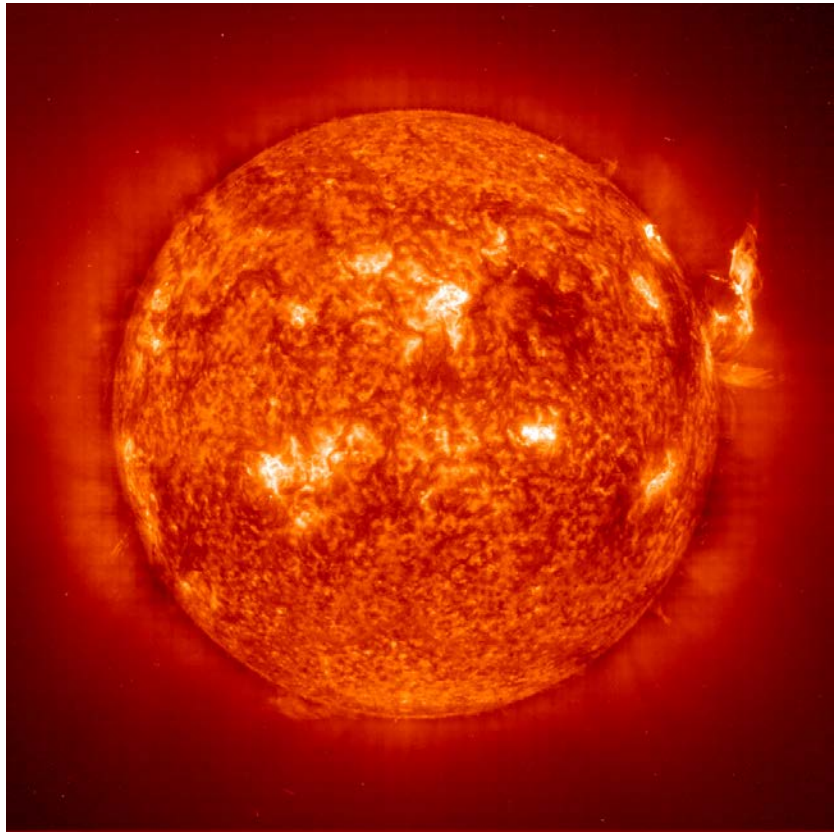
Present Status and Future Prospect of Nuclear Fusion

Prof. Dr. Yong-Su Na

What is nuclear fusion?

Origin of Star Energy

Le groupe d'étoiles des Pléiades (2002), Robert Gendler

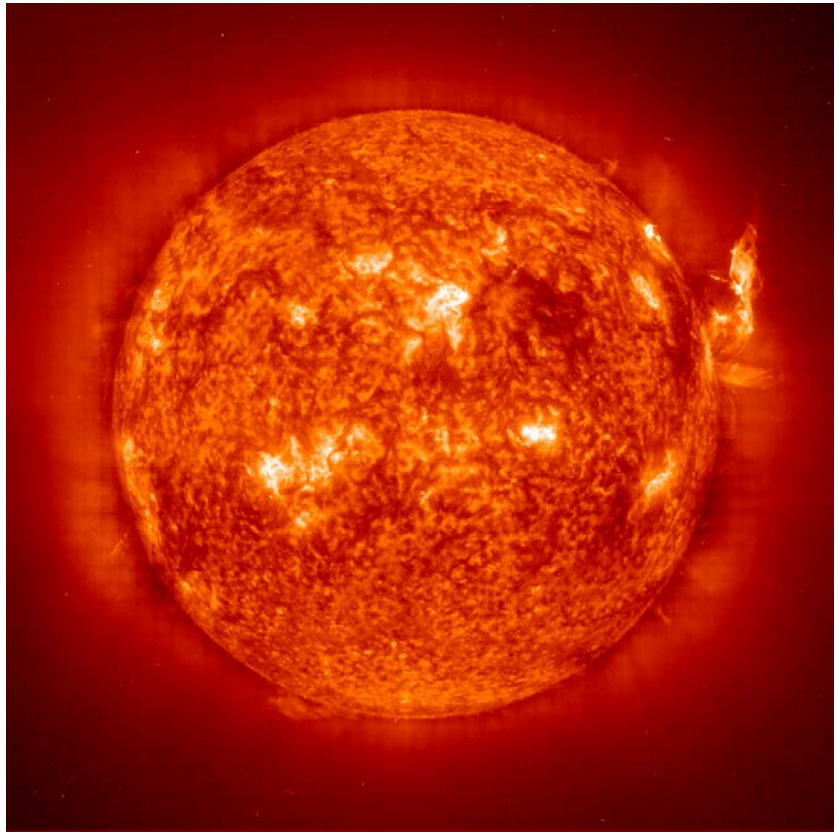


NASA/European Space Agency (1999)

Origin of Star Energy

Le groupe d'étoiles des Pléiades (2002), Robert Gendler

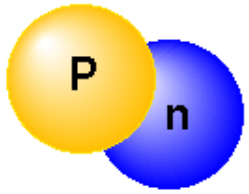
Thermonuclear fusion

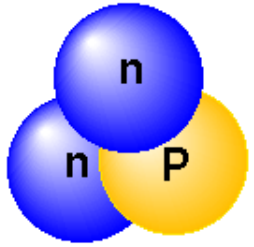


NASA/European Space Agency (1999)

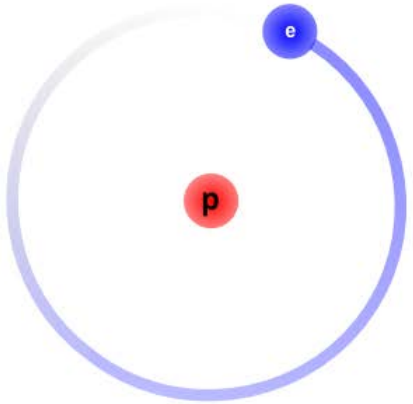
Nuclear Fusion Reaction

Deuterium (Deuteron)



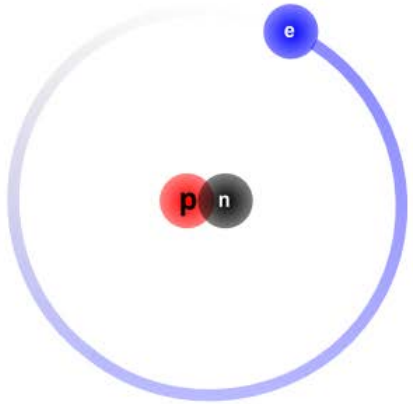


Tritium (Triton)



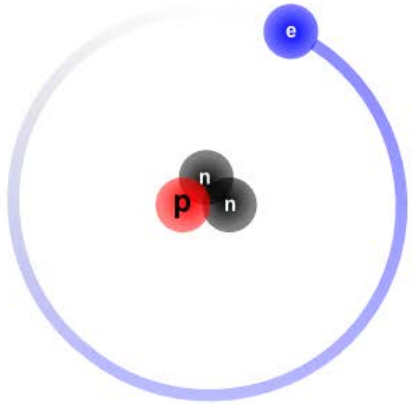
$^{1}_{1}H$

Hydrogen (H)



$^{2}_{1}H$

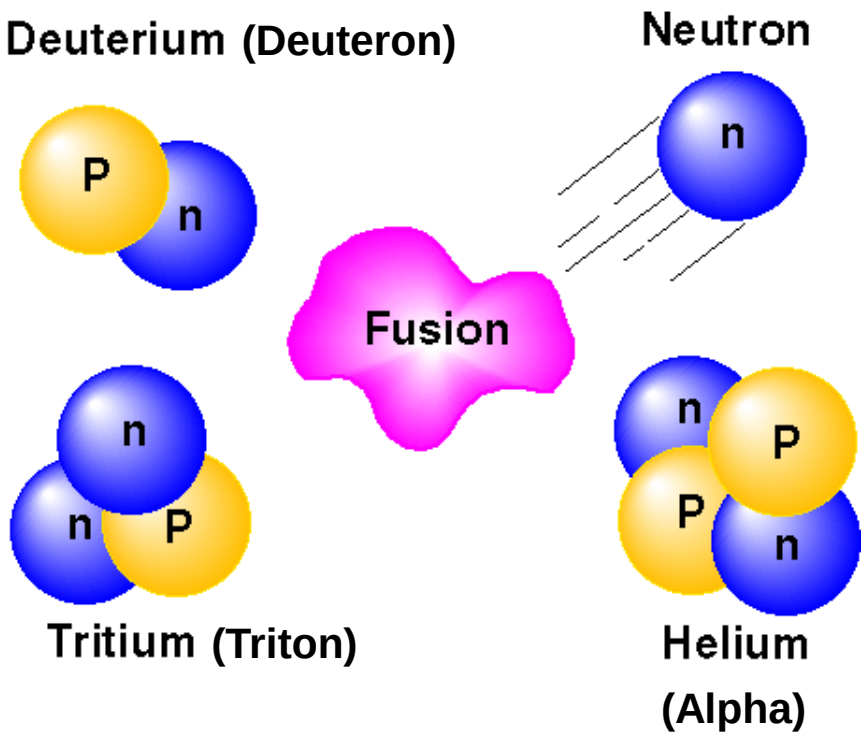
Deuterium (D)



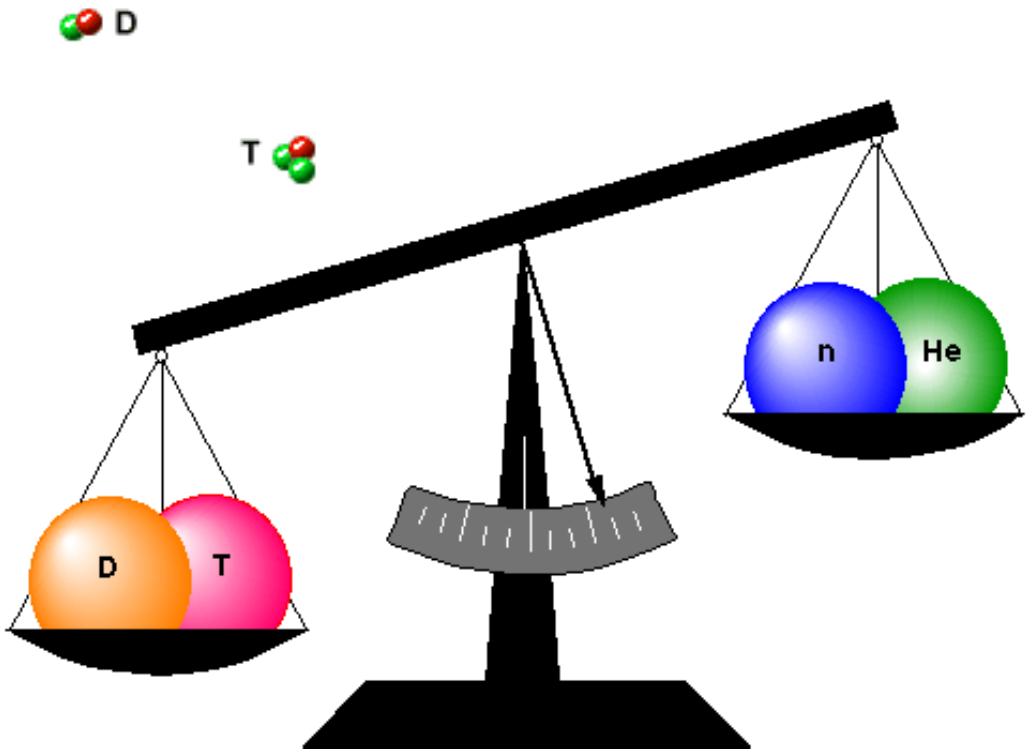
$^{3}_{1}H$

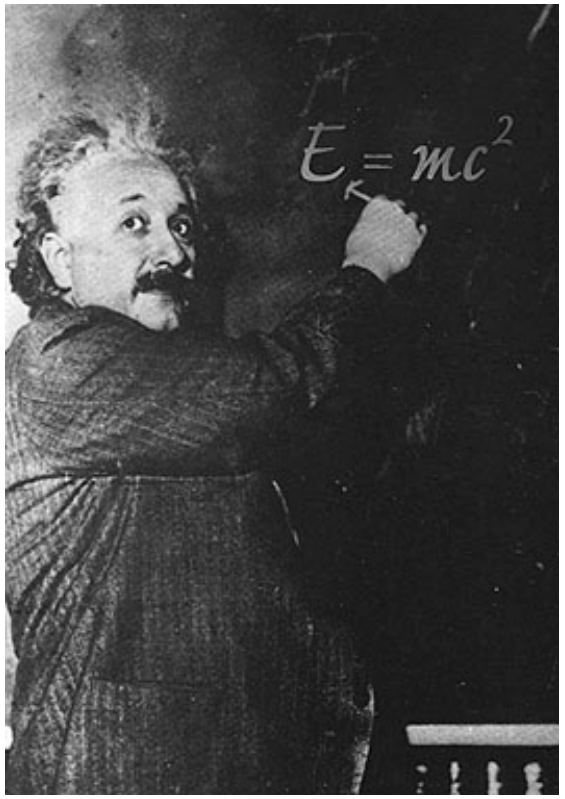
Tritium (T)

Nuclear Fusion Reaction



Nuclear Fusion Reaction

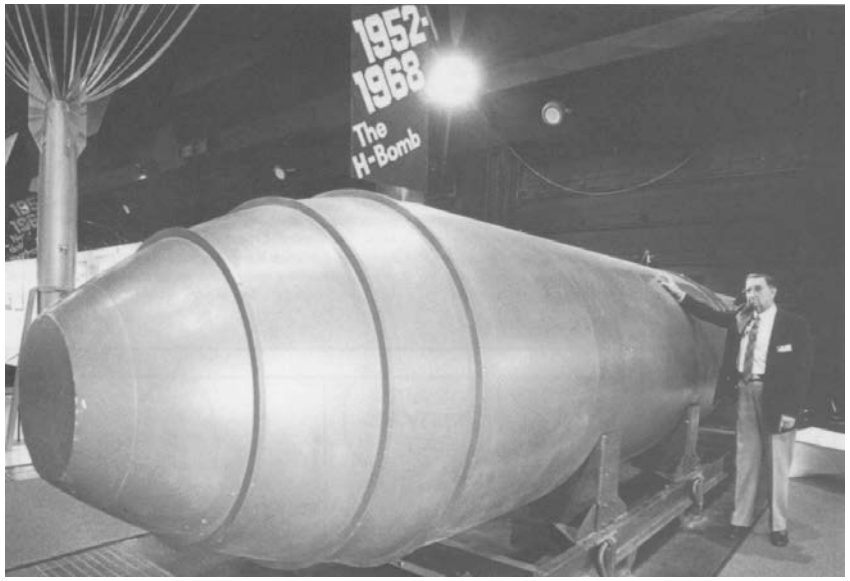




[출처]
http://www.meteoweb.eu/2011/09/e-possibile-superare-la-velocita-della-luce-teoria-della-relativita-a-rischio/88437/, Dec, 2014

Converting mass defect into energy → Fusion energy

Utilisation of Fusion Energy

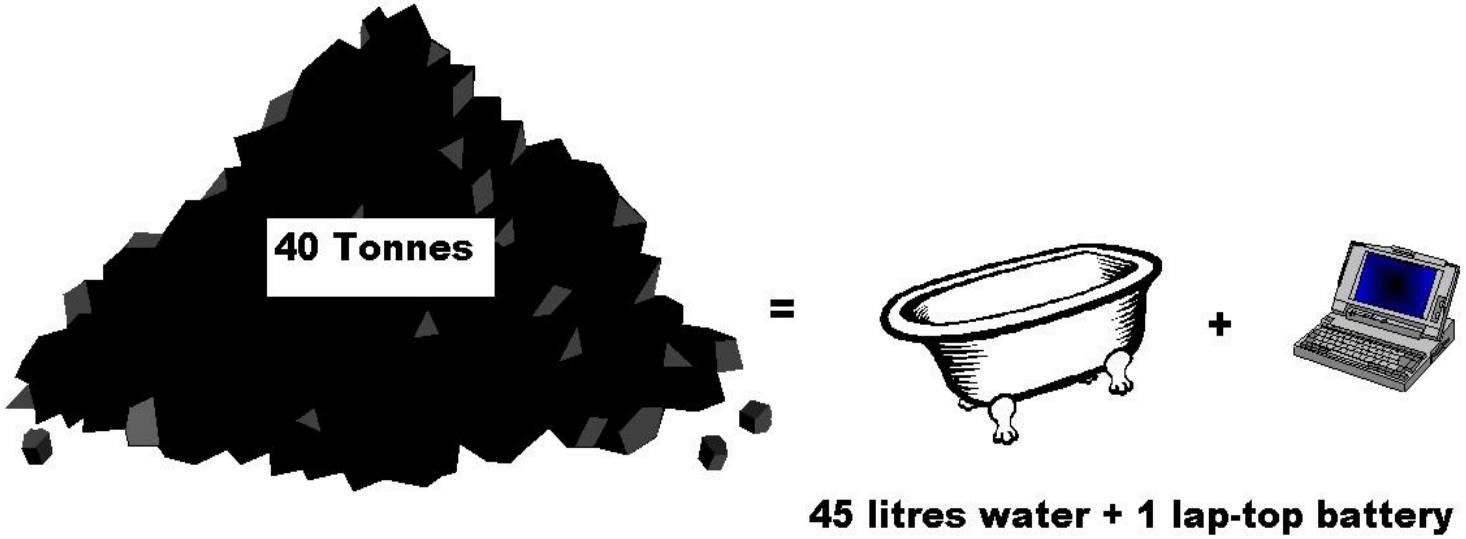


A Mark-17 Hydrogen bomb at the National Atomic Museum

Ivy Mike (1 November 1952)

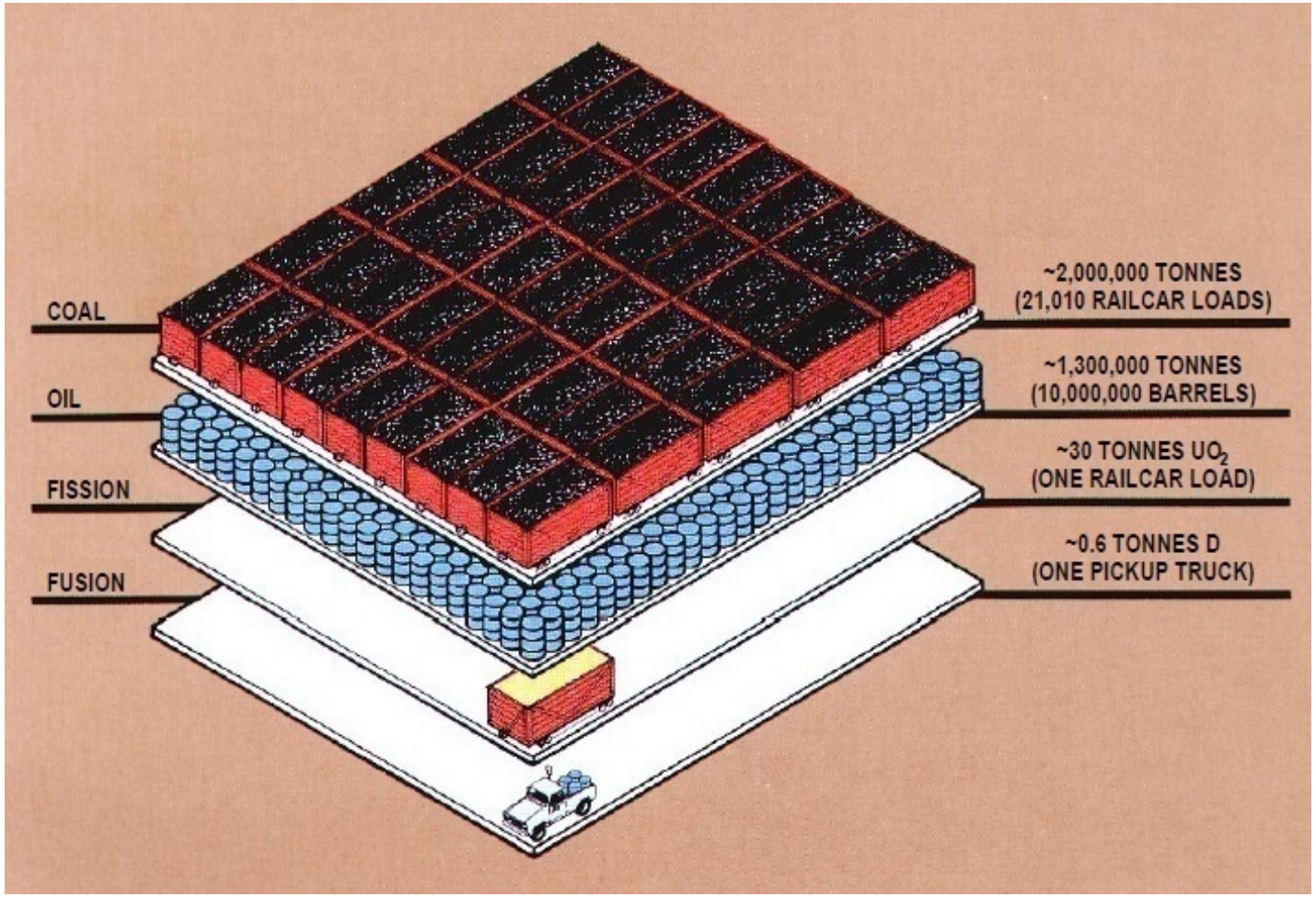
Peaceful use of the fusion energy?

