History, Development and Future of TRIGA® Research Reactors

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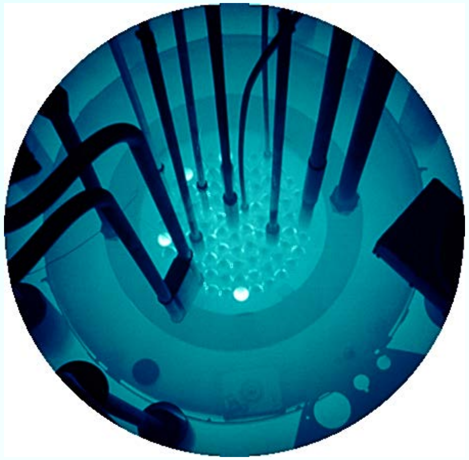

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History, Development and Future of TRIGA ® Research Reactors

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TRIGA HISTORY (1)

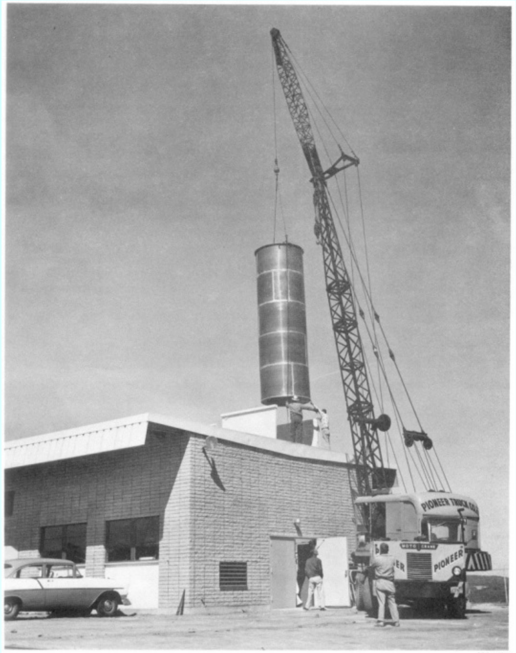
- TRIGA®

  Training

  Research

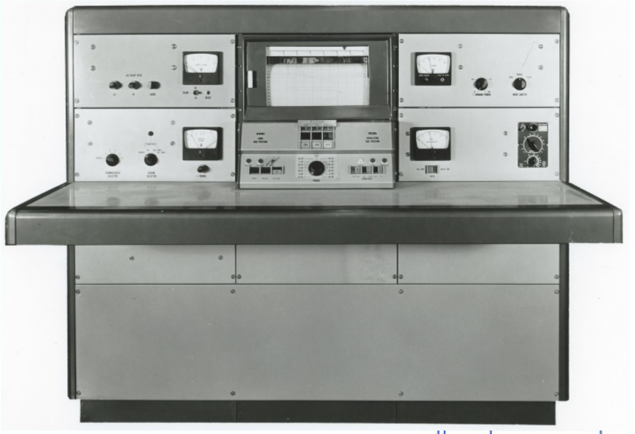
  Isotope Production

  General Atomic



Reactor tank being lowered into TRIGA Mark Building at General Atomic

Original 10 kW TRIGA in San Diego



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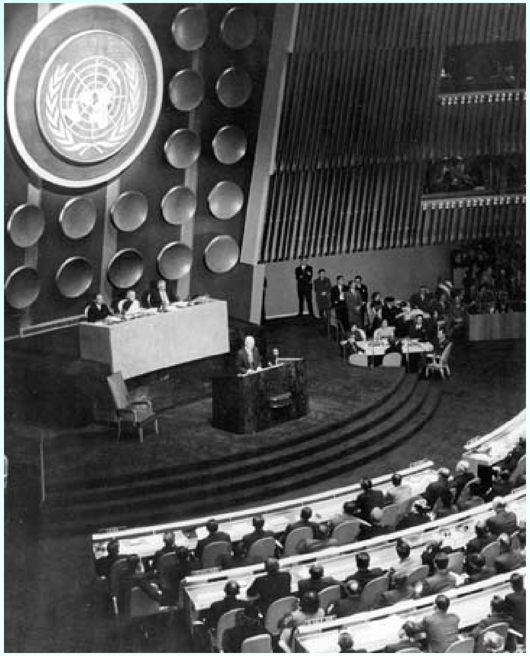
TRIGA HISTORY (2)

- **Atoms for Peace** was the title of a speech delivered by **U.S. President Dwight D. Eisenhower** to the UN General Assembly in New York City on **December 8, 1953.**



"It is with the book of history, and not with isolated pages, that the United States will ever wish to be identified. My country wants to be constructive, not destructive. It wants agreement, not wars, among nations. It wants itself to live in freedom, and in the confidence that the people of every other nation enjoy equally the right of choosing their own way of life."

