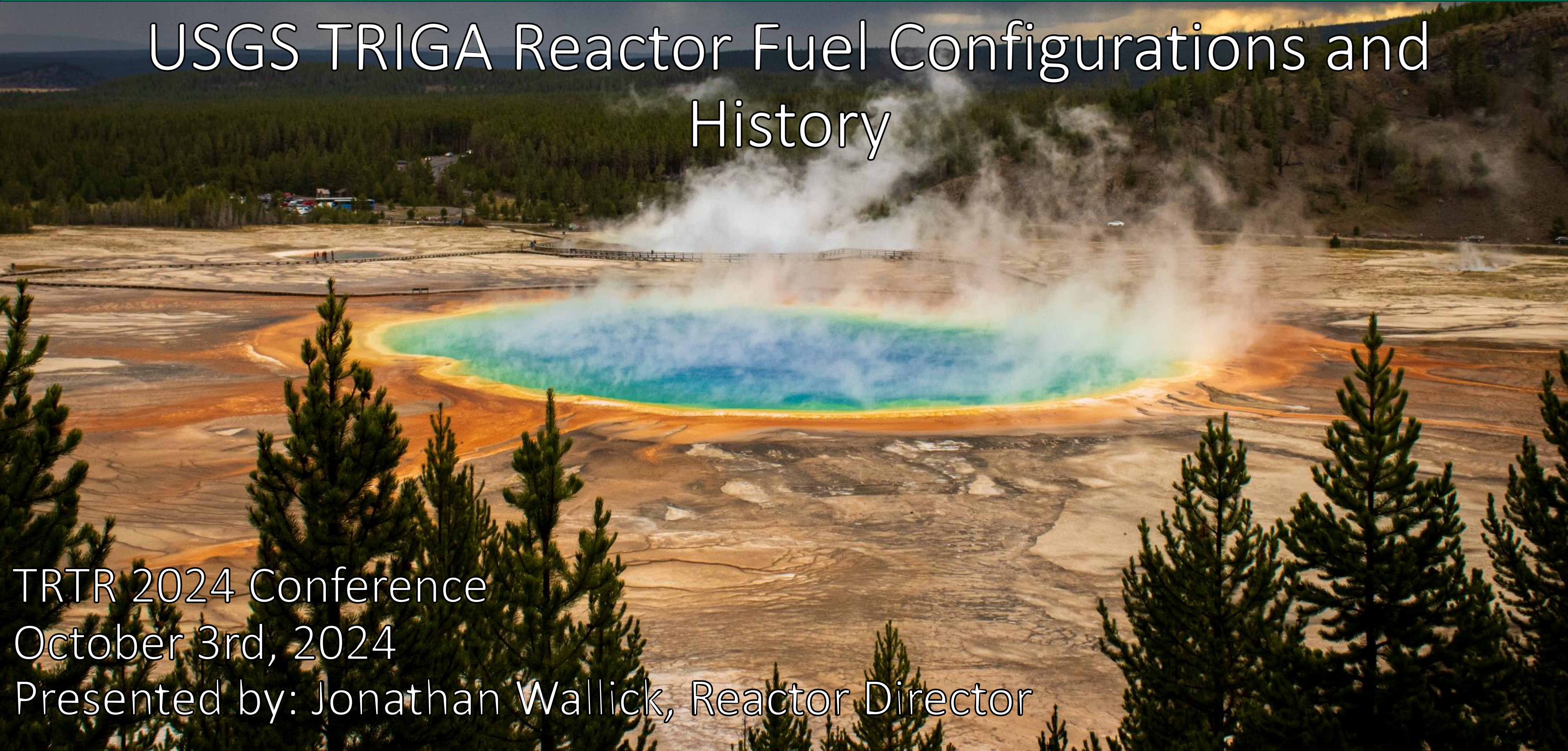
USGS TRIGA Reactor Fuel Configurations and History



TRTR 2024 Conference
October 3rd, 2024
Presented by: Jonathan Wallick, Reactor Director