Peaceful Use of the Fusion Energy

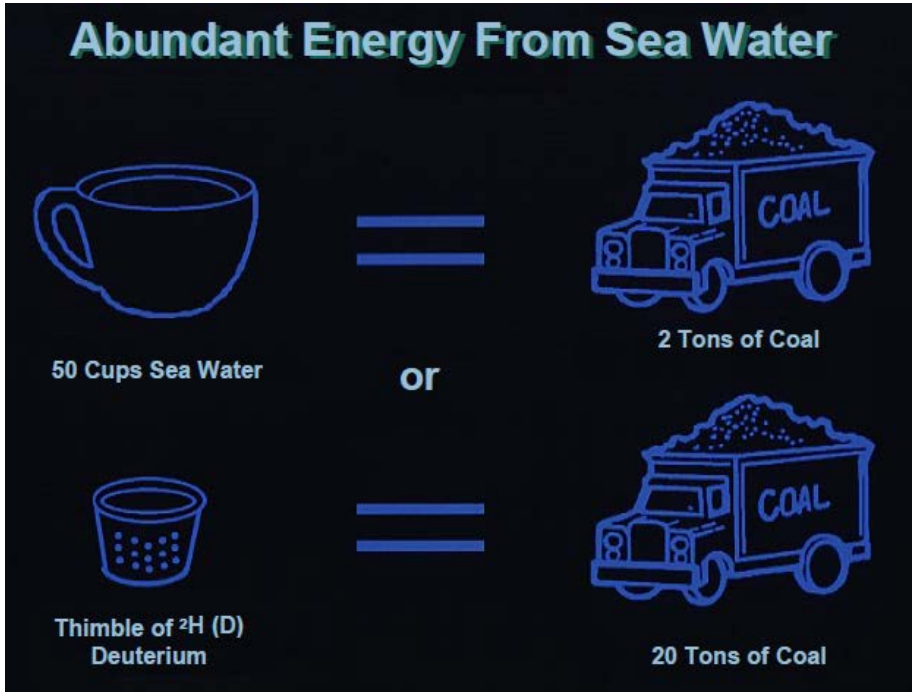


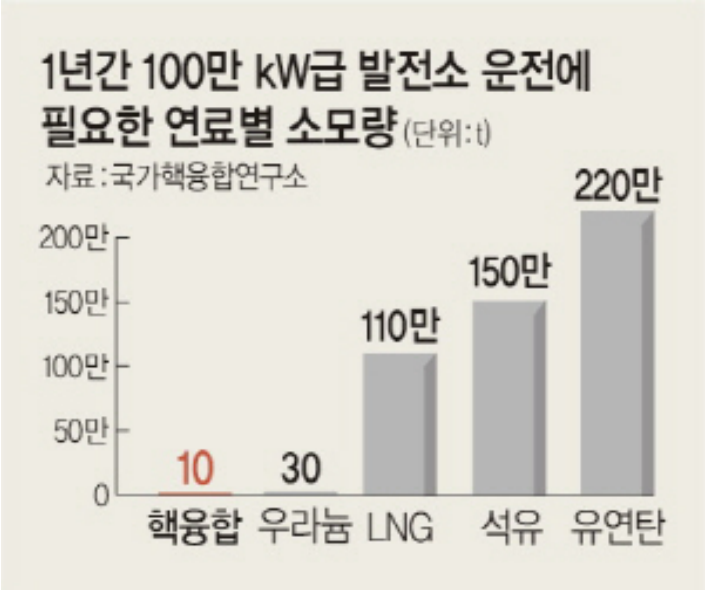
- Lithium in one laptop battery + half a bath-full of ordinary water (≥ one egg cup full of heavy water) = 200 MW

Peaceful Use of the Fusion Energy

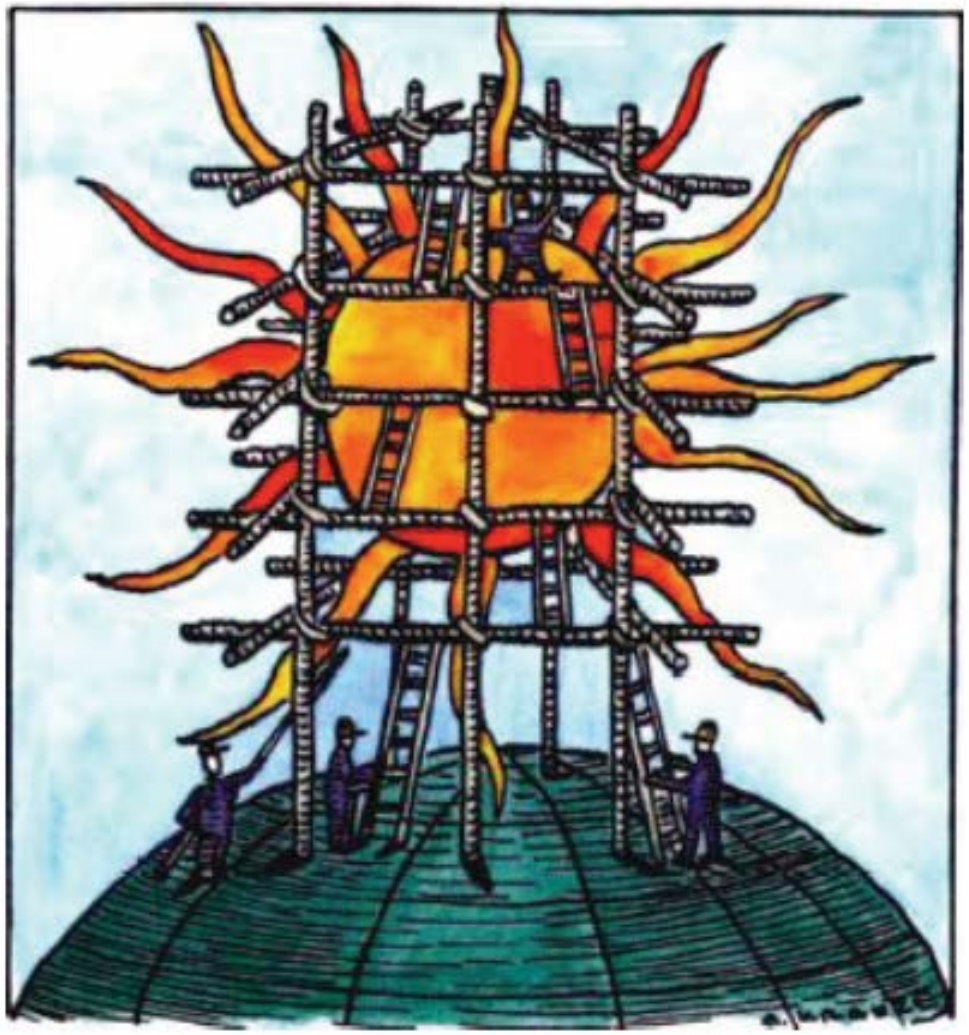


Peaceful Use of the Fusion Energy





Build a Sun on the Earth

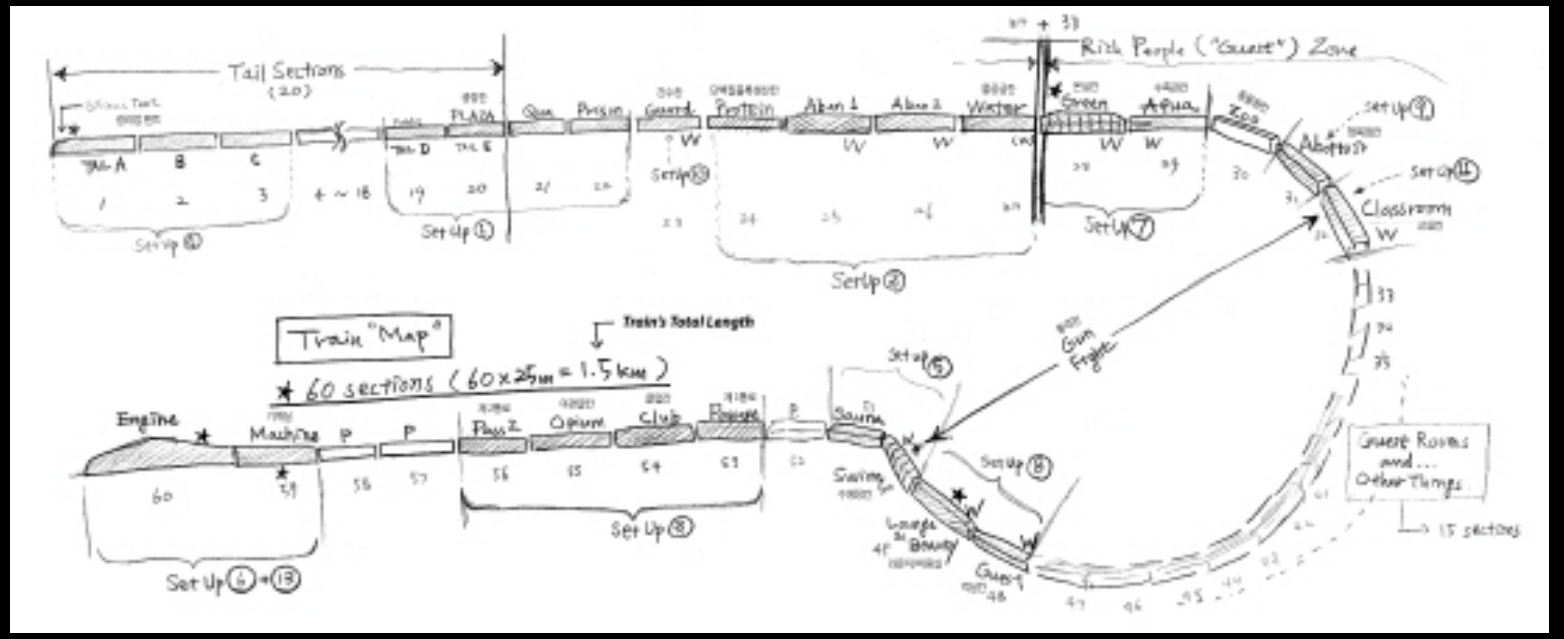


Iron man (2008), Disney

Iron Man

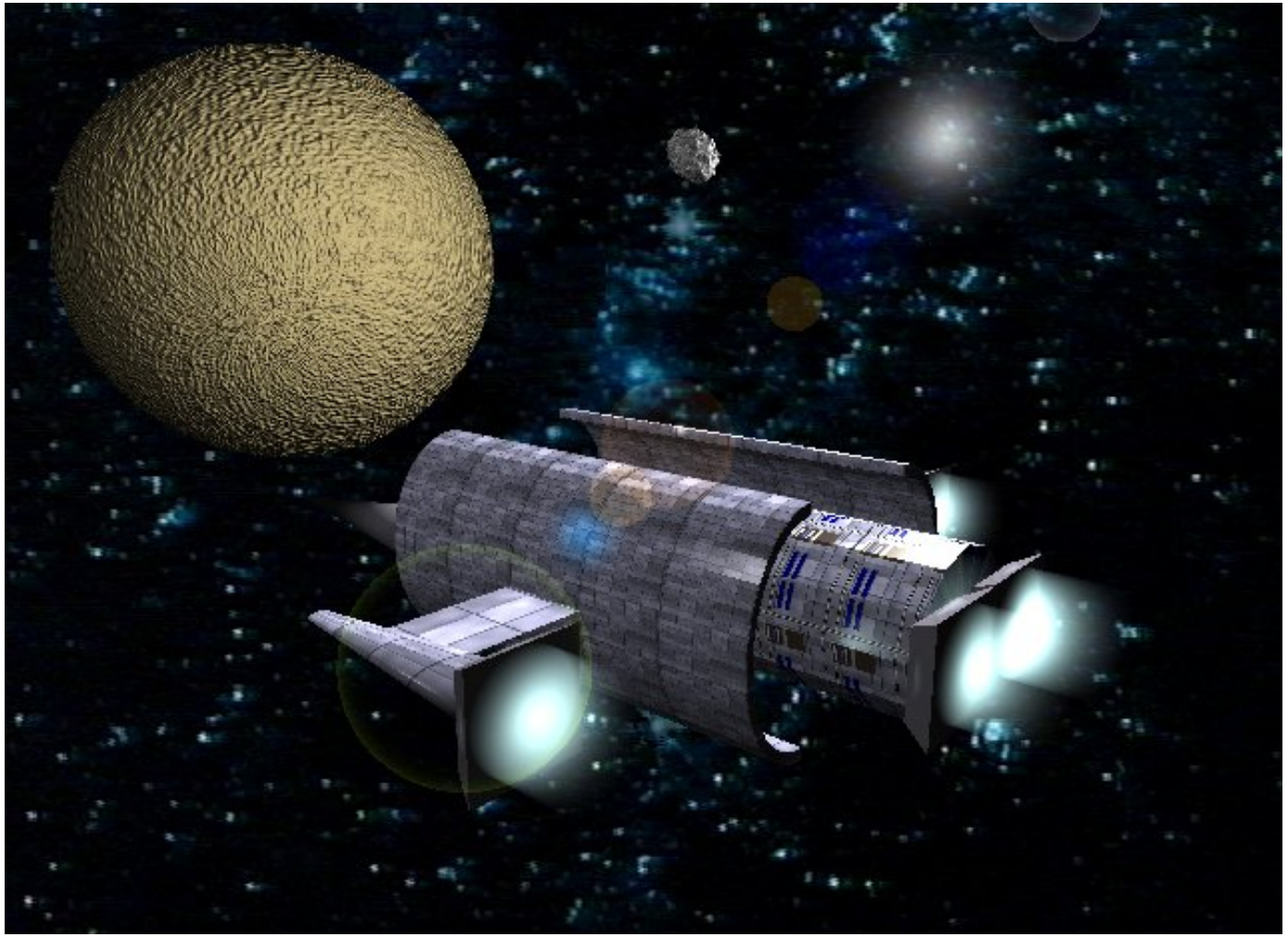

나는 닫힌 문을 열고 싶다
2013년 봉준호 감독의 새로운 세계
설국열차
SONG KANGHO
SNOWPIERCER 2013


제 작 모호필름, 오퍼스픽처스
제공/배급 CJ엔터테인먼트

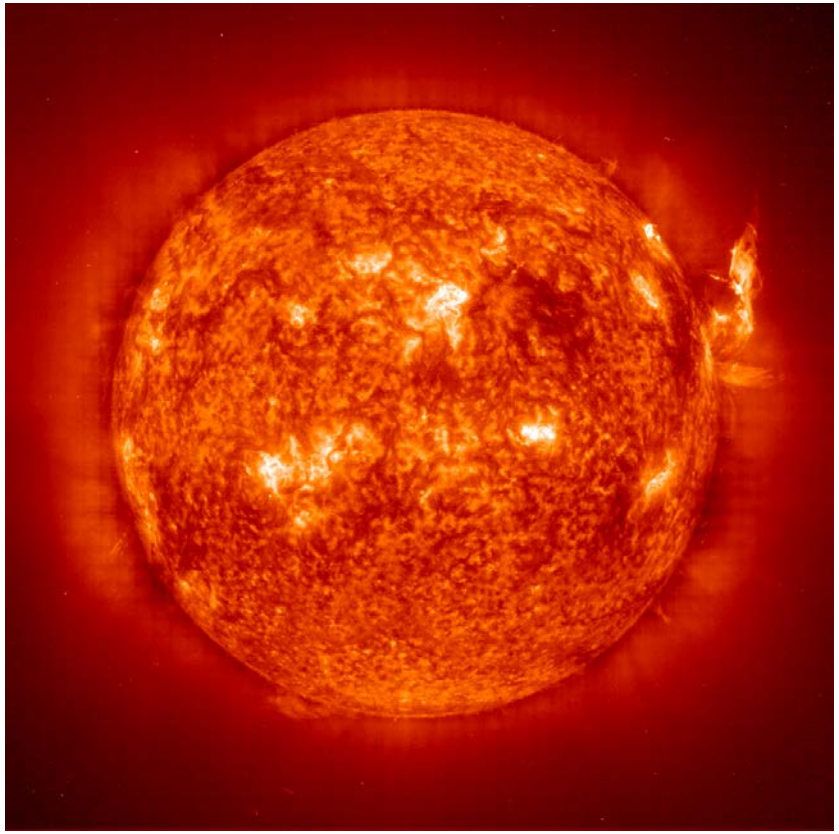

Tail Sections (20)
Rich People ("Guest") Zone
Train "Map"
Train's Total Length
★ 60 sections (60 × 25m = 1.5km)
Engine
Set Up ①
Set Up ②
Set Up ③
Set Up ④ ~ ⑬
Set Up ⑤
Set Up ⑥
Set Up ⑦
Set Up ⑧
Set Up ⑨
Set Up ⑩
Set Up ⑪
Gun Fight
Guest Rooms and... Other Things
15 sections

How to confine the hot sun?

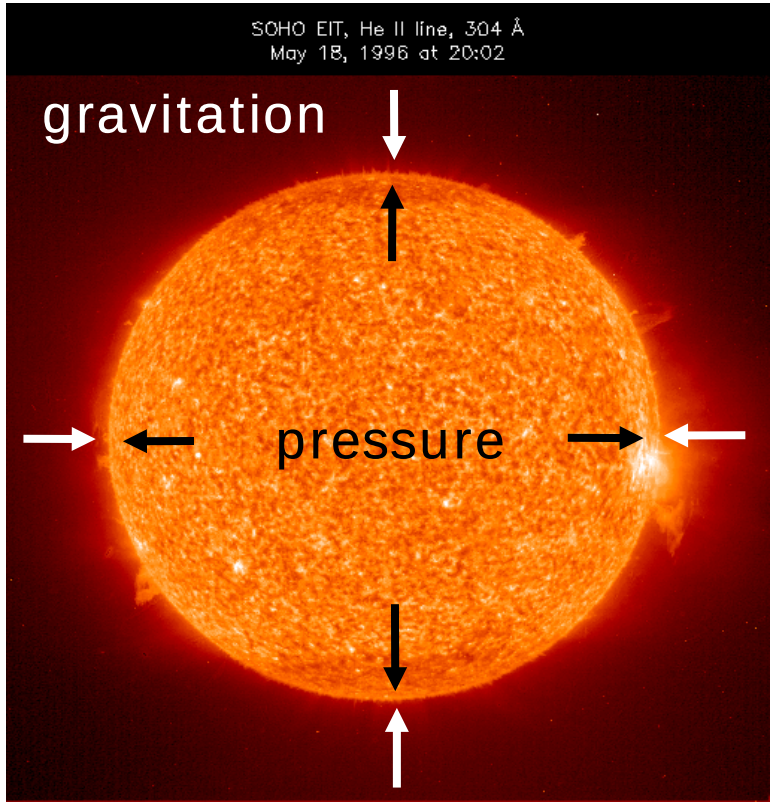
Confinement



Gravitational Confinement

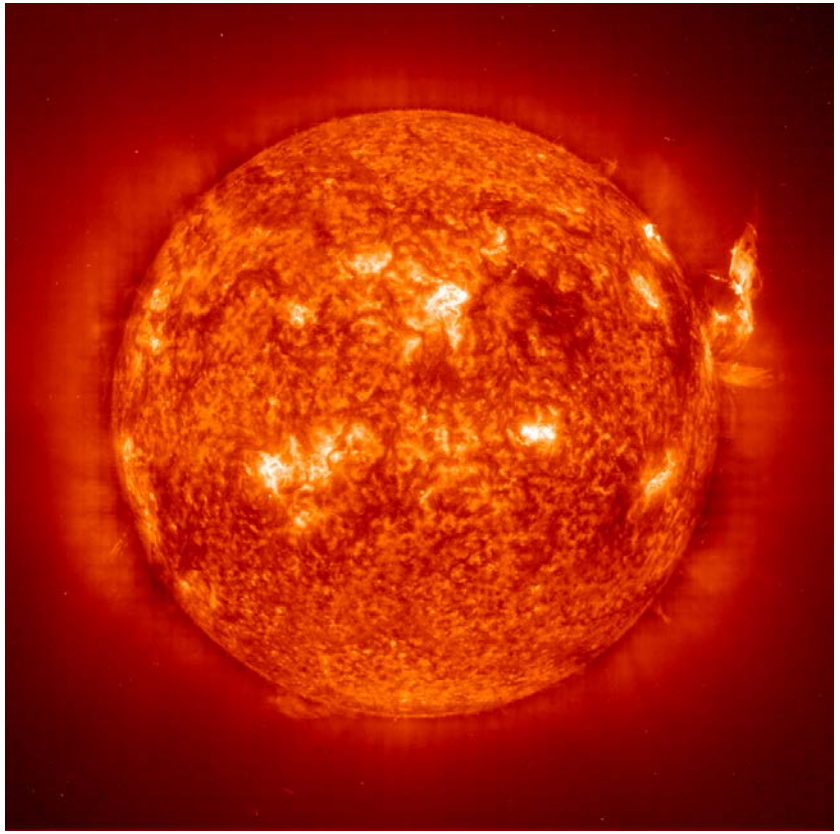


The sun



Equilibrium in the sun

Gravitational Confinement

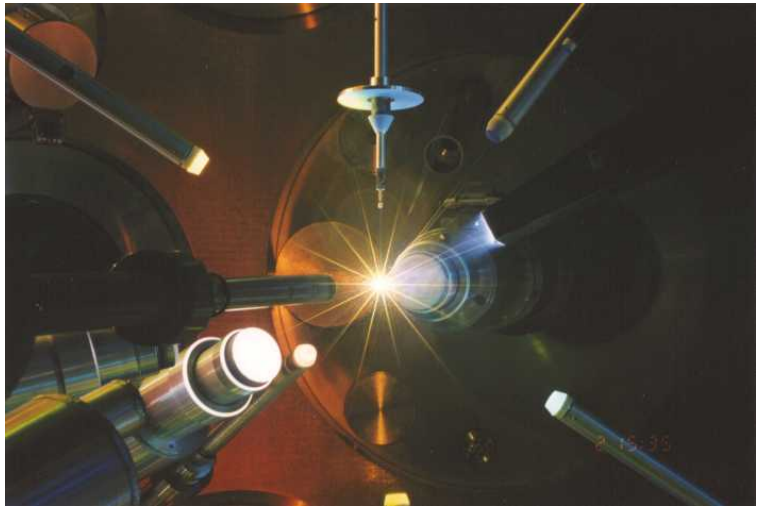


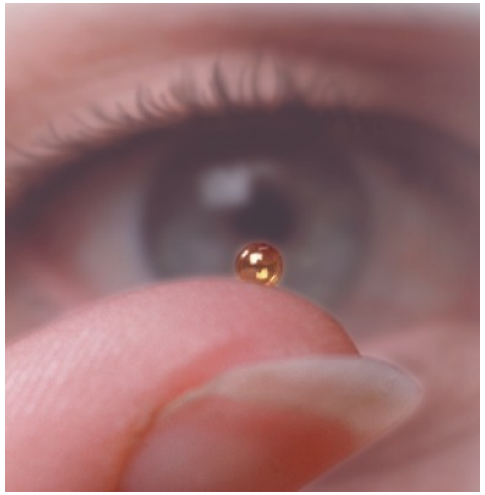
The sun

Black Hole

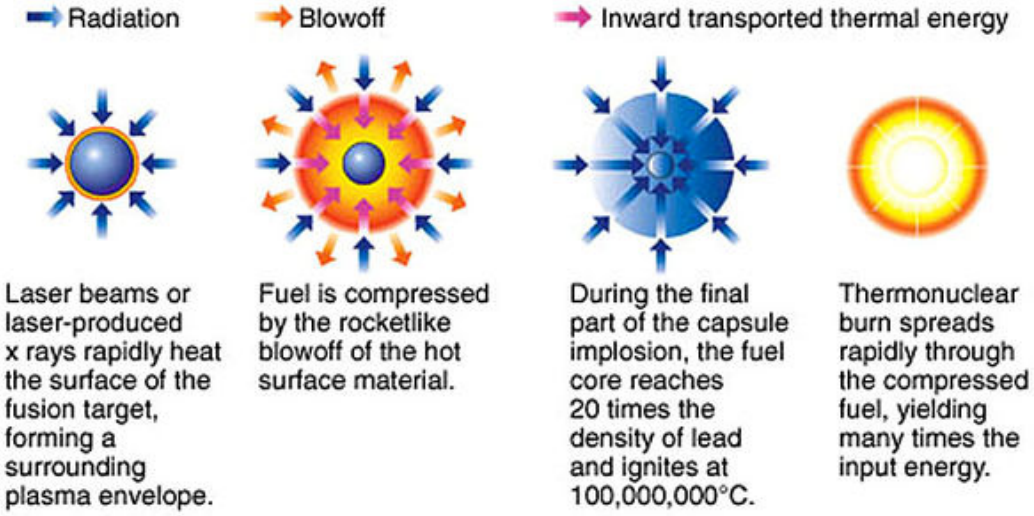
Interstellar (2014),
Warner Brothers/Paramount/Legendary