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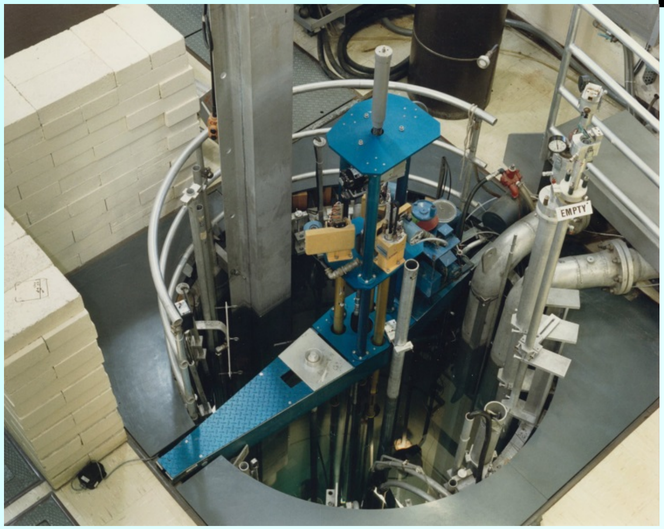
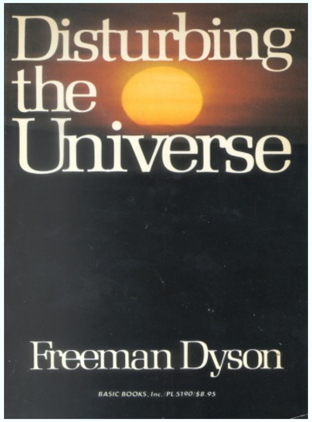
THE BIRTH OF TRIGA (3)

Original TRIGA in San Diego

1958 - 1995



- **THE SO-CALLED SAFE REACTOR WAS ORIGINALLY EDWARD TELLER'S IDEA.**
  - *"... a reactor so safe that it could be given to a bunch of high school children to play with without any fear that they would get hurt ..."*
  - *"... inherent safety means that its safety must be guaranteed by the laws of nature and not merely by the details of engineering ..."*



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TRIGA HISTORY (4)

- **TRIGA was developed to be a reactor that,** in the words of Frederic de Hoffmann, head of General Atomics, **was designed to be "safe even in the hands of a young graduate student."**

- **Edward Teller** headed a group of young nuclear physicists in San Diego in summer 1956 to design a reactor which could not, by its design, suffer from a meltdown.

TRIGA HISTORY (5)

- The design was largely the suggestion of **Freeman Dyson.**

- The prototype for the TRIGA nuclear reactor (TRIGA Mark I) was commissioned on **3 May 1958** in San Diego and operated until shut down in 1995.

- It has been designated as a nuclear historic landmark by the American Nuclear Society.