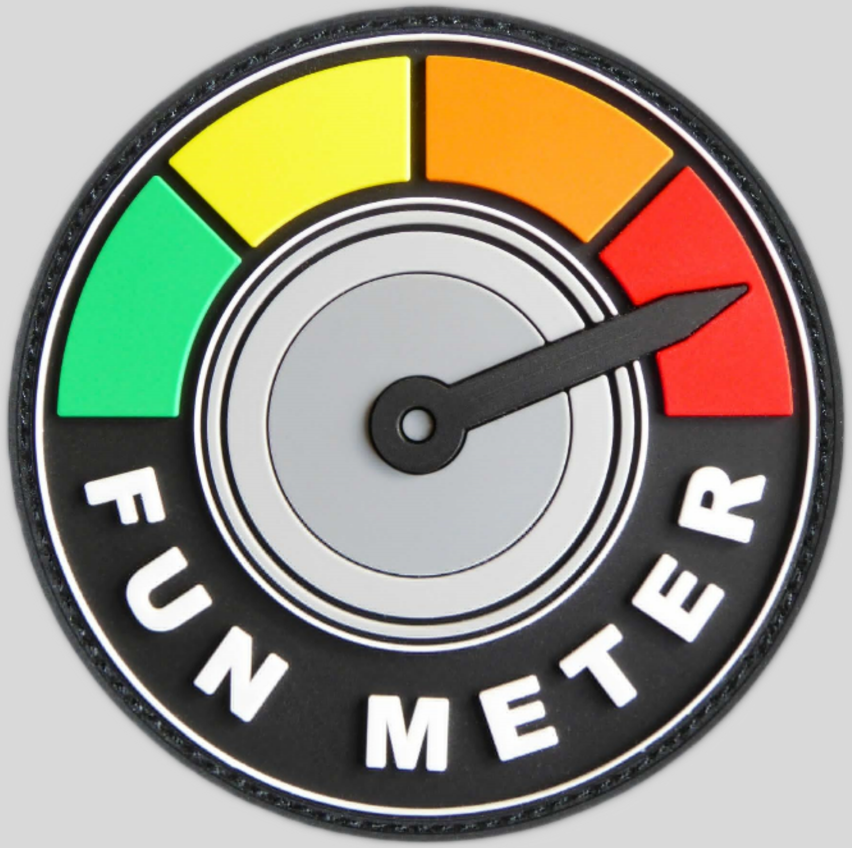
Overview

- Fuel Inspection August 2023
  - Primary Issues Identified and Reports
- Length Determinations
  - Fuel Sources
  - Categories of Documentation
  - Building a Timeline
- Internal Configurations
  - Samarium Discs
  - Molybdenum Discs
  - Zirconium Rods
- Results
  - SAR Updates
  - Other Actions

Everybody likes new fuel

Fuel Inspection 2023

- First inspection since April 2018
  - Used underwater camera
  - Seven elements out of place
  - FEMT giving apparent incorrect measurements.
  - Aluminum oxide layer observed on all aluminum-clad elements
- Halted inspection and suspended operations for a full investigation.
  - Four reports, 76 pages total, 31 corrective actions identified.
  - Root cause and safety culture analysis performed.



