Tokamak

Fall, 2022

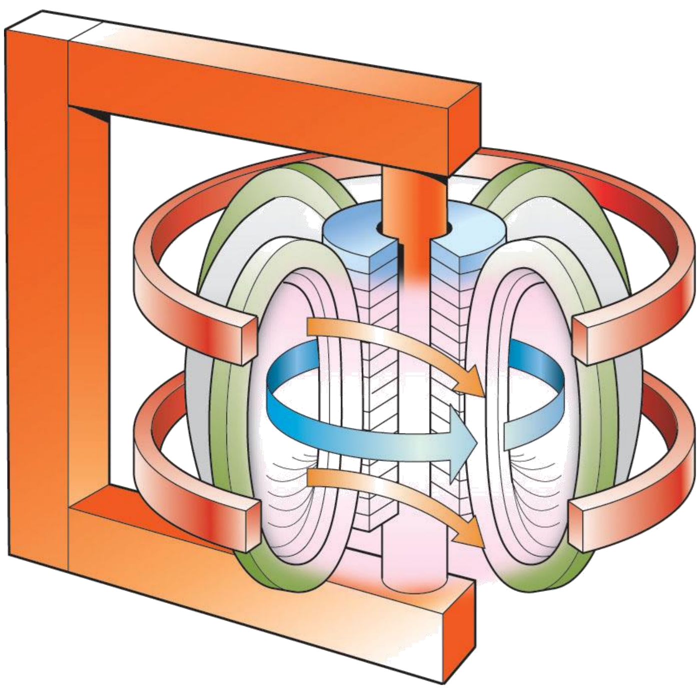
Kyoung-Jae Chung

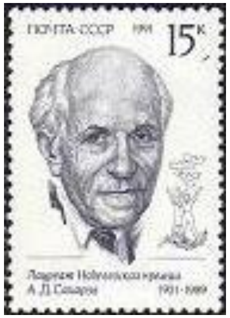
Department of Nuclear Engineering

Seoul National University

Tokamak

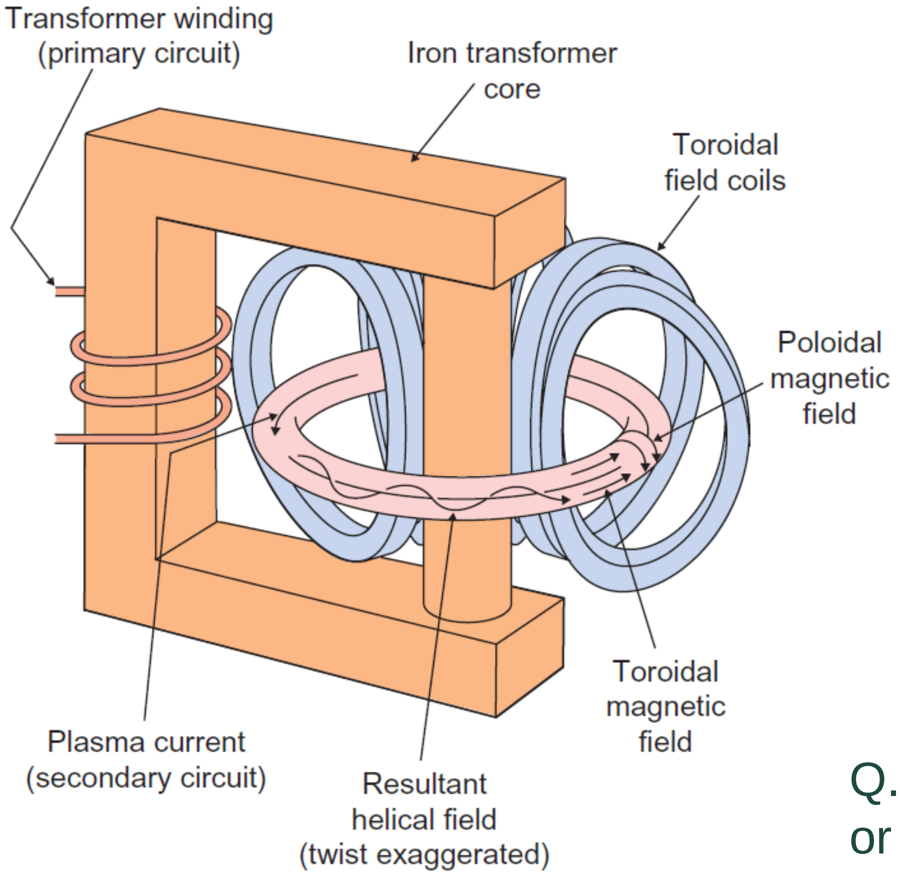
- The name tokamak comes from the Russian words **to**roidalnaya **ka**mera **ma**gnitnaya **k**atushka meaning “toroidal chamber magnetic coils.”
- It was developed by a team led by Academician Lev Artsimovich on an idea of Andrei Sakharov and Igor Tamm in 1952.
- This device was unveiled at the 1958 Geneva Conference. The tokamak turned out to be the one that worked the best and is the leading type of magnetic plasma container today.





Basic features

- There are two main magnetic fields. One of them, known as the toroidal field, is produced by a copper (or superconducting) coil wound in the shape of a torus. The second magnetic field, the poloidal field, is generated by an electric current that flows in the plasma. This current is induced by a transformer action.



