EASTERHEGG 2019

BUN INTENDED

Nuclear Propulsion

from the somewhat reasonable to the utterly insane

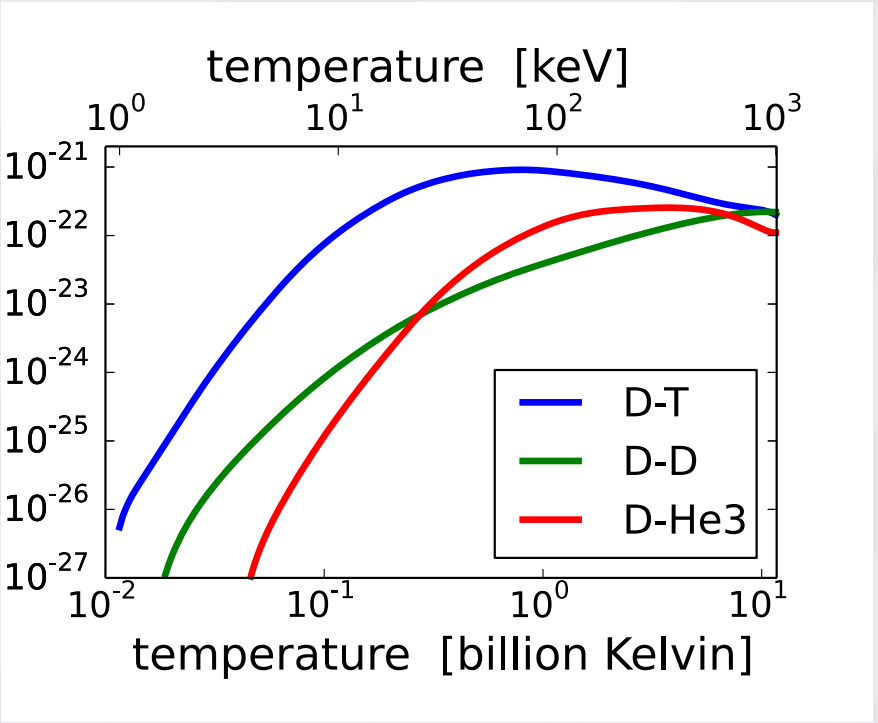
By Paul Hayden

Rocket Science

- Make things go fast by any means necessary

Fusion Challanges

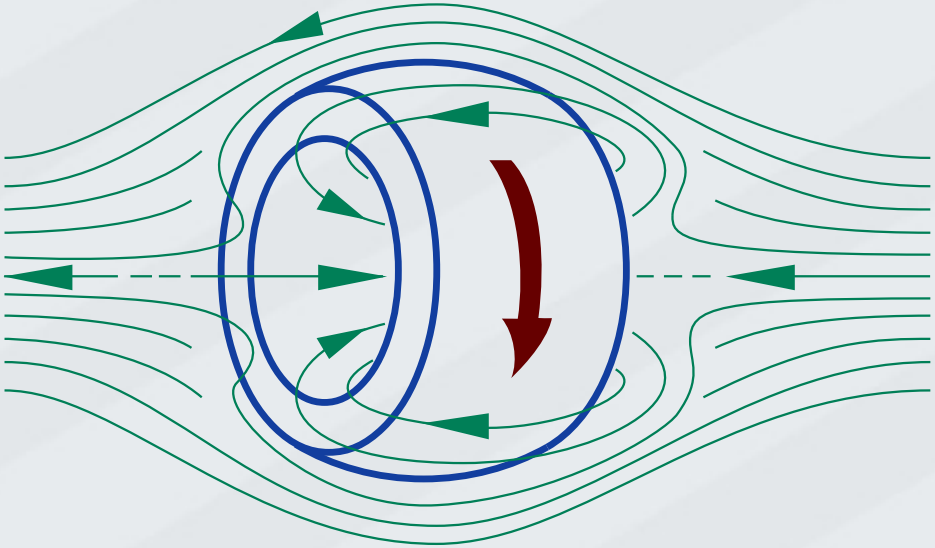
- Keep temperature high
- Keep pressure up
- Can’t touch walls



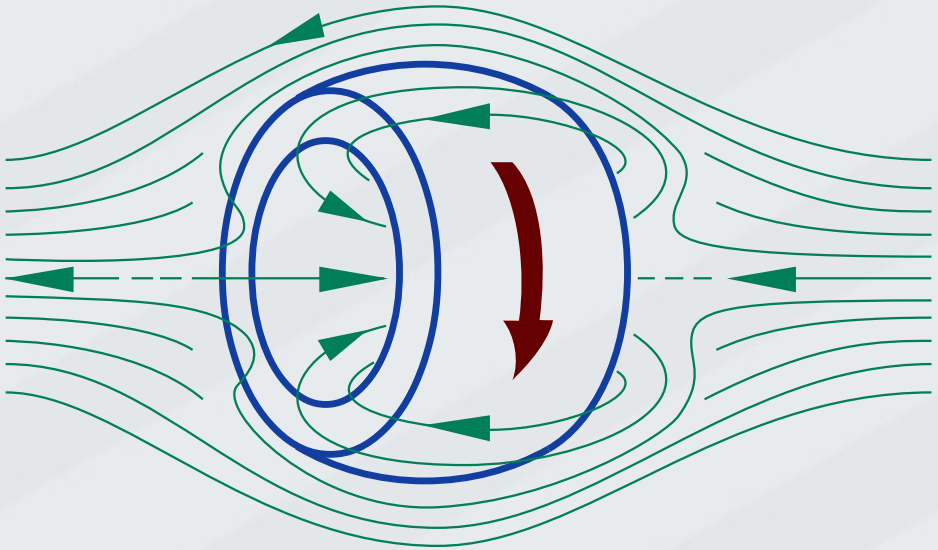
Let’s poke a hole into the plasma!

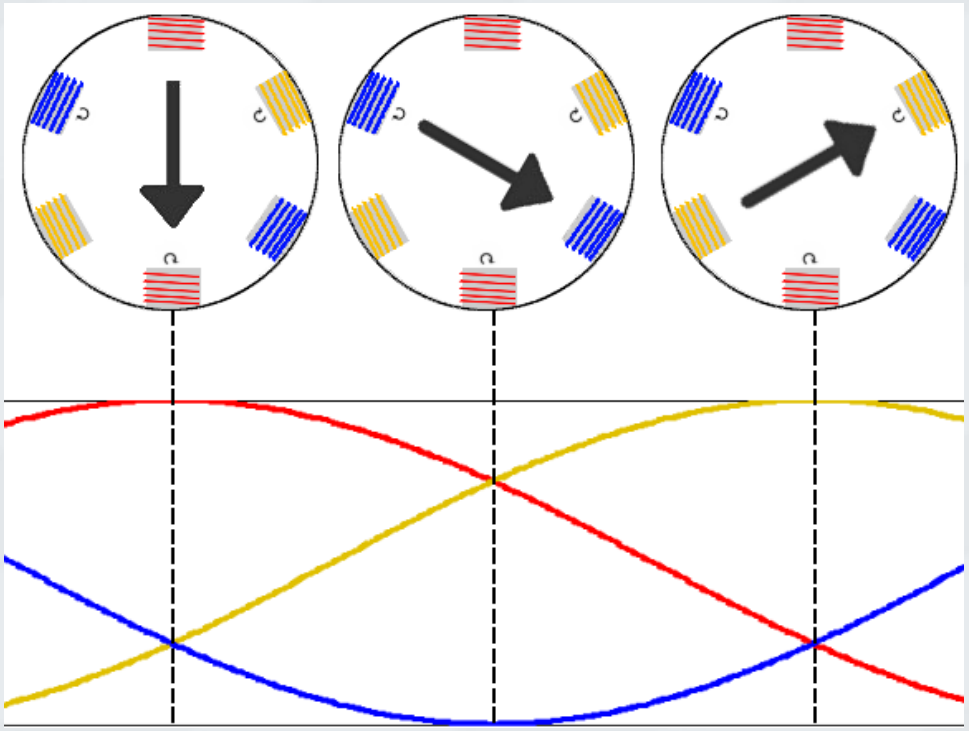
Field Reversed Configuration

- Establish magnetic field in plasma
- Reverse magnetic field
- Magic thanks to penetration depth
- ~~Profit!~~ Current!
- No full mathematical model



