Fusion Neutrons: Advanced Nuclear Technologies and Decarbonisation

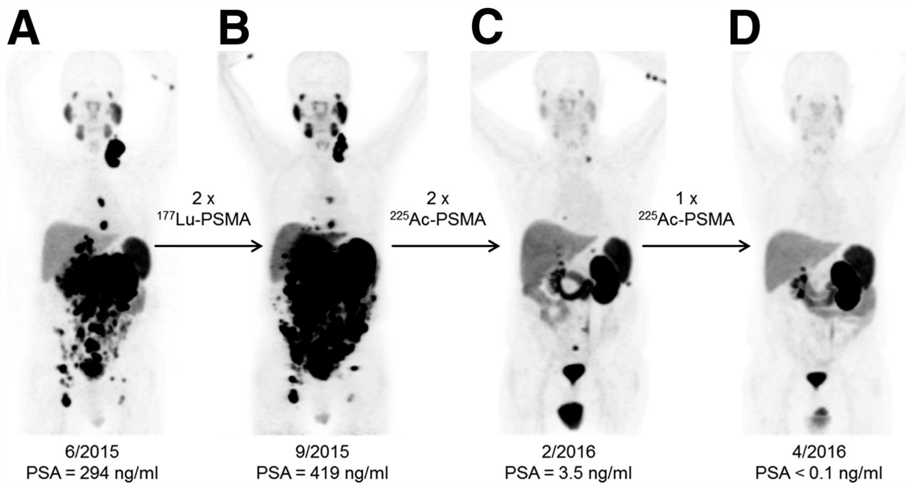
- Introduce history of **nuclear technologies**.
- Describe applications of **fusion neutrons**.
- **Dive** into **Astral Systems**, who we are and what we do.
- **Give** examples of how **fusion can benefit fission** and **vice versa**.

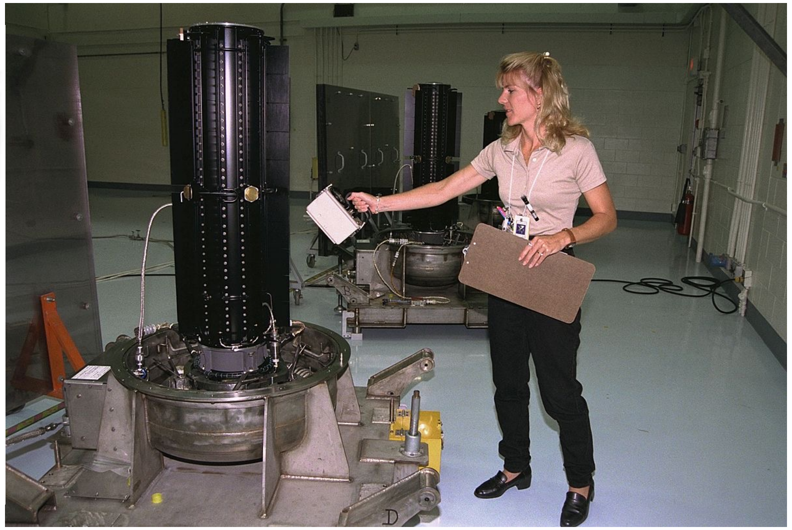
Nuclear Technologies: Early History

ASTRAL SYSTEMS

SOUTH WEST NUCLEAR HUB

- **1953: Then-US President Eisenhower** makes his "**Atoms for Peace**" speech where he sought to suggest a means to **transform the atom** from a **scourge** into a **benefit for mankind**.
- This led to **policy makers**, **industry**, and **academia** to pursue **nuclear technologies** with **societal benefit**.
- Resulting in **breakthroughs** such as **food sterilization**, **crop mutation**, **nuclear medicine**, **RTG's for space missions**, and much more.