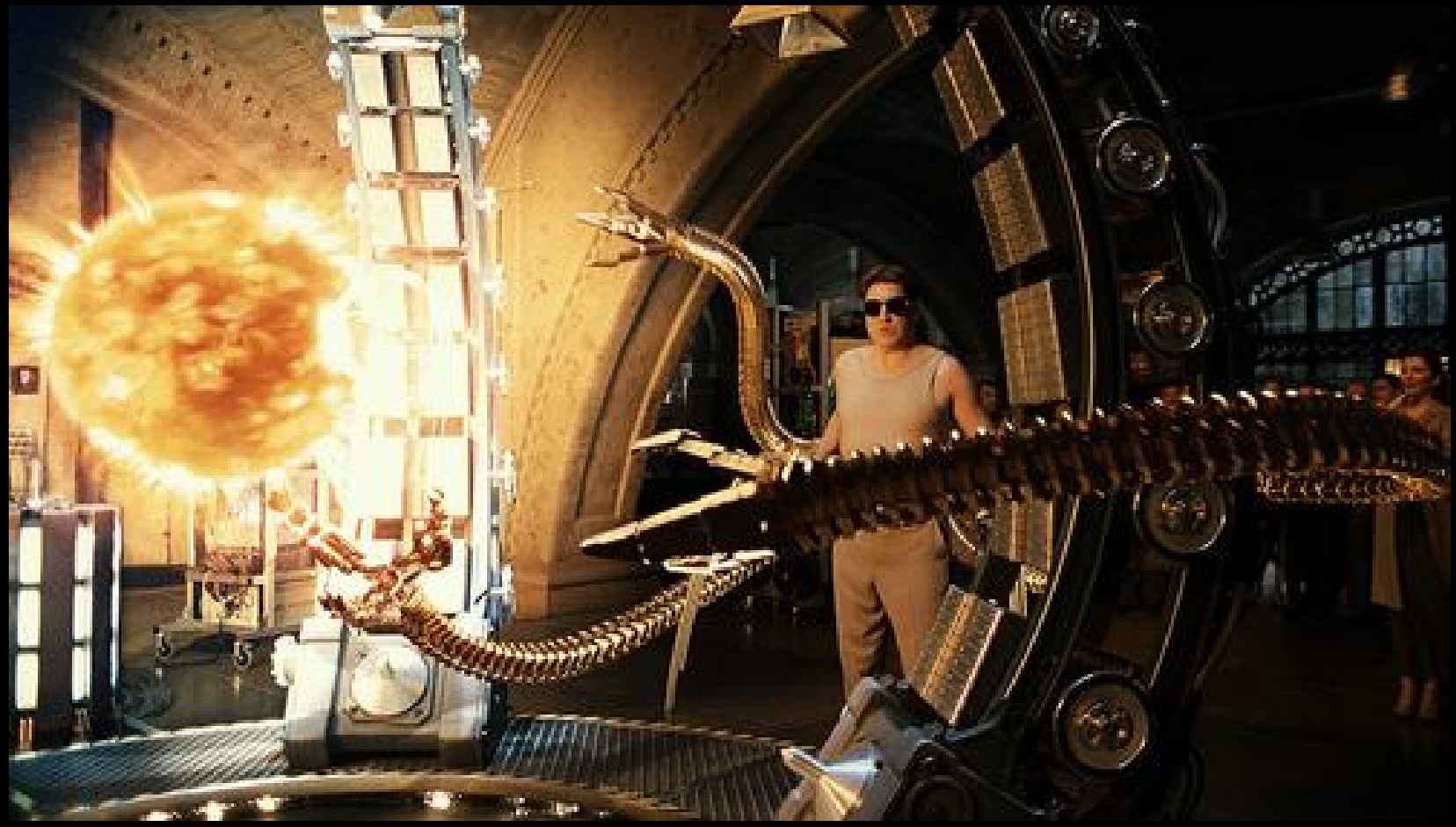
Inertial Confinement





Fusion fuel microcapsule (micro balloon)





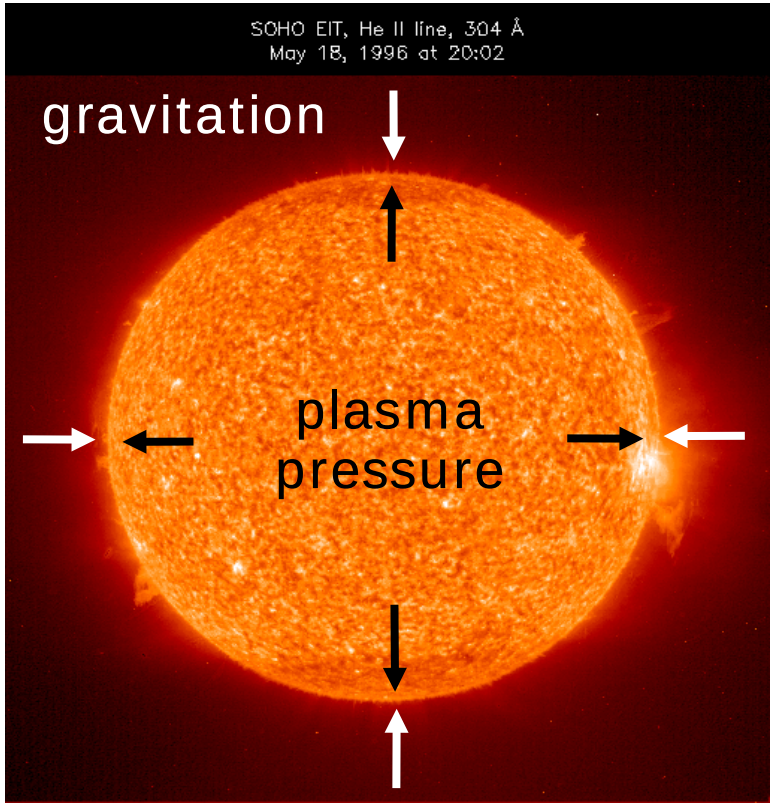
Spiderman 2 (2004), Columbia Pictures

Spiderman II

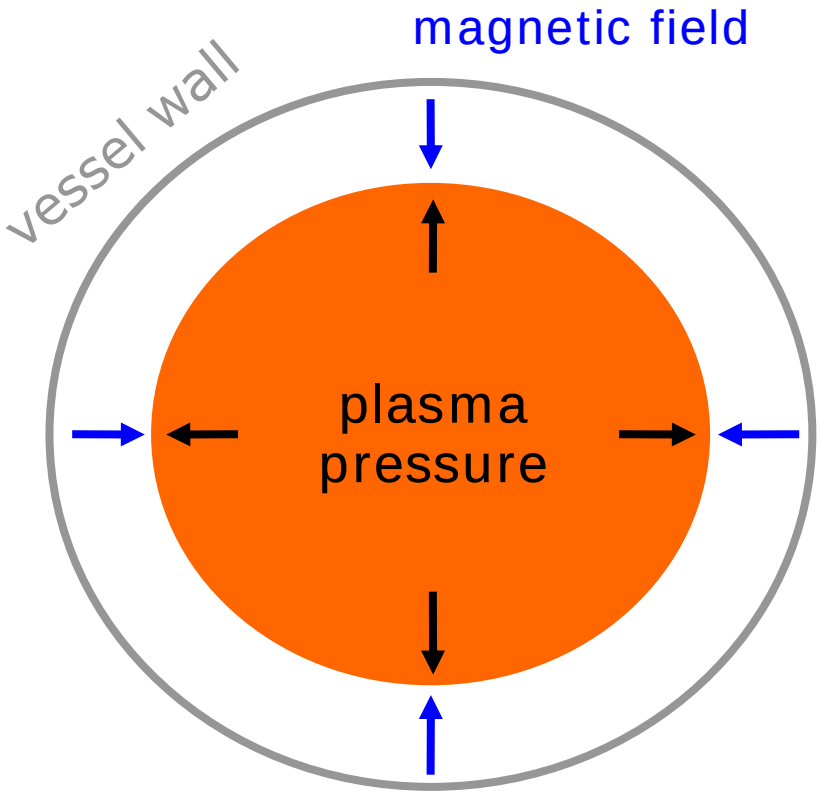
Spiderman 2 (2004), Columbia Pictures

Magnetic Confinement

- Imitation of the Sun on Earth



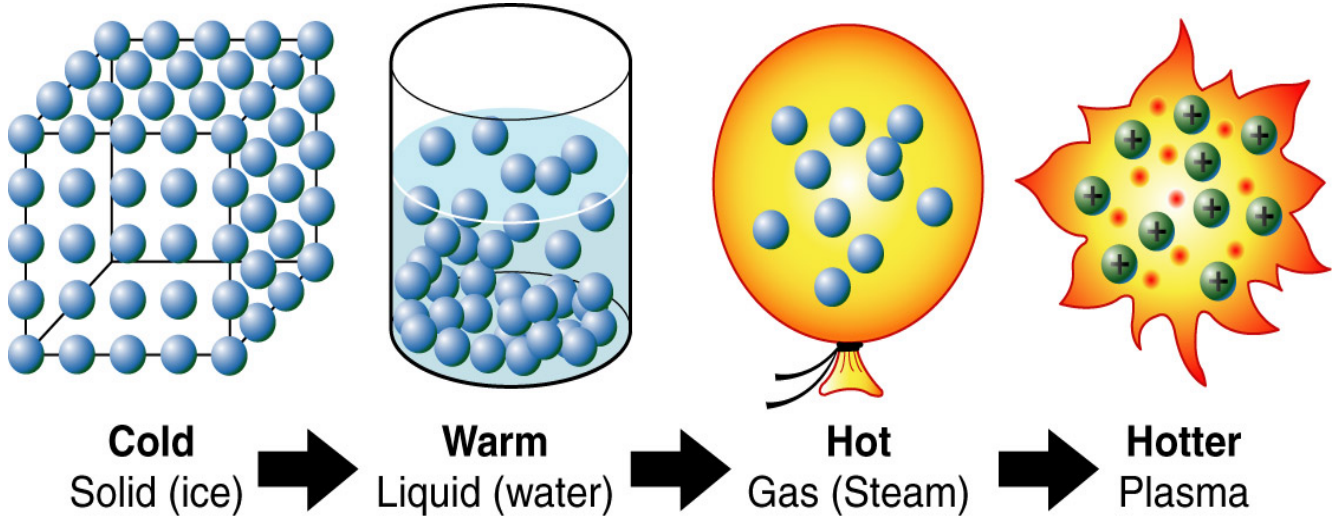
Equilibrium in the sun

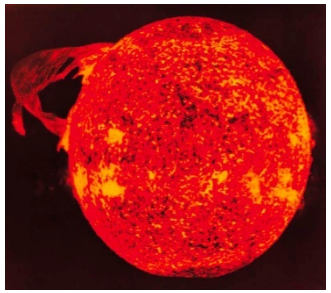


Plasma on earth

Plasma – The 4th State of Matter

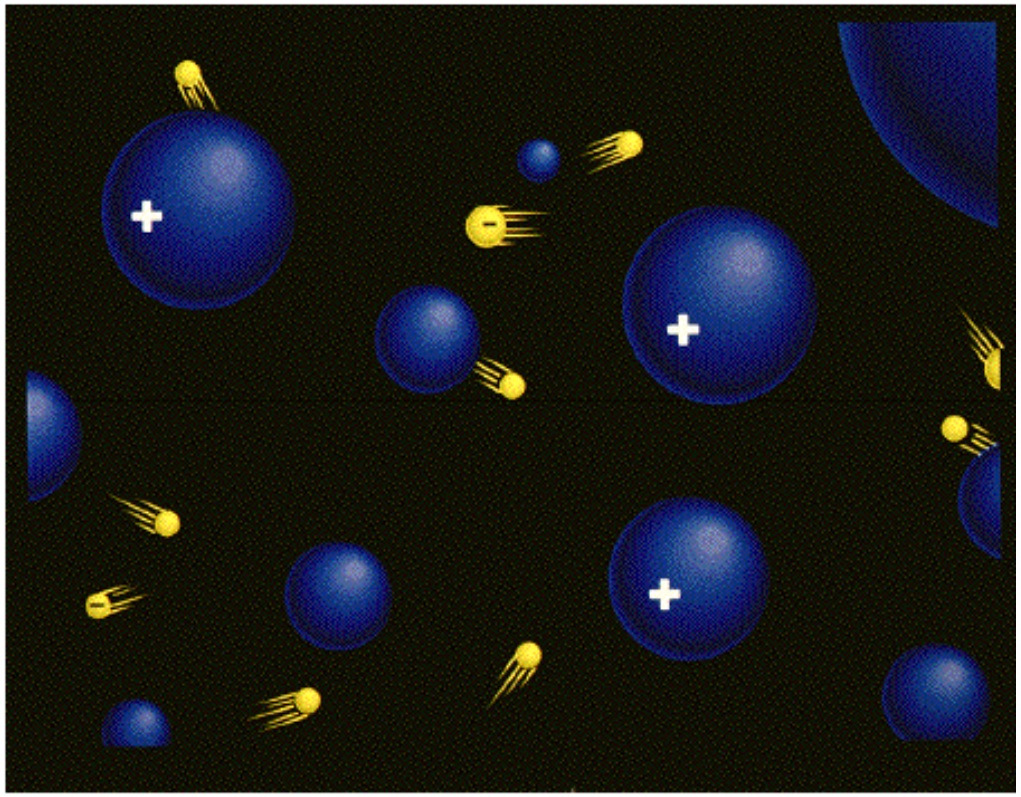




The 4th state of matter

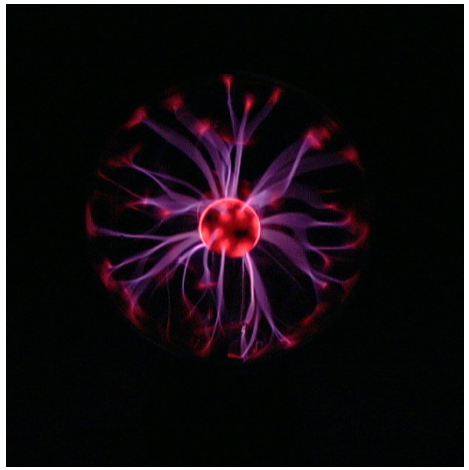
Plasma – The 4th State of Matter

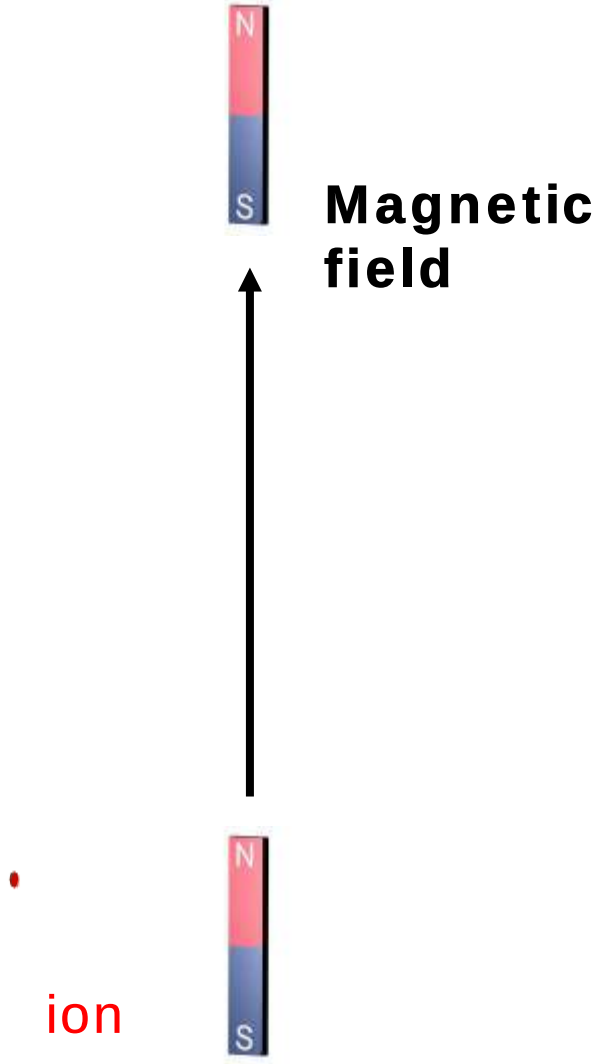


Ions and electrons are separated.