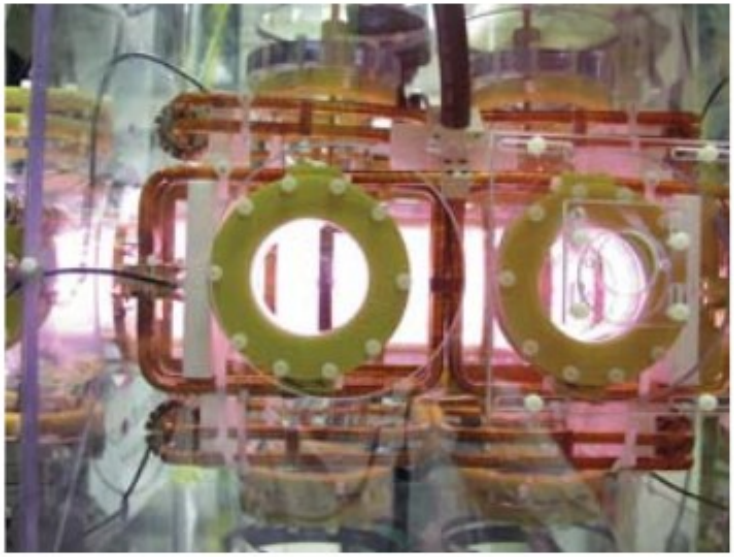
Stabilise By Magnetic Turning

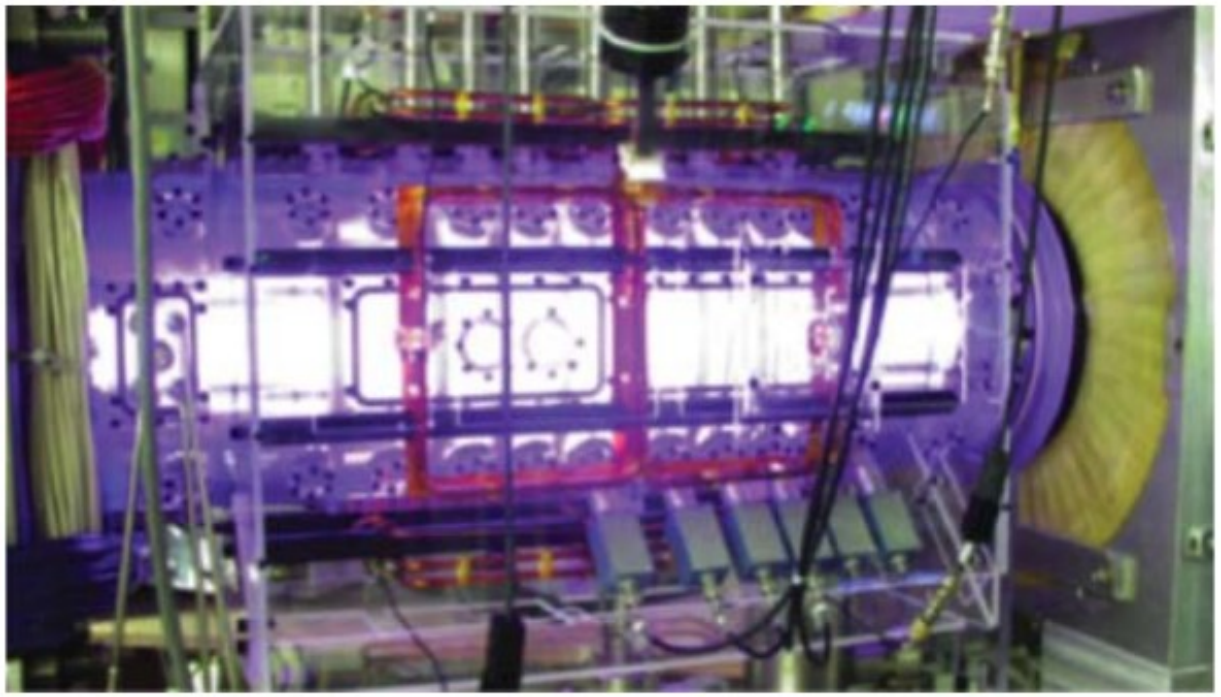




Princeton Field Reverse Configuration

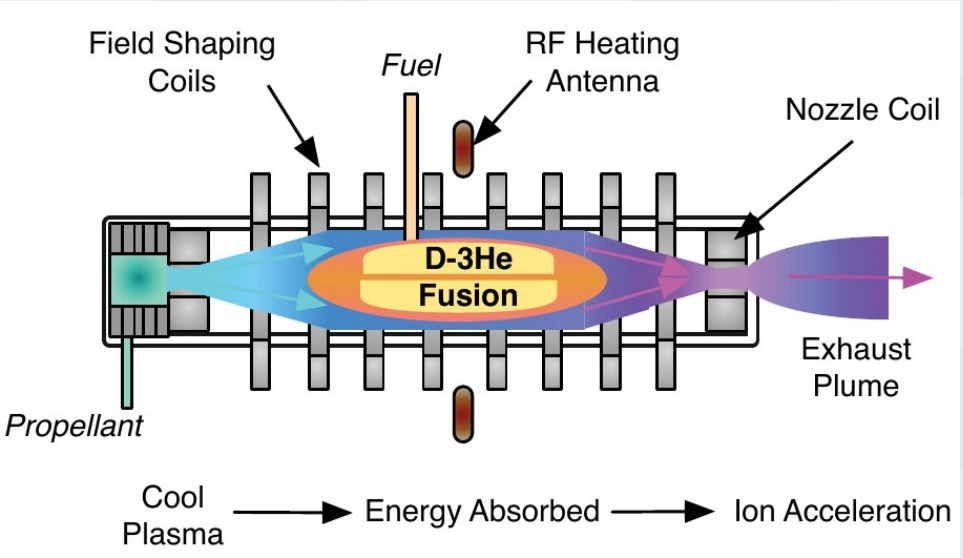
Use **two** coils for turning





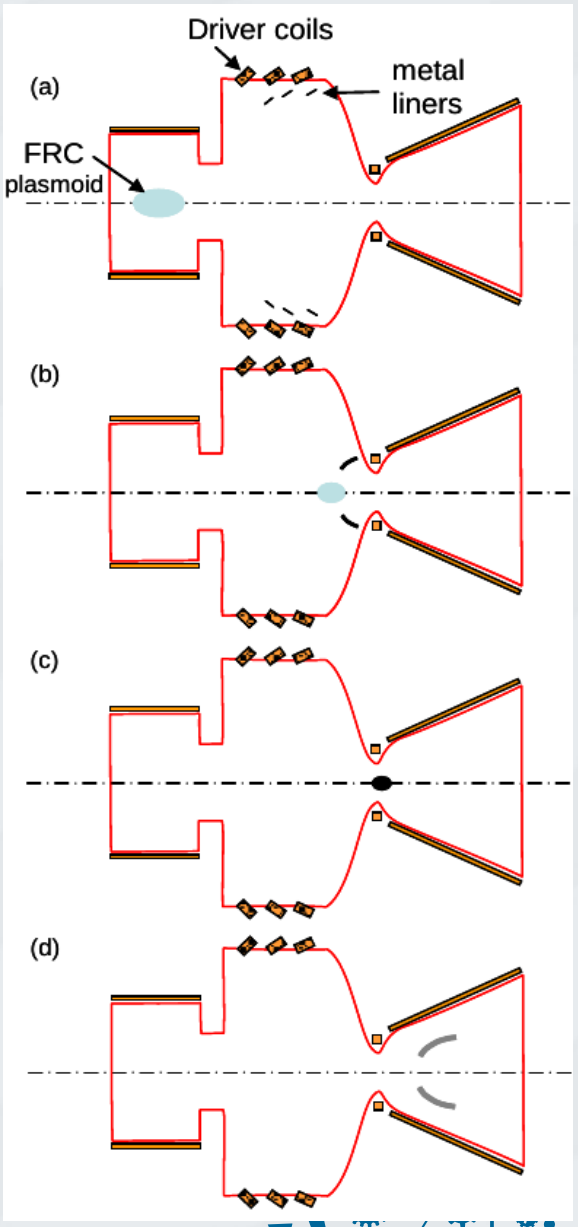
PFRC Claims

- ^{3}He fusion
- Low neutron production
- 1-10 MW reactor