Advanced Nuclear Technologies: Fusion

ASTRAL SYSTEMS

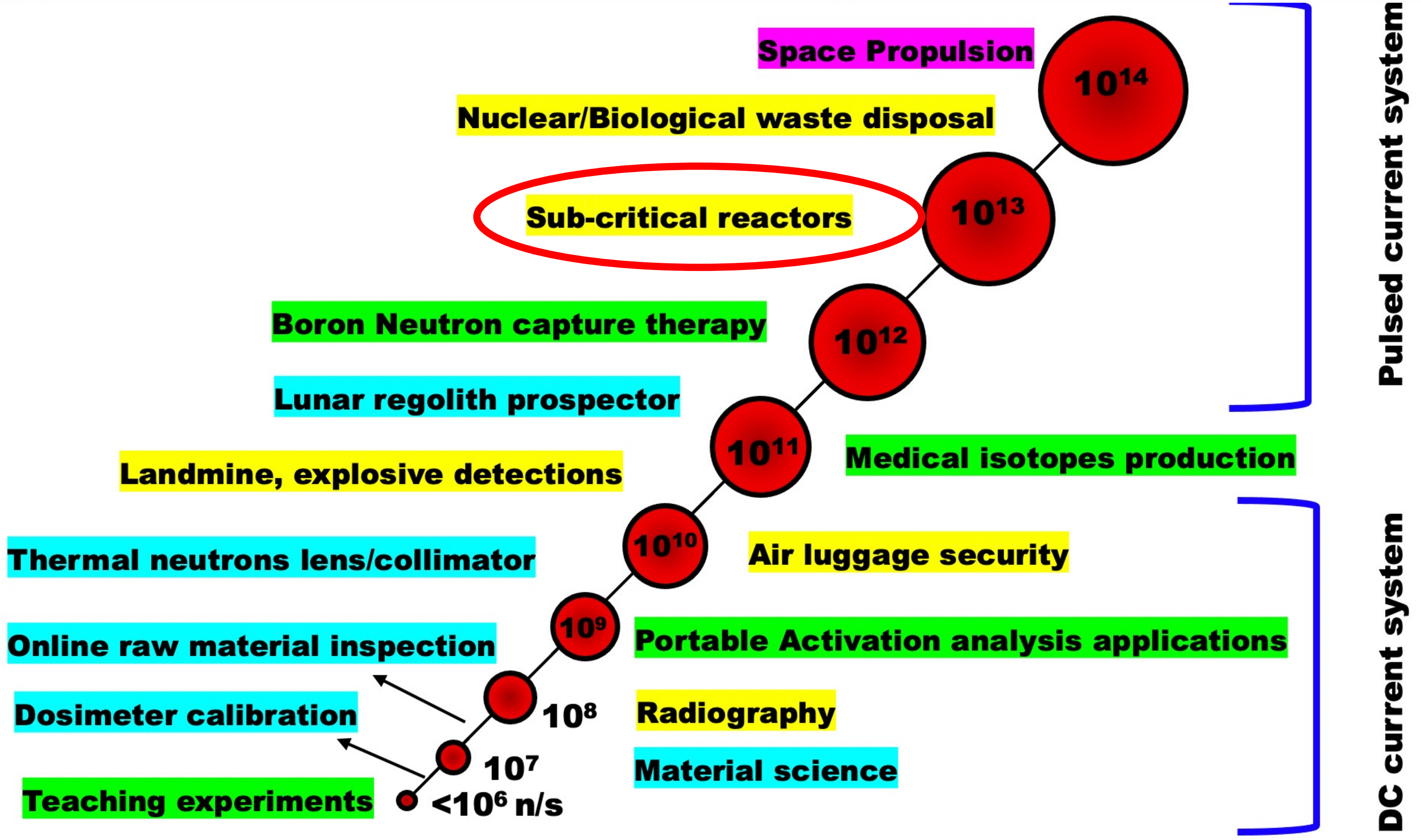
SOUTH WEST NUCLEAR HUB

$${}^{2}_{1}D + {}^{2}_{1}D \rightarrow {}^{3}_{2}He\,(0.82\,MeV) + n^{0}\,(2.45\,MeV)$$

$${}^{2}_{1}D + {}^{3}_{2}He \rightarrow {}^{4}_{2}He\,(3.6\,MeV) + p^{+}\,(14.7\,MeV)$$

$${}^{2}_{1}D + {}^{3}_{1}T \rightarrow {}^{4}_{2}He\,(3.5\,MeV) + n^{0}\,(14.1\,MeV)$$

- The **fusion rate** of a **reactor** can be represented by the **number** of **fusion events per second**, or **Neutron Production Rate** (**NPR**).
- As **fusion reactor technologies advance**, **higher rates** and more **continuous operation** can be **achieved** which **unlocks new applications** and **markets**

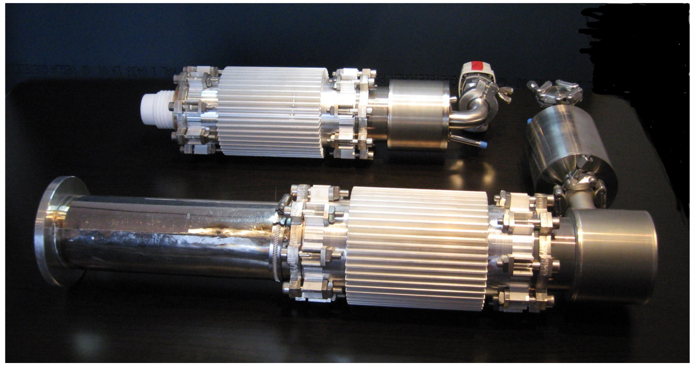


ASTRAL SYSTEMS

Astral: History

SOUTH WEST NUCLEAR HUB

Website



Two short chambers.

NSD-Fusion
ASTRAL SYSTEMS
Neutron Generators

Outside cowling removed, showing fins for air cooling.

Water cooled high-output system.

Example Customers:

- CERN
- Grafenrheinfeld nuclear power plant
- Mannheim University
- Purdue University
- Texas A&M University
- Sheffield University
- IAEV Brazil
- CSIRO
- Poland for Online Coal Analysis
- South Korea for Materials Testing