$$\nabla \times E = -\frac{\partial B}{\partial t}$$

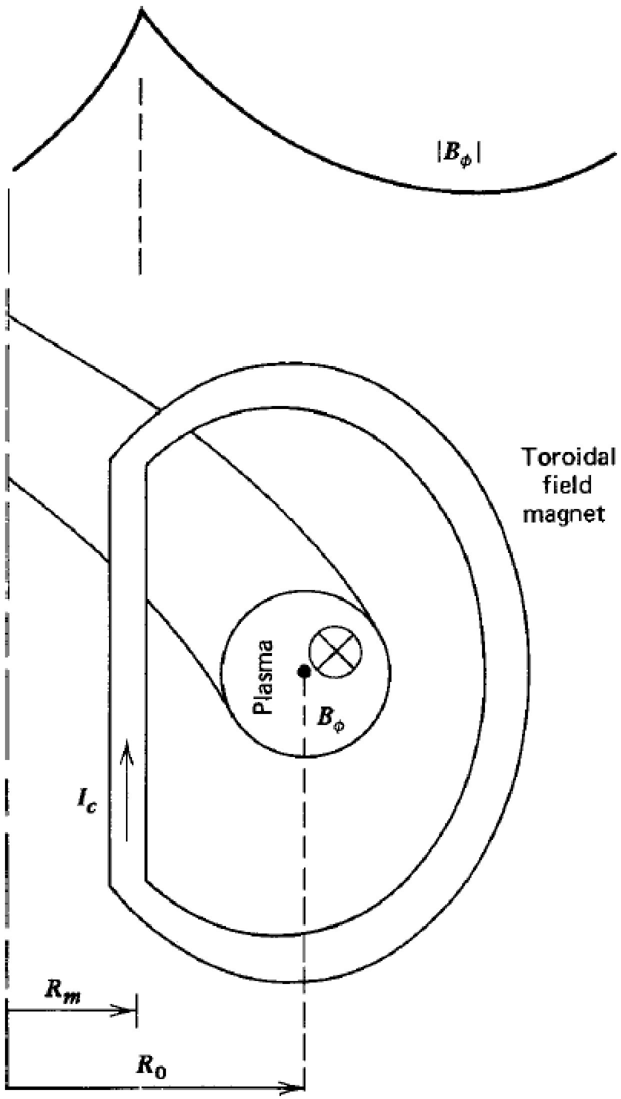
$$I = \frac{V}{R} \; or \; J = \frac{E}{\eta}$$

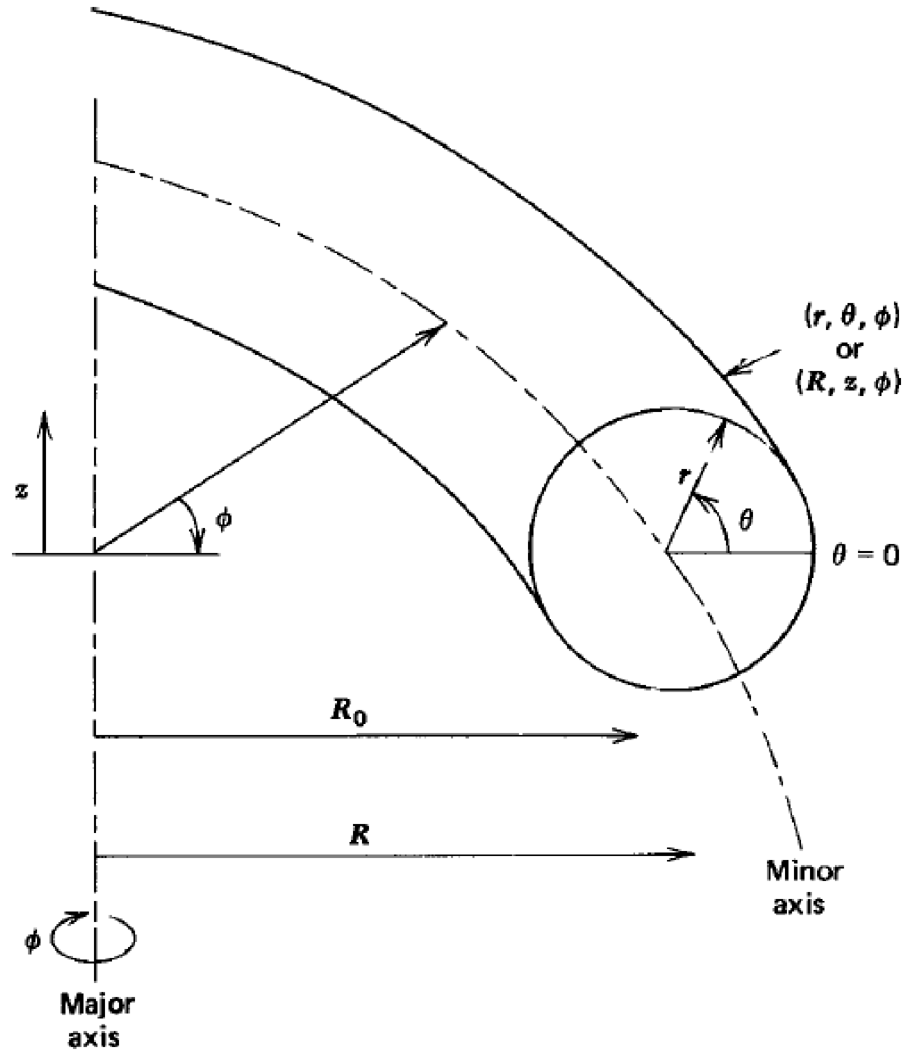
$$\nabla \times H = J$$

$$B_{pol} \sim I_{plasma} \sim E_{tor} \sim \frac{dI_{primary}}{dt}$$

Q. What is different from toroidal pinch or stellarator?

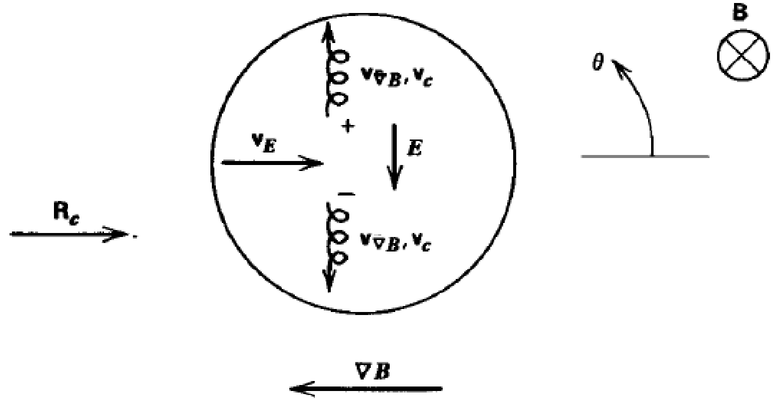
Coordinate system



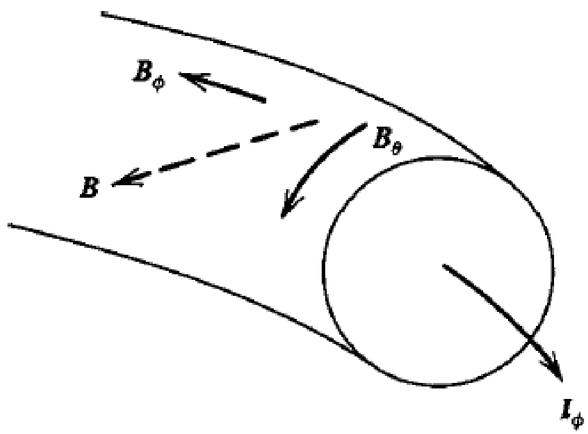


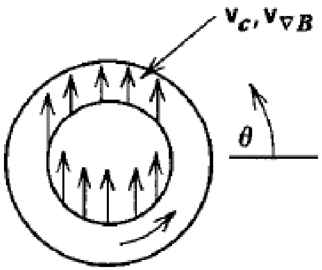
Need for poloidal field

- Confinement is not possible with a purely toroidal field because the ∇B and curvature drifts.