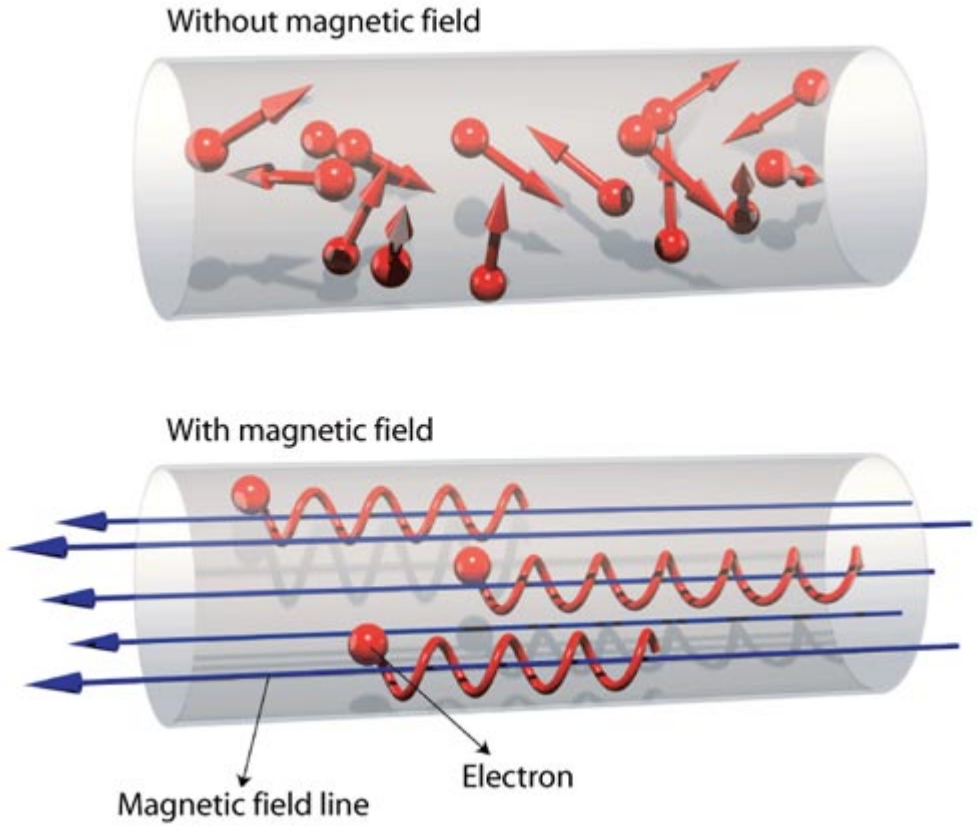
Plasma – The 4th State of Matter

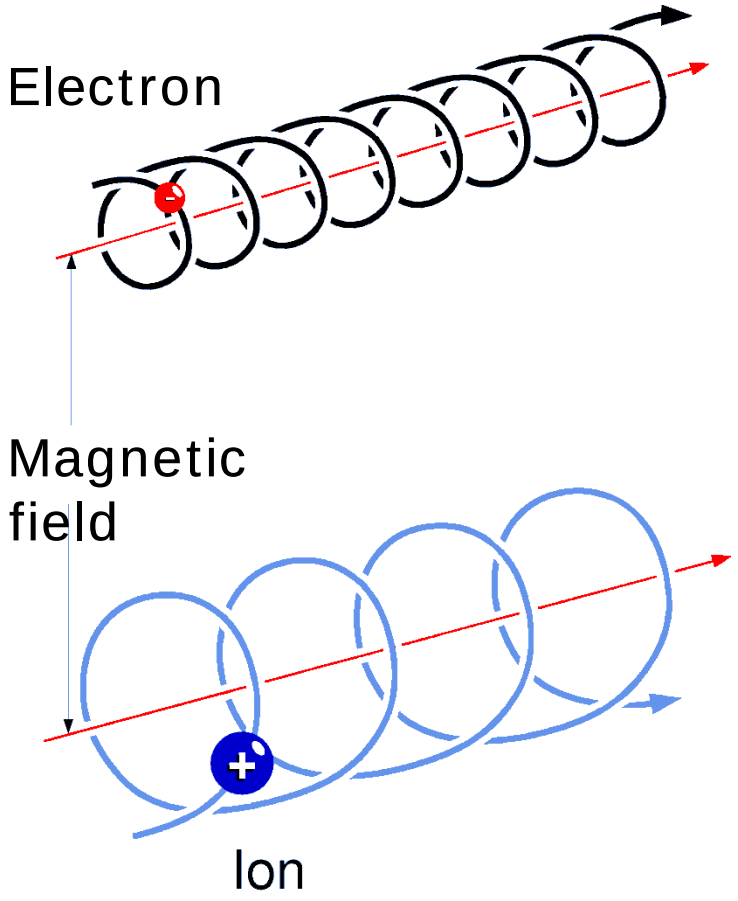
Magnetic Confinement



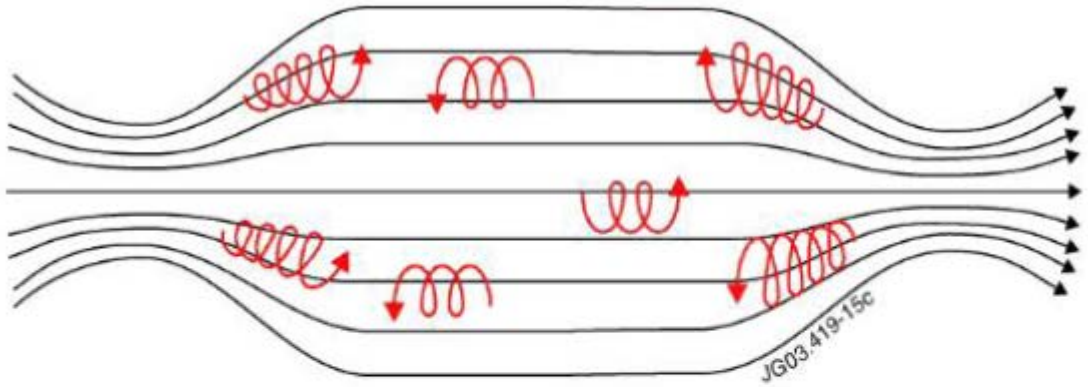


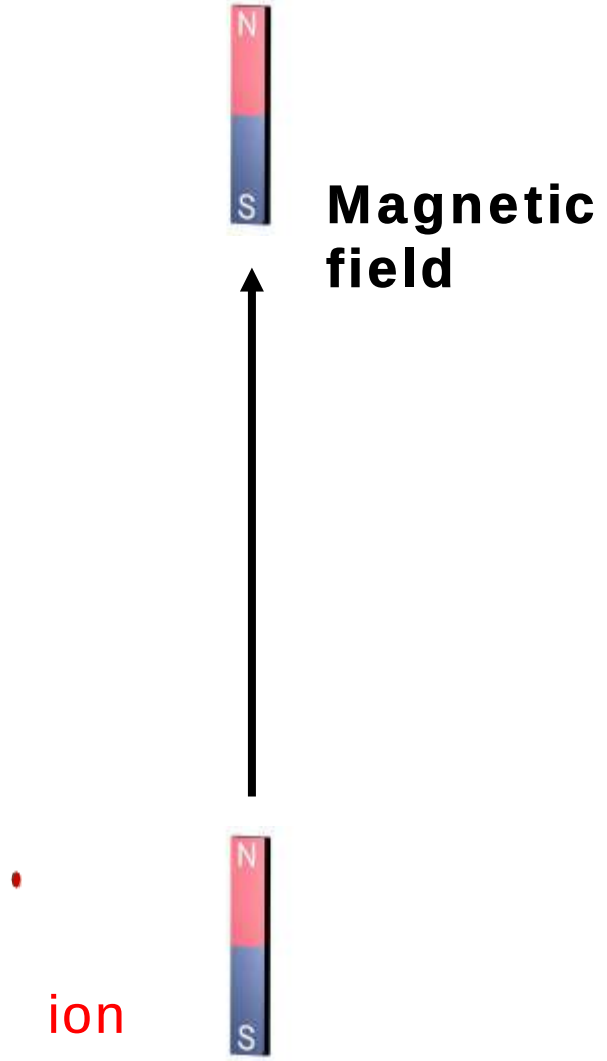
Magnetic Confinement



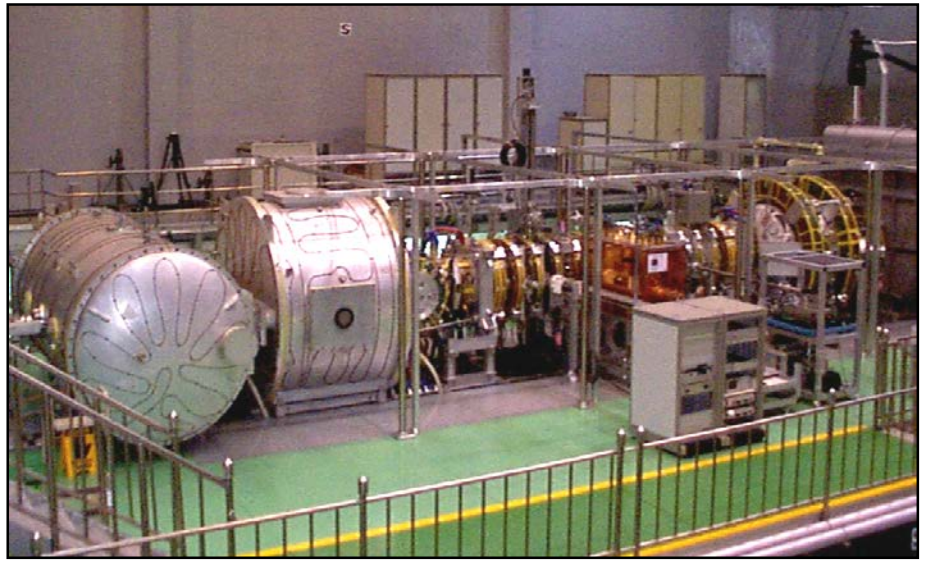


Magnetic Confinement



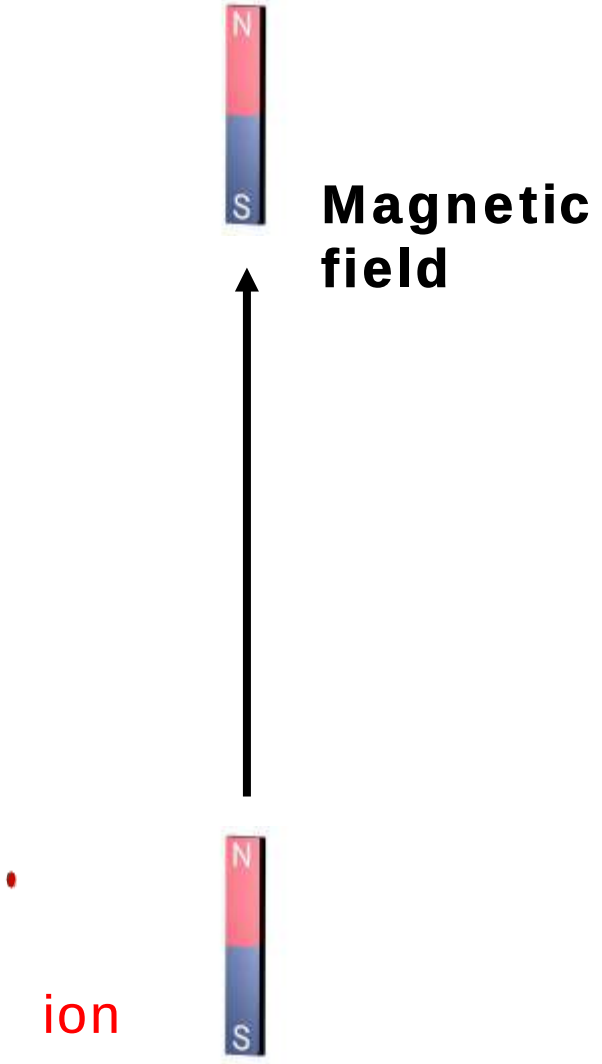


Magnetic Confinement

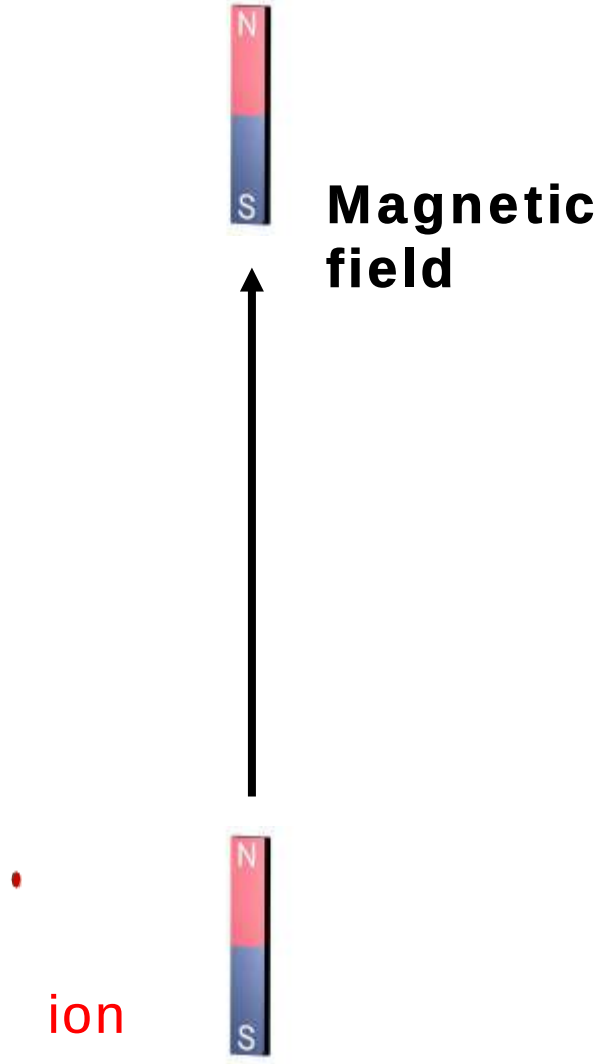


Mirror Machine

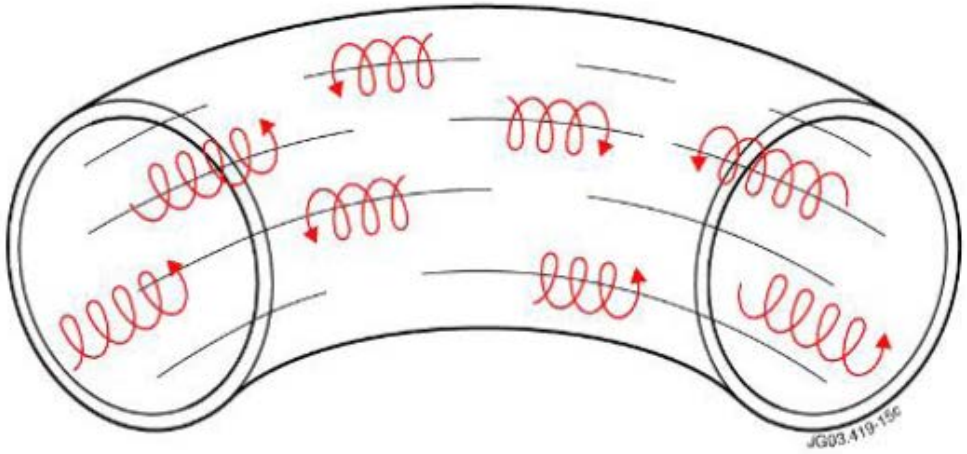
old Hanbit Device in NFRI

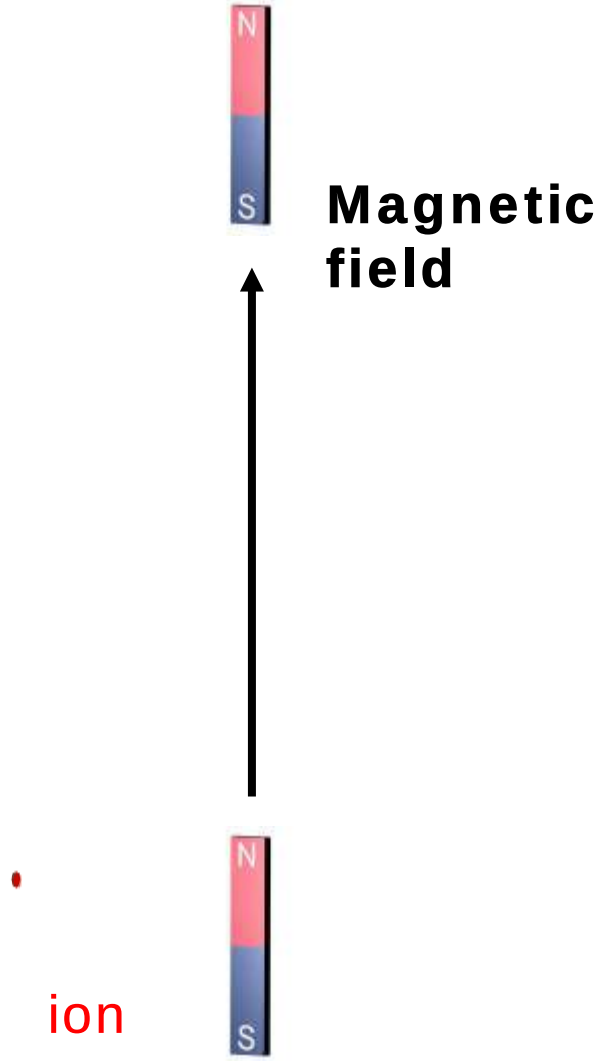


Magnetic Confinement



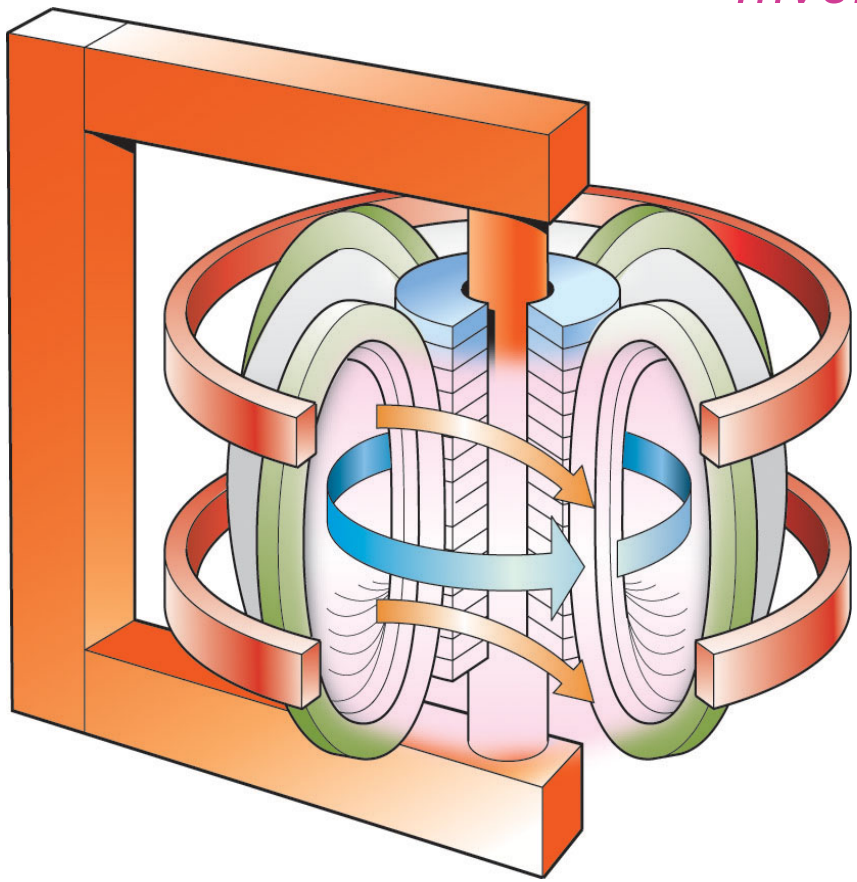
Magnetic Confinement

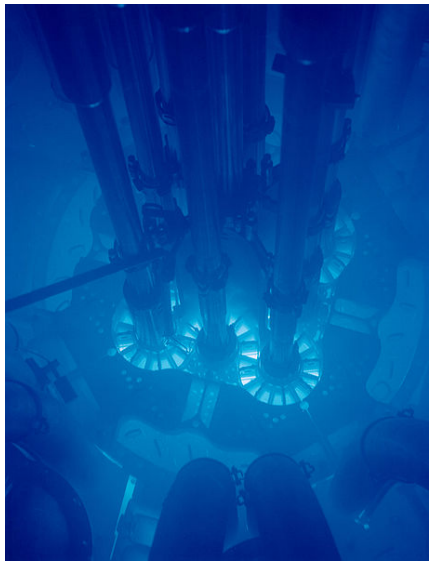




Tokamak

Invented by Tamm and Sakharov in 1952

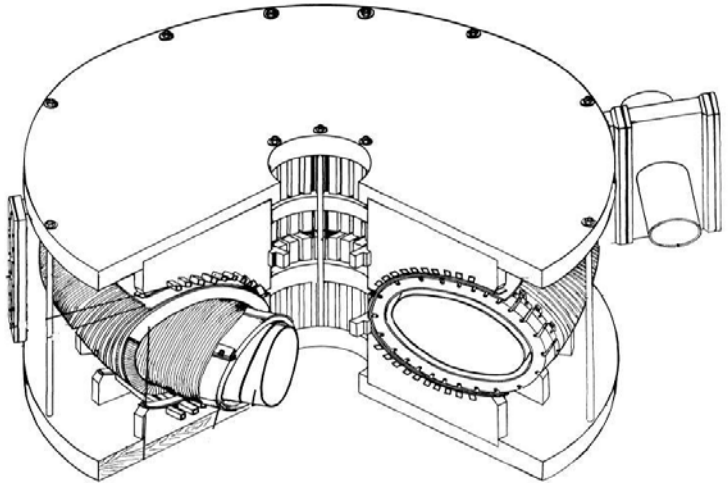




Toroidalnaja **ka**mera **ma**gnitnaja **k**atushka
(Toroidal chamber magnetic coil)

Tokamak

Invented by Tamm and Sakharov in 1952



Cutaway of the Toroidal Chamber in Artsimovitch's Paper *Research on Controlled Nuclear Fusion in the USSR*

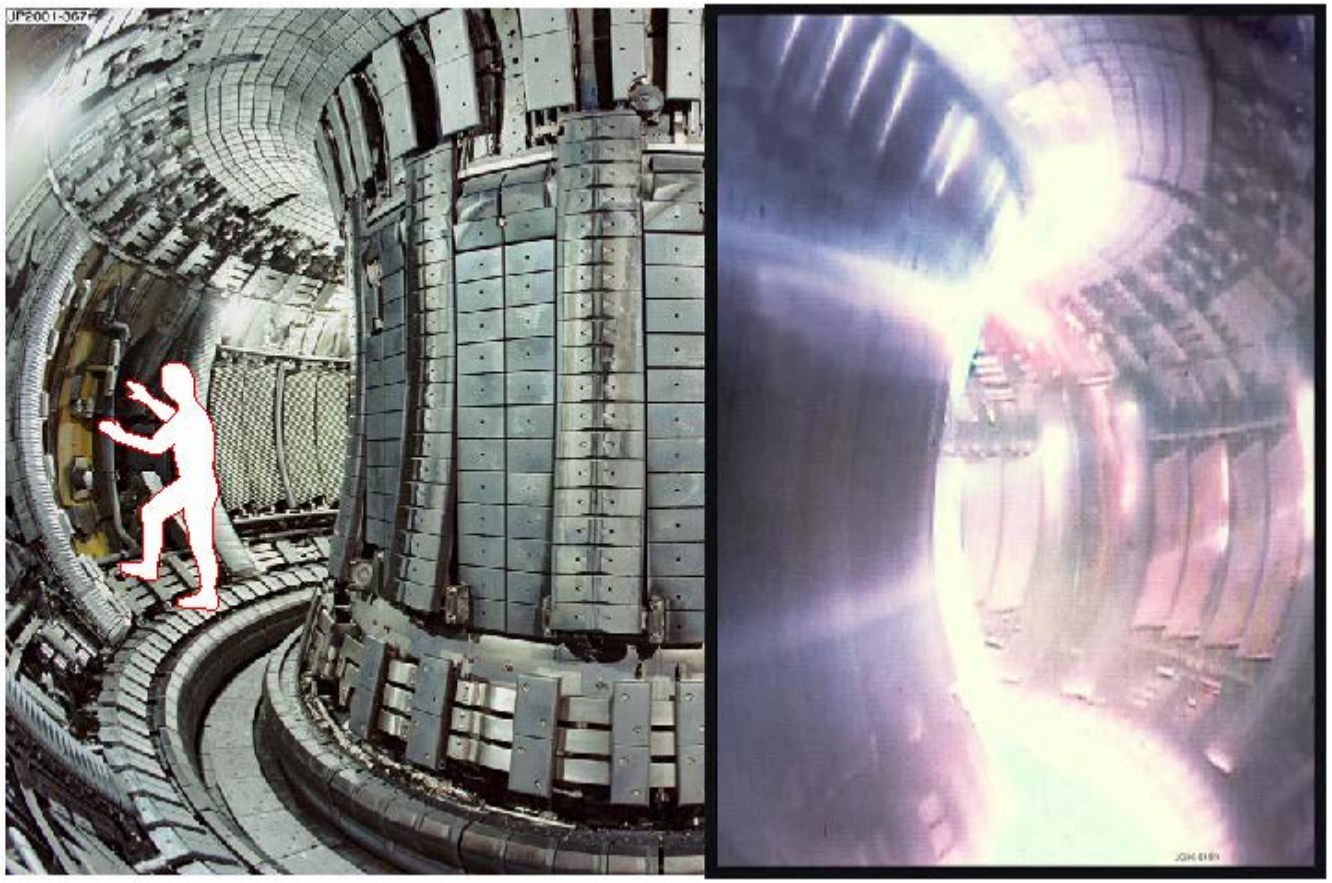
Toroidalnaja **ka**mera **ma**gnitnaja **k**atushka
(Toroidal chamber magnetic coil)

Iron Man

Iron man (2008), Disney

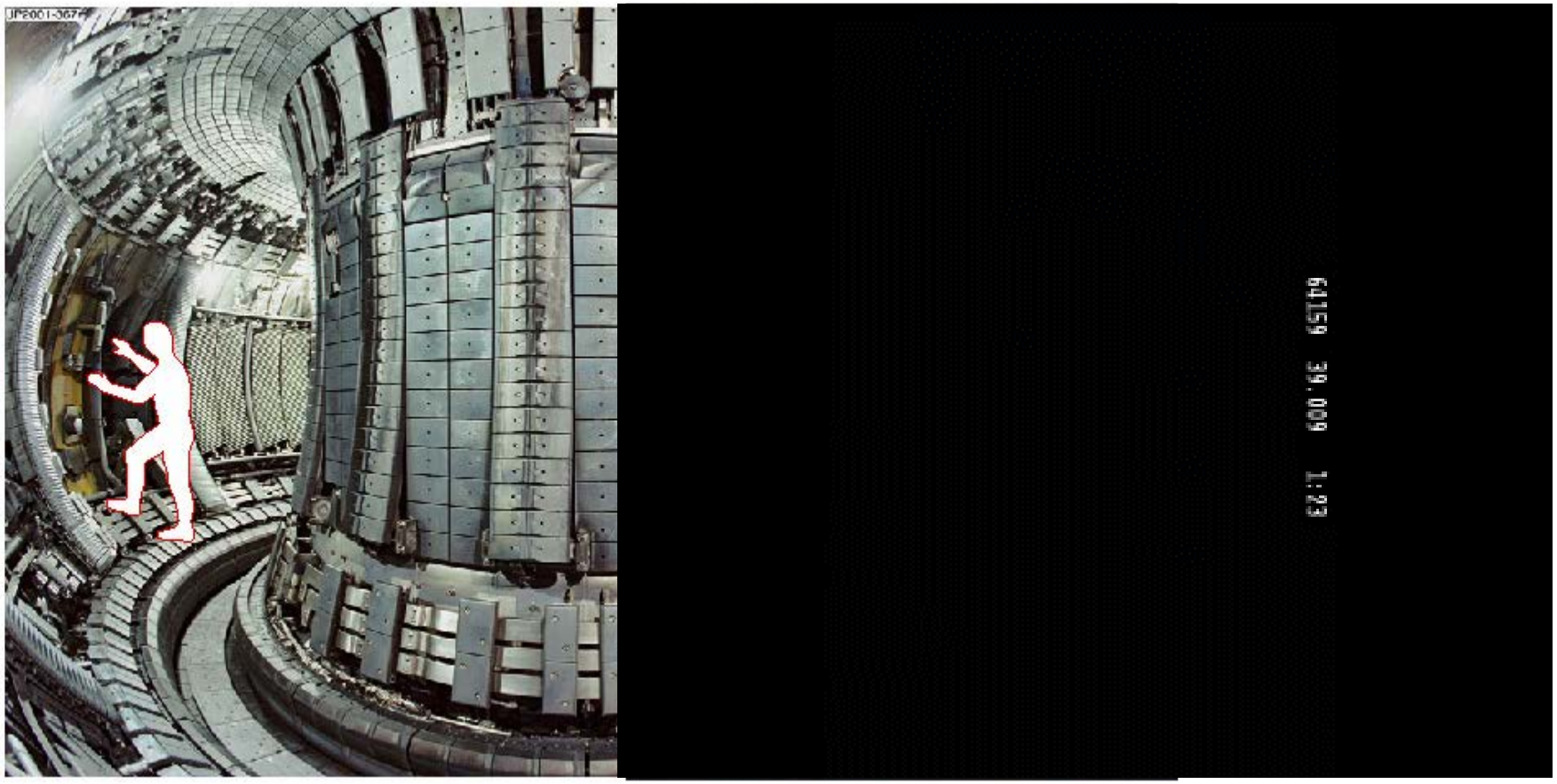
Tokamak

JET (Joint European Torus): R_0 = 3 m, a = 0.9 m, 1983-today



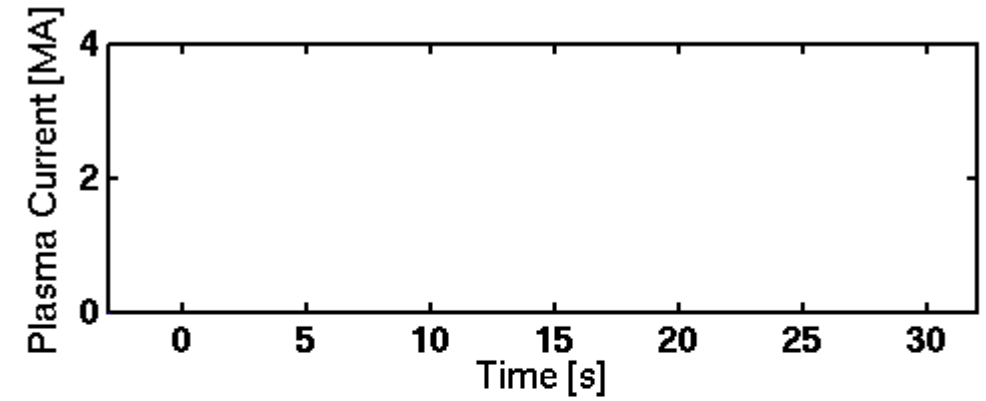
Tokamak

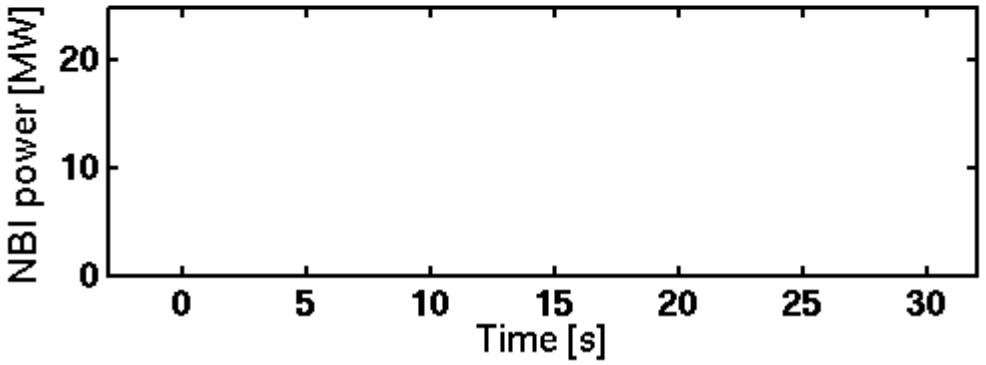
JET (Joint European Torus): R_0 = 3 m, a = 0.9 m, 1983-today