- Heat source for propulsion plasma



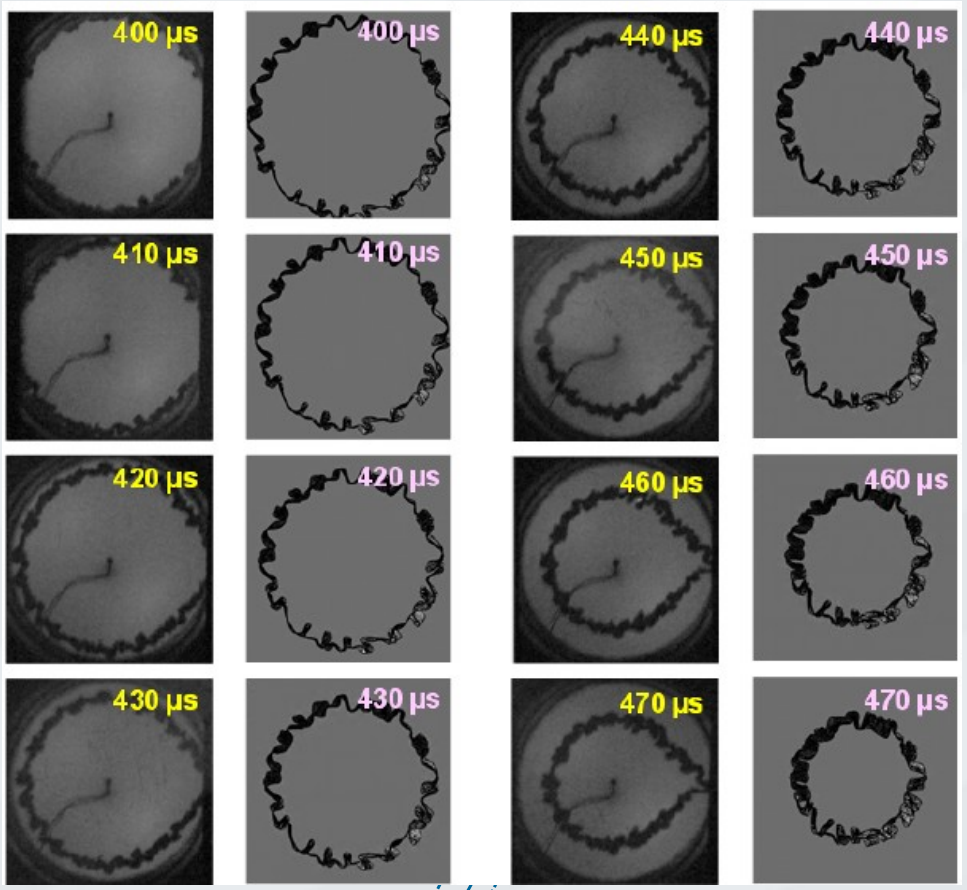
Magneto Inertial Fusion

- Accelerate 3 metal bands towards plasma-ball
- Increasing magnetic flux compresses plasma
- Start fusion by compression-wave



MIF Claims

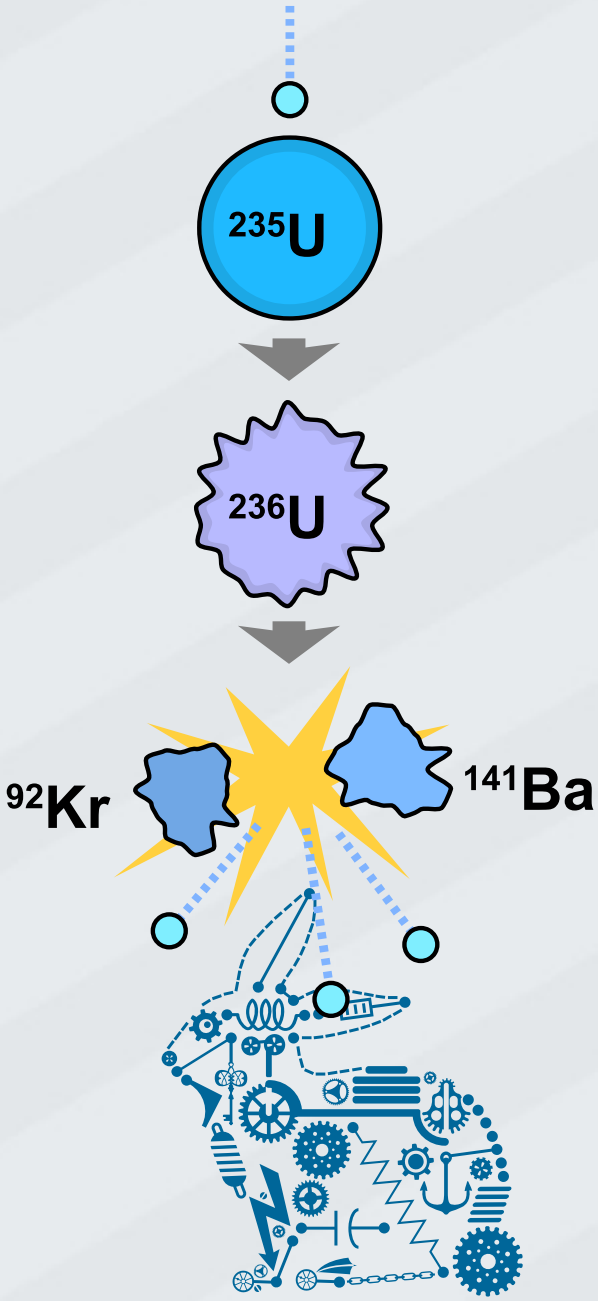
- 36 MW Power at 15 MT Mass
- Fire every 14 sec
- Need shock-absorbers



What about fission?