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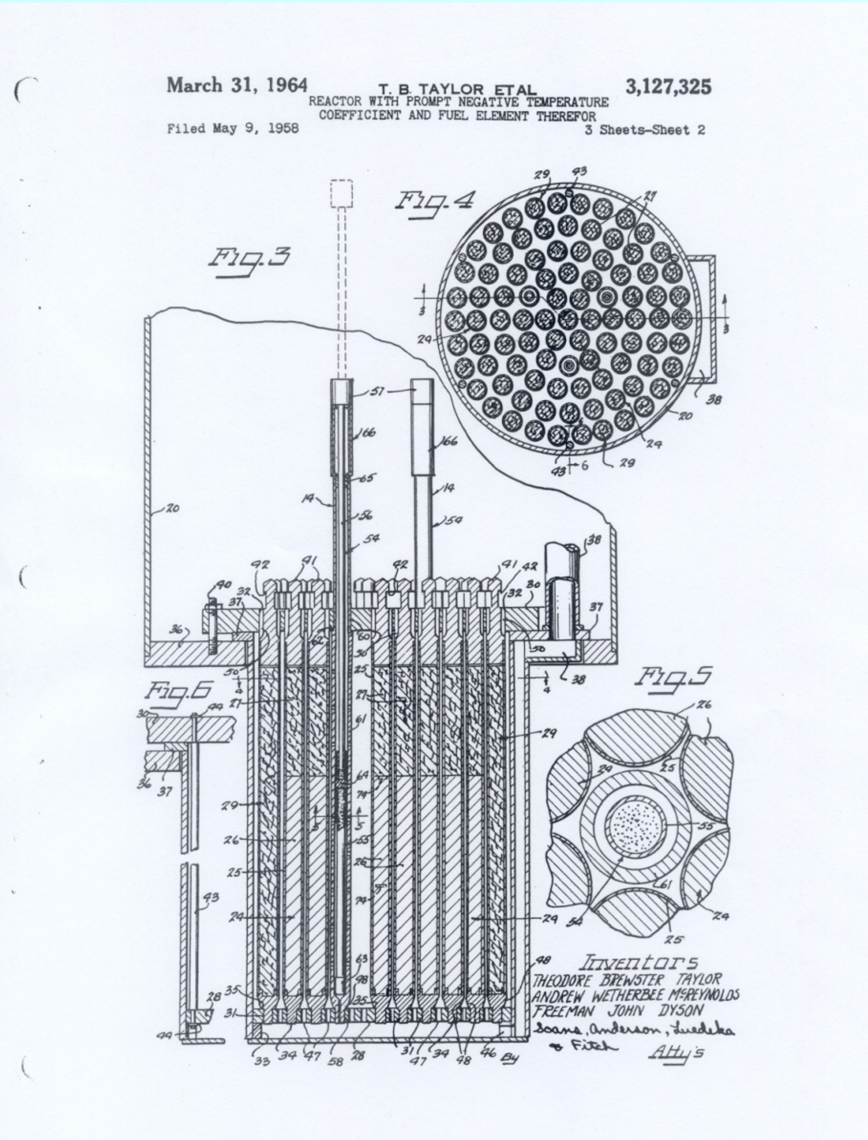
TRIGA Original Patent