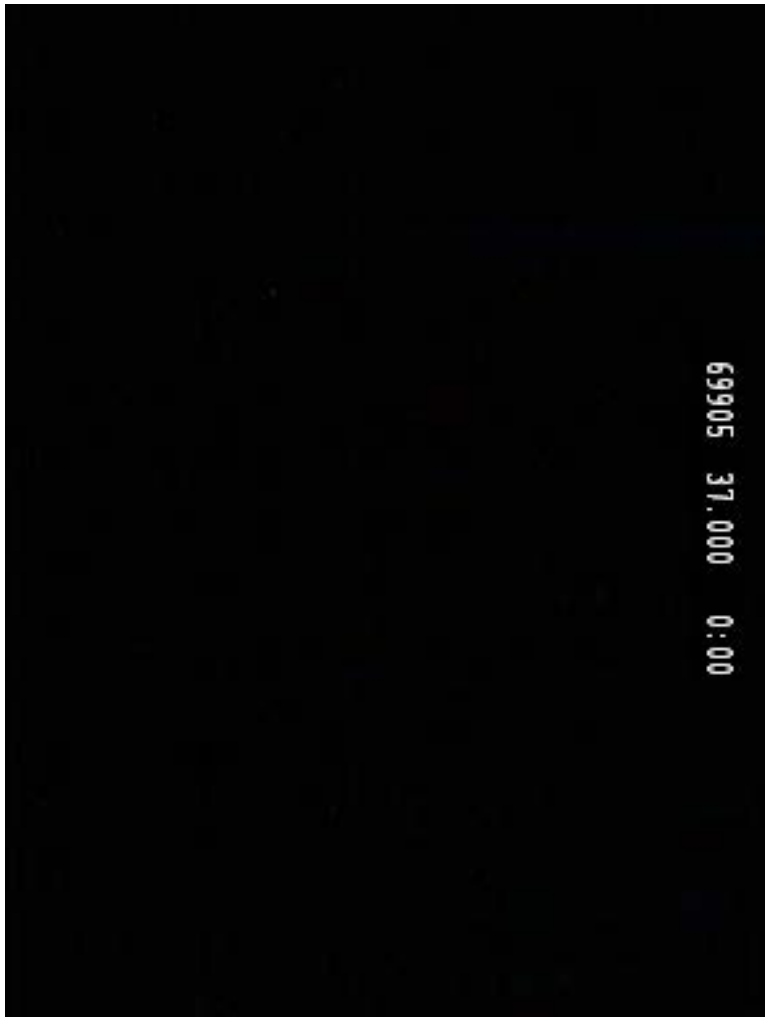
Tokamak

Plasma initiation	Current Ramp-up	High power phase	Plasma quench





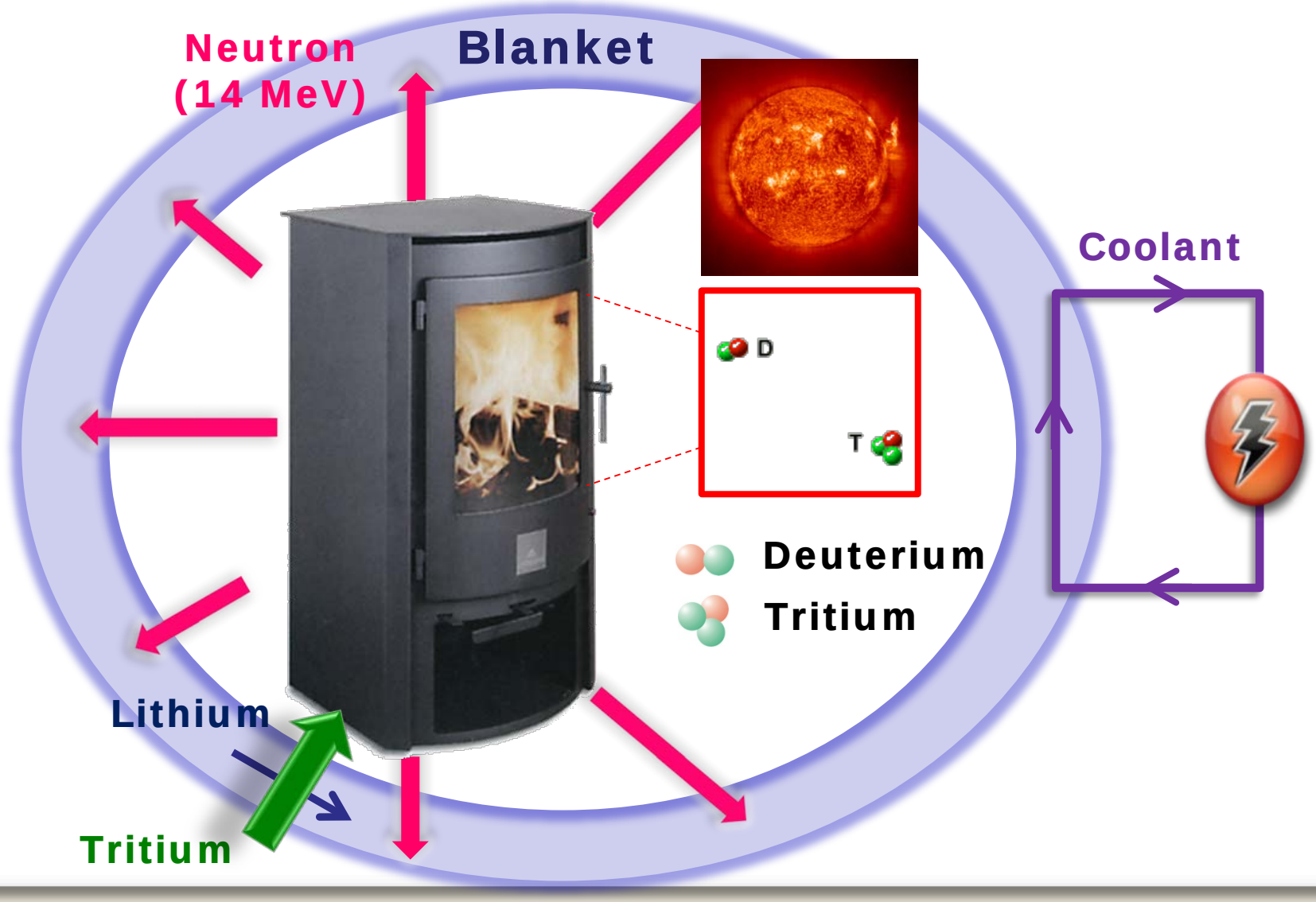
JET pulse 69905 (B_T=3.1T)



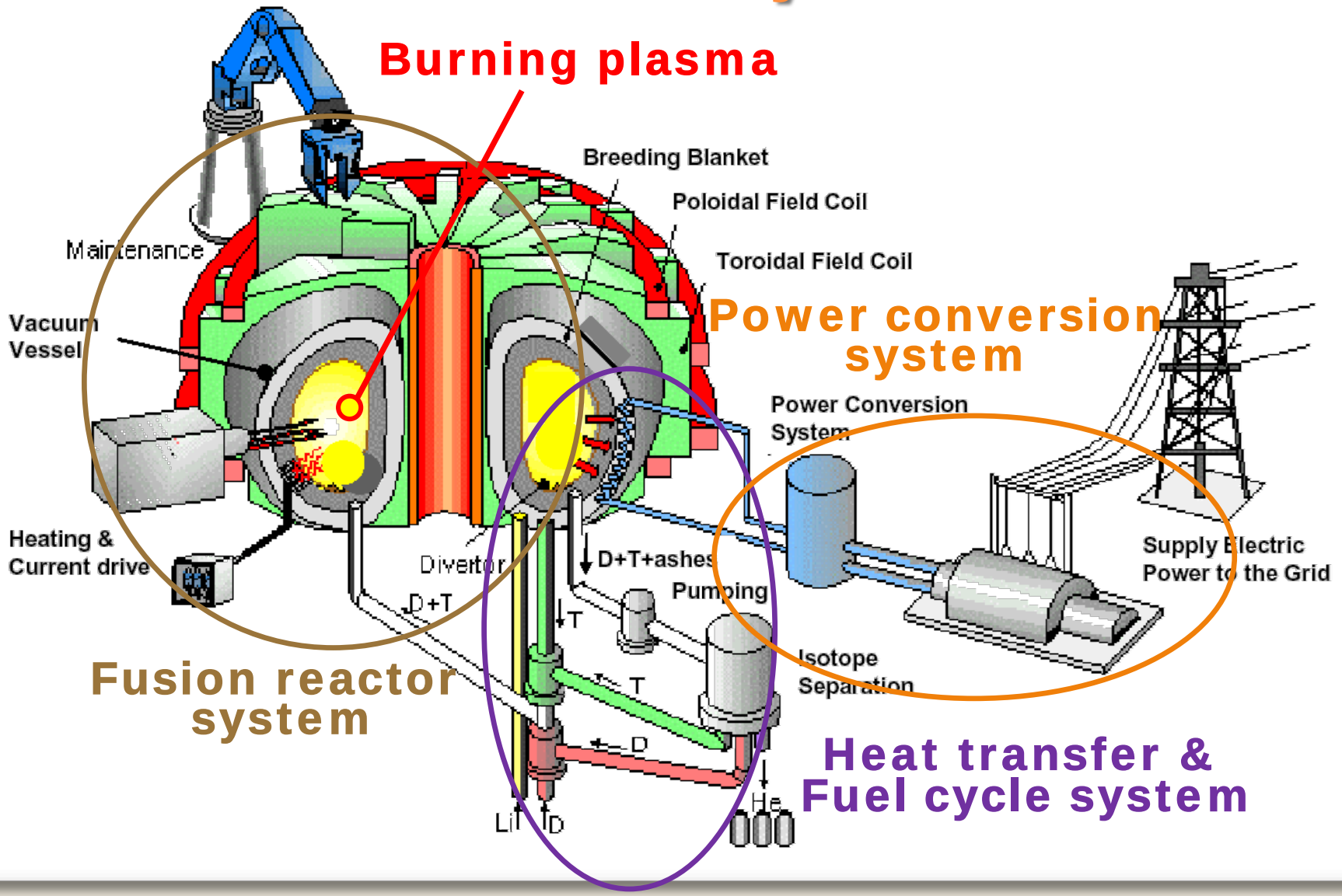
Tokamak

http://cafe.naver.com/gamebox26.cafe?iframe_url=/ArticleRead.nhn%3Farticleid=16140

Fusion Power Plant System

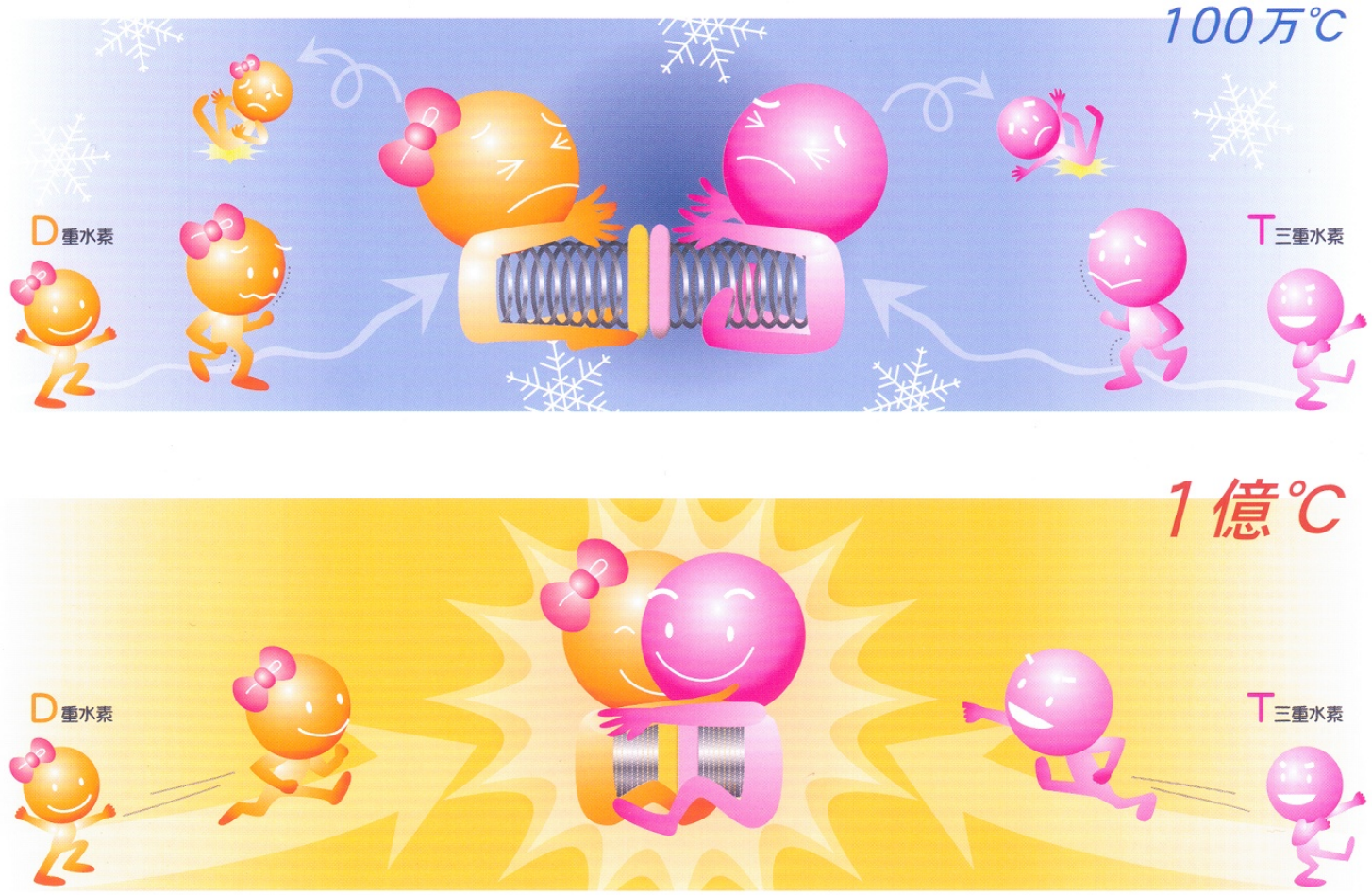


Fusion Power Plant System

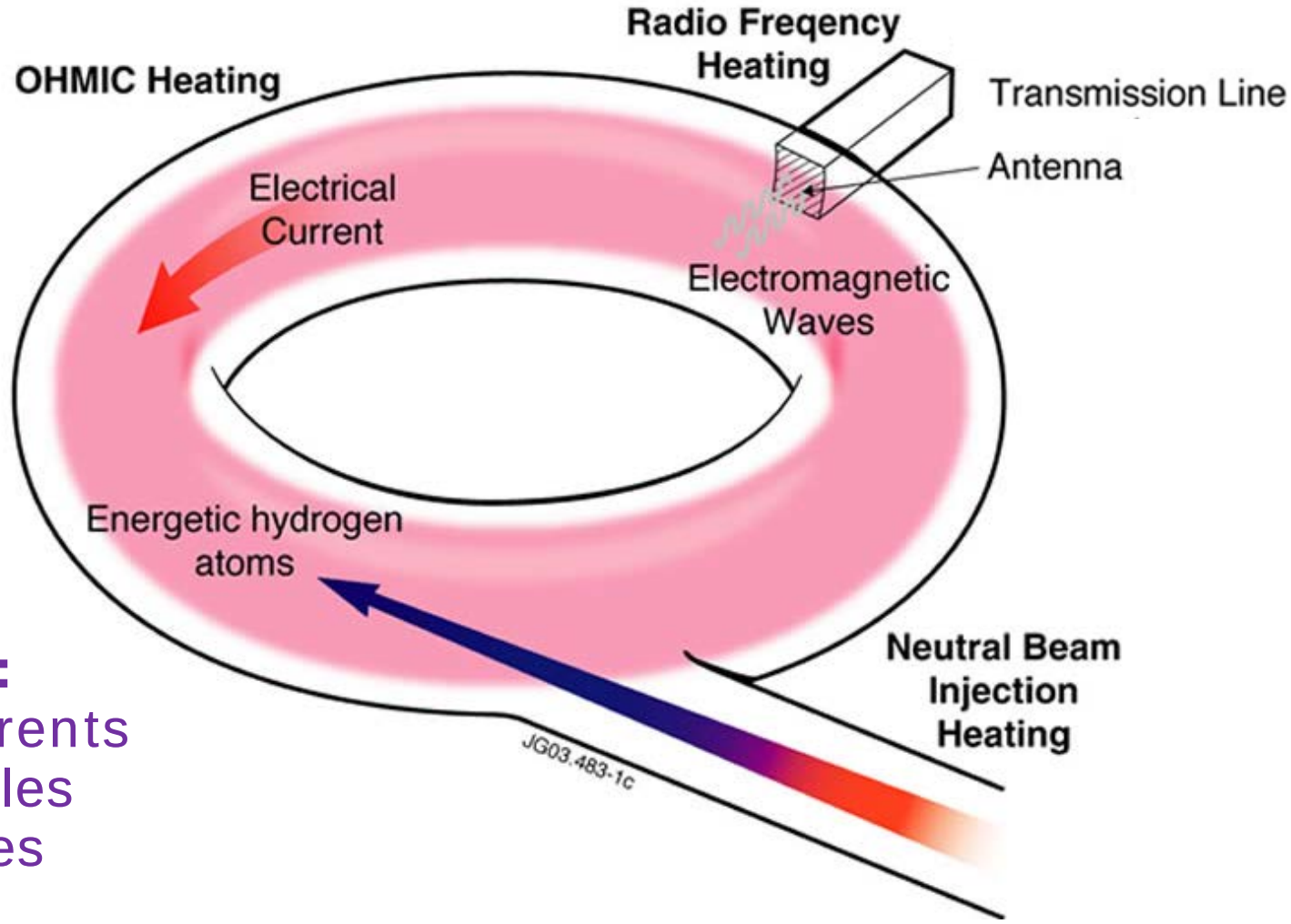


How to heat the plasma?

Why plasma heating?



Plasma Heating



Heating with:

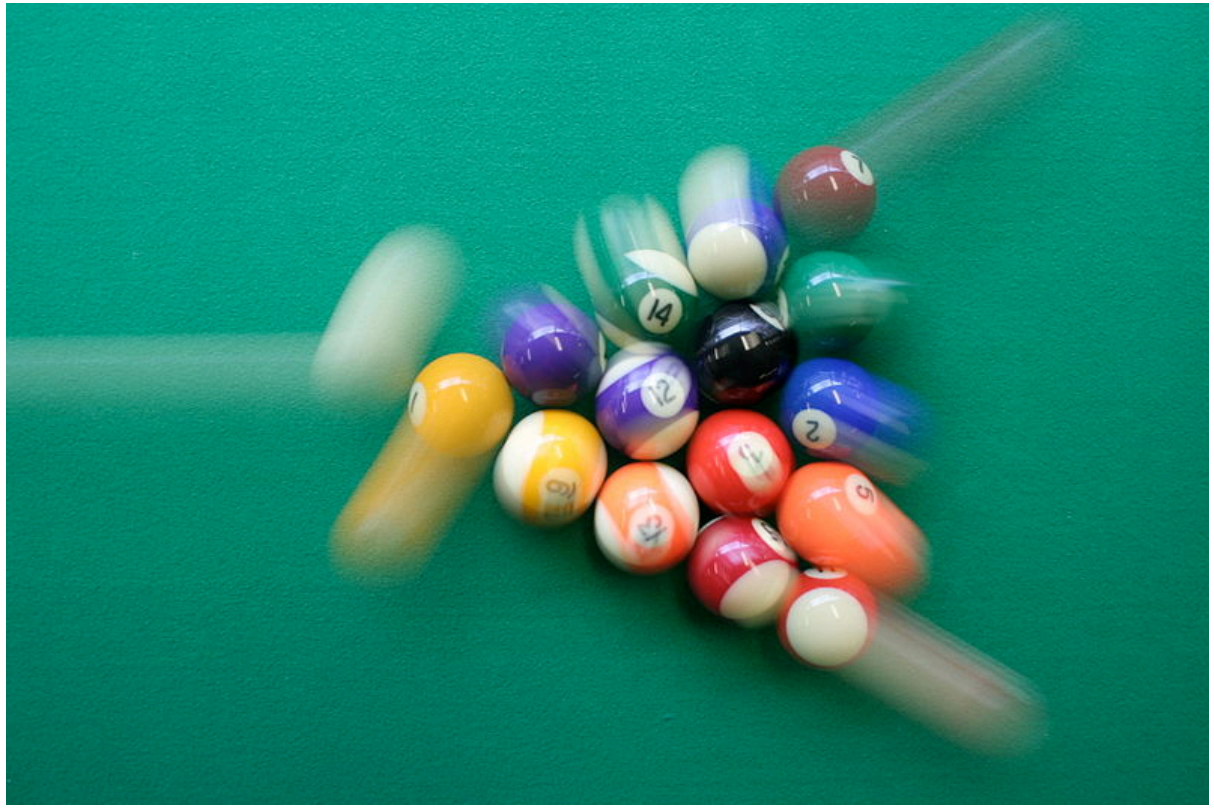
- ohmic currents
- fast particles
- microwaves

Plasma Heating– Ohmic Heating

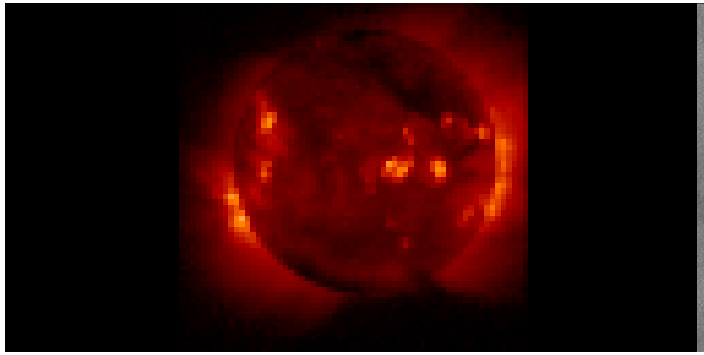
SAMIK Electric blanket

Auction, Korea (2014)

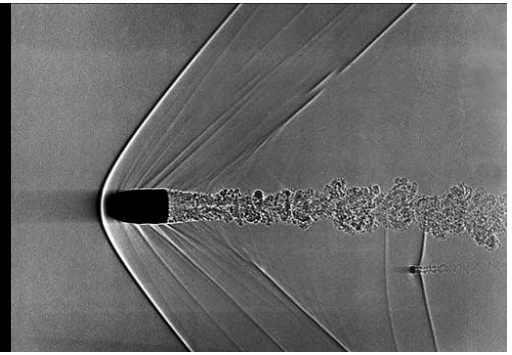
Plasma Heating– Neutral Beam Injection (NBI)



Plasma Heating– Neutral Beam Injection (NBI)



Plasma



Neutral beam

NBI

Andy Warhol

http://www.nasa.gov/mission_pages/galex/20070815/f.html

Plasma Heating– Neutral Beam Injection (NBI)

Injection of a beam of neutral fuel atoms (H, D, T) at high energies (E_b > 50 keV)