- When a poloidal field is superimposed on the toroidal field, the radial displacement due to the curvature and ∇B drifts is averaged out.





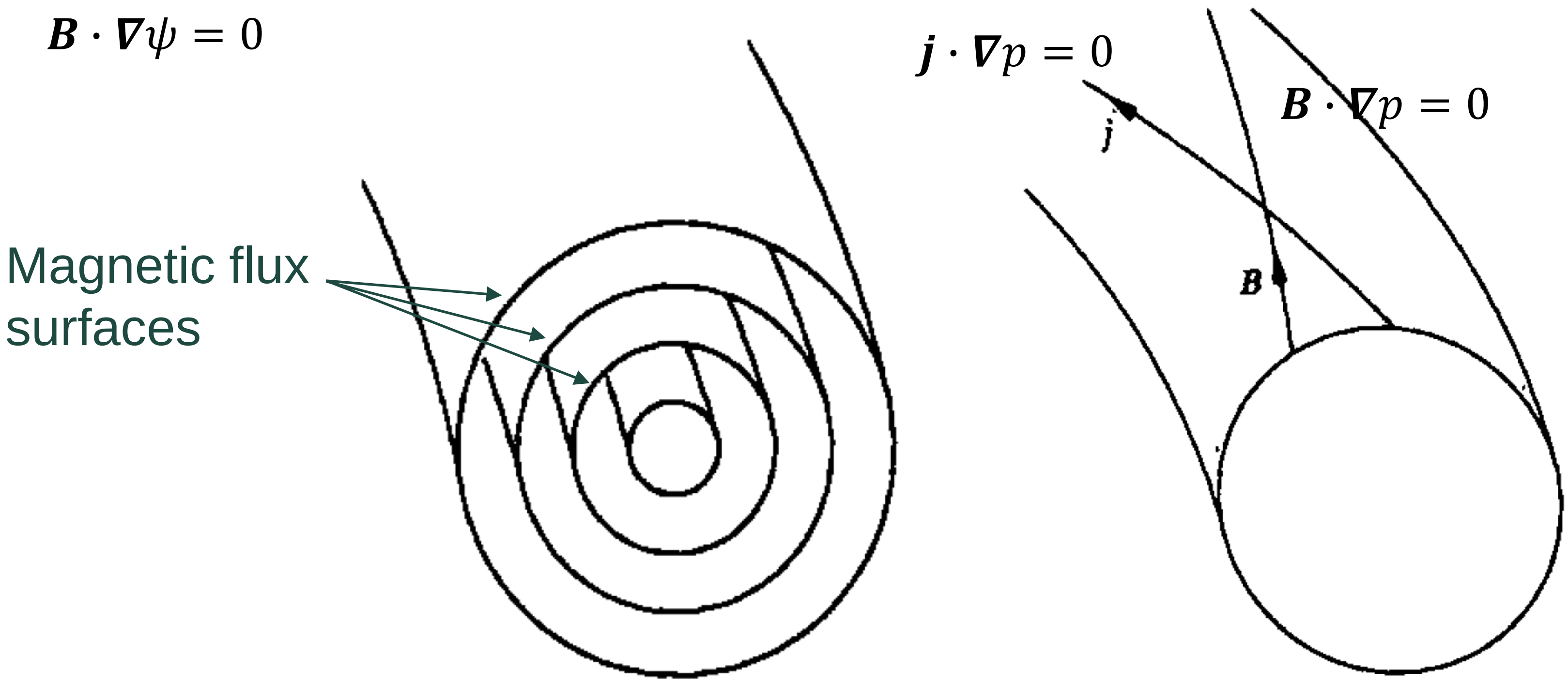
Equilibrium and magnetic flux surface

- The basic condition for equilibrium is that the magnetic force balances the force due to the plasma pressure.

$$\boldsymbol{j} \times \boldsymbol{B} = \boldsymbol{\nabla} p$$

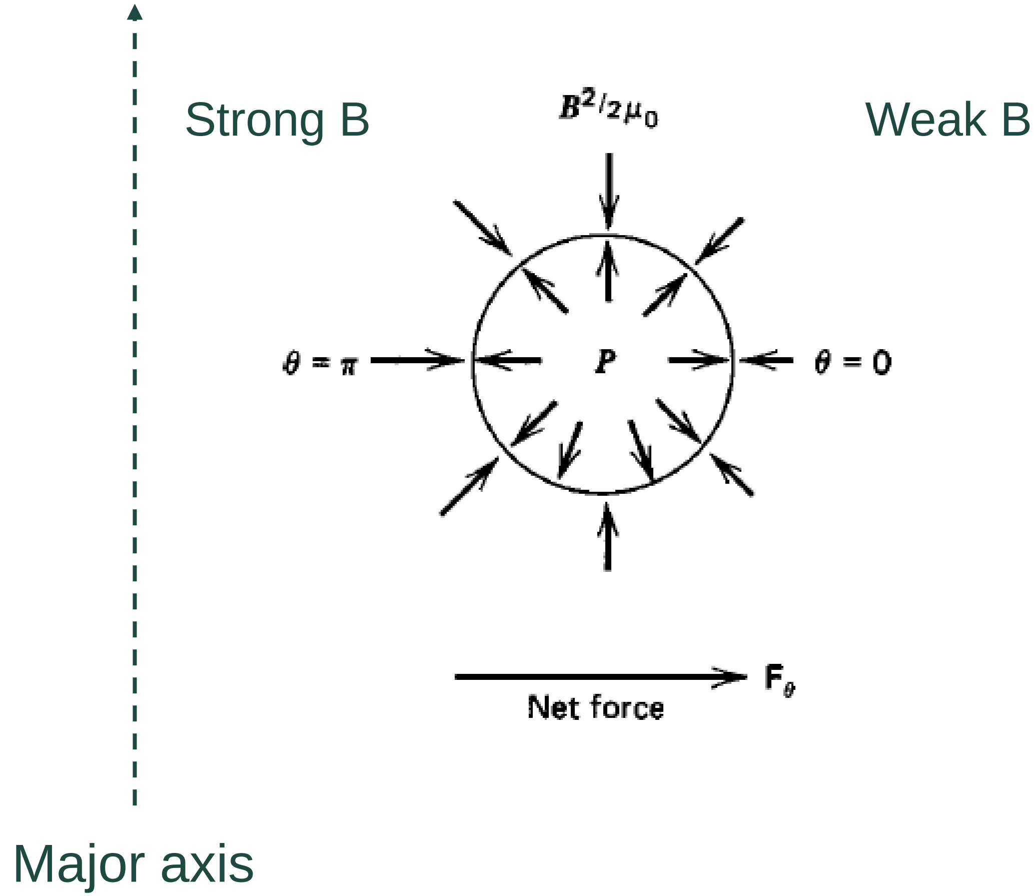
- In studying tokamak equilibria, it is convenient to introduce the poloidal magnetic flux function ψ. The ψ satisfies