USGS
science for a changing world

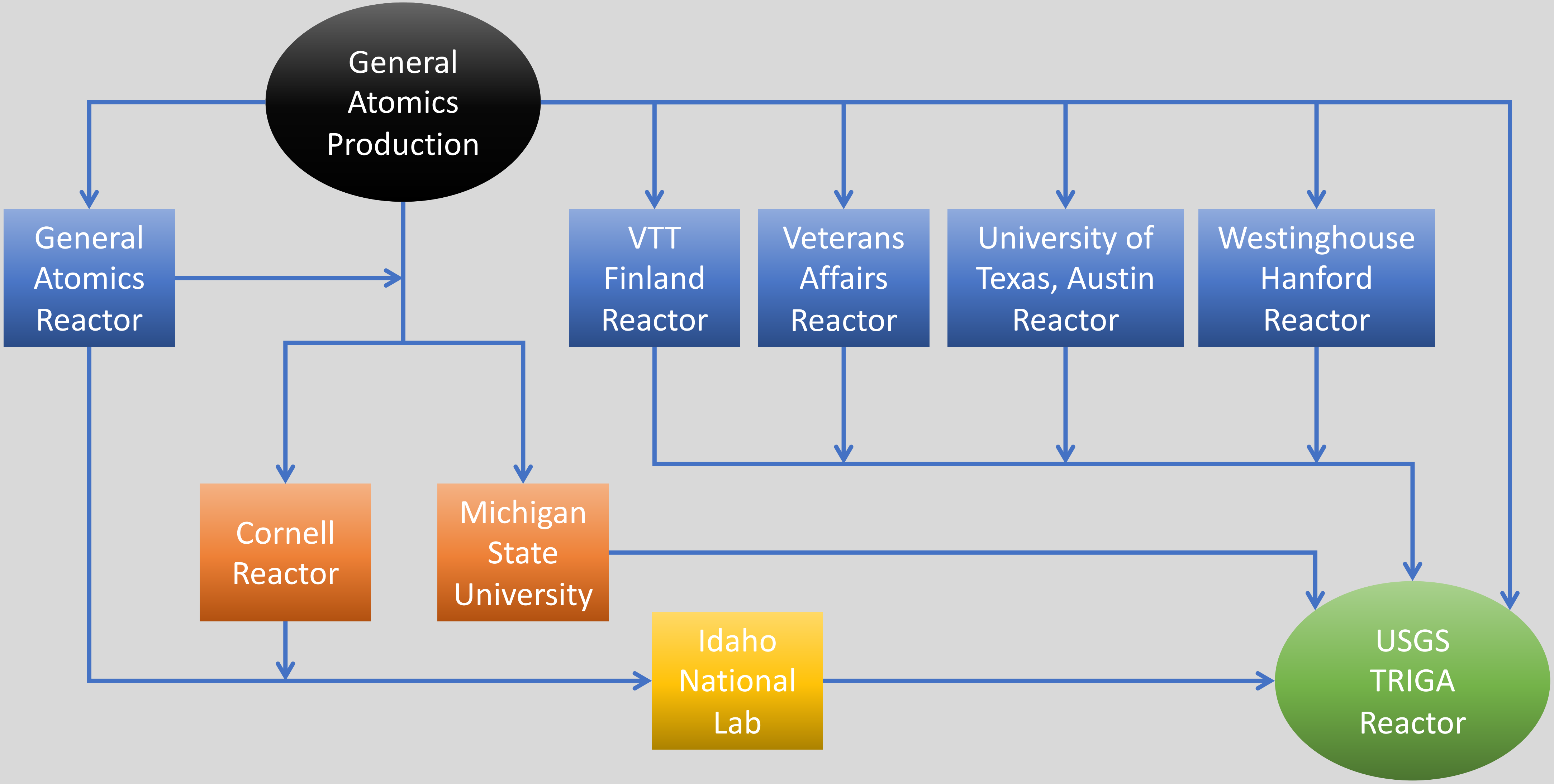
FEMT Usage Findings

- Review of all measurements conducted with FEMT.

FEMT Configuration	Percent Invalid
Setup A	0%
Setup B	6%
Setup C	**50%**
Setup D	0%
Setup E	**80%**
Setup F	**67%**

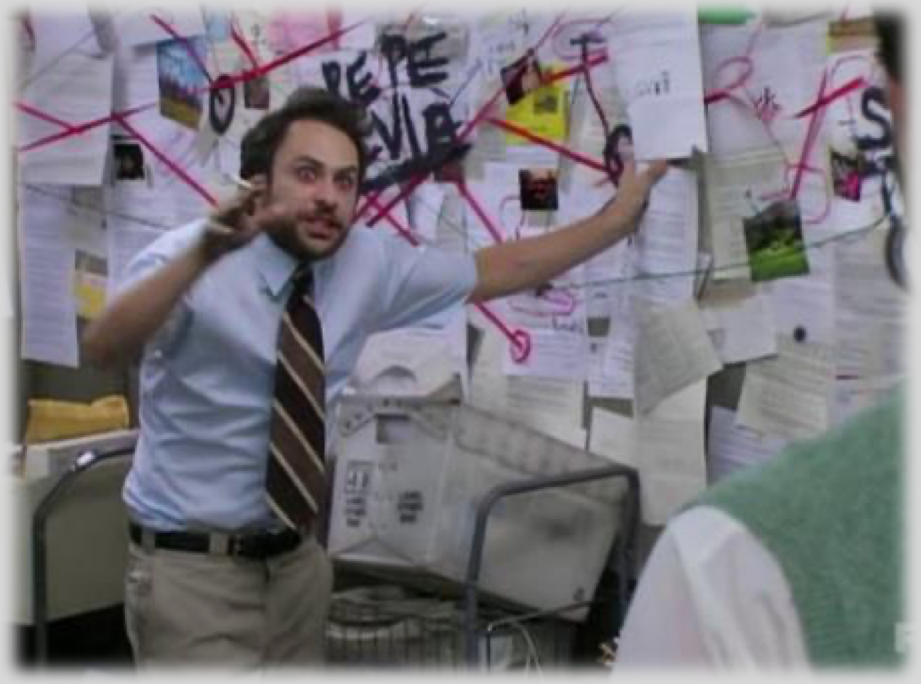
USGS
science for a changing world

Fuel Pathways to GSTR



Timeline Assumptions

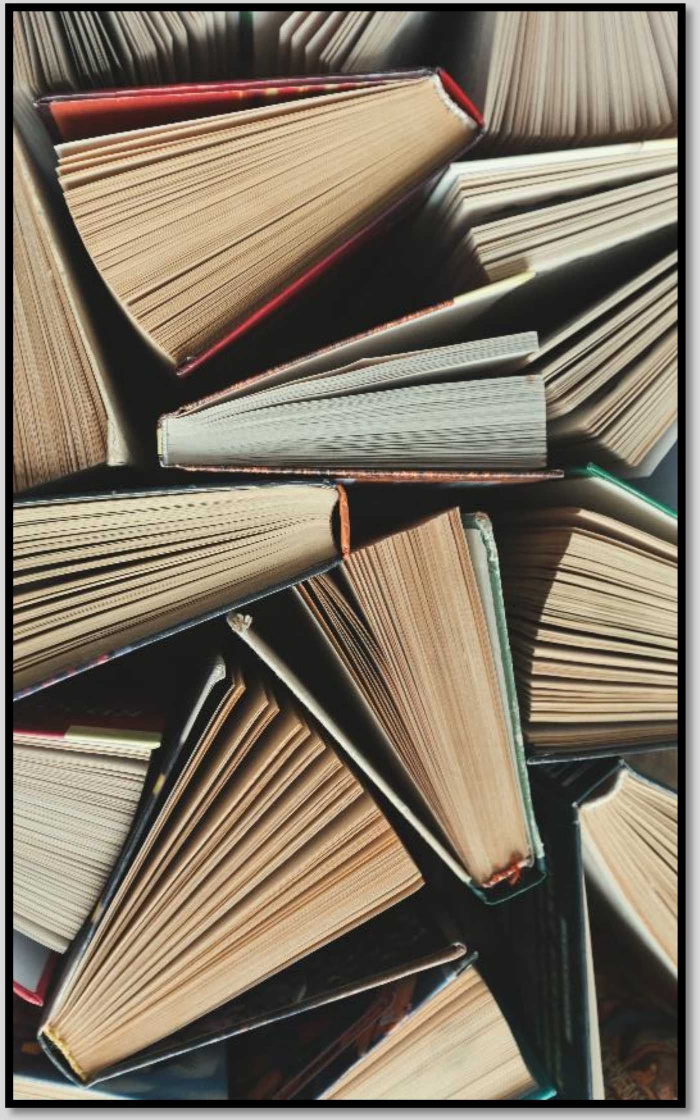
1. Fuel must exist to be installed in a core!
2. Drawings must exist to make fuel.*
3. Serial numbers made in order, no skips, no backsies.**
4. Highest serial number in a delivery considered to be final produced for batch.