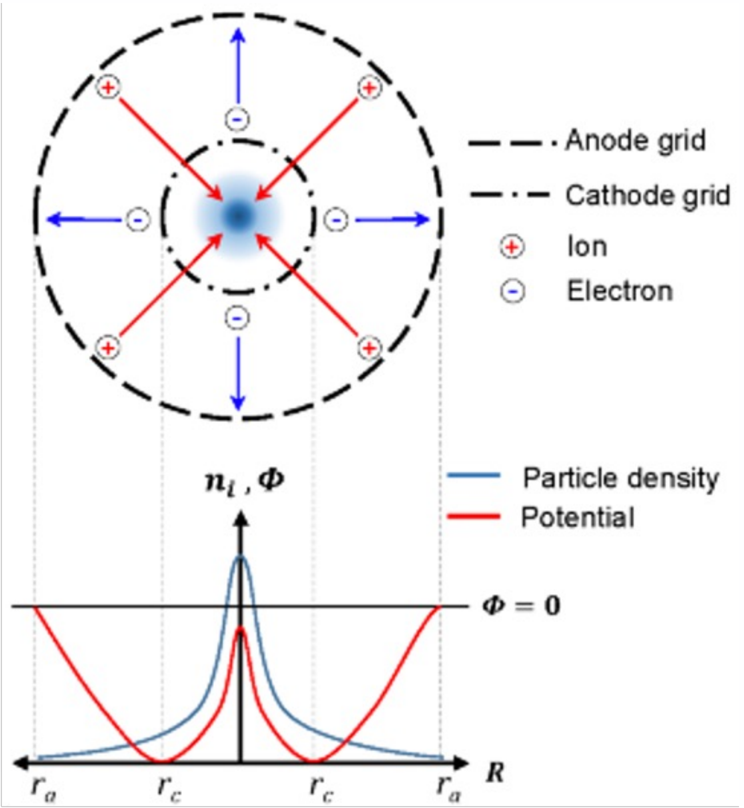
Polyethylene shielded test setup

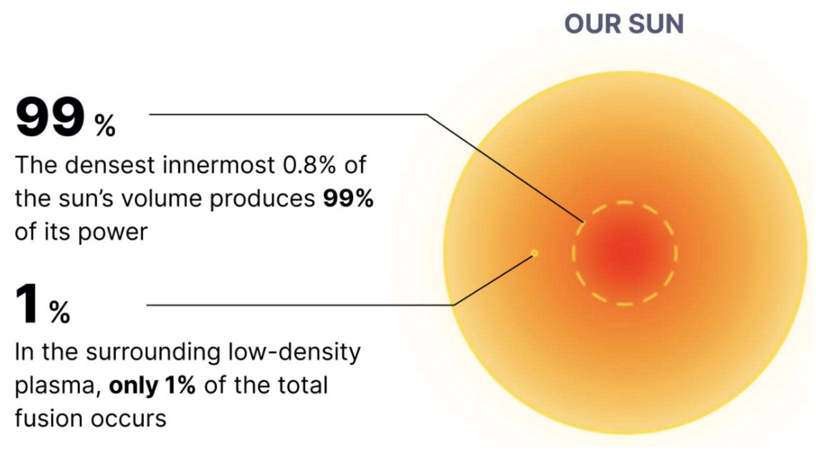
Astral: Multi-State Fusion

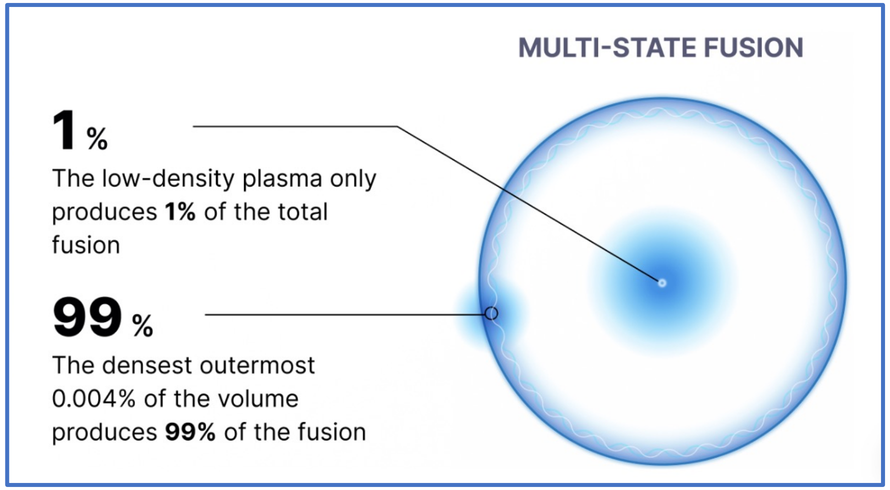
ASTRAL SYSTEMS

SOUTH WEST NUCLEAR HUB

- **Inertial Electrostatic Confinement** (IEC) **Fusion** traditionally uses a **negatively charged cathode** and **low-pressure gas** to initiate a **plasma**, causing **fusion**.
- In our sun, **99%** of the **fusion power** occurs at the **core**, which is a **highly dense environment**. Only **1%** of the **fusion** occurs in the **lower-density outer volume**.
- In our **new systems**, the **plasma** at the center acts as a '**spark plug**' only **contributing 1%** of the **fusion rate**.
- **99%** of the **fusion occurs** in **dense fusion fuel enriched metals**, **unlocking higher performance**.







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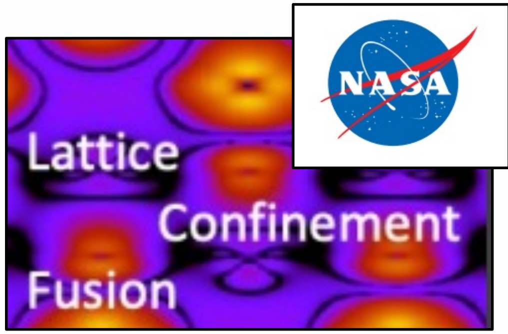
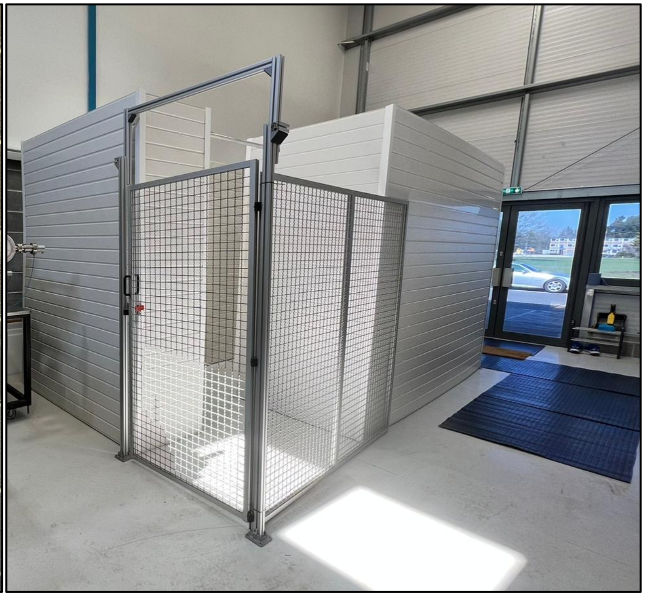
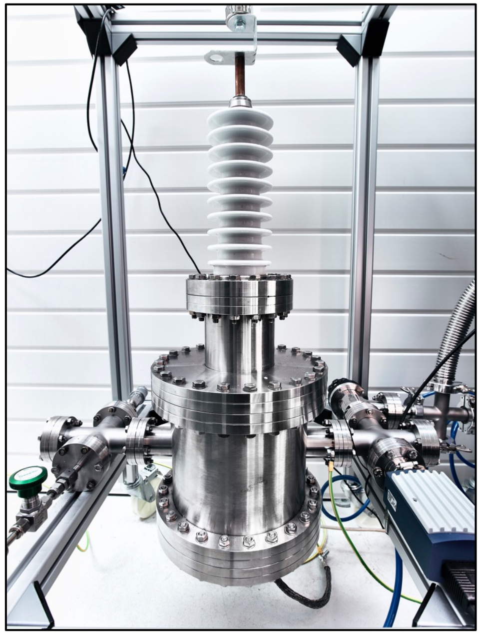