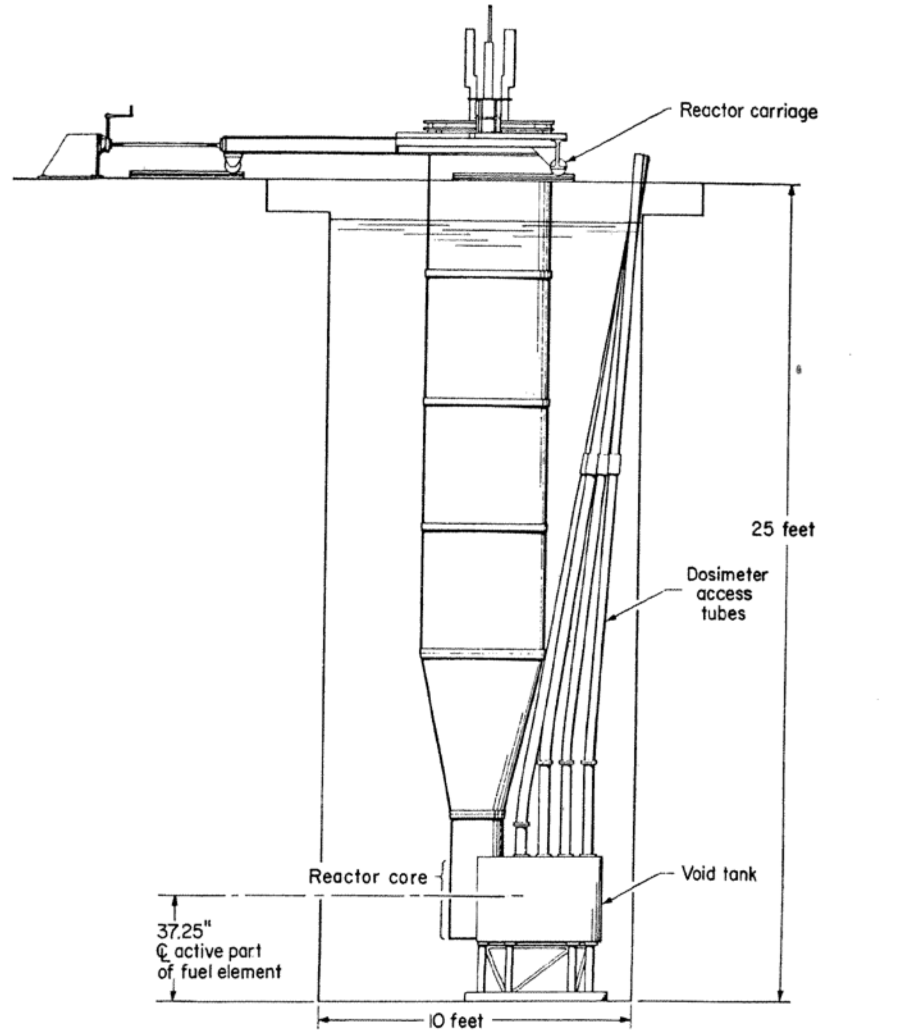
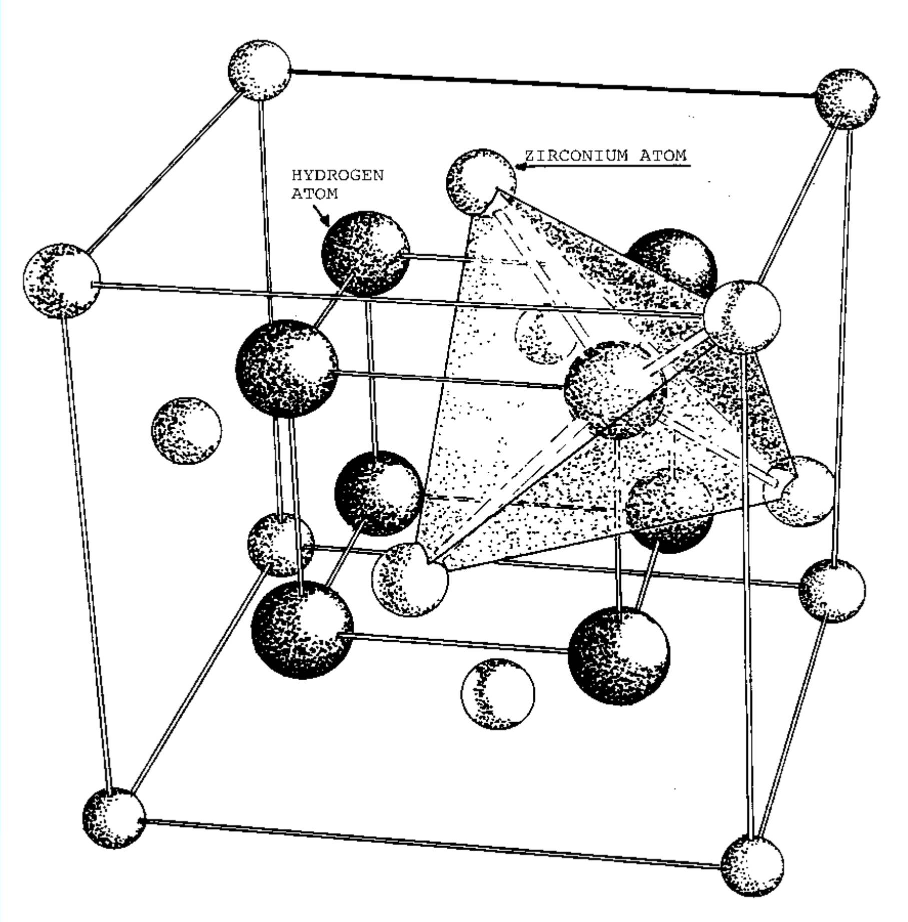


FIG. 3. Schematic of the TRIGA Mark F tank arrangement.

U-Zr-H Unit Cell



The tetrahedral structure of four zirconium atoms (light coloured) surrounding
a hydrogen atom (black) is emphasized for one of the hydrogen atoms.
The hydrogen atom is oscillating depending on the temperature of the fuel

FUEL TECHNOLOGY FOR TRIGA® REACTORS (1)