5. For GA Prototype Mark I, estimated 70 elements needed for core, made 30 days before commissioning.***
6. QA checks require 30 days after manufacture.****
7. Once drawing is approved, only drawing used.

Timeline Documents

1. Material Transfer Form for the Veterans Administration Hospital, Omaha, Nebraska TRIGA Reactor, dated 1959-06-26.
2. ICP/INT-05-817 – Idaho Cleanup Project – TRIGA Fuel Summary Report, dated 2005-03.
3. IAEA-AEC-Finland Supply Agreements, Project Agreement, Correspondence, and Fuel Data/Shipping Records for the FiR1 Finnish Reactor, multiple dates.
4. ORNL/SUB-86-22047/2 / GA-C18542 – Characterization of TRIGA fuel by N. Tomsio, dated 1986-10.
5. CCN 310470-PJB-39-10 – Approval of the General Atomics Fuel and Packaging RSD-7-8-10-Attachment, dated 2010-07-01.
6. USGS original and subsequent fuel receipt documents for fuel purchased from General Atomics, multiple dates.
7. General Atomics quality assurance documents for elements 11842 and 11843, received from University of Texas at Austin on 2015-05-27, dated 2010-09-09.
8. General Atomics document GA-471: Technical Foundations of TRIGA, dated 1958-08-27.
9. General Atomics document GA-7259: TRIGA – A High Performance Steady State/Pulsing Reactor, dated 1966-09.
10. General Atomics document GA-1695 (Revision 4): TRIGA Mark I and Advanced TRIGA Prototype Reactors and Supporting Facilities, dated 1963-08.