Nuclear Chain Reaction Basics

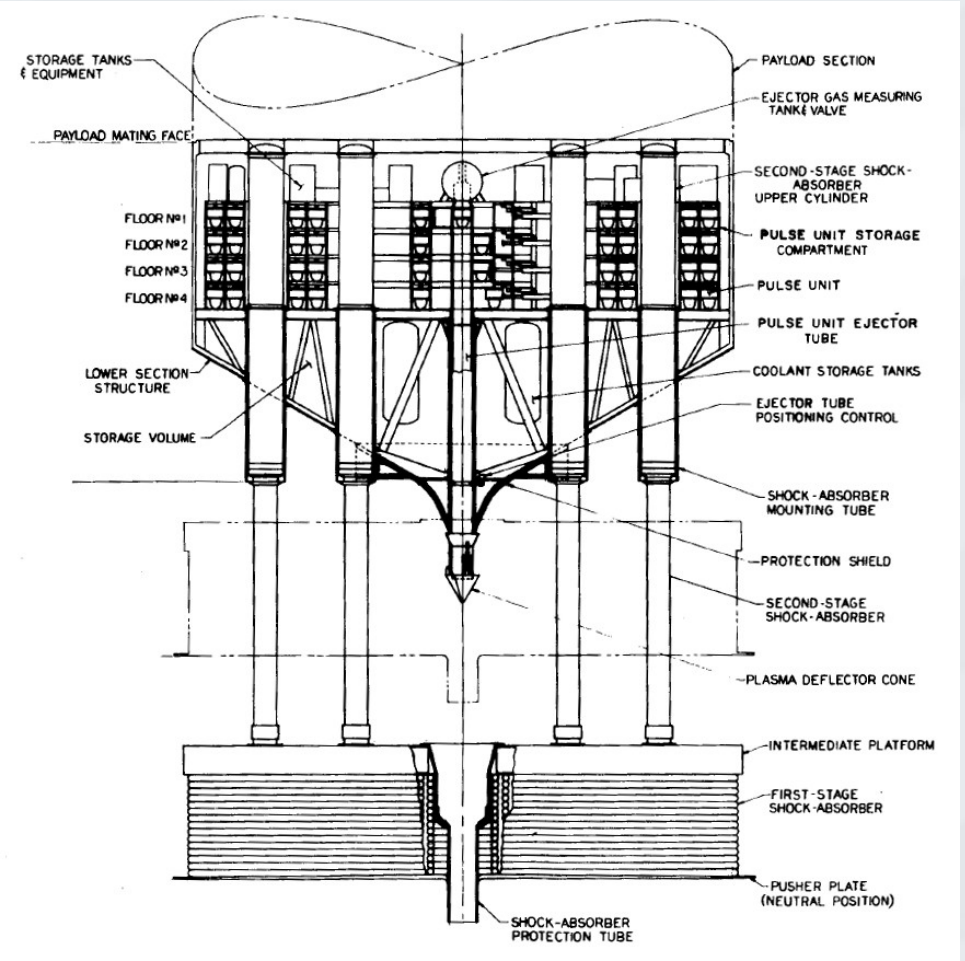
- Throw neutrons at fissile nucleus
- Get new neutrons from split nucleus
- repeat



Project Orion

Riding Nuclear Bombs

- Very well tested technology
- Up to 3% speed of light
- Just 1 radiation death per launch!

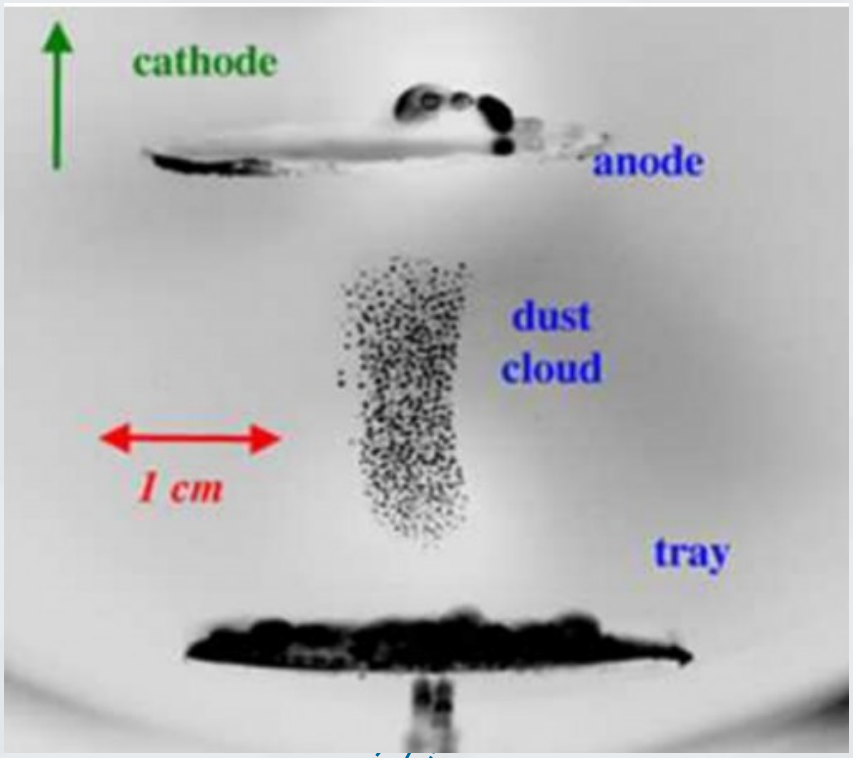


Where Do Neutrons Come From

- Fission releases few *prompt neutrons* — $\sim 10^{-15}$ sec. control constant
- Fission products decay, release *delayed neutrons* — $\sim 10^{-2}$ sec. control constant
- Delay required to control reactors
- No delay → bomb

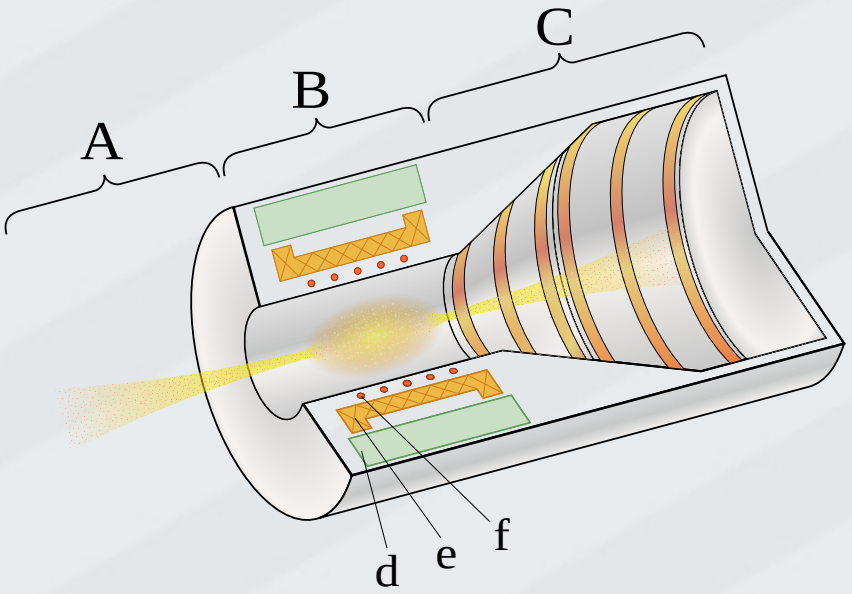
Nuclear Dust Drive

- Keep tiny particles in magnetic field
- Fission fragments leave particles
- Direct particles outwards w. magnets