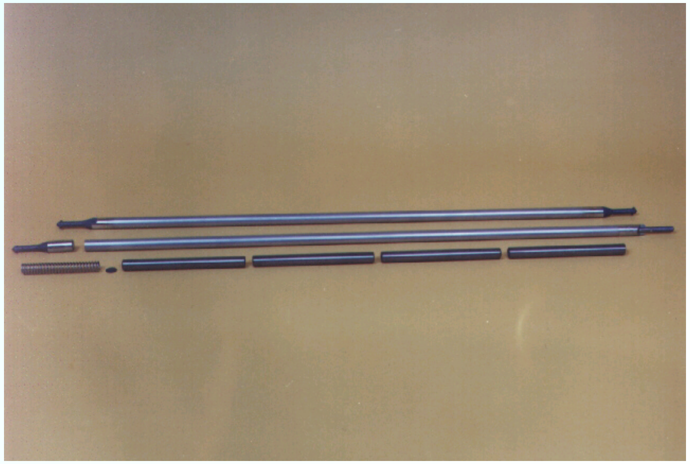
- **$UZrH_x$** metallic alloy fuels were first developed for satellite use — early 1950

- Development continued at GA for research reactors — late 1950- **“warm neutron principle”**

- Early fuels were LEU (19.7% U-235) with low density (<1.0 gU/cm^3). HEU used where extended core life was required.

- Higher density (3.7 gU/cm^3) LEU fuels for high power regimes with long core life are now in use — early 1980