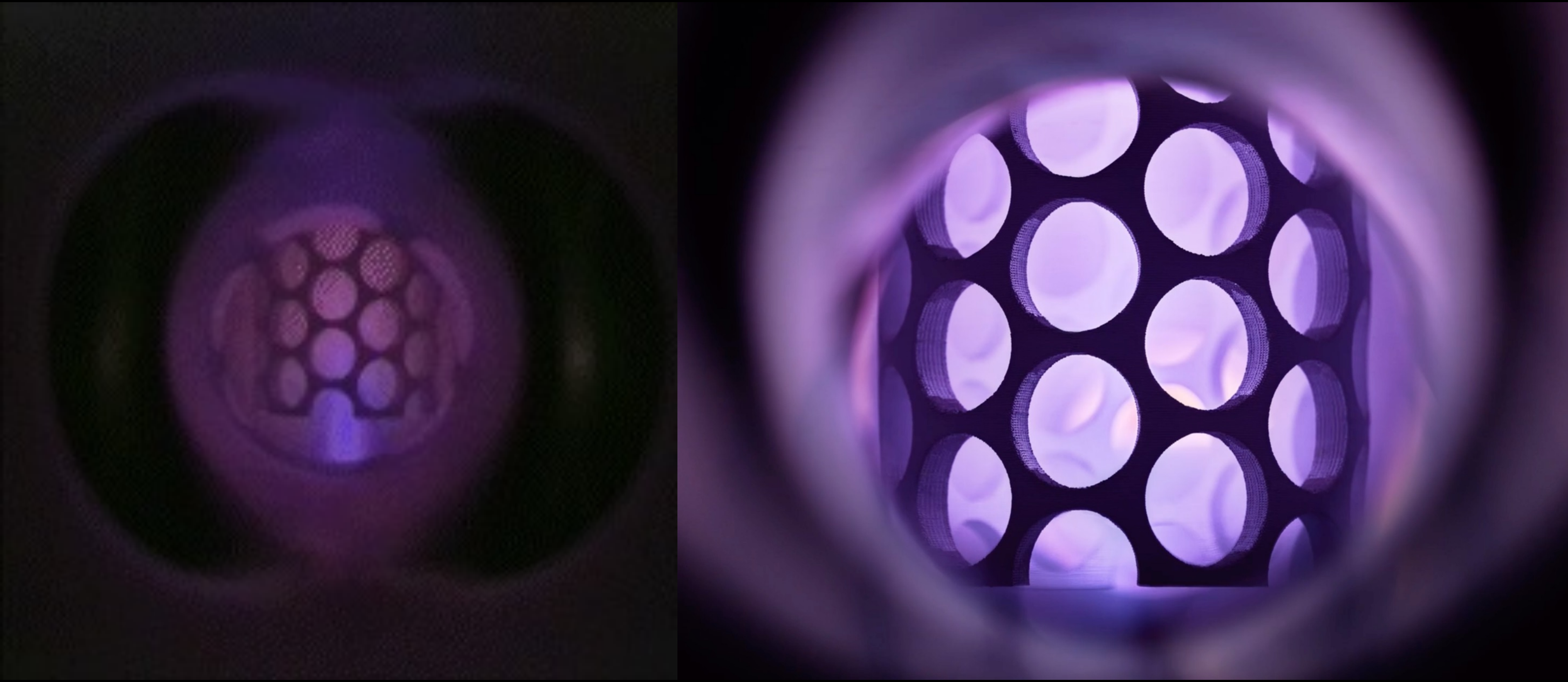
Astral's Fusion Neutron Research Facility