⇓

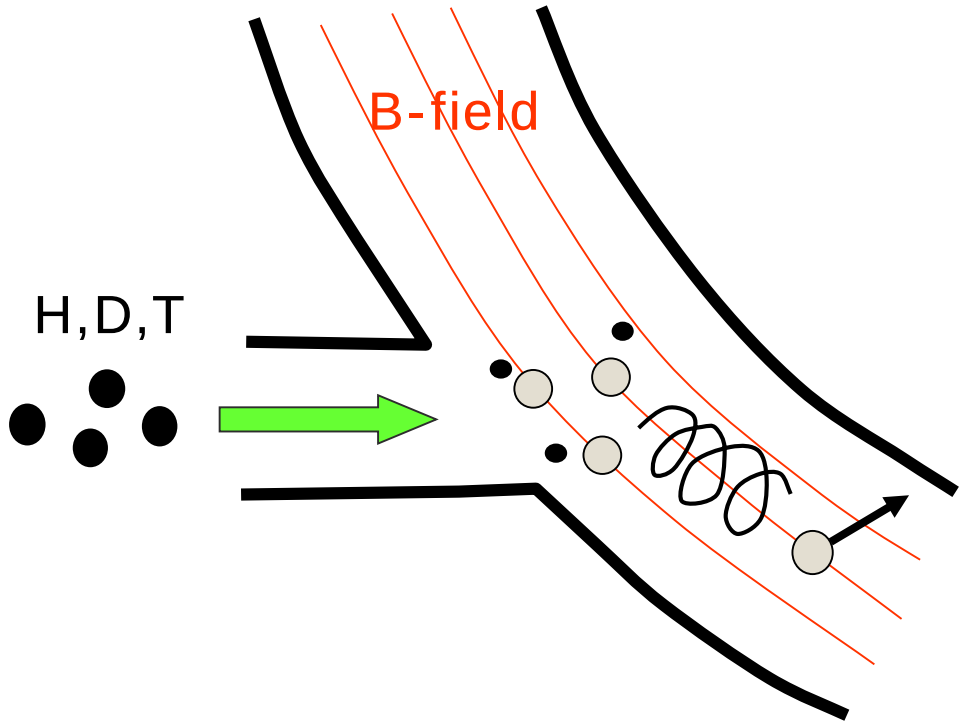
Ionisation in the plasma

⇓

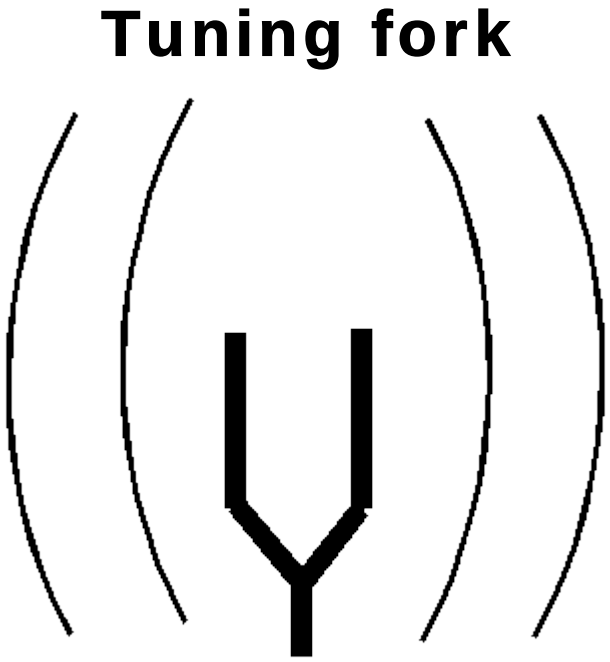
Beam particles confined

⇓

Collisional slowing down

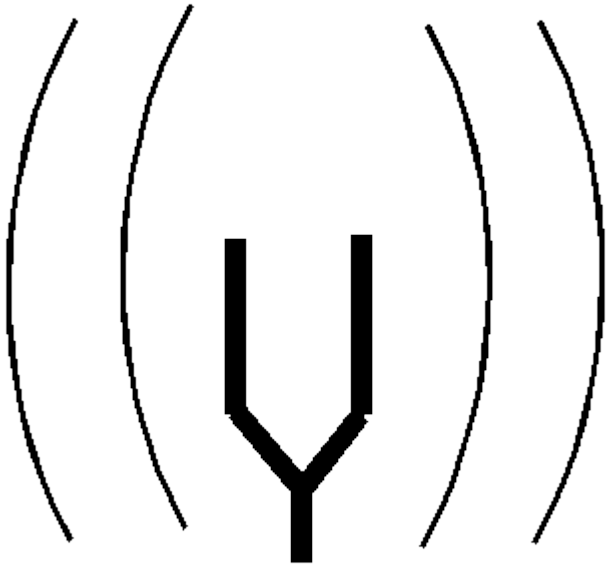


Plasma Heating– Wave (ICRH, ECRH, LHH)

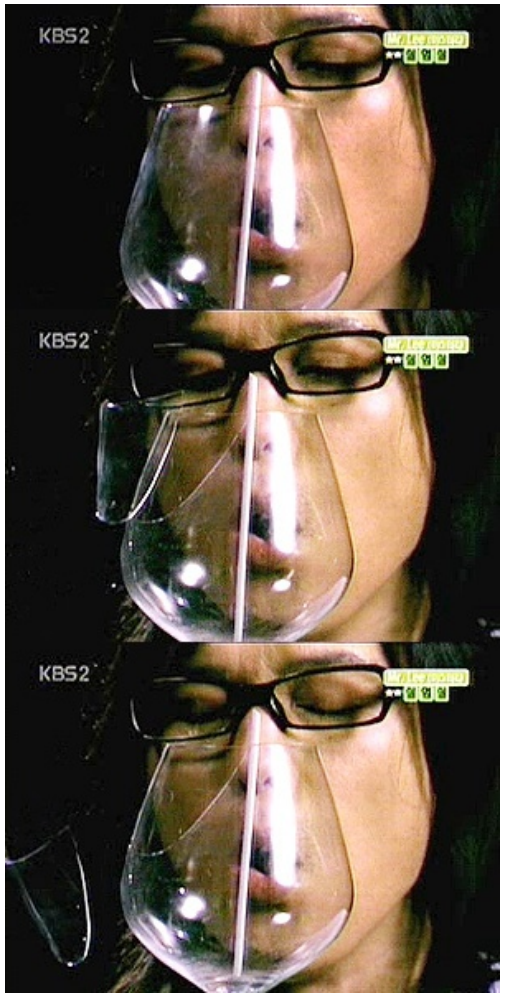


Plasma Heating– Wave (ICRH, ECRH, LHH)

Tuning fork

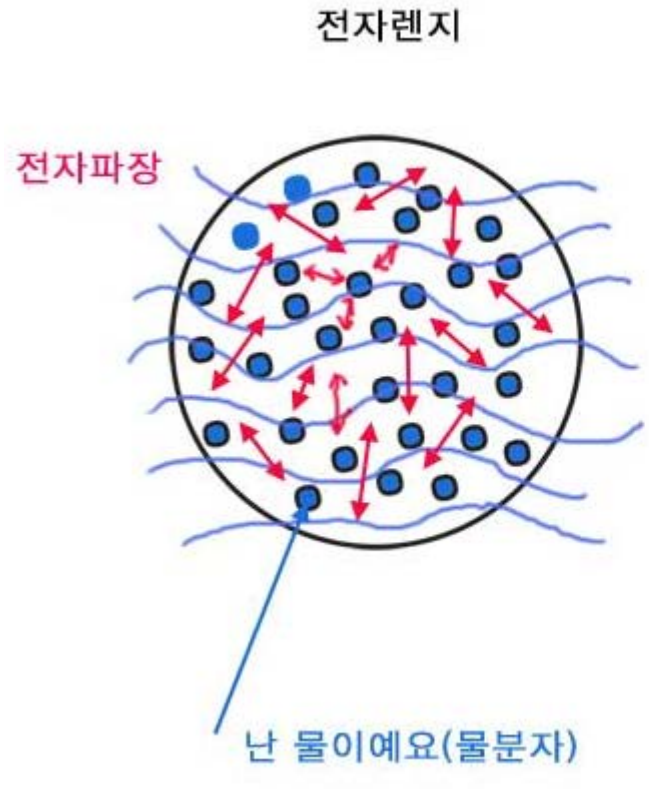


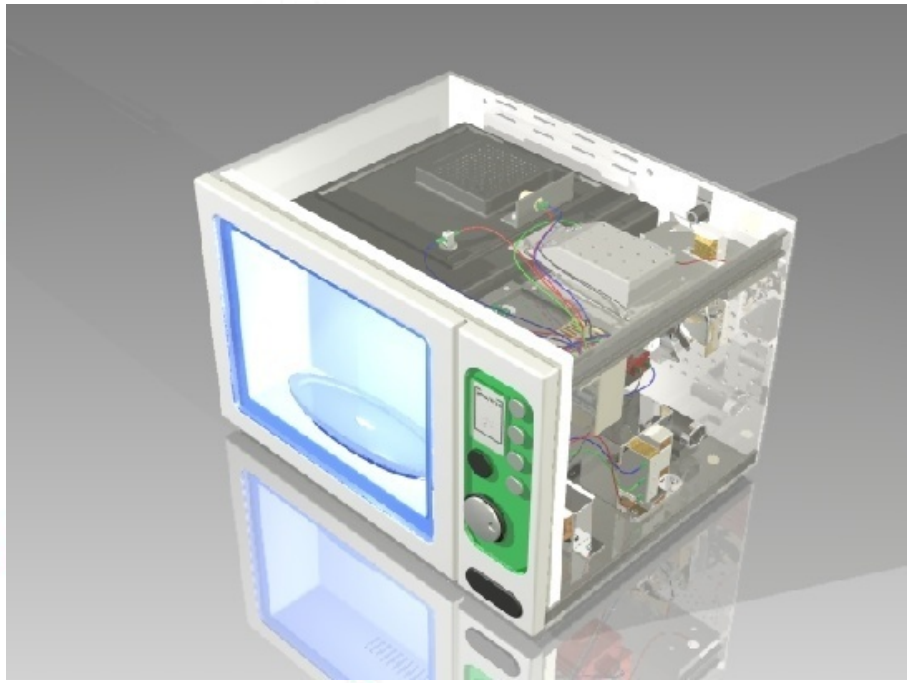
Resonance



KBS. 스펀지:목소리로 와인 잔 깨기. 2006.3.11
http://www.kbs.co.kr/end_program/2tv/enter/sponge/view/vod/1386311_1027.html

Plasma Heating– Wave (ICRH, ECRH, LHH)

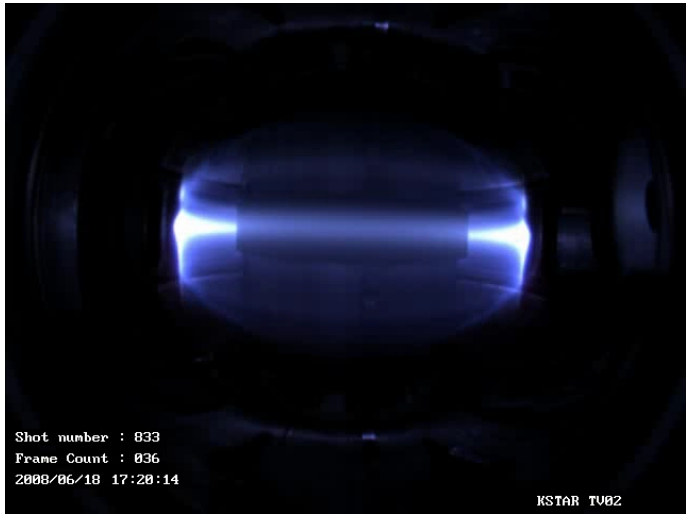




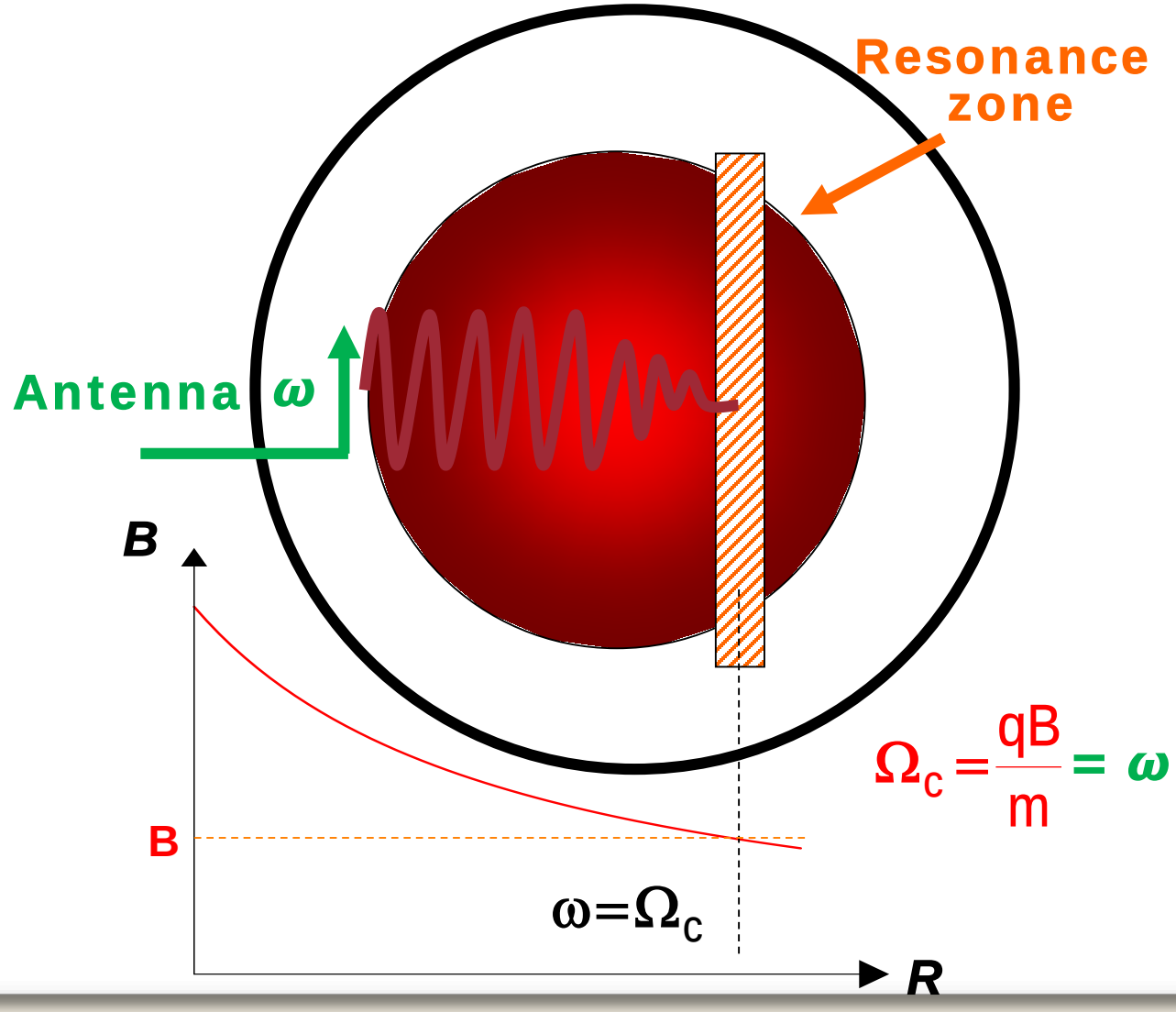
Microwave oven (2.45 GHz)

http://cafe.naver.com/nadobaker.cafe?iframe_url=/ArticleRead.nhn%3Farticleid=82
http://blog.naver.com/rlhyuny27?Redirect=Log&logNo=30029307561

Plasma Heating– Wave (ICRH, ECRH, LHH)



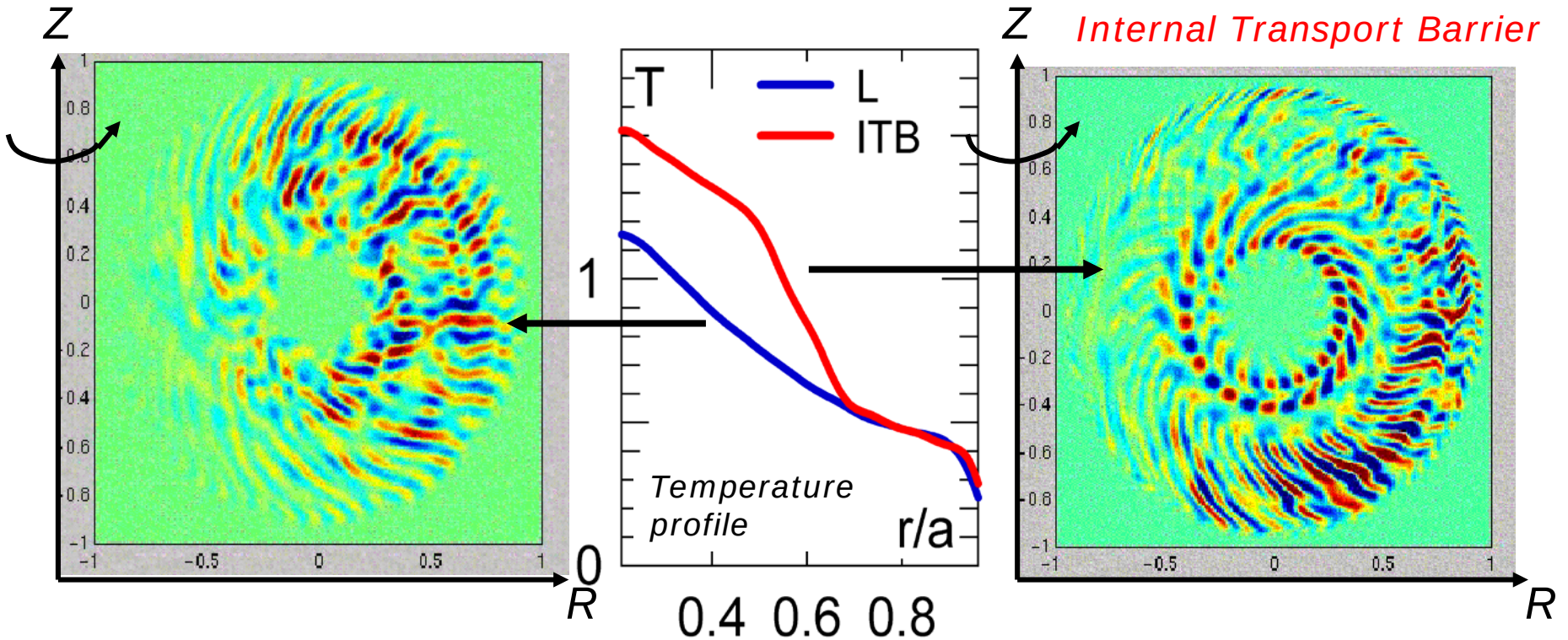
KSTAR first plasma



What are the critical issues?

Stabilisation of Plasma Turbulence

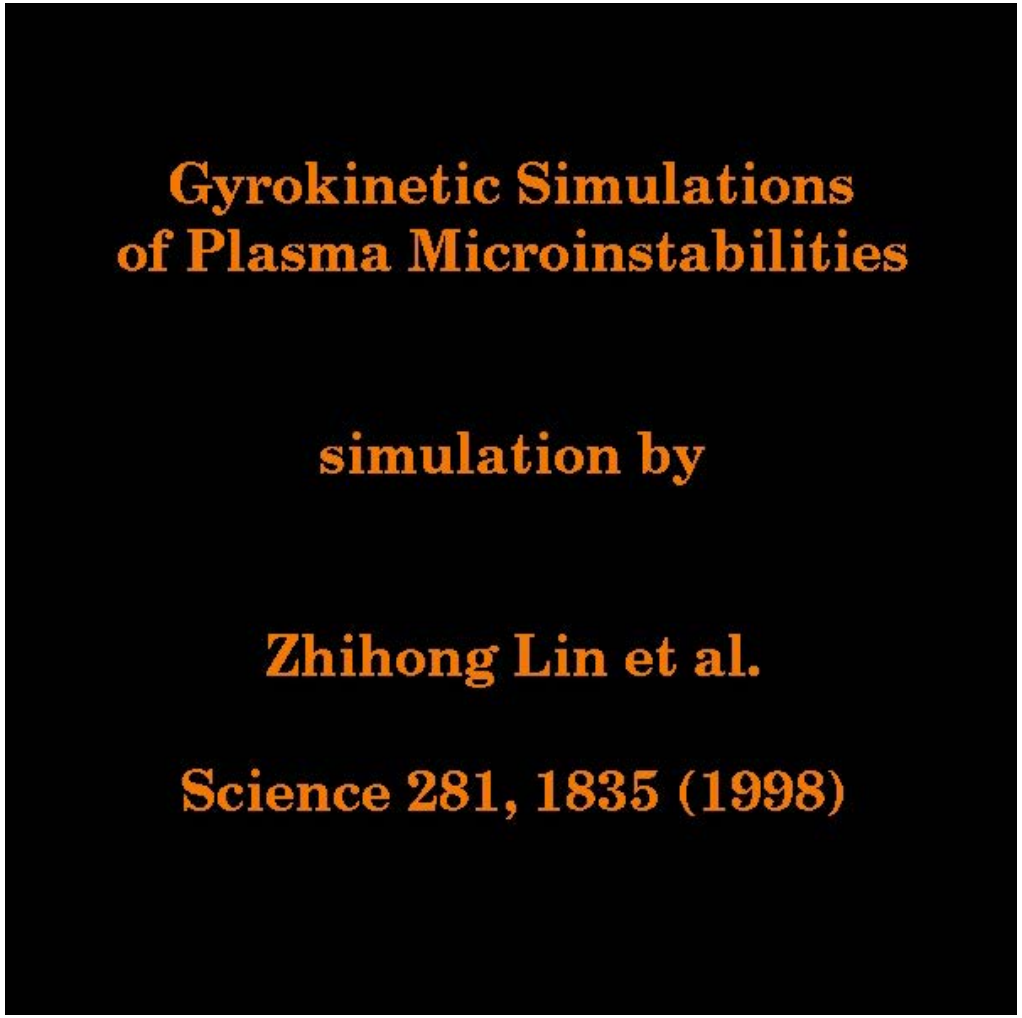
- **Turbulence stabilisation → Increase of plasma pressure**
  → High fusion power