Standard TRIGA Fuel element: diameter ~ 36 mm



High TRIGA fuel element: diameter ~13mm

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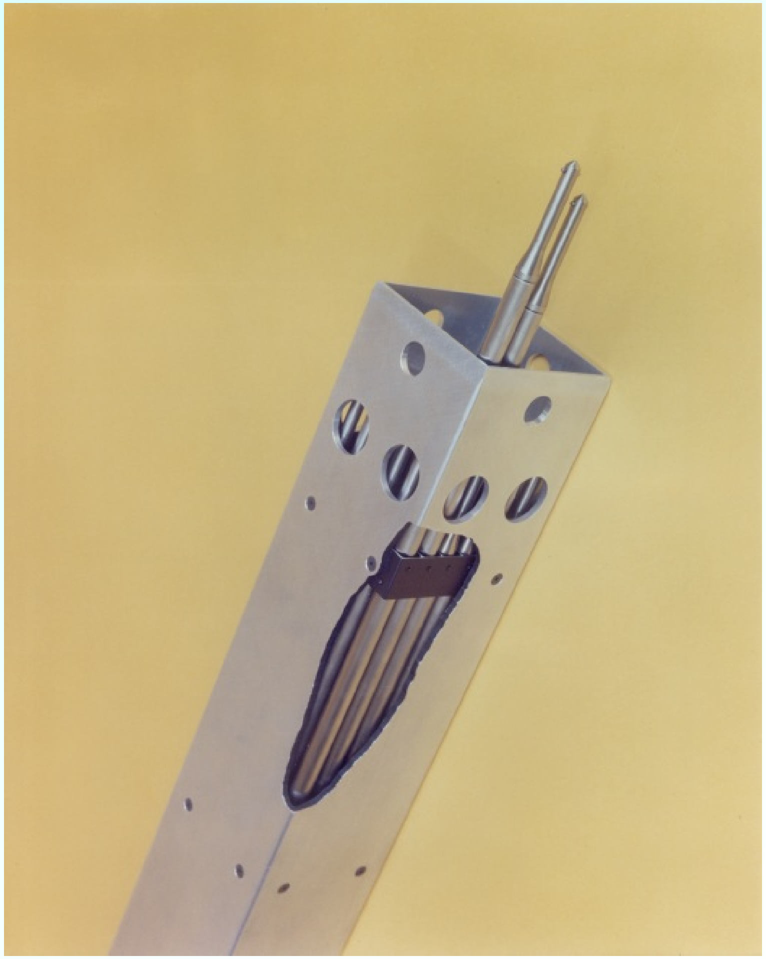
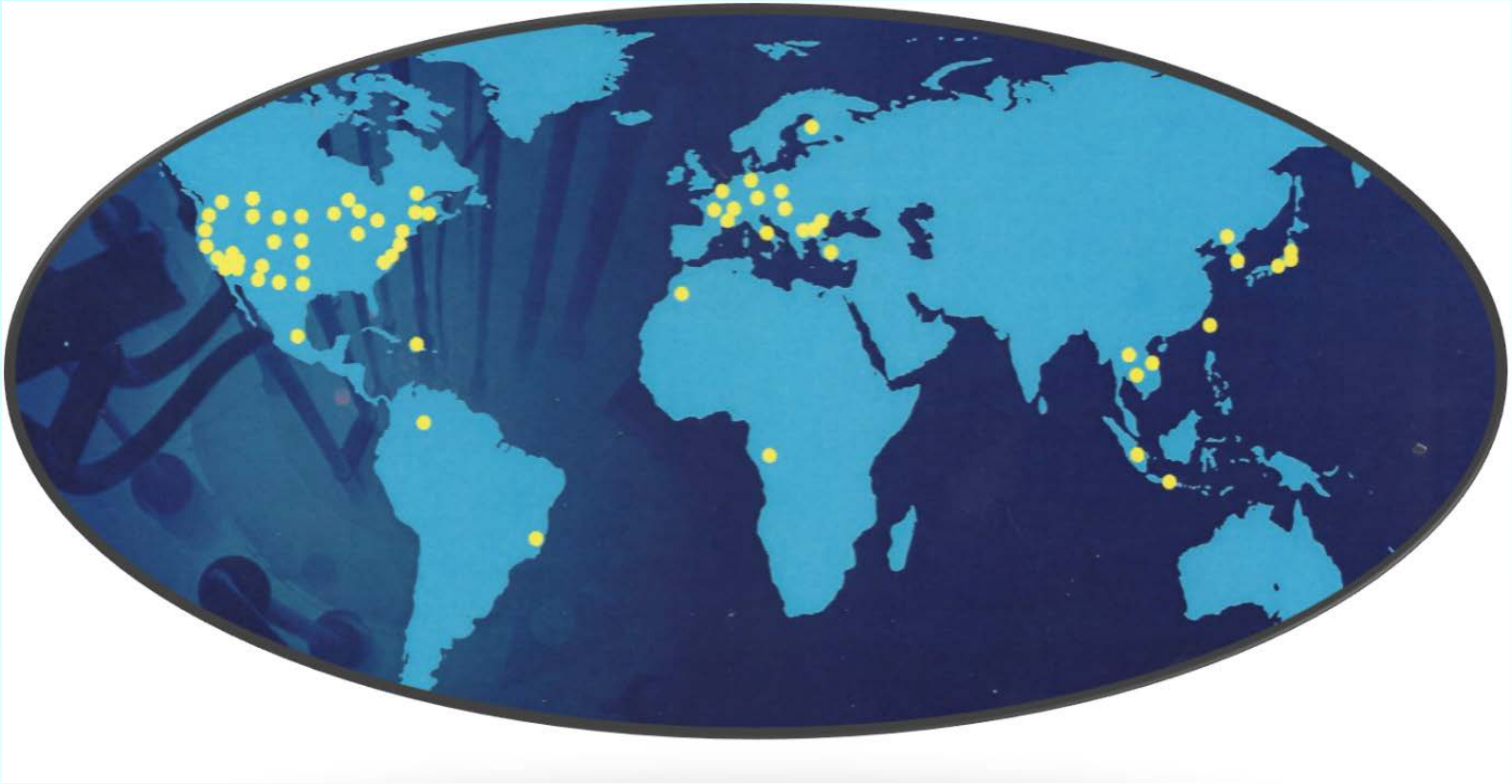
FUEL TECHNOLOGY FOR TRIGA® REACTORS (2)

- **Properties:** Hydrogen – Zirconium ratio from 1.0 to 1.7
- UZrH is chemically stable, it can be quenched at 1200° C with no interactions in water.
- Fuel cladding provides total integrity at fuel temperatures as high as 1150° C (950° C in air).
- UZrH offers far superior retention of fission products, more than 99% of volatile fission products are retained even if all the cladding were removed.