$$\boldsymbol{B} \cdot \boldsymbol{\nabla}\psi = 0$$



Radial force imbalance

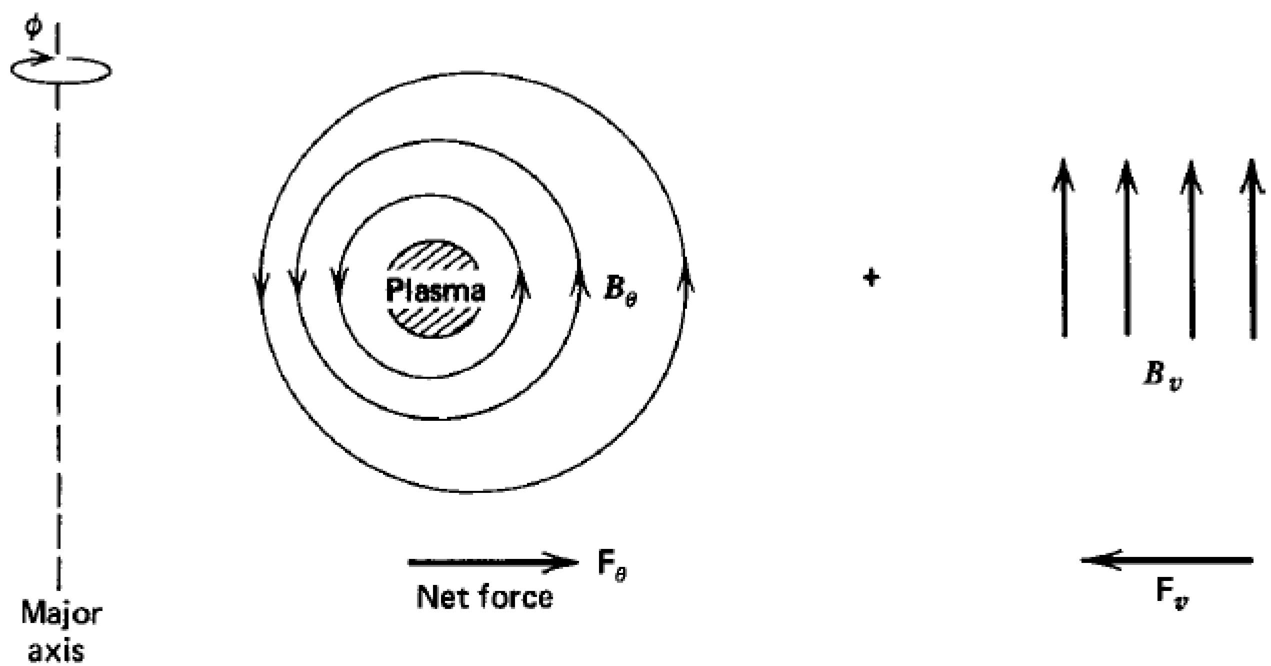
- Since the external surface is an isobaric surface, the kinetic pressure is uniform over the surface. However, the magnetic pressure varies over the surface.



Adding vertical field

- The vertical field interacts with the plasma current I_ϕ (which is out of the page) to produce an inward force.

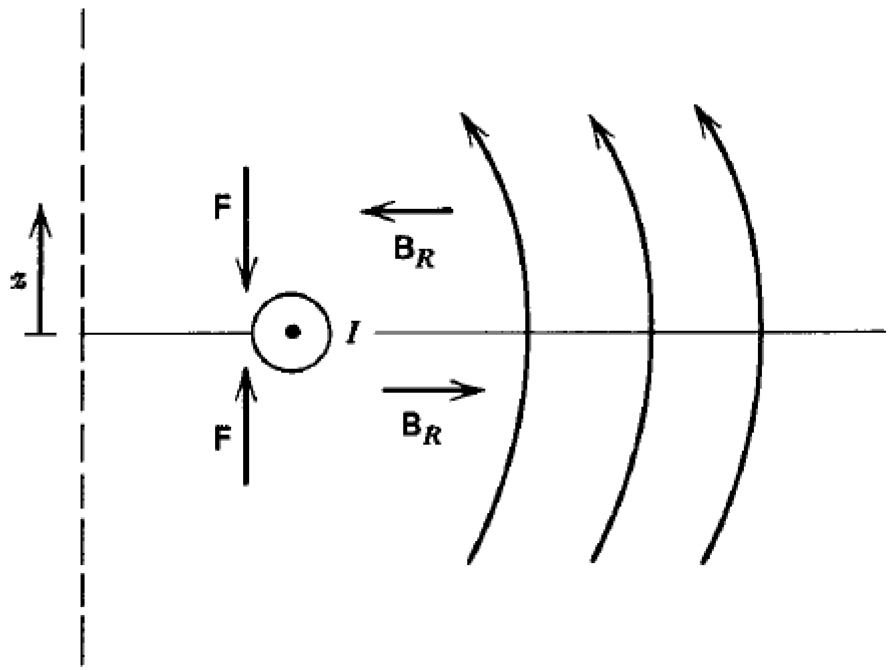
$$\boldsymbol{F_v} = \boldsymbol{I_\phi} \times \boldsymbol{B_v}$$