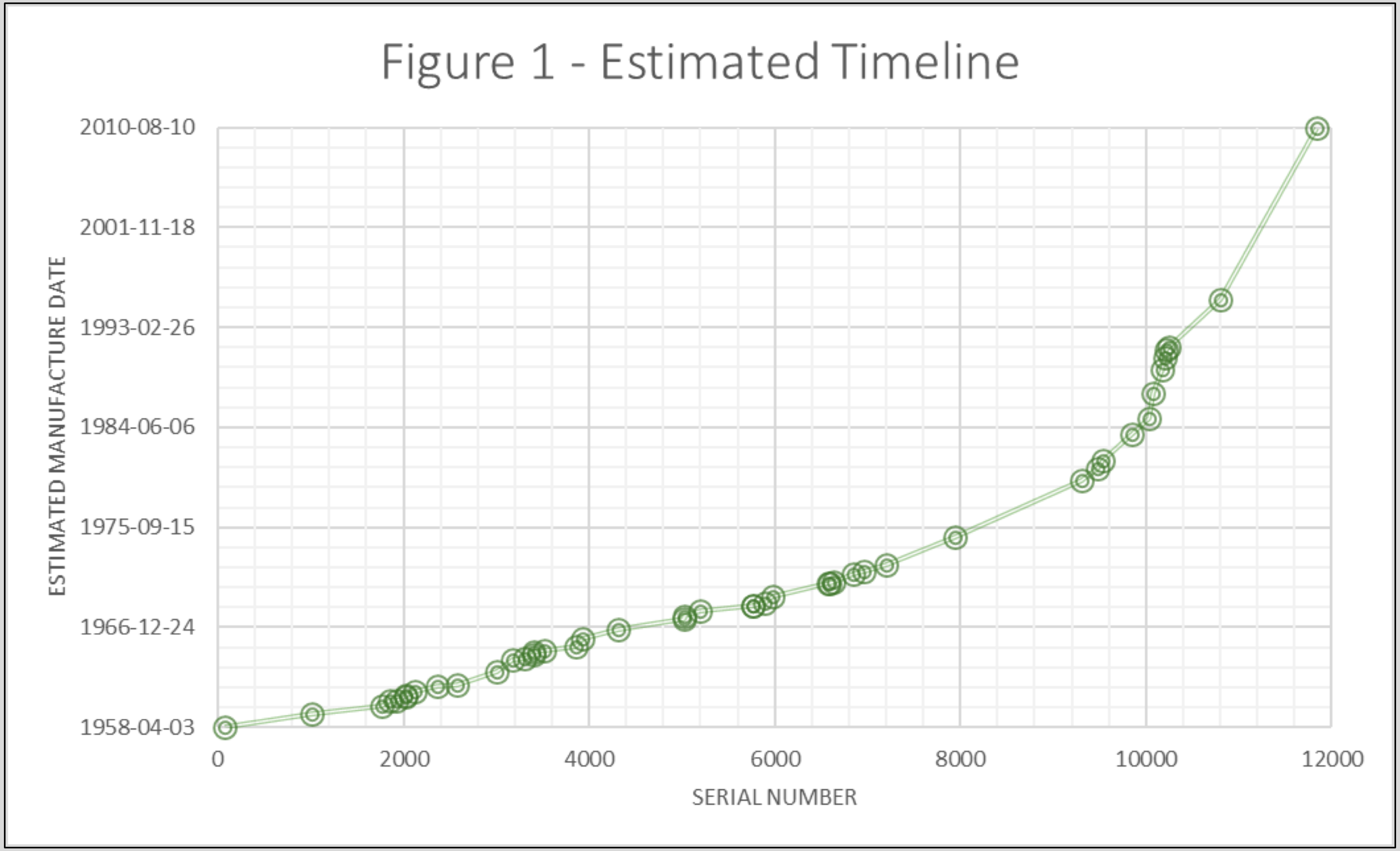
USGS
science for a changing world

Timeline Elements

Serial Number	Estimated Date Fabricated	Avg. Days/Element
70	1958-04-03	0
1010	1959-05-27	0.45
1763	1960-01-26	0.32
1851	1960-07-17	1.97
1923	1960-07-30	0.18
2019	1960-12-11	1.40
2027	1961-01-15	4.38
2122	1961-05-09	1.20
2366	1961-10-30	0.71
2575	1961-12-02	0.16
3004	1963-02-14	1.02
3172	1964-03-02	2.27
3299	1964-04-06	0.28
3400	1964-08-19	1.34
3403	1964-10-21	21.00
3515	1965-01-02	0.65
3859	1965-04-10	0.28
3924	1965-12-20	3.91
4312	1966-10-19	0.78
5016	1967-10-09	0.50
5029	1967-12-04	4.31
5199	1968-06-09	1.11
5762	1968-11-06	0.27
5768	1968-11-17	1.83
5886	1969-02-10	0.72
5980	1969-08-23	2.06
6575	1970-10-12	0.70
6594	1970-10-24	0.63
6628	1970-12-21	1.71
6843	1971-08-02	1.04
6955	1971-11-16	0.95
7201	1972-06-13	0.85
7933	1974-11-03	1.19
9304	1979-11-05	1.33
9474	1980-10-19	2.05
9534	1981-07-04	4.30
9843	1983-10-15	2.70
10038	1985-03-19	2.67
10078	1987-06-06	20.23
10173	1989-06-05	7.68
10207	1990-06-27	11.38
10213	1991-03-31	46.17
10252	1991-06-30	2.33
10807	1995-07-23	2.67
11843	2010-08-10	5.31

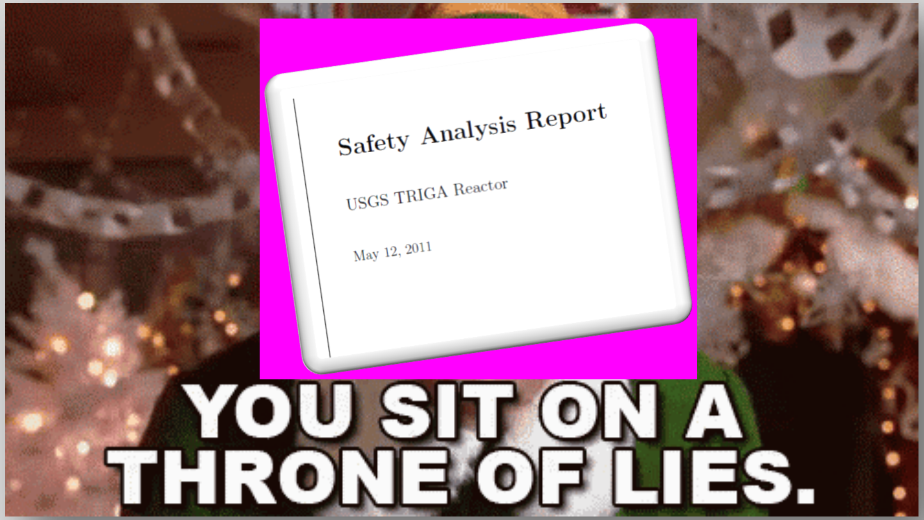
Table 1 – Serial Numbers, Estimated Dates, and Production Time

Timeline Graphic



Fuel Internal Configurations

- Drawings and INL Report:
  - Samarium discs in stainless steel-clad before 1964.
  - Molybdenum discs in all fuel after 1971.
  - Zirconium center rods not added until 1963-05.
- USGS SAR:
  - Samarium discs specifically excluded from stainless.
  - Molybdenum discs are not in any type.
  - Zirconium rods are in all fuel elements.