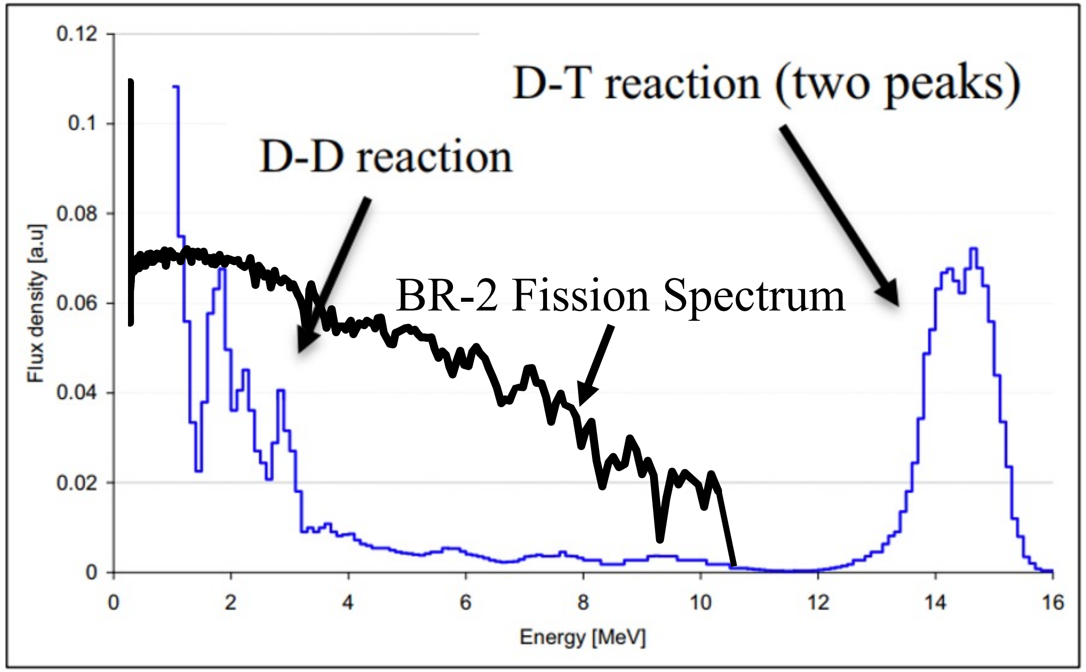
First Plasma

First Neutrons



Fusion Neutrons and Fission Waste

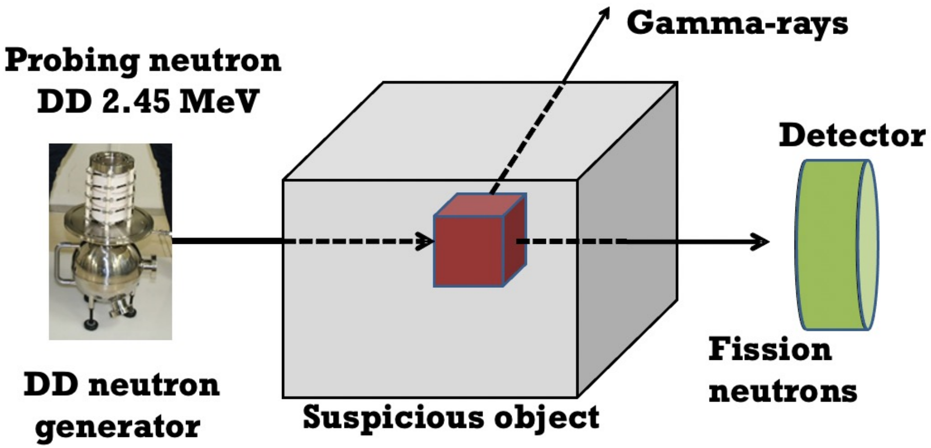
- The **majority** of **fission products** left at the **end** of **reactor life** are **produced** through **neutron interactions** within this **energy range**.
- **Pure fusion** reactions produce relatively sharp energy spectra at **2.45 MeV** for **DD**, and **14.1 MeV** for **DT**.
- **By bombarding nuclear waste with fast neutrons, this can "burn" through some of the long-lived nuclear waste products, such as Curium, built up during operation.**
- This can **unlock additional untapped energy** in the **nuclear fuel** as well as **reduce** the **lifetime** of the waste by **orders of magnitude depending** on the **fuel type**.
- **DoE in the US is actively seeking fusion neutron source capability to help process their nuclear waste repository.**

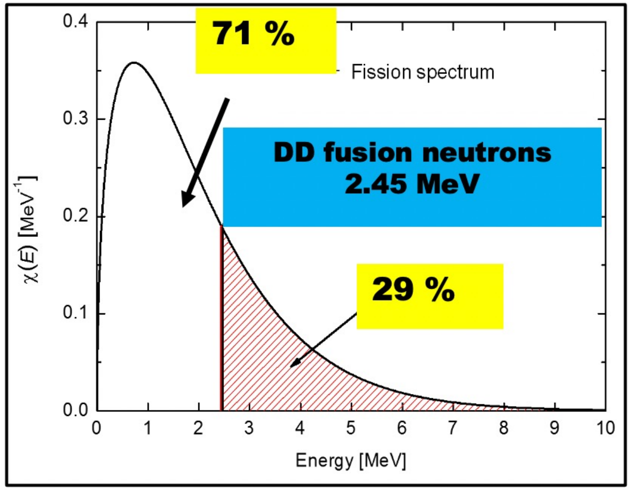


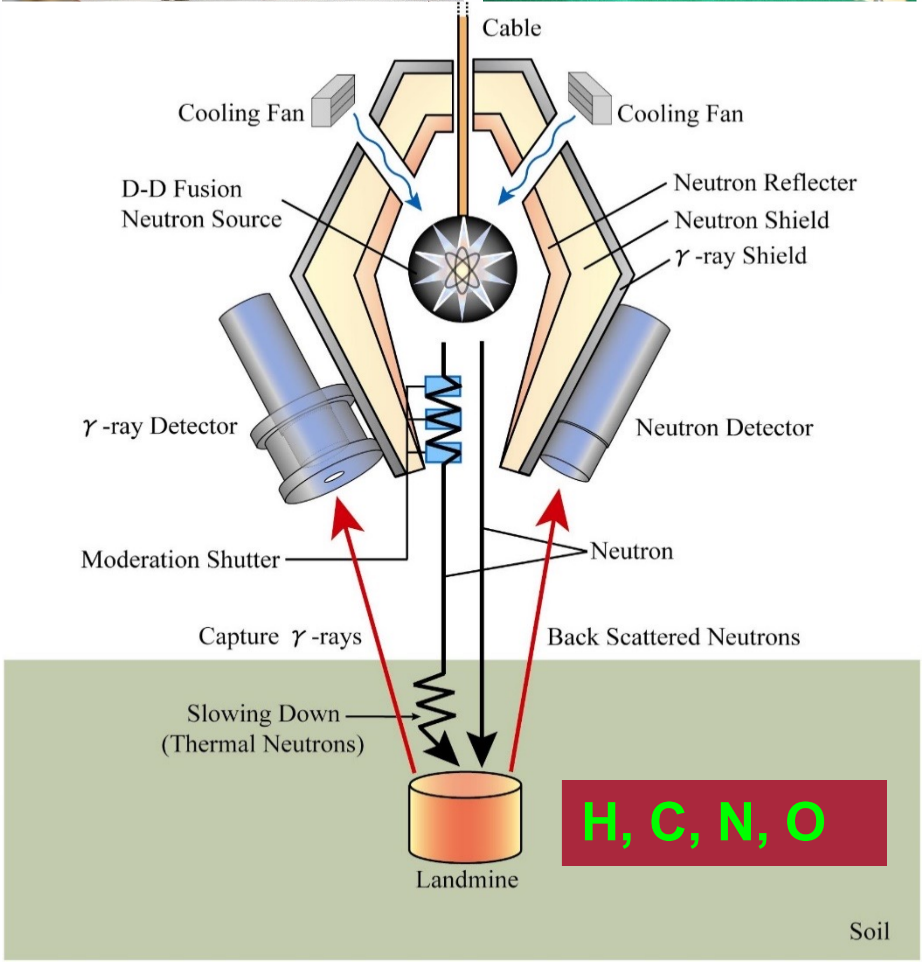
Neutron energy spectrum of a NSD DT system measured by Center Rez in the Czech Republic in 2020