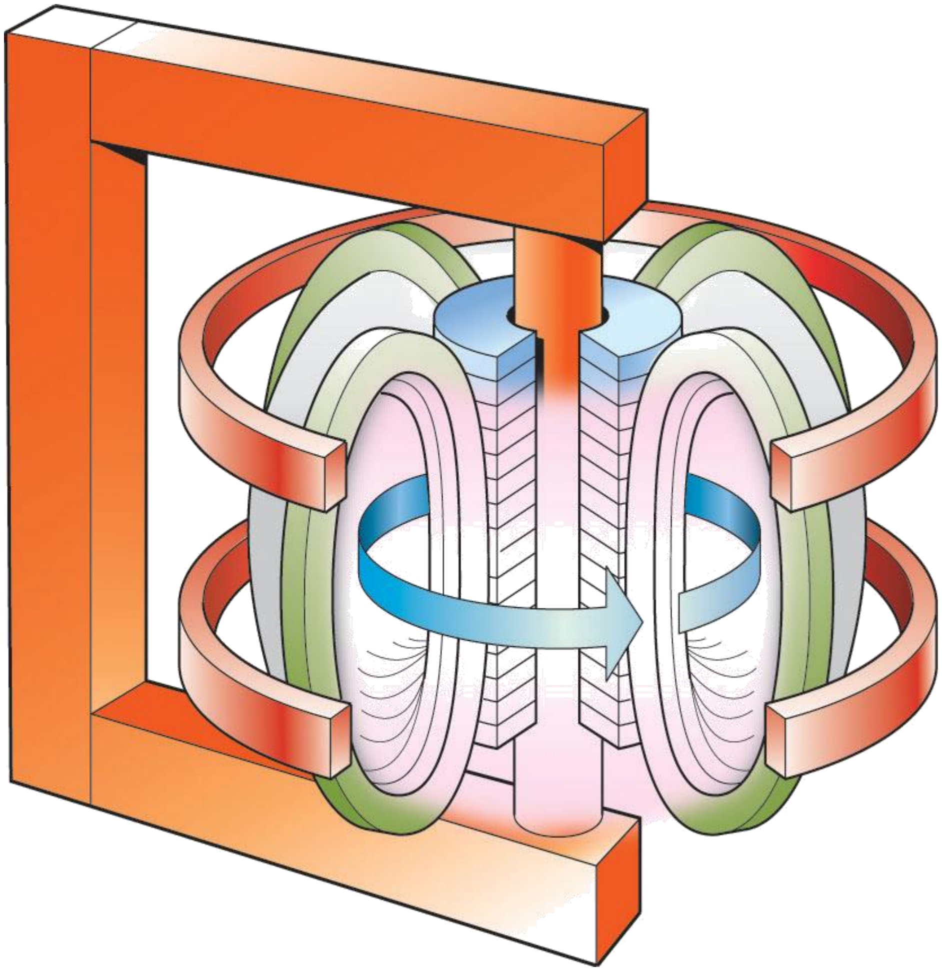
Making good curvature for vertical stability

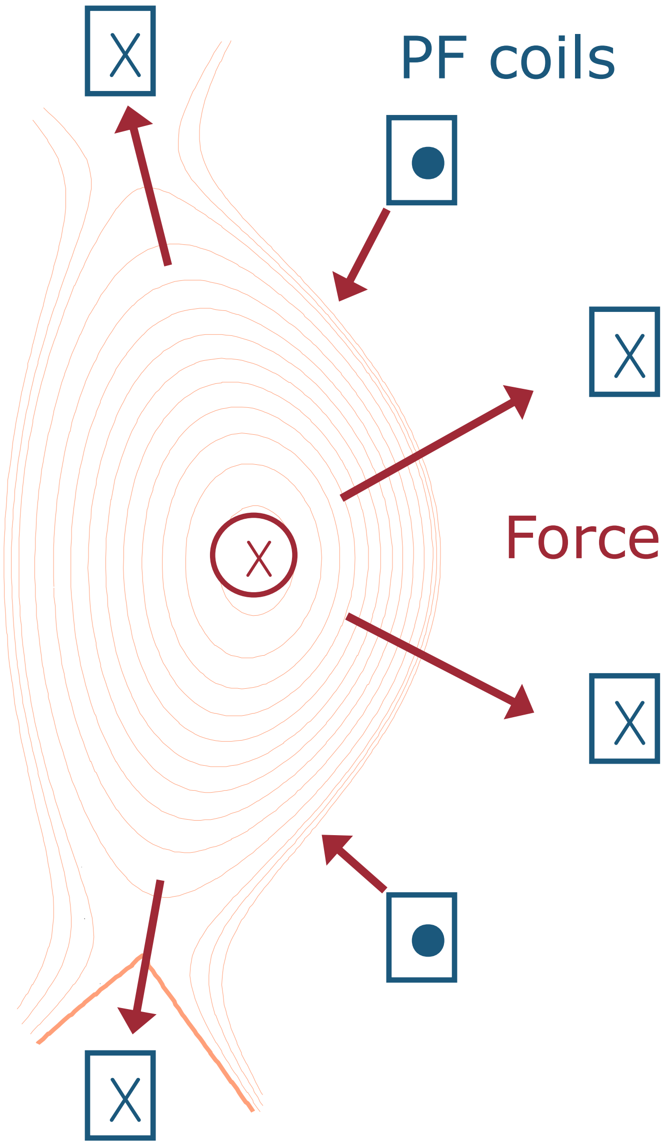
- The radial component of the vertical field must be configured so as to interact with the plasma current to provide a restoring force