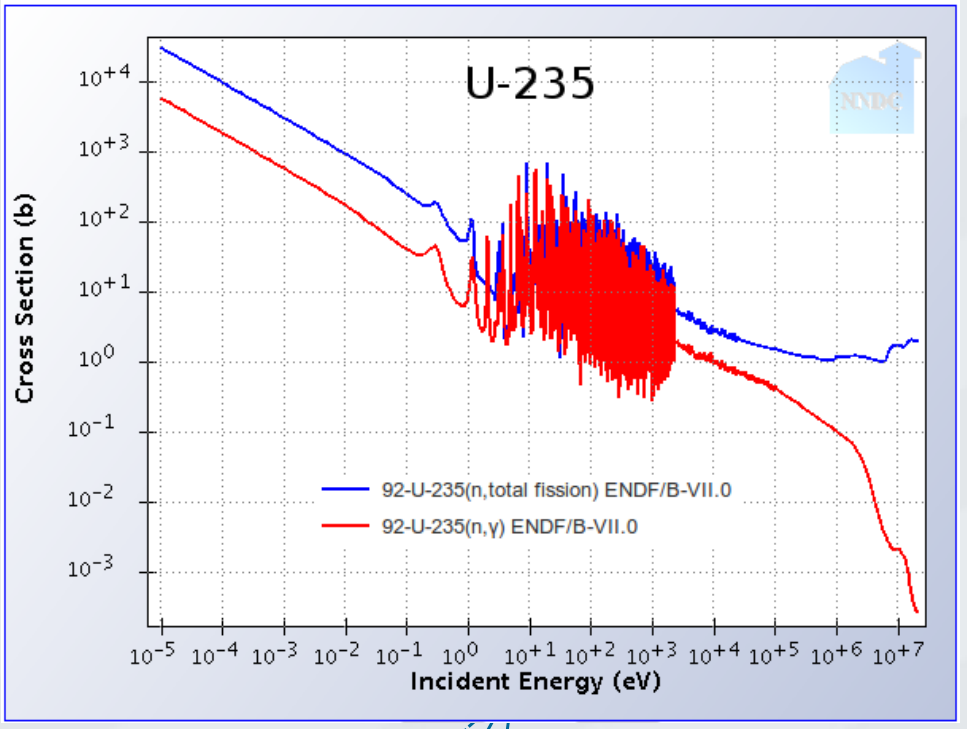
Nuclear Dust Drive

- Heavy Moderator
- I_{Sp} of ~ 1 000 000 s
- ~ 26 GW @ 3000 K
- ~62 GW for “foggy” drive



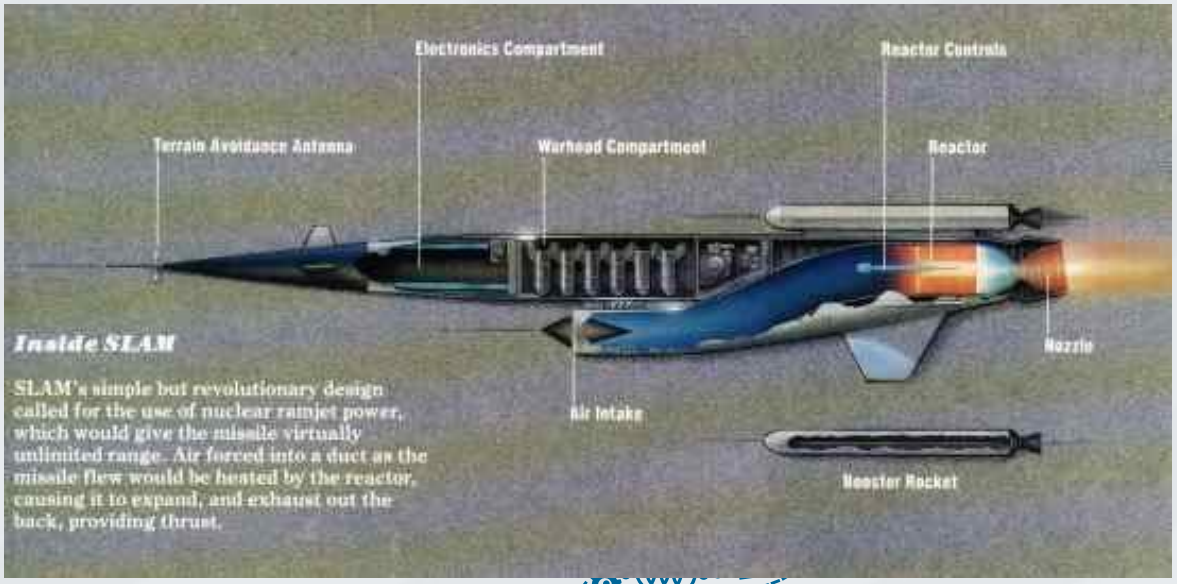
What Neutrons react?

- Neutron speed determines nuclear reaction
- Slow neutrons make fission more likely
- Nuclear reaction creates fast neutrons