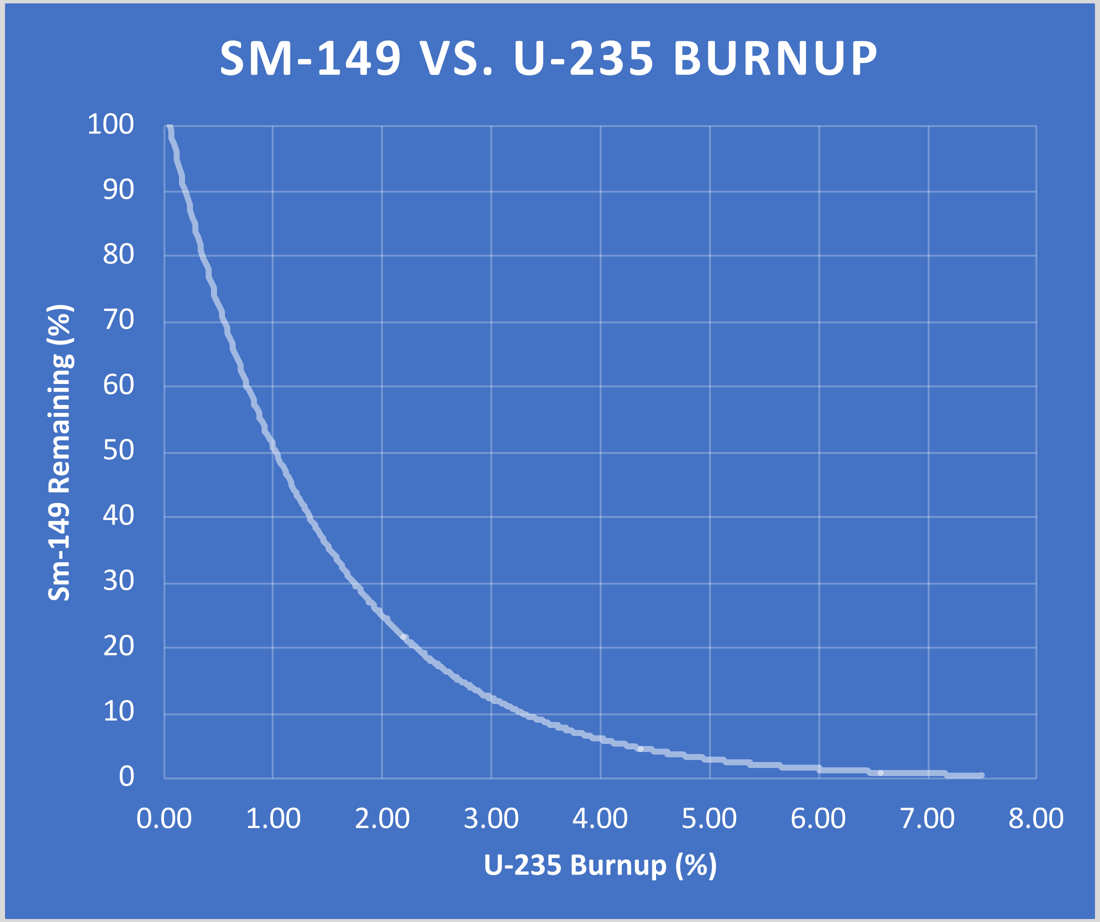
Samarium Discs

- INL Report – Table 7 footnotes:
  - 1c: Removal of the samarium (Sm) disc from drawing T0S210D**130** (original aluminum-clad standard elements) as of revision H on **1964-08-17**,
  - 2b: Removal of the Sm disc from drawing T0S210D**210** (original stainless steel-clad standard elements) as of revision F on **1964-04-10**.

- GA Drawing Revision Notes:
  - **1964-08-17**:
    - T0S210D**130** Rev H, T0S210D**160** Rev D, and T0S210D**210** Rev E all state:
    - Rev. note 5 – measured length 25.125 was from top weld; removed item 9; added “stake (4) places
  - **1964-11-06**:
    - 130 J, 160 E, 170 E, and 210 F all state:
    - Removed item (9/8/16/8), respectively.
    - 210 F added item
  - No revisions on **1964-04-10.**

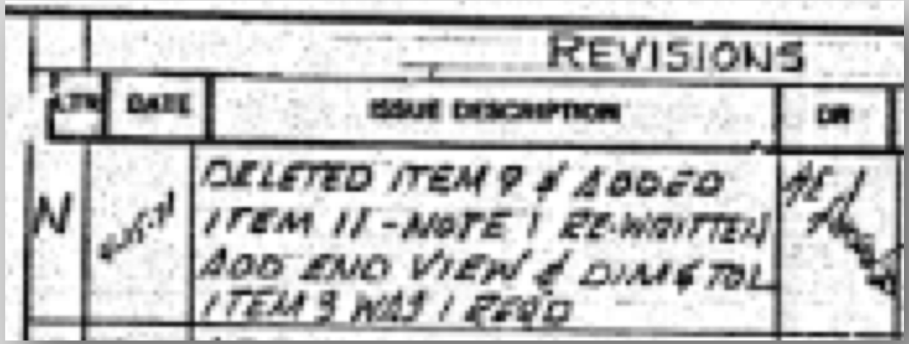
Samarium Discs

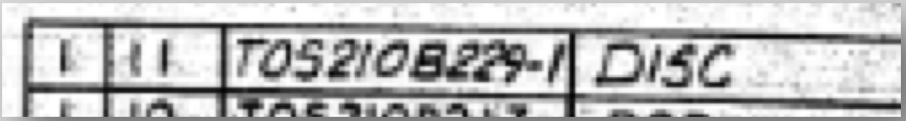
- What is the impact now?
- Sm disc end of life set at 1% of Sm-149 original value.
- Calculations show element U-235 burnup to 7% achieves Sm EOL.
- Agrees with GA-471 (Technical Foundations of TRIGA, 1958), and general understanding on loaded burnable poisons.
- Effectively every element on site with Sm discs is beyond 7% burnup => no current effect.