$$F_v = I_\phi \times B_{vR}$$

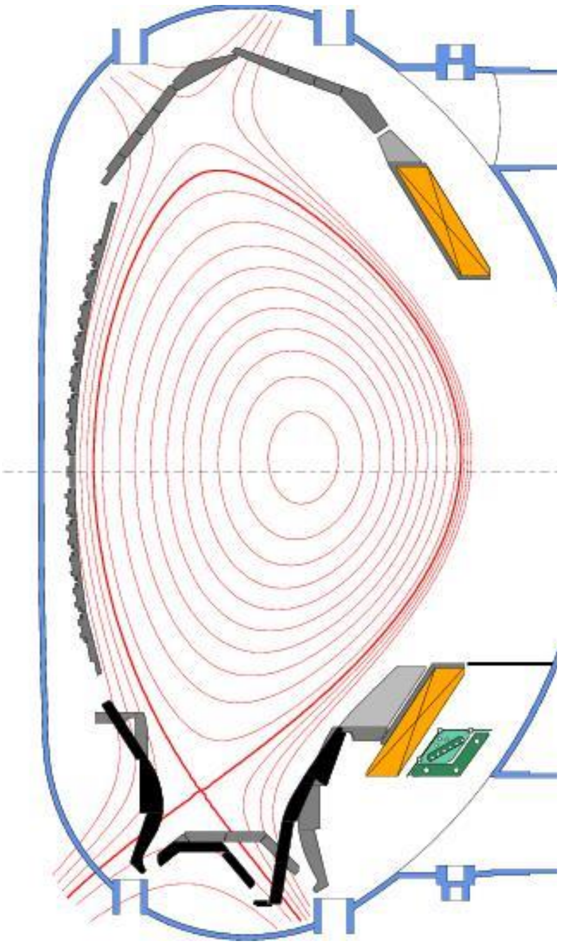


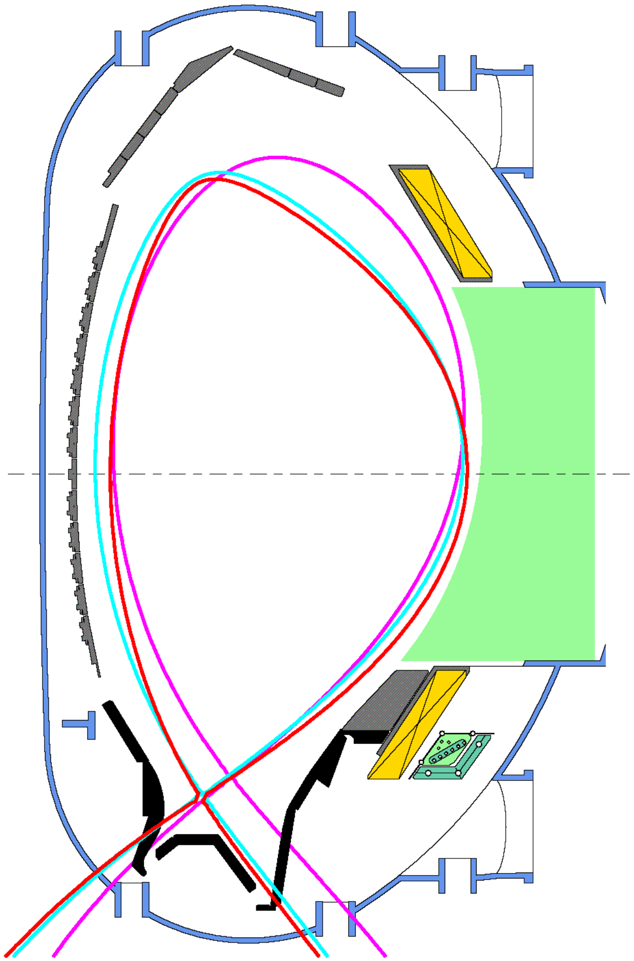
Adding PF (poloidal field) coils





Plasma shape control by PF coil currents