Fusion Neutron Interrogation

- When **neutrons interact** with **matter**, different **reactions** can **produce gamma rays** of **specific energies** which serve as a **unique fingerprint**.
- This allows for the **detection** of **explosives** such as **IED's**, **landmines**, and other **munitions**.
- The **same approach** can be used to **detect fissile material** in **suspicious packages**, where **fission neutrons** can be **distinguished** from **the fusion spectrum** used to **interrogate**.

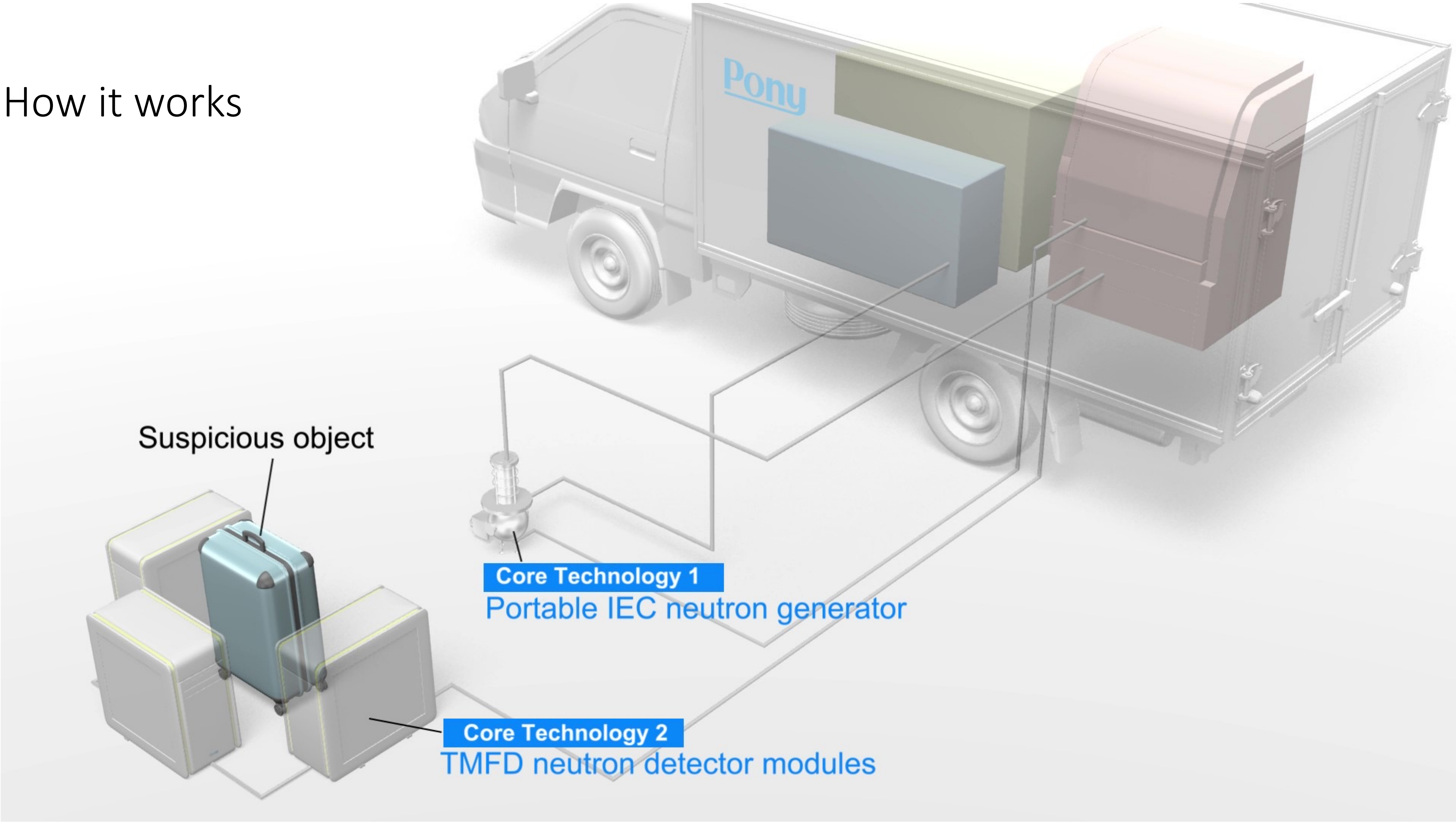






Courtesy of Dr Mahmoud Bakr and collaborators at the Kyoto University Research Reactor in Kumatori, Osaka; Dr Yoshiyuki Takahashi and Prof Masuda Kai