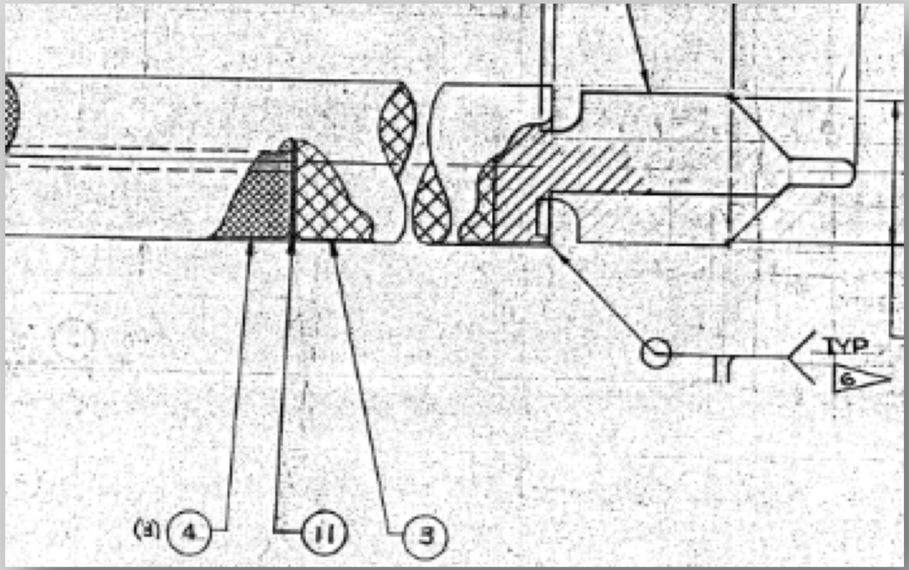


Molybdenum Discs

- Used to prevent potential fusing of graphite to fuel meat.
- Included in all variants starting 1971-04-15 with Revision N.
- USGS SAR explicitly excluded moly discs from all fuel types.
- Given effectively inert function on neutronics and other performance, no major issue, only regulatory / documentation.