High power TRIGA fuel assembly

66 TRIGA Reactors in 23 Countries



Steady State Power from 20 kW to 14 MW

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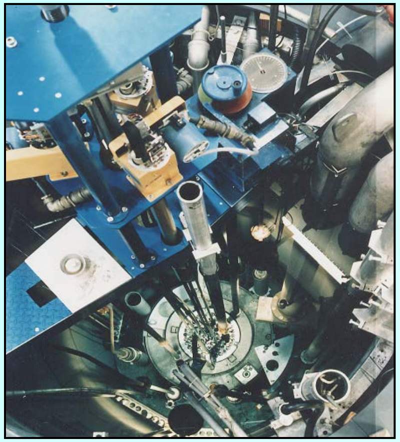
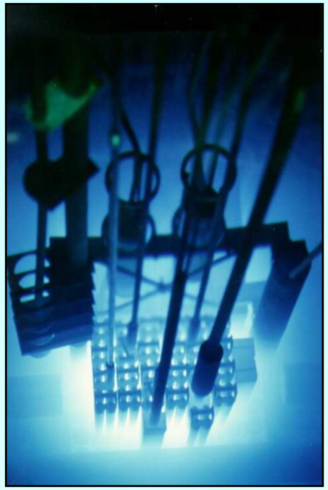
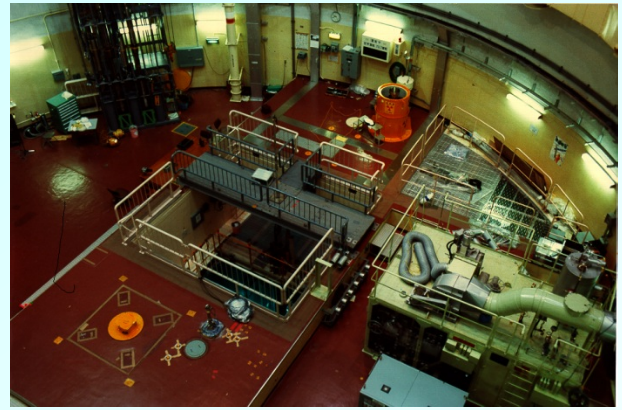
TYPES OF TRIGA REACTORS

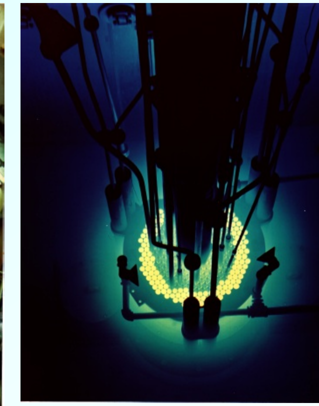


Underground Mark I
General Atomics



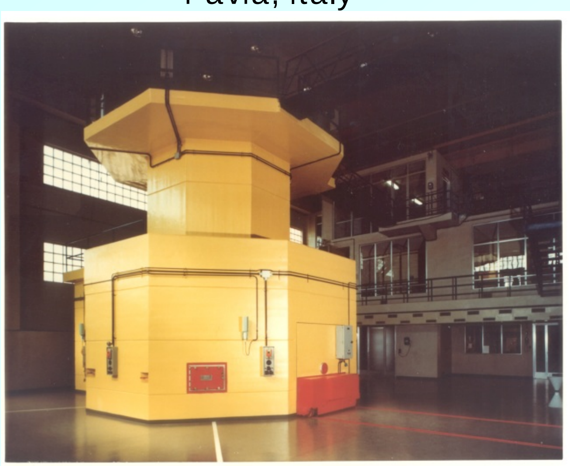
MTR Conversion
University of Maryland



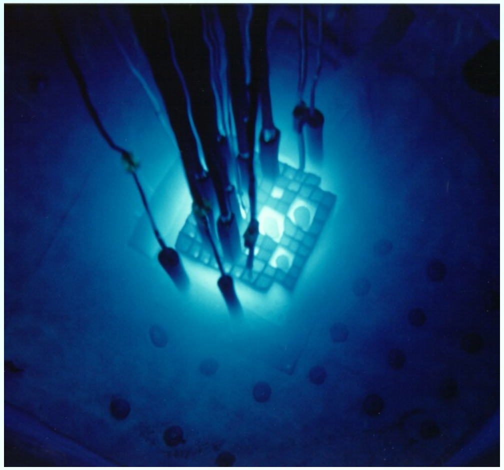


High Power Pulsing Reactor
Tokai Mura, Japan

Above ground Mark II
Pavia, Italy



14 MW MultipurposeReactor
Romania



Moveable Core Mark III
Munich, Germany

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FUEL SITUATION TODAY

- GA transferred it's fuel production operations to CERCA Plant in Romans/France in 1996 (TRIGA International, SAS)
- Due to post-Fukushima safety and security upgrades mandated, fuel production was stopped in March 2013
- At present production is expected to start again ~2017.
- The main problem is that individual TRIGA reactor operators cannot commit themselves for the need of a specific number of TRIGA fuel elements to be supplied at a given date
- If TRIGA fuel is not available, this could lead to a permanent shut down of many TRIGA reactors around the world in the near future