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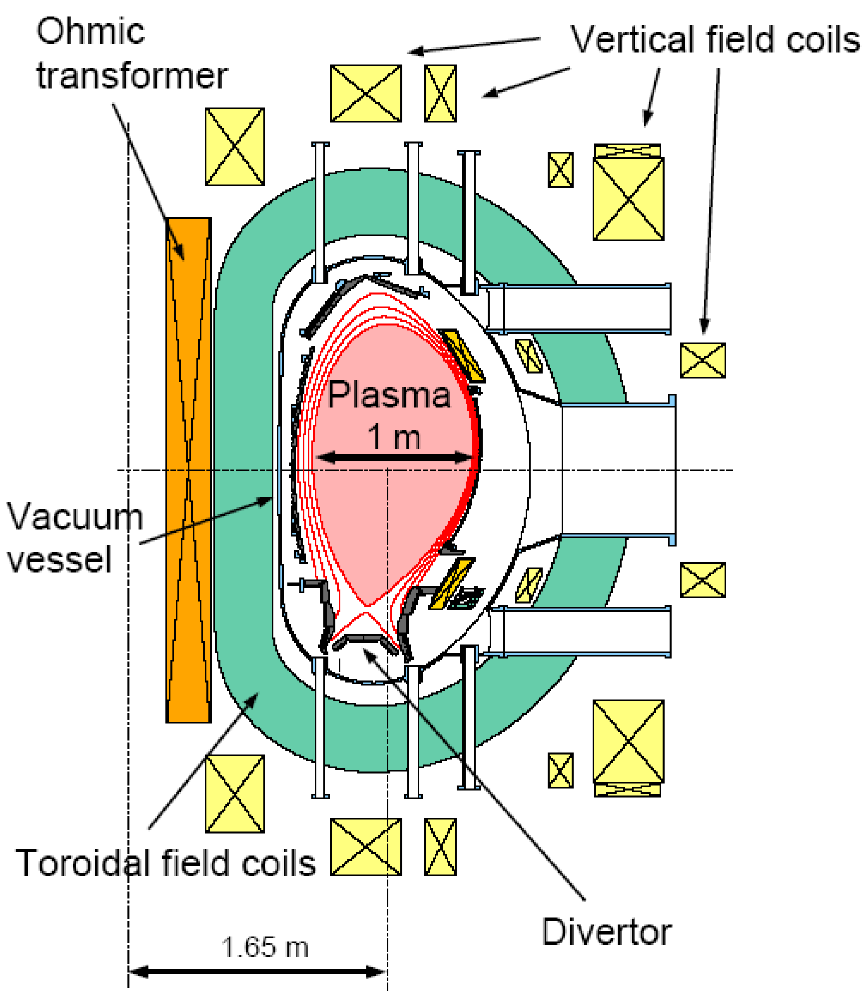
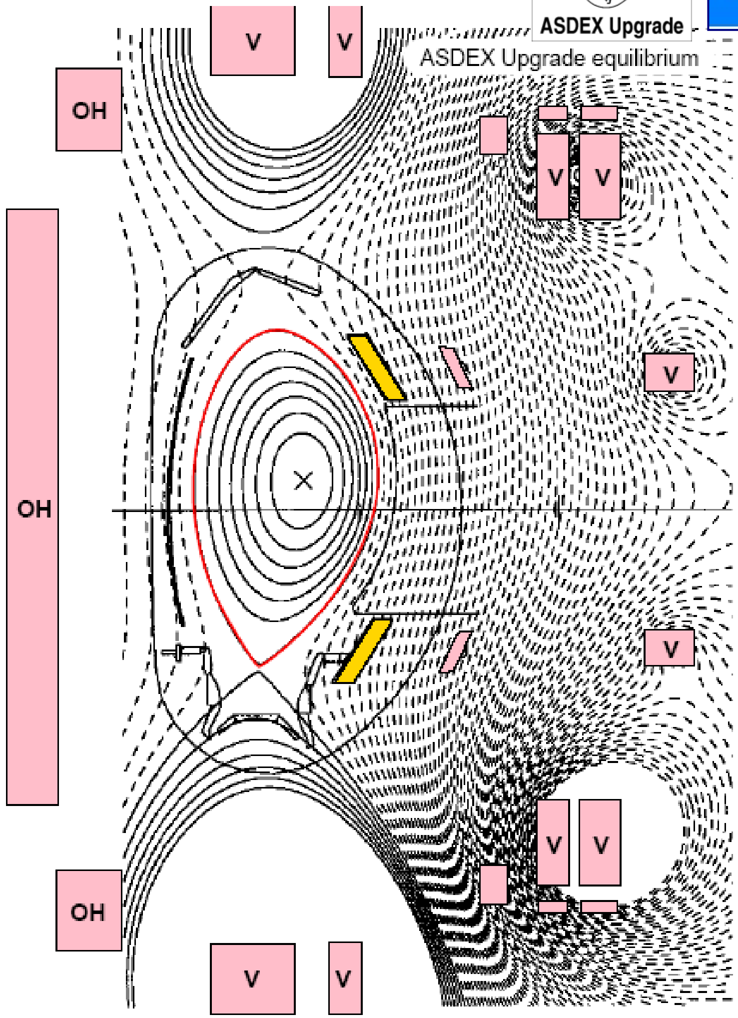
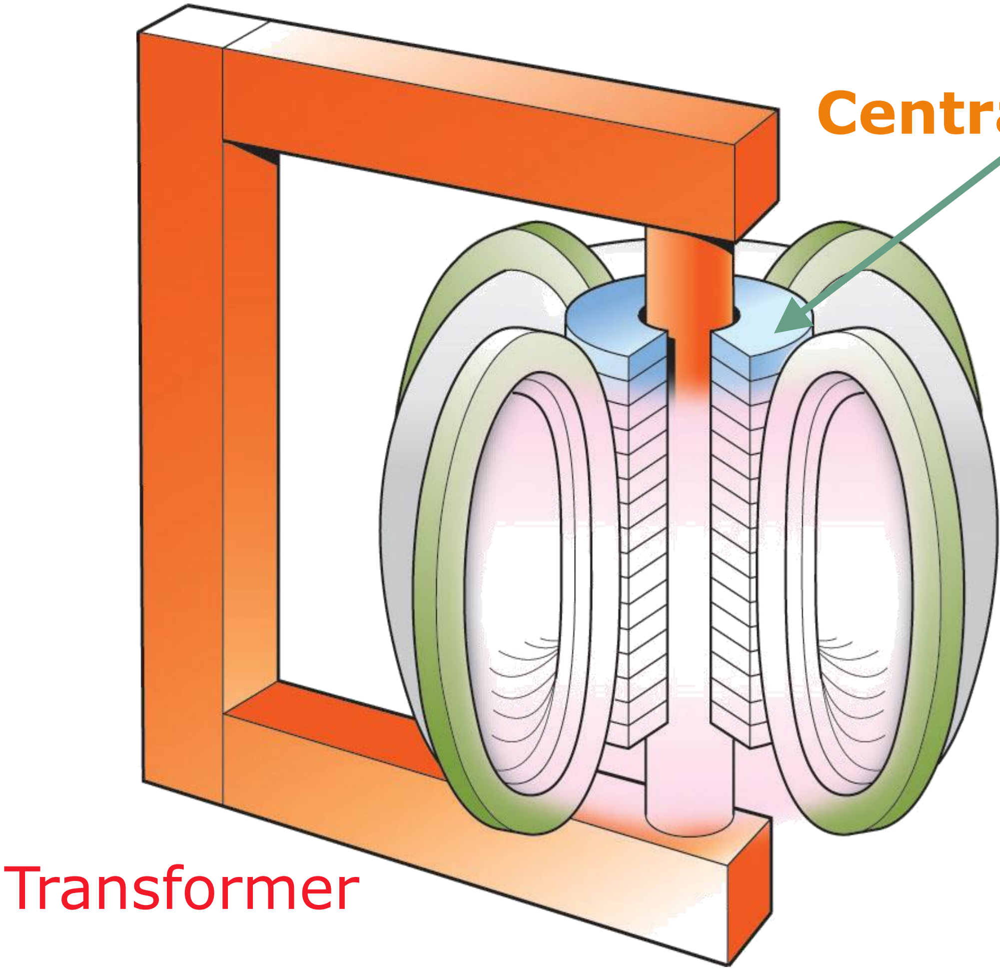
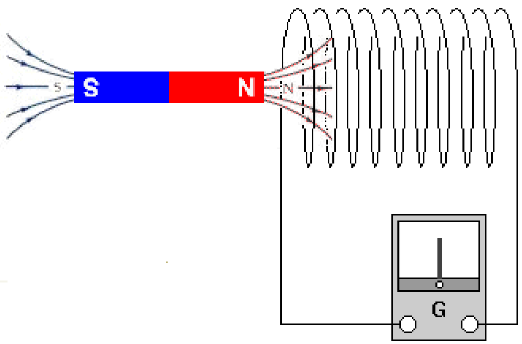