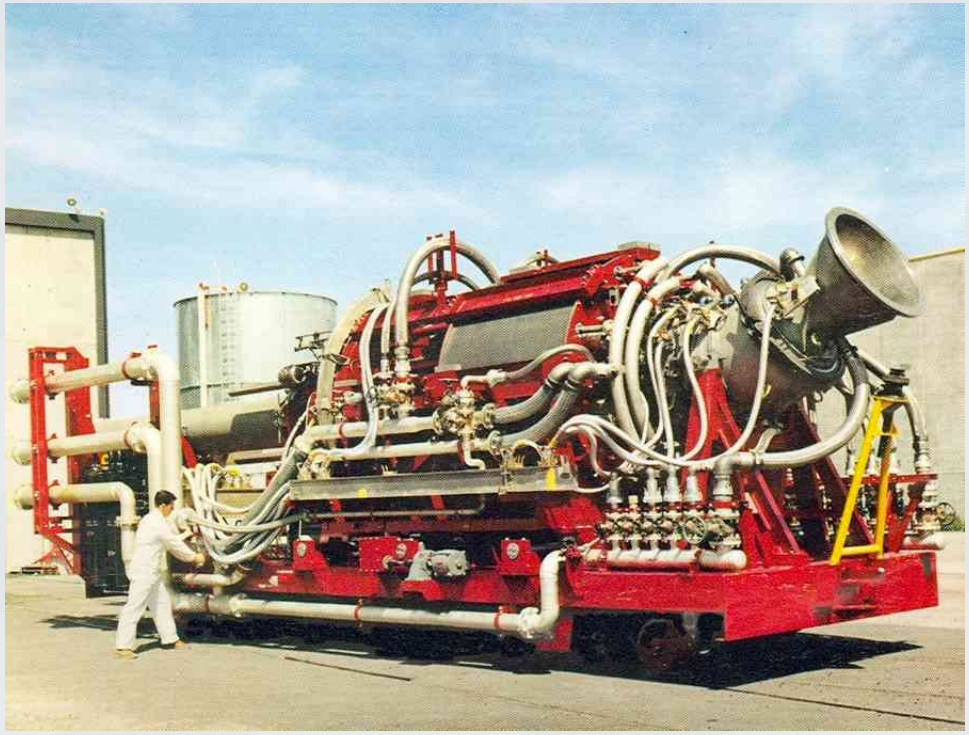


Project Pluto

- Transport nuclear bombs using a nuclear reactor



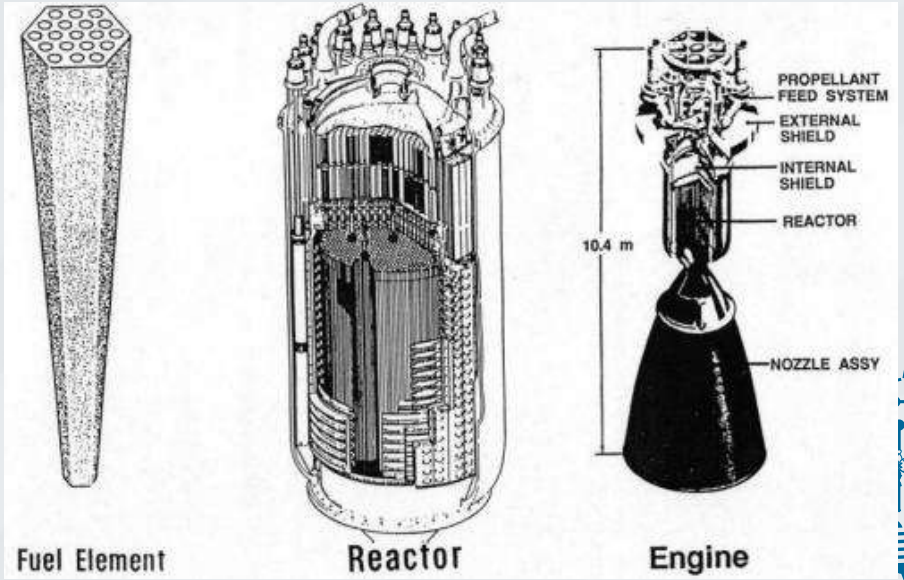
Project Pluto



Project Pluto

- No radiation shielding
- Operate reactor near auto ignition temperature
- No pilot

Project Rover

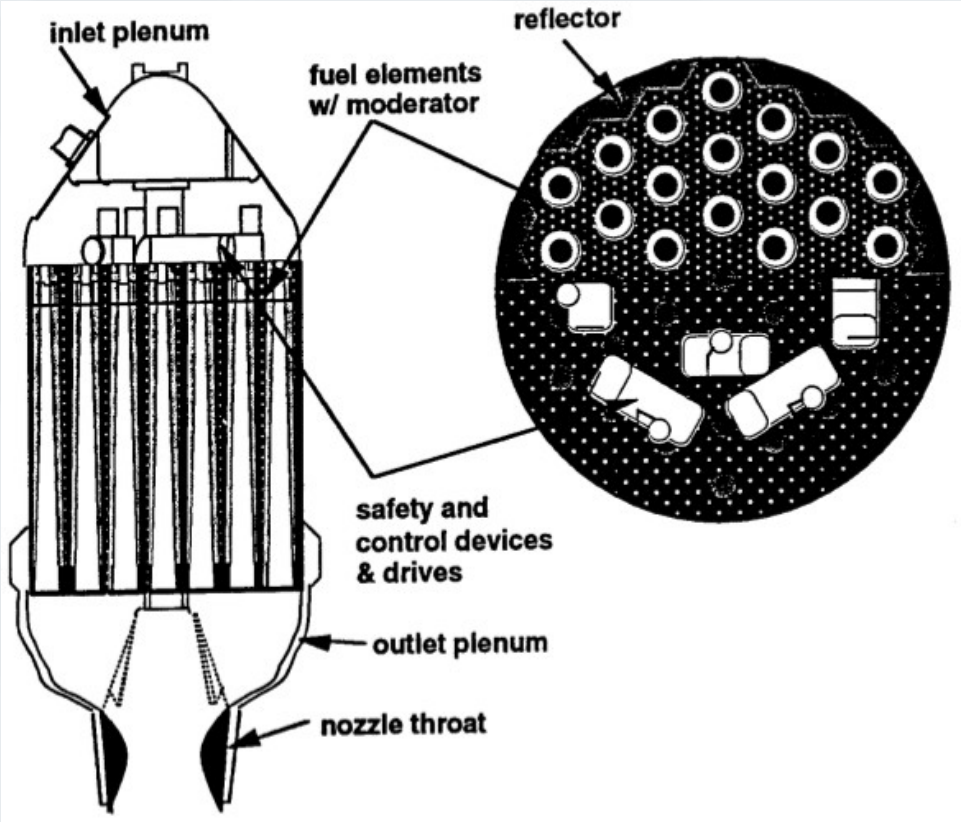


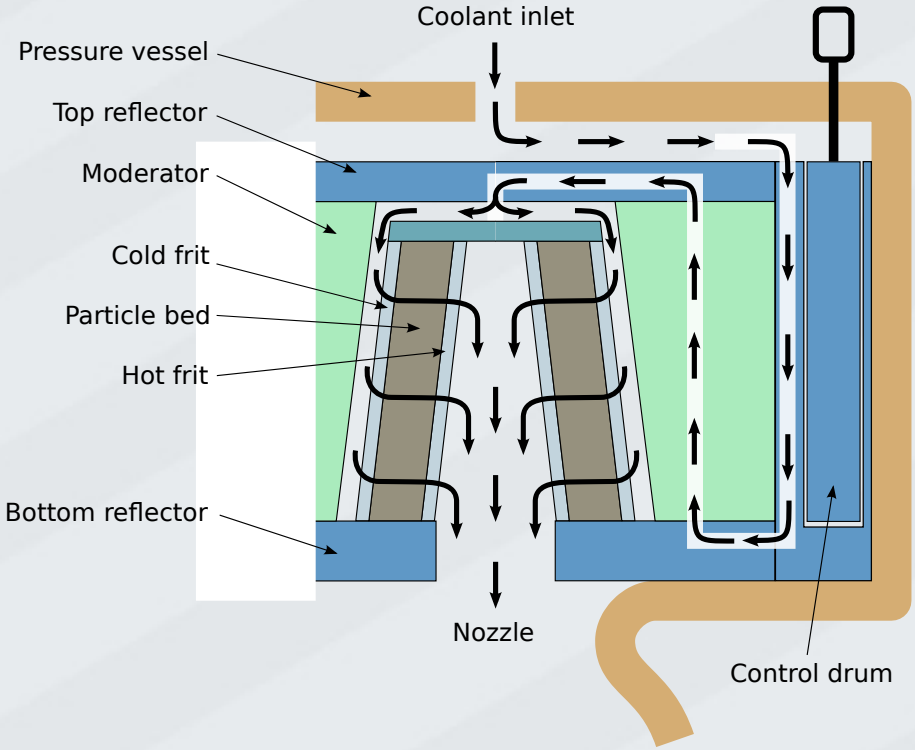
Project Rover

Kiwi TNT

- Prompt critical Kiwi

Project Timberwind





Project Timberwind - aftermath

Introduction. In 1987, the Strategic Defense Initiative Organization (SDIO) began research and development on a nuclear propulsion system for a rocket that would intercept hostile ballistic missiles. The project was protected under a special access program named TIMBER WIND. Between FYs 1987 and 1991, SDIO budgeted approximately $139 million for the program.