Contour lines of electric potential

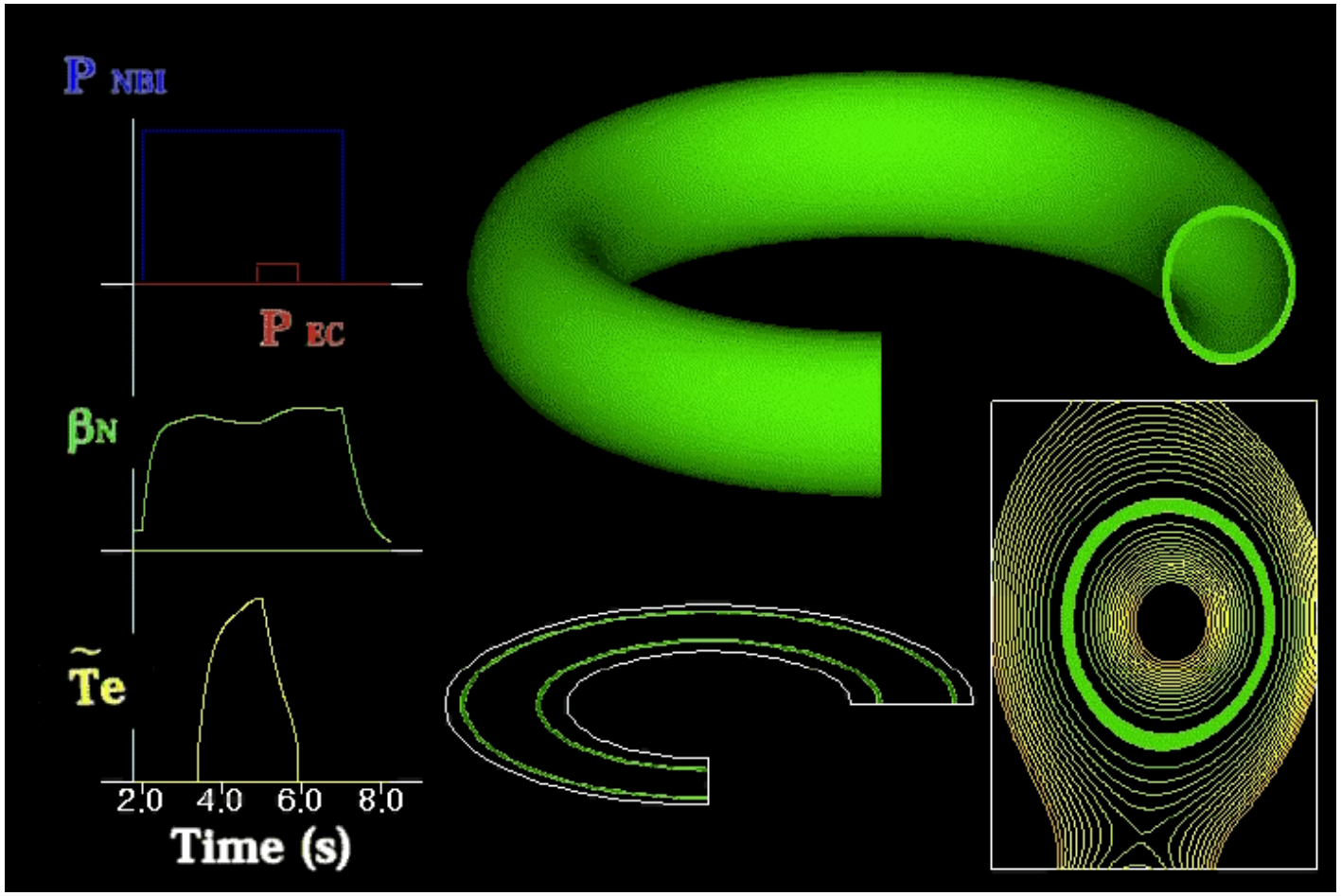
Contour lines of electric potential

Stabilisation of Plasma Turbulence

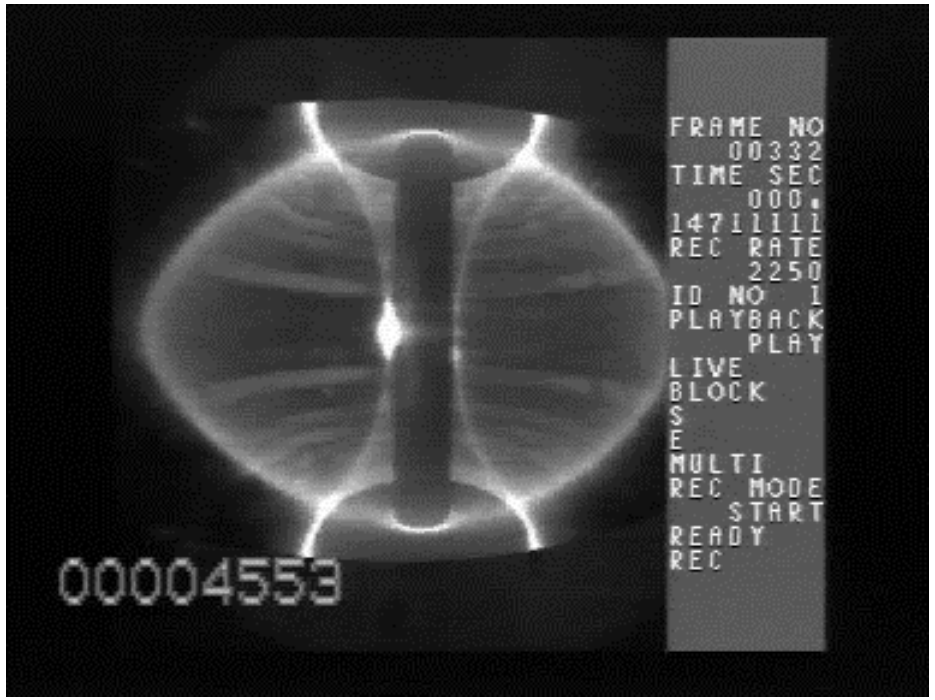


Suppression of Plasma Instabilities

- **Suppression of Neoclassical Tearing Mode by ECCD**

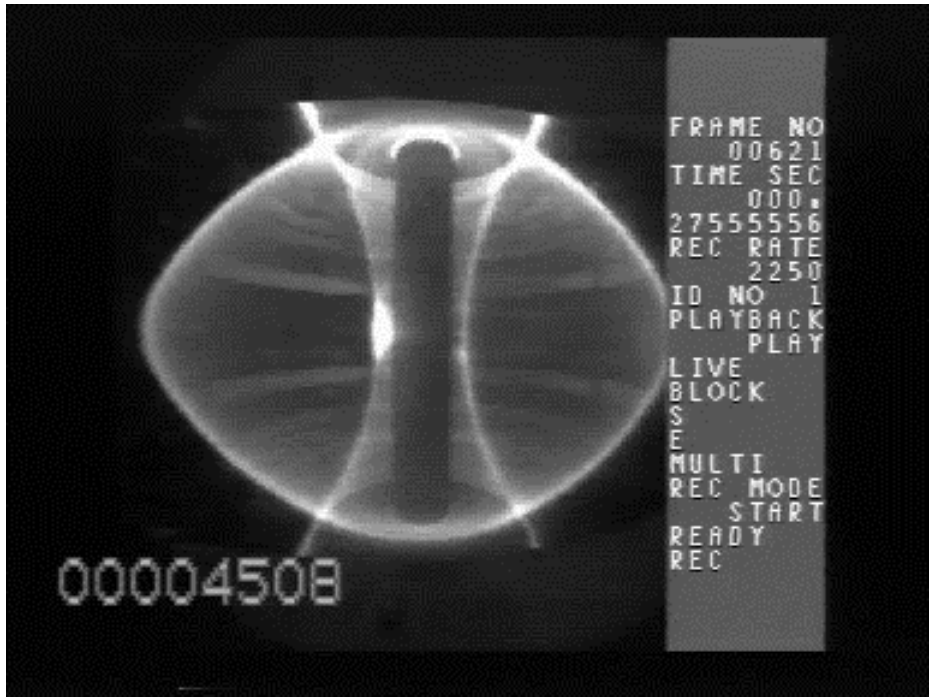


Edge Region Instability and Disruption



Edge Localised Mode

Vertical displacement event
→ Disruption

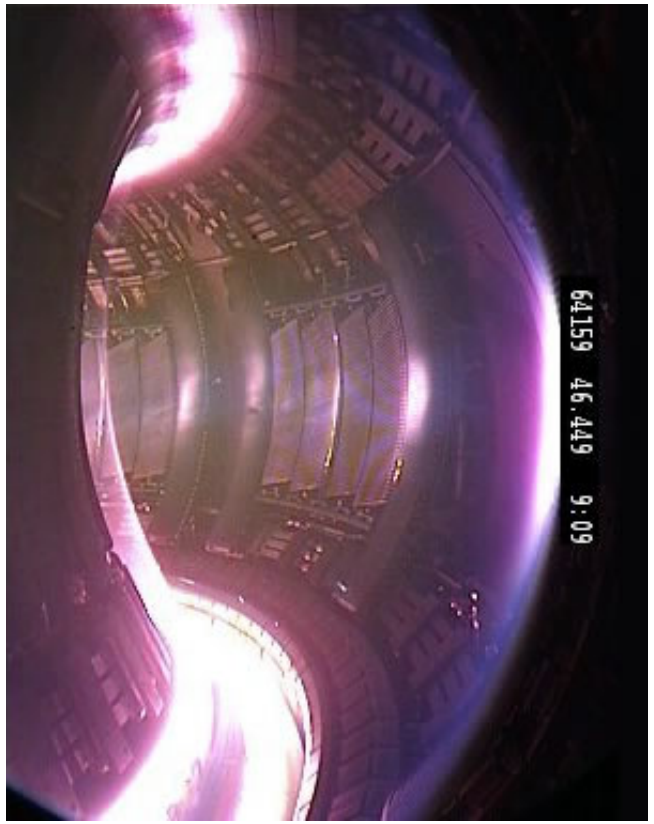


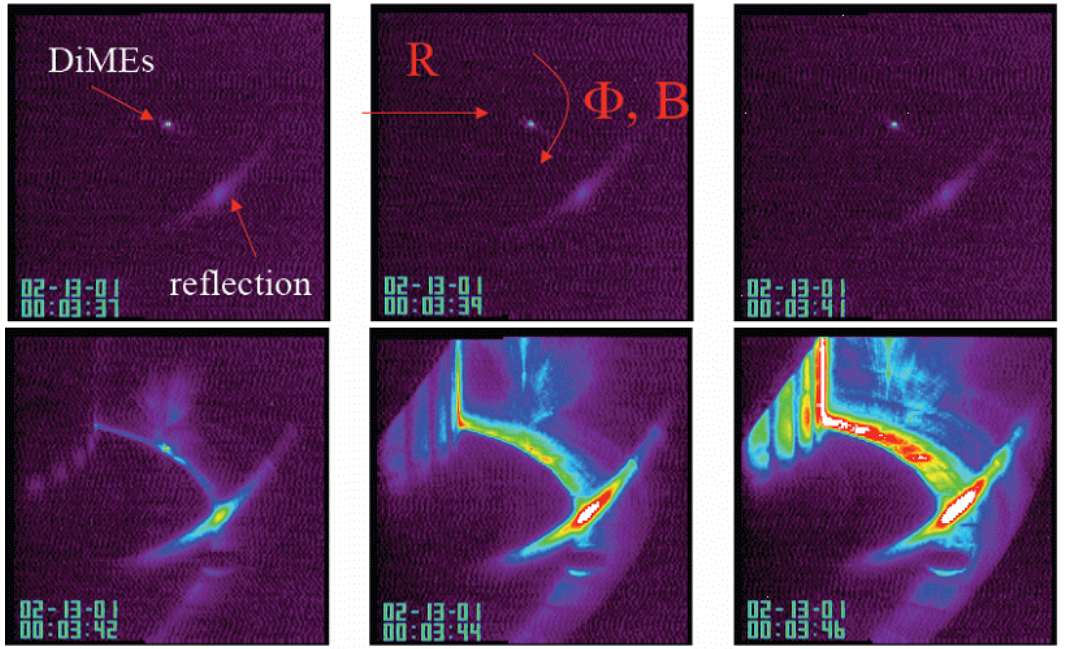
MAST
MEGA-AMPERE SPHERICAL TOKAMAK

The Sun Train

http://cafe.naver.com/gamebox26.cafe?iframe_url=/ArticleRead.nhn%3Farticleid=16140

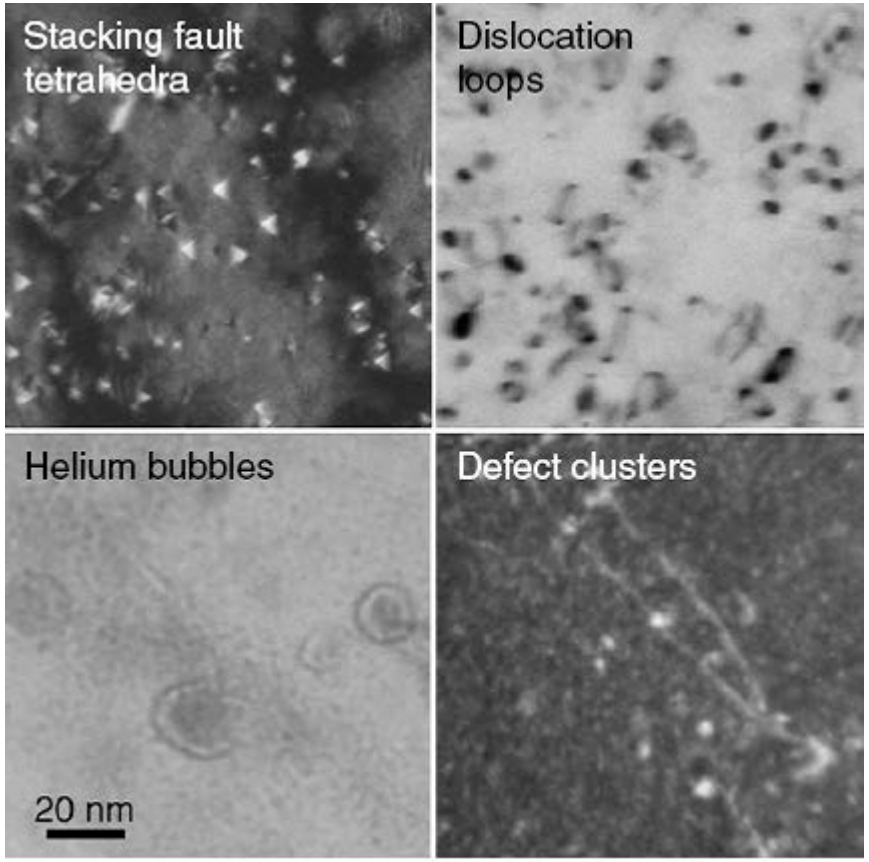
Plasma– Wall interactions





- High heat flux to the surrounding materials

Radioactivation of Materials



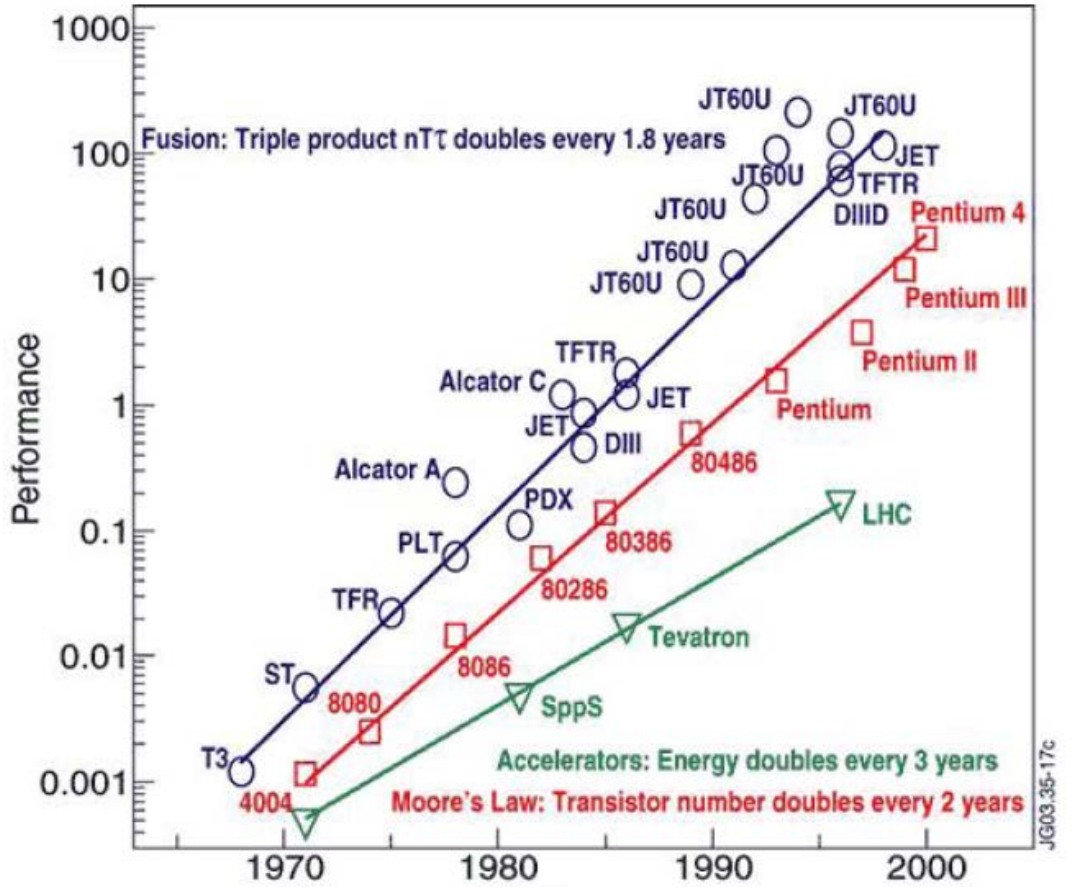
- **Neutron impacts on materials**

What are the current status and future prospect?

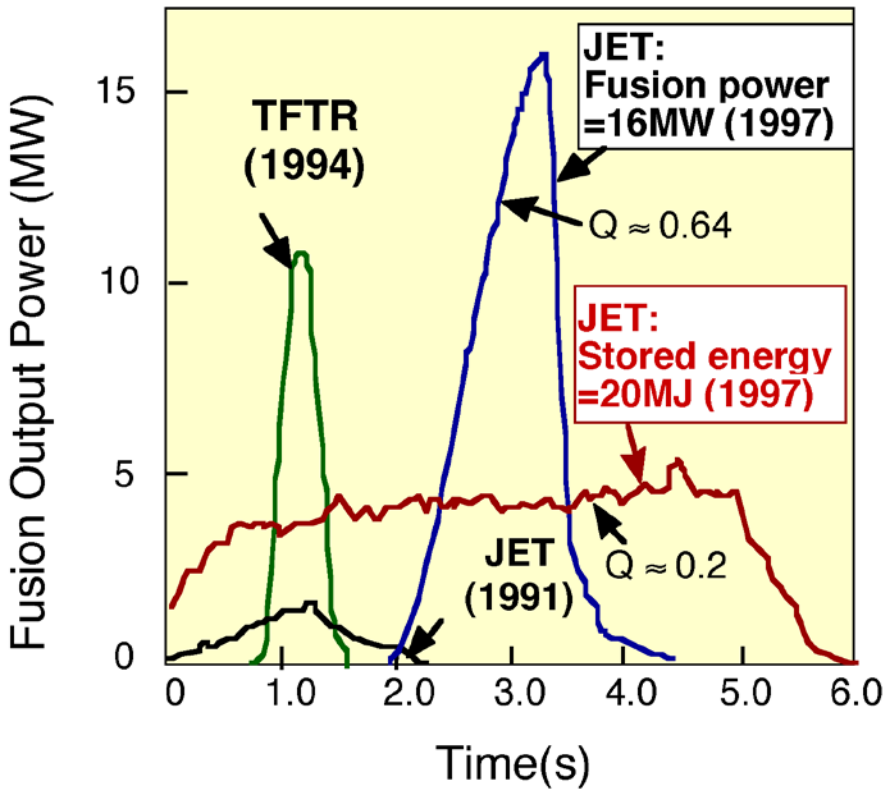
Status of the Tokamak Research

- Progress in fusion can be compared with the development of computer chips and particle physics accelerator energy.

- D-T Tokamaks produced significant fusion power:
  - TFTR (USA), JET (EU)



Status of the Tokamak Research

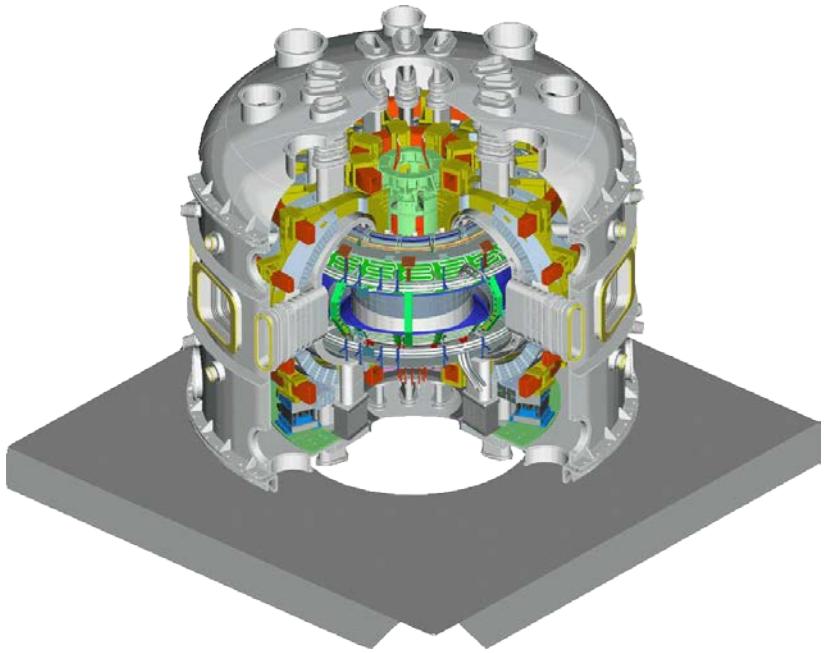


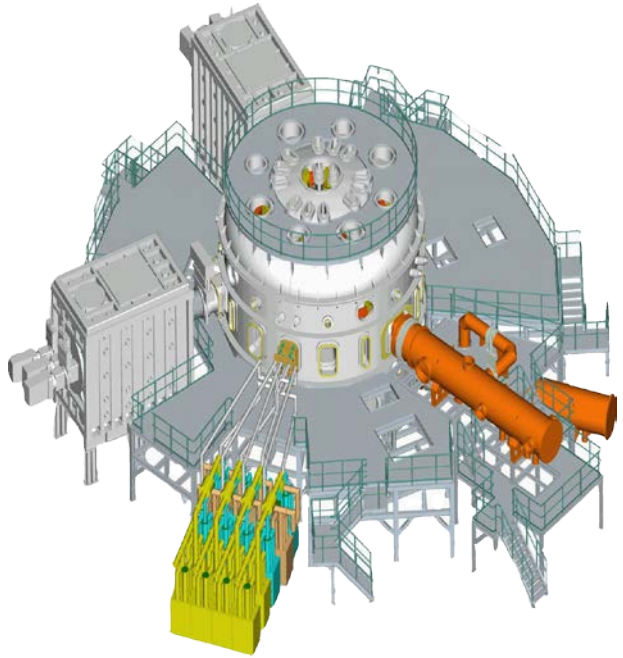
$$Q = \frac{\text{fusion output power}}{\text{input power}}$$

- **D-T tokamaks produced significant fusion power:**
  - TFTR (USA) ~10 MW in 1994
  - JET (EU) 16 MW (Q=0.64) in 1997

KSTAR Project

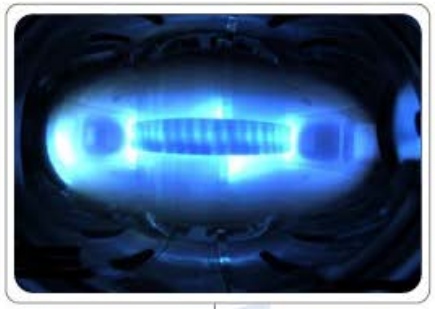
- **K**orea **S**uperconducting **T**okamak **A**dvanced **R**esearch
  - superconducting tokamak using ITER-relevant magnets
  - capability of reactor-relevant plasma performances





- Objective - To integrate optimized plasma performance and continuous operation as a step toward an attractive tokamak fusion reactor