How it works

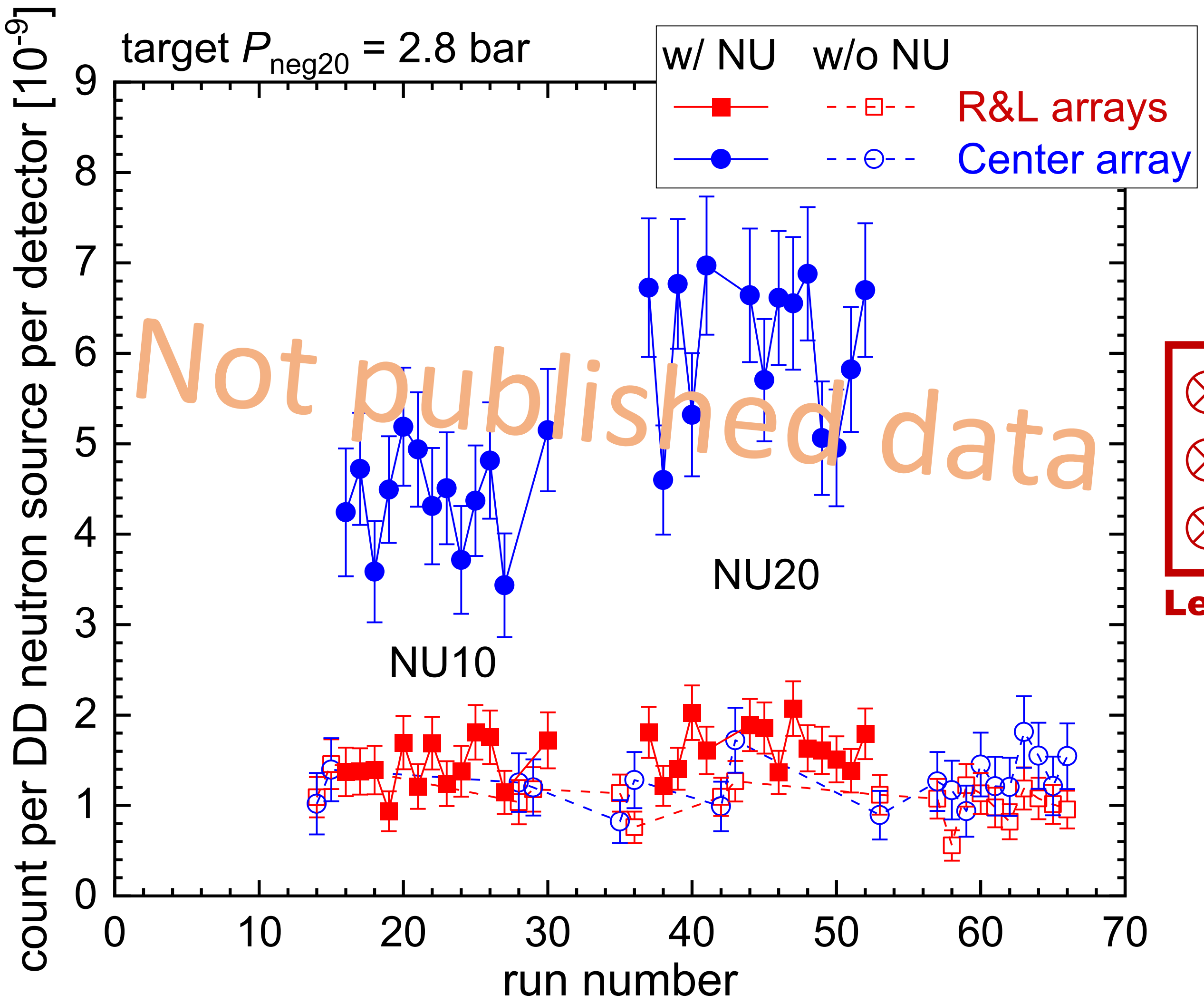


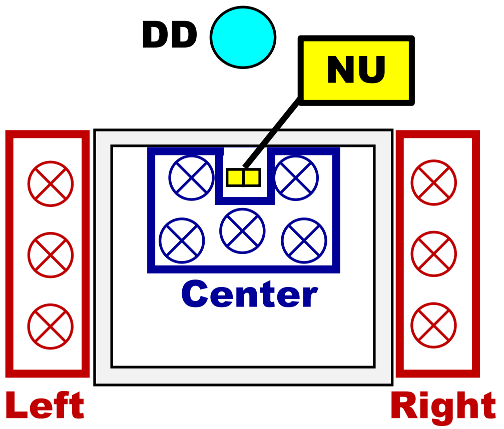
Courtesy of Dr Mahmoud Bakr and collaborators at the Kyoto University Research Reactor in Kumatori, Osaka; Dr Yoshiyuki Takahashi and Prof Masuda Kai

First detection experiment (Results)

Run-by-run variation and trend

- Only runs with DD source and at Pneg =2.8 bar are shown below.