- Improvement on neutron shielding (Boron Aluminum Titanium Hydride)

Slowing Down Neutrons

- Elastic scattering with other nuclei

- Similar mass allows maximum energy transfer

  → Hydrogen ideal moderator

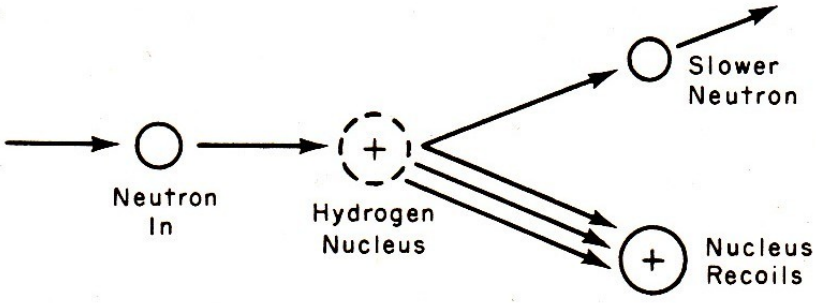
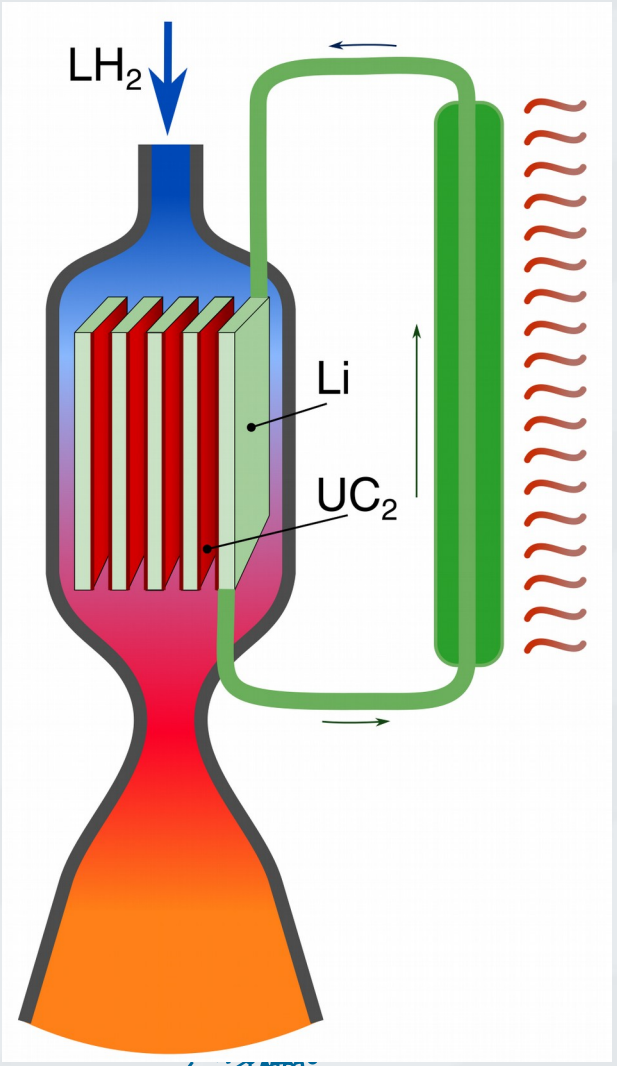


Fig. 6—Elastic scattering.

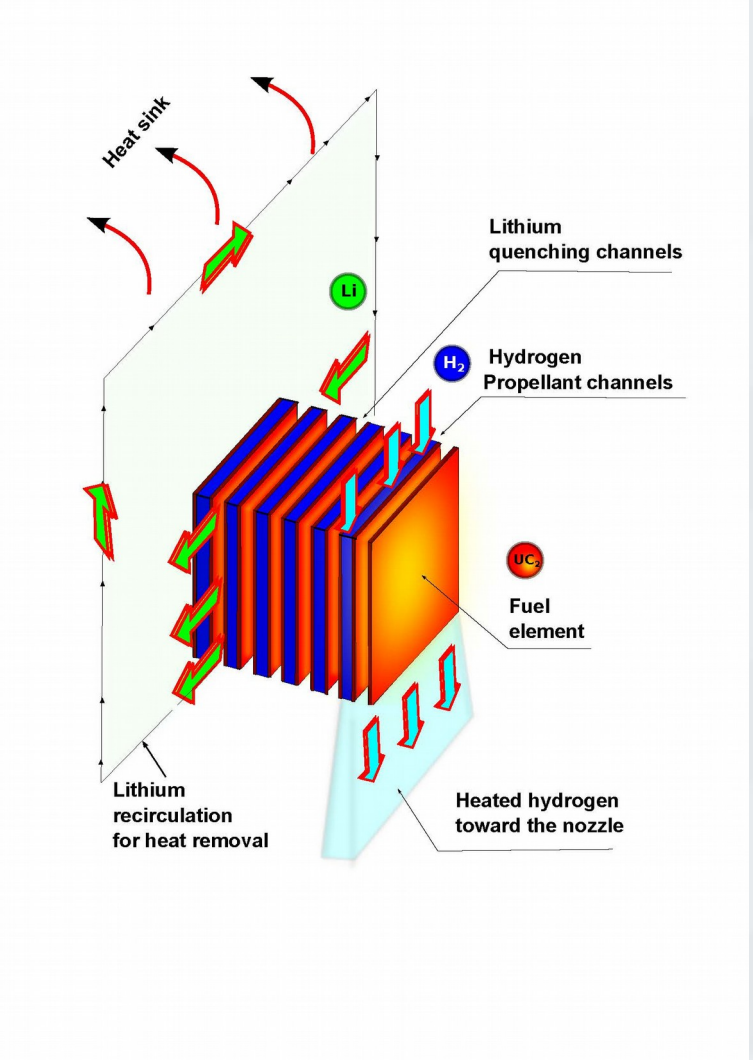
Pulsed Nuclear Thermal Rocket

- Briefly drive reactor very up
- Heat H_2 with fast neutrons
- Remove fission fragments with Lithium



Pulsed Nuclear Thermal Rocket

- Require prompt critical bursts of ~10 kHz
- Lithium provides cooling
- Lithium needs cooling



Pulsed NTR Challenges

- Requires 10 kHz capable neutron-blinds

- Fission fragments need to be removed – along with 95% of thermal energy

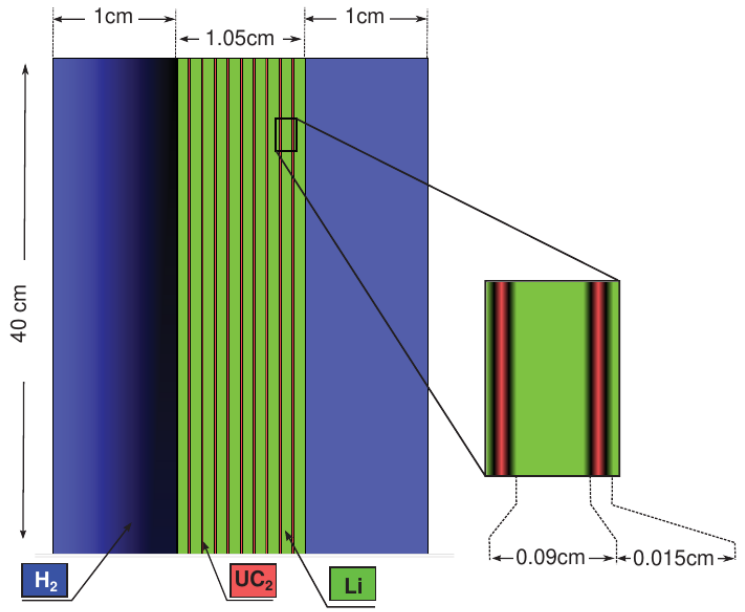
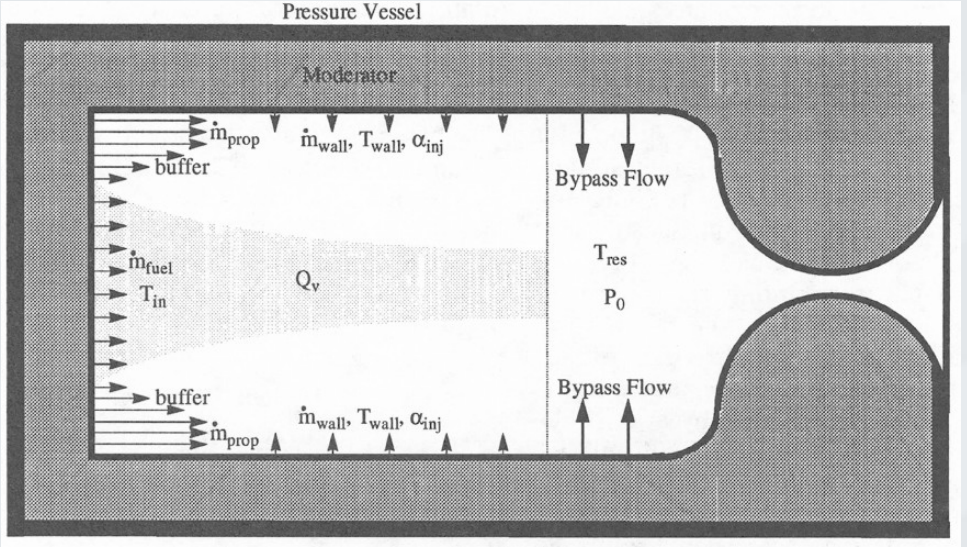


FIG. 7: Reference unit cell.