KSTAR Project



1995
Launch of KSTAR Project

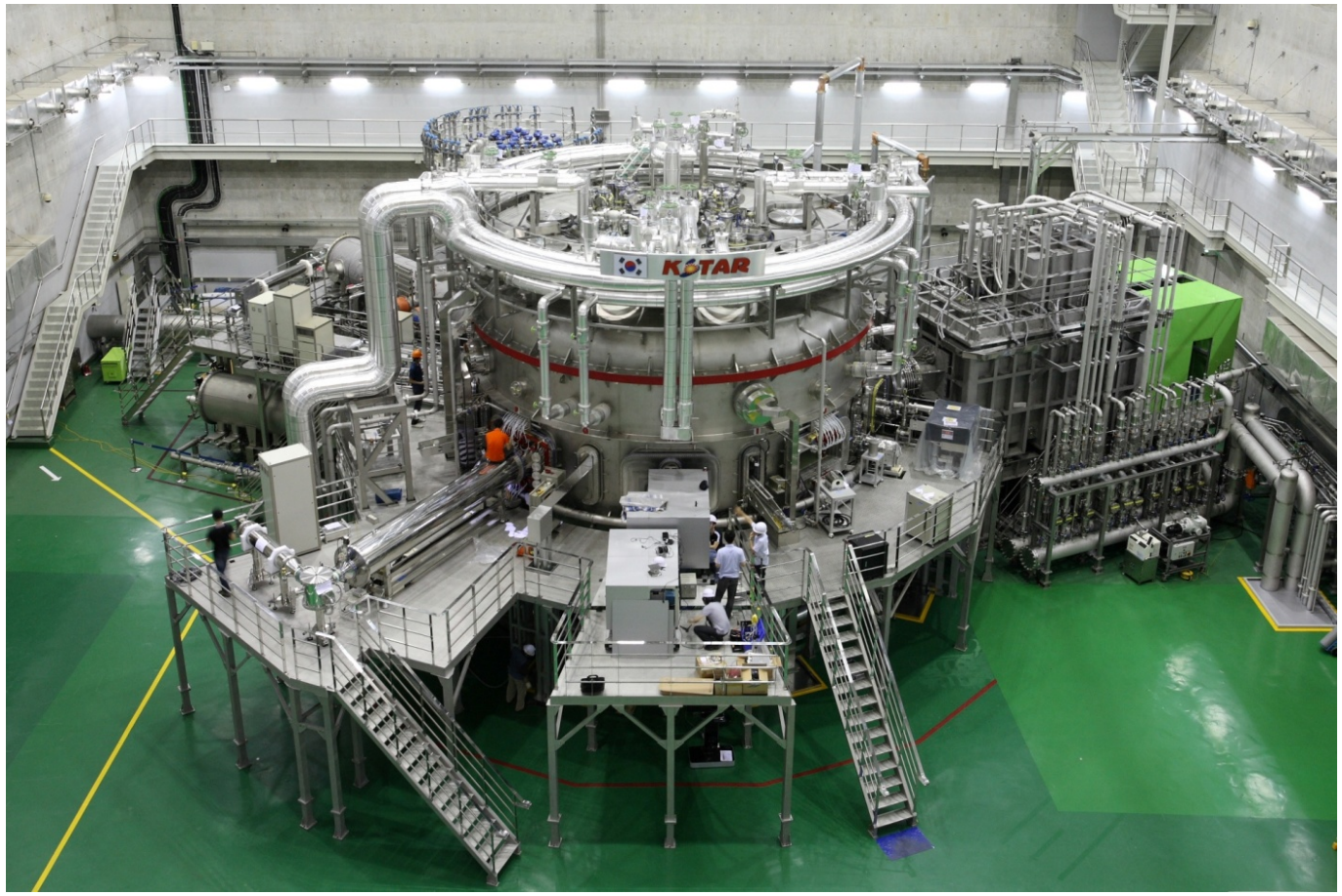
1995~1997
Basic Design and R&D

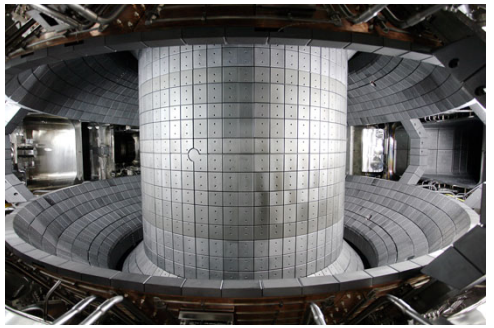
1998~2001
Engineering Design and Facility Construction

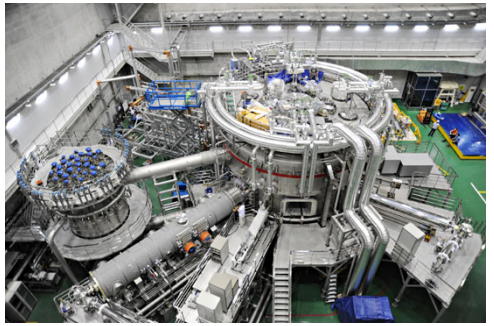
2002~2007
Construction of KSTAR

June 2008
First Plasma

KSTAR Project

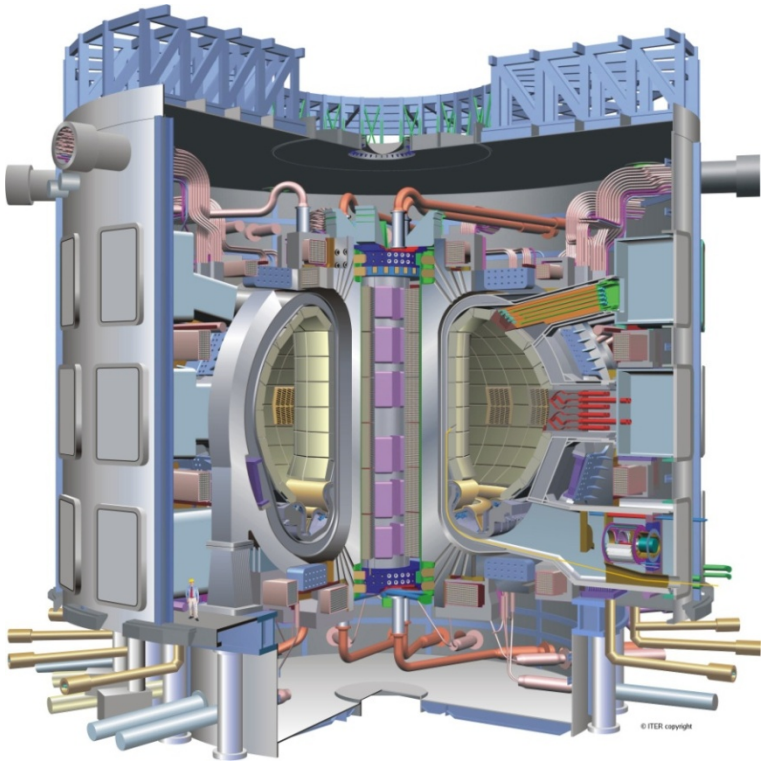






ITER Project

- **I**nternational **T**hermonuclear **E**xperimental **R**eactor
  - "the way" in Latin
  - the essential next step in the development of fusion



- Objective - To demonstrate the scientific and technological feasibility of fusion power.
  - The world's biggest international research project

ITER Project

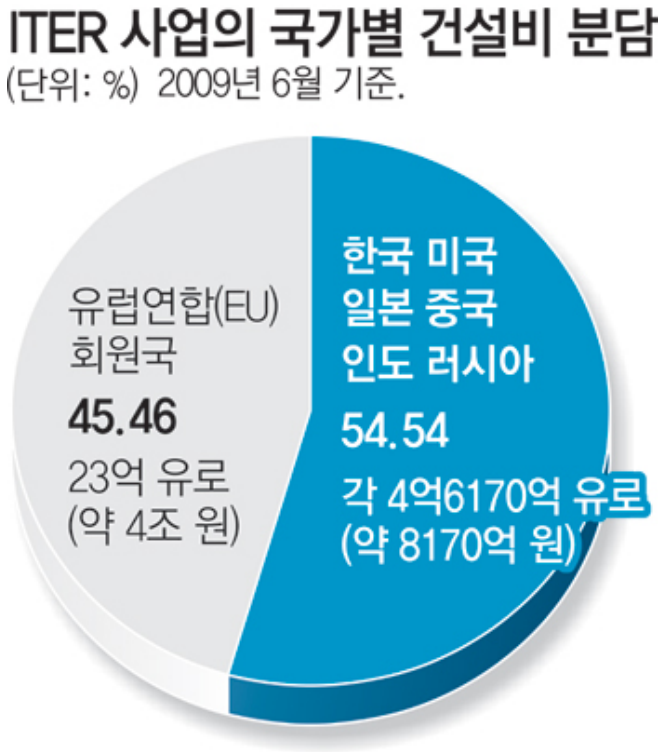
- **I**nternational **T**hermonuclear **E**xperimental **R**eactor
  - “the way” in Latin
  - the essential next step in the development of fusion

ITER 서명식, 2006.11.23, 과학기술부

ITER Project

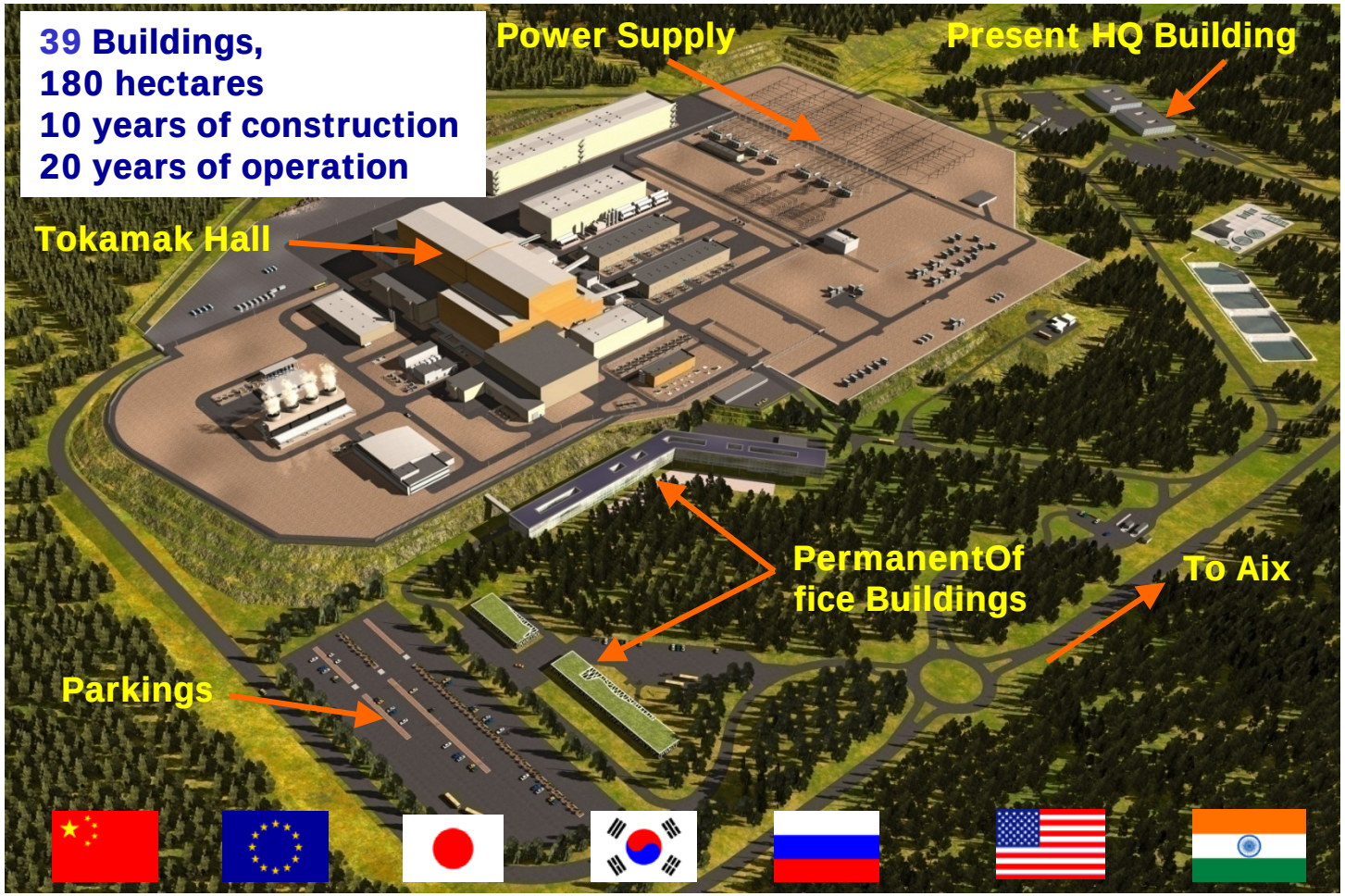
- **I**nternational **T**hermonuclear **E**xperimental **R**eactor
  - "the way" in Latin
  - the essential next step in the development of fusion

http://blog.naver.com/science_u



자료: 교육과학기술부

ITER Project

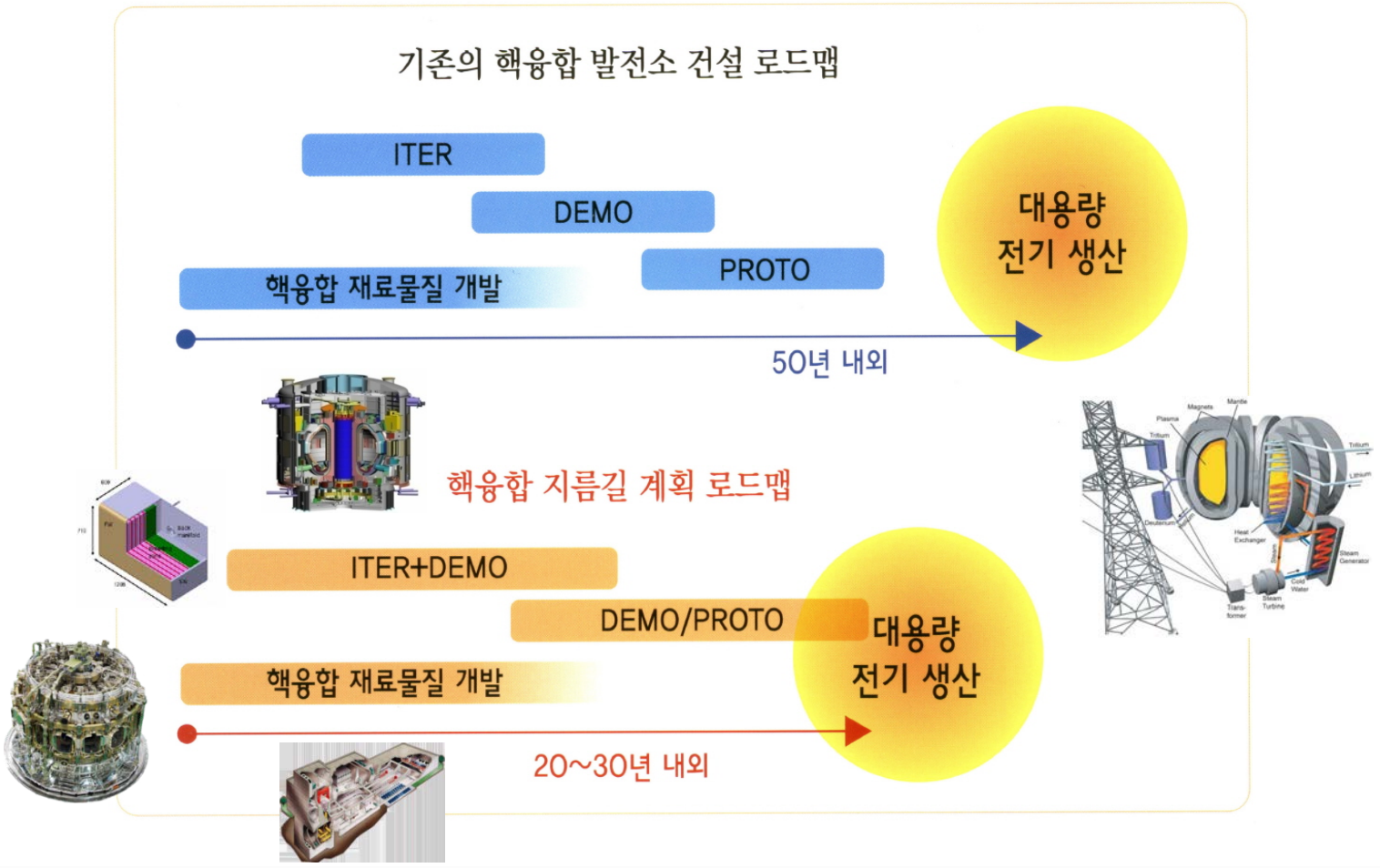


ITER Project

June 19, 2017

Fusion Energy Development

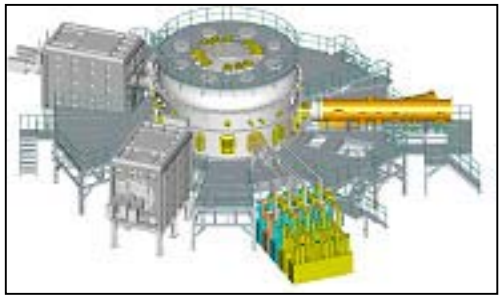
- **The Fast Track Approach**



Korean Plan for Fusion Energy Development

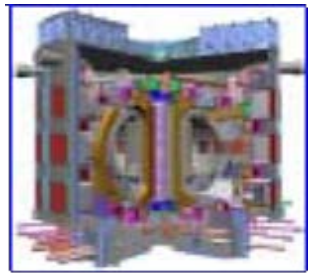
2007년 이후
KSTAR

- 고성능, 고효율 장시간 운전연구



~2025
ITER

- 연료 연구
- 열 이용 연구
- 재료 연구
- 공학 연구



2040년대 중반
DEMO

- 실질적인 발전 실현
- 시스템 최적화
- 경제성 구현

2050년대
상용화

- 대용량 전기생산

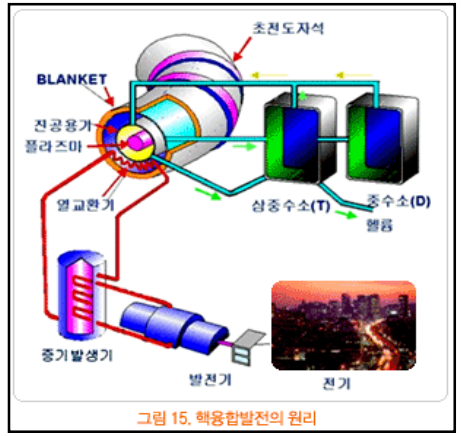


그림 15. 핵융합발전의 원리

Summary

I What is nuclear fusion?

II How to confine the hot sun?

III How to heat the plasma?

IV What are the critical issues?

V What are the current status and future prospect?

VI Closing remarks

“At the launch of Cambridge University’s Big Data Institute, we recently asked the physicist Stephen Hawking to describe the one idea that would transform our society. He chose nuclear fusion – the process of releasing energy by transforming hydrogen atoms into helium,”

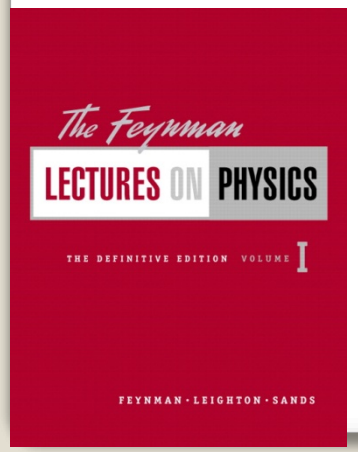
- November 18, 2016, BBC

“High temperature superconductivity will provide cheap power transmission and rapid transport, and nuclear fusion would give us an unlimited supply of clean energy,”

Stephen Hawking

"We have already obtained energy from uranium; we can also get energy from hydrogen, but at present only in an explosive and dangerous condition. If it can be controlled in thermonuclear reactions, it turns out that the energy that can be obtained from 10 quarts of water per second is equal to all of the electrical power generated in the Unites States. With 150 gallons of running water a minute, you have enough fuel to supply all the energy which is used in the United States today! Therefore it is up to the physicist to figure out how to liberate us from the need for having energy. ***It can be done.*** *"*

Feynman Lectures on Physics I, p.4-8

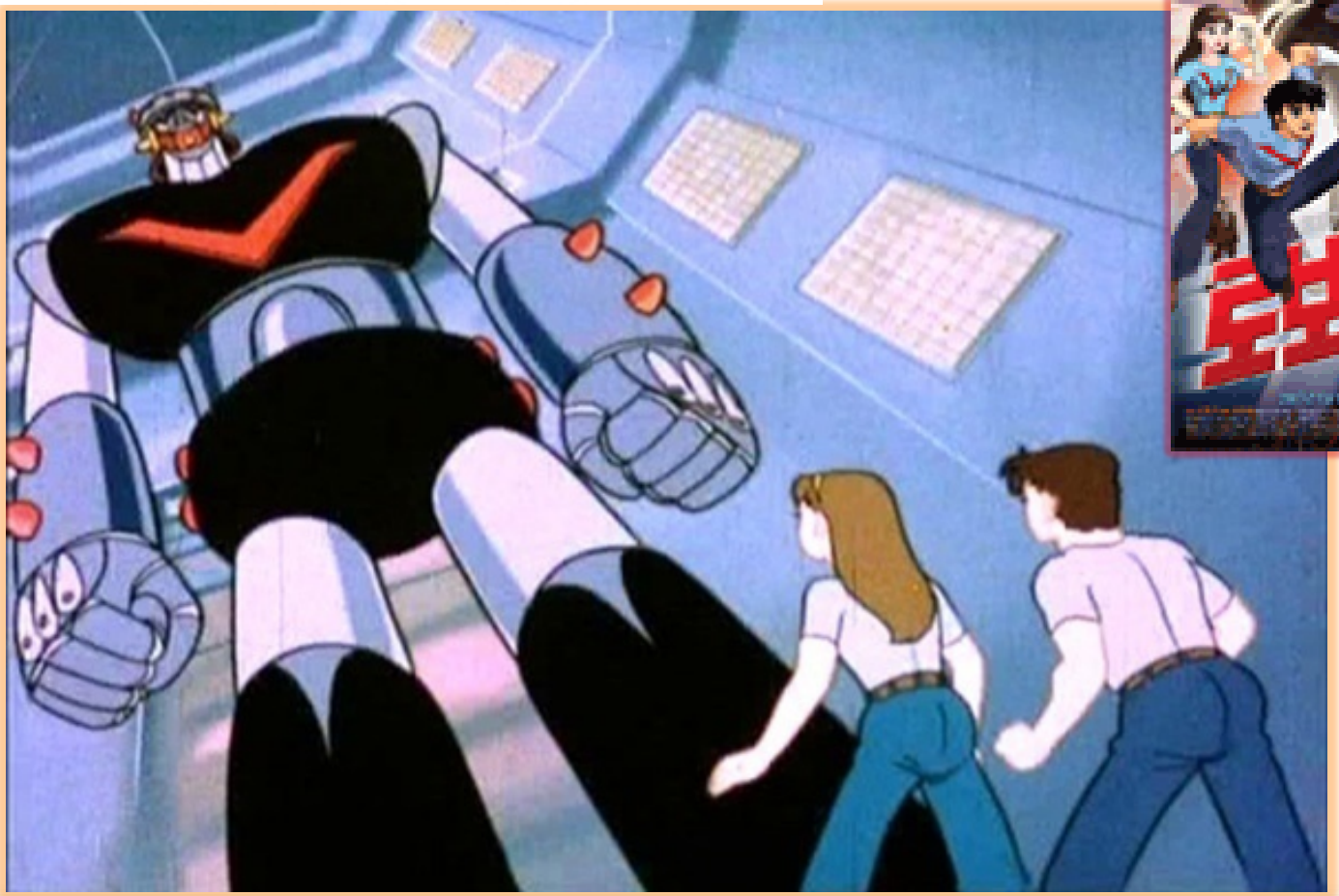


When he was asked how long it would take to build the first fusion power plant, the Soviet physicist Lev Artsimovich – one of the pioneers of tokamak research – replied that "fusion will be there when society needs it." That time is fast approaching, and with the construction of ITER finally about to start, efforts are now gearing up for the longer –term prospect of fusion energy.

- "Fusion: the way ahead, Physics World March 2006

“The entire cost of the fusion development programme is equal to only a week of spending in the international energy markets.”

- I. Cook, IAEA 2005



로보트태권V (1976), 신씨네