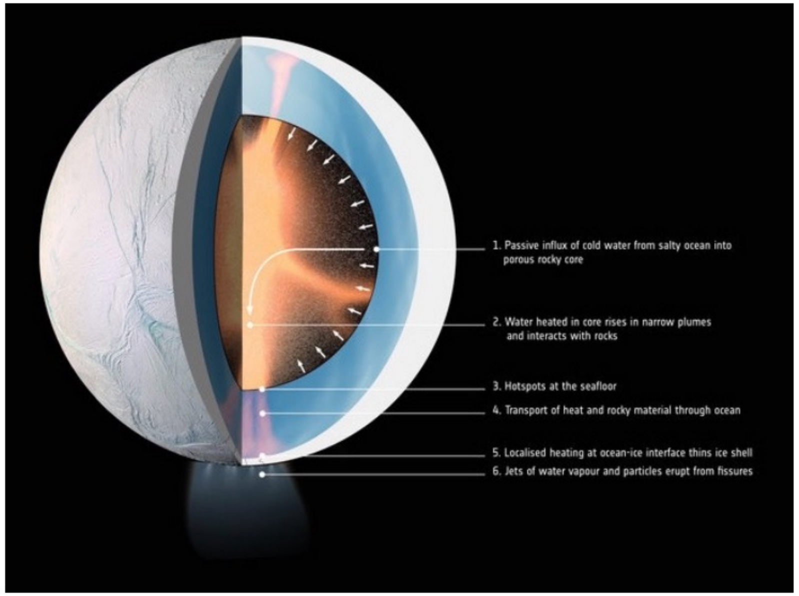
1e6 n/s DD neutrons continous
27 CTMFD unites
70 g of NU inside 10 kg polyethylene
140 g of NU inside 20 kg polyethylene

Courtesy of Dr Mahmoud Bakr and collaborators at the Kyoto University Research Reactor in Kumatori, Osaka; Dr Yoshiyuki Takahashi and others

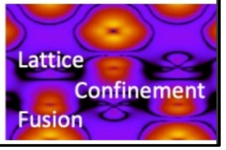
Fusion Hybrid Reactors for Space

- Ocean Worlds Exploration Program
  - Search for Extraterrestrial Life
  - Enceladus: icy world candidate
  - Challenges
    - Operate under extreme environmental conditions
    - Break through up to 40 km thick ice
  - Lattice Confinement Fusion (LCF) Fast Fission can provide power and heat transfer

GRC Tunnelbot



Enceladus Cutaway

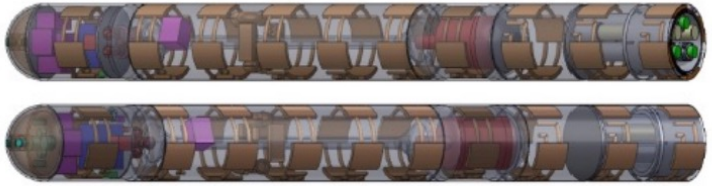


THERESA L. BENYO*, Ph.D. · Analytical Physicist · Principal Investigator (PI) • LAWRENCE P. FORSLEY · Experimental Physicist · Deputy PI RODGER DYSON, Ph.D. · Research Engineer · Power Energy Conversion • MICHAEL BECKS · Systems Engineer · MCNP Modeling

Fusion Hybrid Reactors for Space

Robotic Probe Specifications/Options

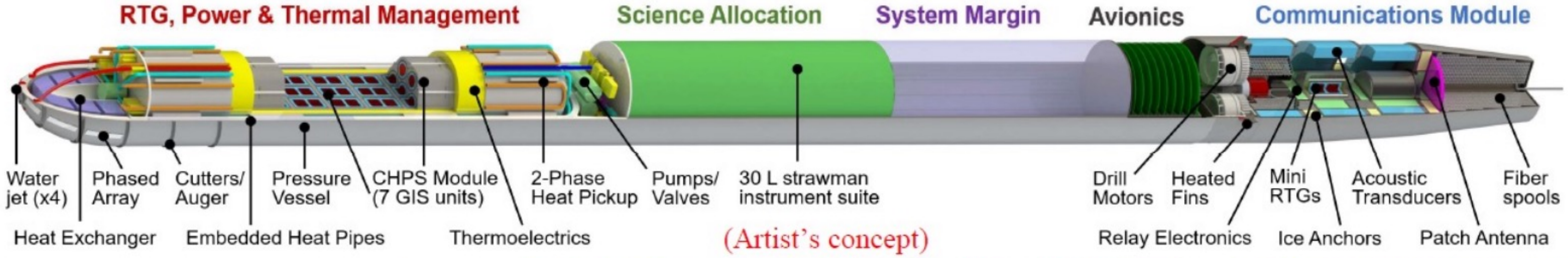
- Europa Tunnelbot



Subsystems:
Science
Thermal
Attitude Determination and Control
Communications
Power
Command and Data Handling
Structures

Figure 16.—Additional transparent views of Europa Tunnelbot reactor case.

- Cryobot



(Artist's concept)

System (Margined)	
Mass	350 kg
Volume	150 L
Length	3.1 m (cylinder) 3.9 m (total)
Diameter	23 cm

Mobility System	
Speed (cold layer)	4.4 km/yr
Speed (warm layer)	17.2 km/yr
Detectable hazard	1 cm (estimated)
Steering radius	10 m (estimated)
Debris Removal	Waterjet / drill

Power/Thermal System	
Total Heat	10.5 kWt
Peak Power	1 kWe
Skin temperature	25 C
WJ flow rate	3 L/min
Survival pressure	53 MPa

Communication System	
Data (primary)	1 kbps
Data (secondary)	100 bps
# Relays	3
Relay power	10 W
Fiber Length	70 km

Figure 1.—Tunnelbot reaching ocean after deploying communication repeaters and anchor (artist impression).

- The **concept requires ~40 kWt power** to **melt** through the **ice shelf**.
- **Initial calculations** suggest this may be possible with a **high-output DD Fusion system** and **sub-23 cm diameter fissile blanket**.

Theresa L. Benyo*, • Lawrence P. Forsley, *"Accessing Icy Worlds Using Lattice Confinement Fusion (LCF) Fast Fission"*, NIAC Presentation Slides, 2023

The End ☺

Website

Thanks you to all of our collaborators domestic and international.

See you for the Q&A session.

LinkedIn