Open Cycle Gas Core Rocket

- Boil uranium fuel in reactor
- Keep off the walls with boiling H_2
- Expel H_2 with as little fuel as possible

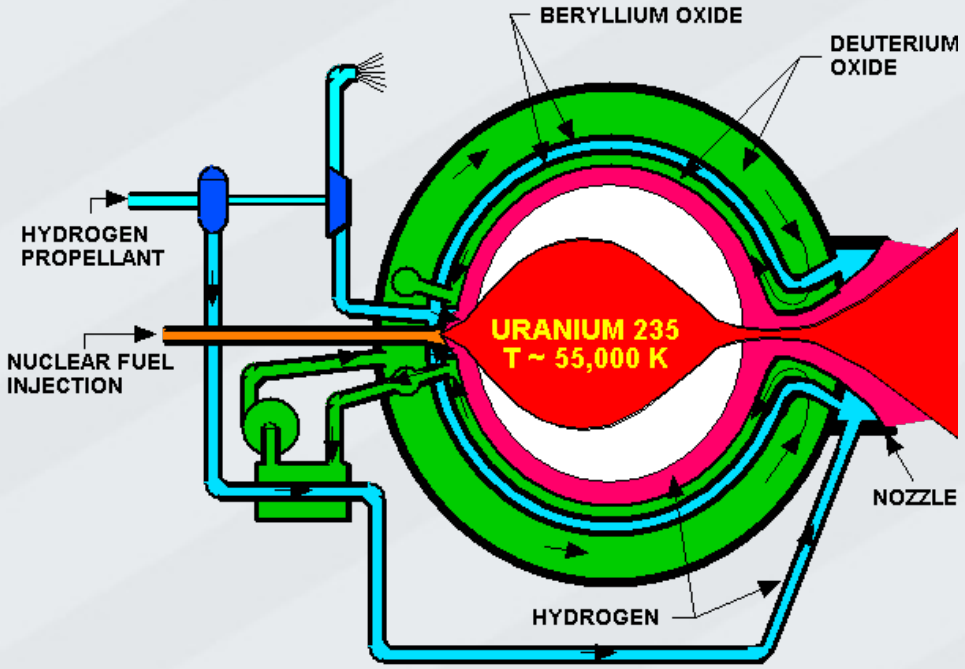


Open Cycle Gas Core Rocket

- Require ~ 1000 bar

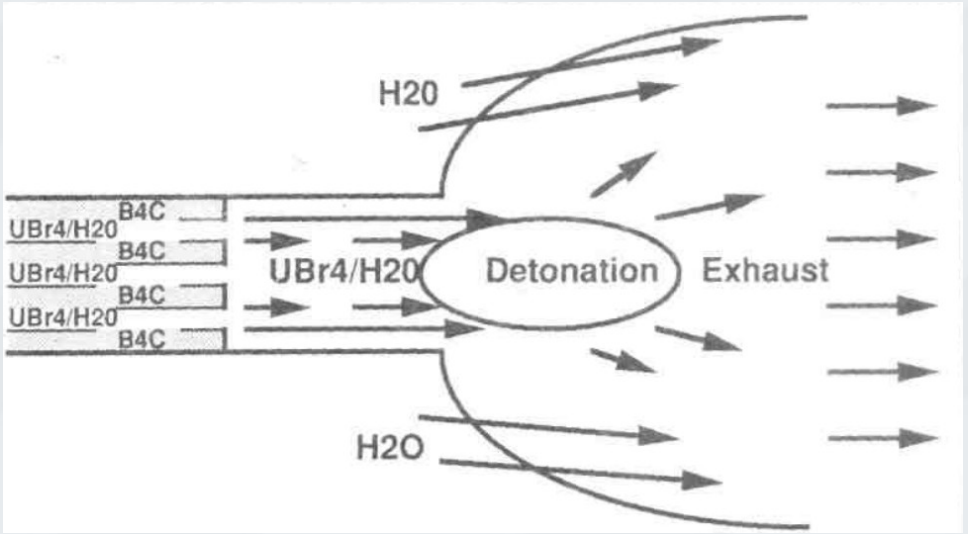
- Fuel has ~2 min. to burn, propellant ~2 sec. to heat

- H_2 dissociates at ~52 000 K



Nuclear Salt Water Rocket

- Uranium salts dissolved in water
- Stored in boron-tubes
- Needs constant flow (of ~ 66 m/s)



Nuclear Salt Water Rocket

- **6 x 60 cm tube**
- I_{sp} = 6700 s
- F = 13 MN
- P = 871 GW
- 196 kg/s
- p = 11 500 bar

- **RS-25 (Shuttle)**
- I_{sp} = 452 s
- F = 2.23 MN
- P = 10 GW
- 1400 kg/s
- p = 206 bar

Believe In Riding Nuclear Bombs!

©Clyde Caldwell

sources

- 2: https://djrutland1.wordpress.com/2013/05/02/kerbal-space-program-the-monster-and-whippet-rocket-program/
- 3,5,6,12,17,22,25,29,32: wikimedia commons
- 7,8: Thomas, Paluszek, Cohen, Glasser: Nuclear and Future Flight Propulsion – Modeling the Thrust of the Direct Fusion Drive, 2018 Joint Propulsion Conference, doi:10.2514/6.2018-4769
- 9,10: Slough et.al.: Electromagnetically Driven Fusion Propulsion, 2013 33rd International Electric Propulsion Conference
- 13: http://www.rhysy.net/project-orion.html
- 18: https://whatisnuclear.com/fast-reactor.html
- 20: https://keptelenseg.hu/tudomany-technika/nuklaris-hajtasu-bombazok-98767
- 20: https://popgun.ru/viewtopic.php?f=147&t=250223&start=330
- 19,21: http://www.merkle.com/pluto/pluto.html
- 26: Audit Report on the Timberwind Special Access Program, 1992-12-16
- 27: www.chemicalbiological.net/The%20Neutron%20Bomb_What%20You%20Can%20Do.html (eyesore, you have been warned)
- 30: Arias: On the Use of a Pulsed Nuclear Thermal Rocket for Interplanetary Travel, 2016 Propulsion and Energy Forum, doi:10.2514/6.2016-4685
- 31: David I. Poston & Terry Kammash (1996) A Computational Model for an Open-Cycle Gas Core Nuclear Rocket, Nuclear Science and Engineering, 122:1, 32-54, doi: 10.13182/NSE96-A28546
- 33: Zubrin: NUCLEAR SALT WATER ROCKETS: HIGH THRUST AT 10,000 SEC ISP, 1991 Journal of The British Interplanetary Society, Vol. 44, pp. 371-376
- 35: http://www.projectrho.com/public_html/rocket/engines.php