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Education and Training at University Level

- Nuclear Technology
- Radiochemistry
- Nuclear Physics
- Safeguards
- Radiation Protection and Dosimetry
- Geology
- Biology
- ……and many more fields (i.e. TRIGA Vienna, Mainz, Ljubljana, Pavia)

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NAA & Radiosiotope Production

- Ultra short lived NAA (Mainz)
- Medium power TRIGA reactors provide adequate flux to meet most national and regional needs for commonly used medical isotopes
- Geochronology: academic research, example: pumice distribution after the Santorin eruption 3500 years ago in the Eastern Mediterranean area

Transmutation Research

- Change of material properties through neutron/gamma irradiation
- Power level above 2 MW necessary (i.e. Romania, University of California)
- Gemstone colorization: to enhance or influence the colour of gemstones, in Europe not allowed but has been carried out at US and Asian TRIGA reactors

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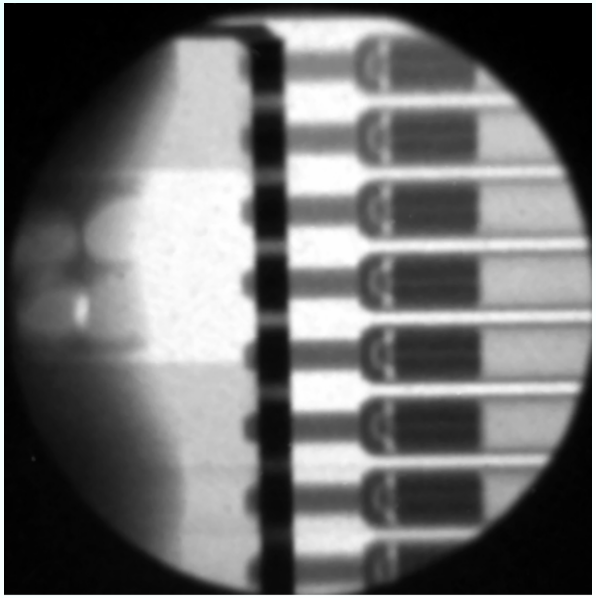
Neutron Radiography

- Static- and/or real-time neutron radiography and tomography
- Carried out at many TRIGA reactors
- TRIGA at UC Davis initially devoted to real time NR of aircraft wings, but now performs other NR
- NR of nuclear fuel,moisture in building materials

NR of the end caps of a fresh WWER 440 fuel element 3.6% enriched



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Neutron- and Solid State Physics

- Using radial-, tangential- or piercing beam ports
- Various types of collimators installed
- Experiments such as
  - ultra small angle neutron scattering,
  - neutron diffraction and
  - neutron interferometry (first demonstrated at TRIGA Vienna in 1974)

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Boron Neutron Capture Therapy

- Originally demonstrated at 250 kW Mushashi TRIGA
- Advantage of TRIGA reactors due to flexibility and simple design
- Easy access to irradiation positions (thermal column)
- TRIGA reactor in Finland was devoted to BNCT with good results
  - Permanently shut down in May 2015 due to financial reasons

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NPP Operators Training & Retraining

- Practical training in reactor physics and kinetics
  (neutron flux measurement, control rod calibration, temperature coefficient, void coefficient, subcritical multiplication)

- Practical training in reactor instrumentation
  (compensated ionization chambers, fission chambers, self-powered neutron detectors)

- Practical training in radiation protection
  (personnel monitoring, area monitoring, environmental monitoring)

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Challenges for TRIGA Reactors

- Continued supply of TRIGA fuel in the long term due to lack of sufficient demand to justify the costs of operating a dedicated fabrication facility,
- Back end options related to the spent nuclear fuel return to the country of origin programme (2016/2019 deadline for non-US located reactors),
- As demand for new research reactors continues to decrease and the workforce ages, there are valid concerns about continuing technical support at a high level from the original reactor manufacturer.

Challenges for TRIGA Reactors

- Strengthen regional and global cooperation among TRIGA facilities toward the development of solutions for common issues and challenges, including fuel front-end and back-end options;
- Enhance TRIGA reactor utilization through common and complementary products and services as well as exchange of experiences and practices;
- Increased viability and visibility of TRIGA reactor operation in the future through contacts and effective relationships with national and international stakeholders.

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