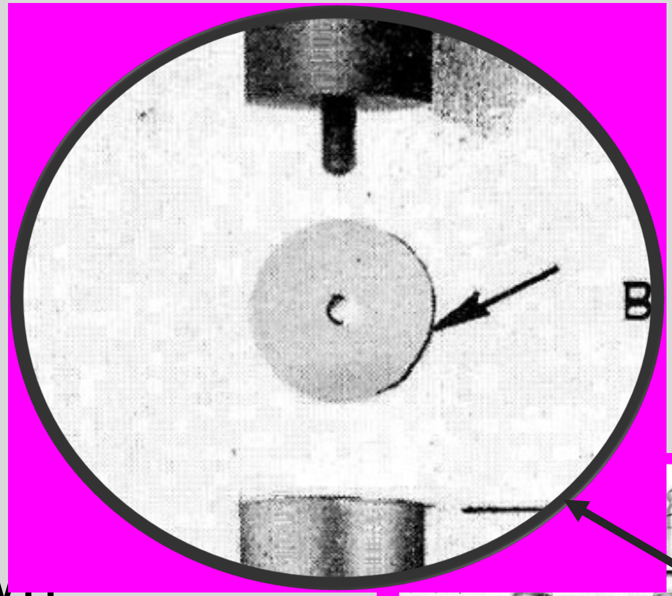


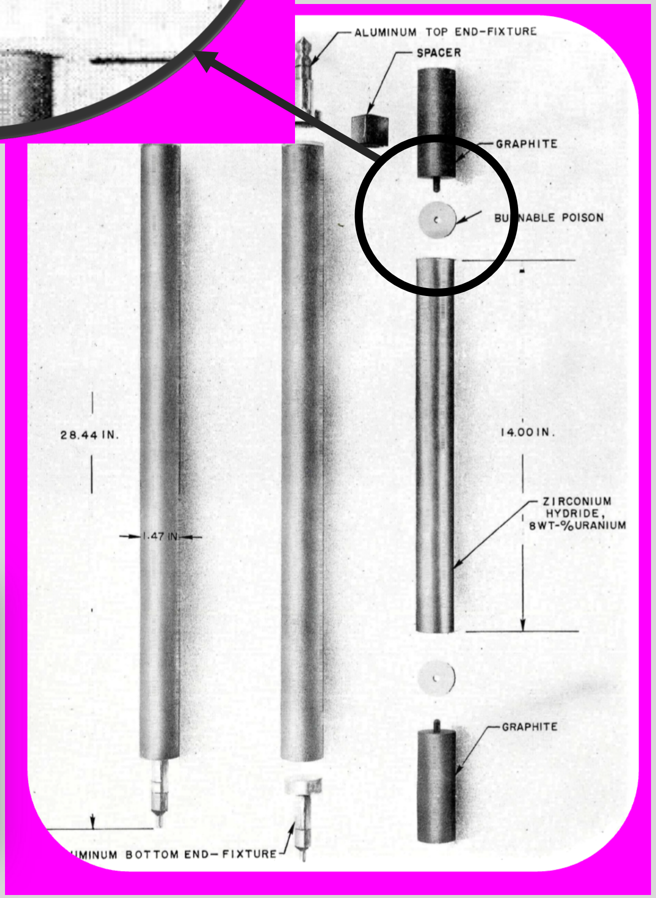




Zirconium Rods (Al Clad)

- INL Report – Table 7 footnote 2a:
  - T0S210D**210** (original stainless steel-clad standard elements) Rev. B added axial zirconium rods as of **1963-05-28**.
- Image from GA-471 (1958-08-27) shown of aluminum-clad element construction, but no drawings show hole until 1964.
- Always 1.0 H/Zr ratio, to common understanding and documentation.





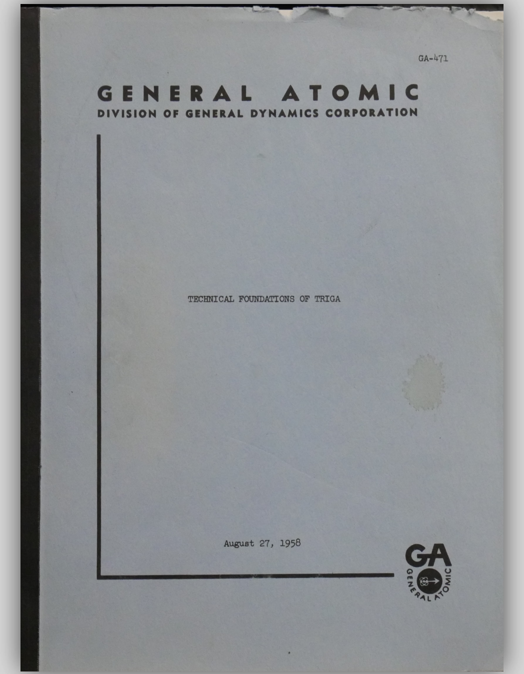
SAFETY OF THE REACTOR

Chemical Stability of the Fuel Elements

The fuel elements are clad in 0.030 in. of high-purity aluminum (type 6061). It is well known that this material suffers very slight corrosion

Zirconium Rods (SS Clad)

- If H/Zr ratio is 1.0, then temp limit of 530° C applies to early SS-clad.
- GA-471 describes many experiments of up to 2.0 H/Zr without central hole.
- Evidence given by GA-7259 (1966-09).
- Supported by GA-1695 (1963-08), describing ATPR's fuel ratio of 1.7


GA-471

GENERAL ATOMIC
DIVISION OF GENERAL DYNAMICS CORPORATION

TECHNICAL FOUNDATIONS OF TRIGA

August 27, 1958

GA GENERAL ATOMIC

3. Stainless steel clad U-$ZrH_{1.7}$ fuel elements (steady-state/pulsing). By increasing the hydrogen content by 70%, the phase transition is eliminated and the fuel material remains in a single-phase to temperatures well in excess of 1000°C.

Bonus Finding: Aluminum Versions

- VA Omaha Fuel:
  - Delivered 1959-06,
  - No pulsing capability,
  - Predates 160 drawing,
  - **Steady-state only fuel (probable)**

1. Aluminum clad U-Z rH$_{1.0}$ (steady state). Used for steady-state operation up to 250 kw with natural convection cooling of the core.

- VTT Finland Fuel:
  - Delivered 1962-03,
  - Pulse capability,
  - Made after 160 drawing
    - Within 3 months,
  - **Steady-state and pulsing fuel (probable)**

2. Aluminum clad U-Z rH$_{1.0}$ (steady-state/pulsing). These fuel elements, similar to the steady-state fuel elements above, are fabricated using different techniques to permit routine pulsing. The steady-state performance is up to 250 kw and routine pulsing up to 250,000 kw ($2.00 reactivity insertion) with a graphite-reflected configuration. These fuel elements have also been used in a water-reflected configuration for pulsing up to 1,200,000 kw. High performance operation with these fuel elements is limited to fuel temperatures below 500°C because of a phase transition at ~530°C.

USGS
science for a changing world

How well do you do fuel?

- Misplaced trust and confidence in programs and documentation.
- Historical programs need reassessment, improvement, best practice incorporation.
- For reactors, especially TRIGA, fuel is the ultimate safety mechanism.
- Poorly maintained fuel leads to unnecessary failures -> no health consequences, but perception and reputation damage.

Nobody likes bad fuel

Contact Information and Questions

If you have any questions after the presentation or conference:

- Jonathan Wallick
  - Reactor Director at USGS TRIGA Reactor Facility
  - jwallick@usgs.gov
  - (303)236-1463