Basic tokamak operation

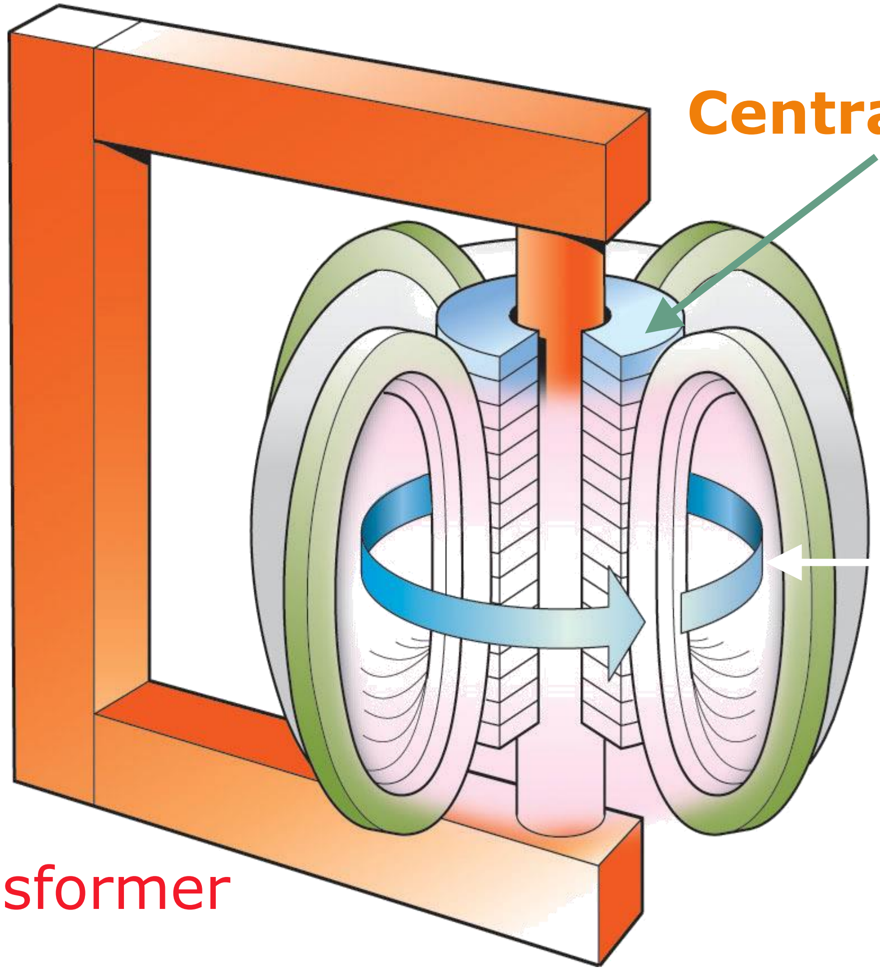


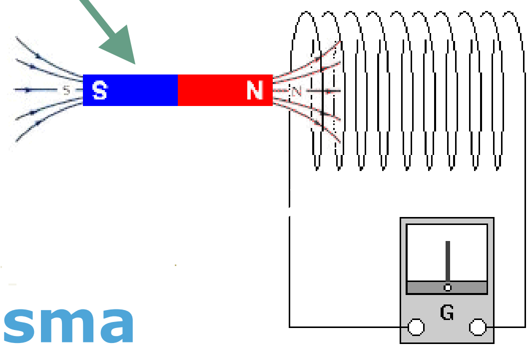


Faraday's law

$$v = -\frac{d}{dt}\int_S B \cdot ds$$

Basic tokamak operation





$$-\frac{\partial \mathbf{B}}{\partial t} = \nabla \times \mathbf{E}$$

$$\Rightarrow \quad -\frac{d\psi_{trans}}{dt} = \oint \mathbf{E} \cdot d\mathbf{l}$$

$$\Rightarrow \quad E_{\phi} = -\frac{1}{2\pi R}\frac{d\psi_{trans}}{dt}$$

$$\Rightarrow \quad J_{\phi} = \sigma E_{\phi}$$

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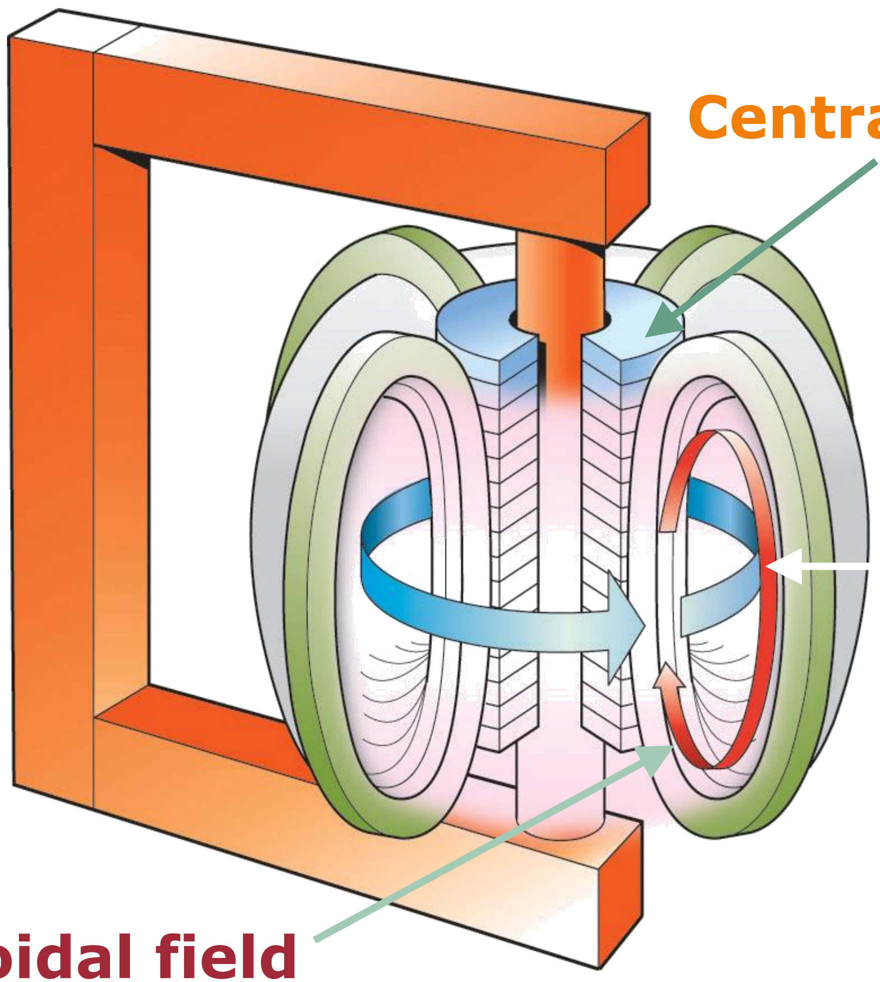

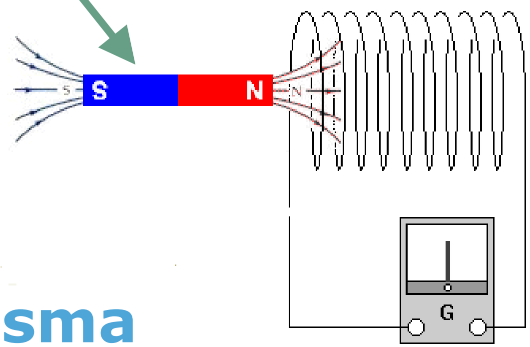

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Pulsed Operation!

Pulsed operation

Faraday's law

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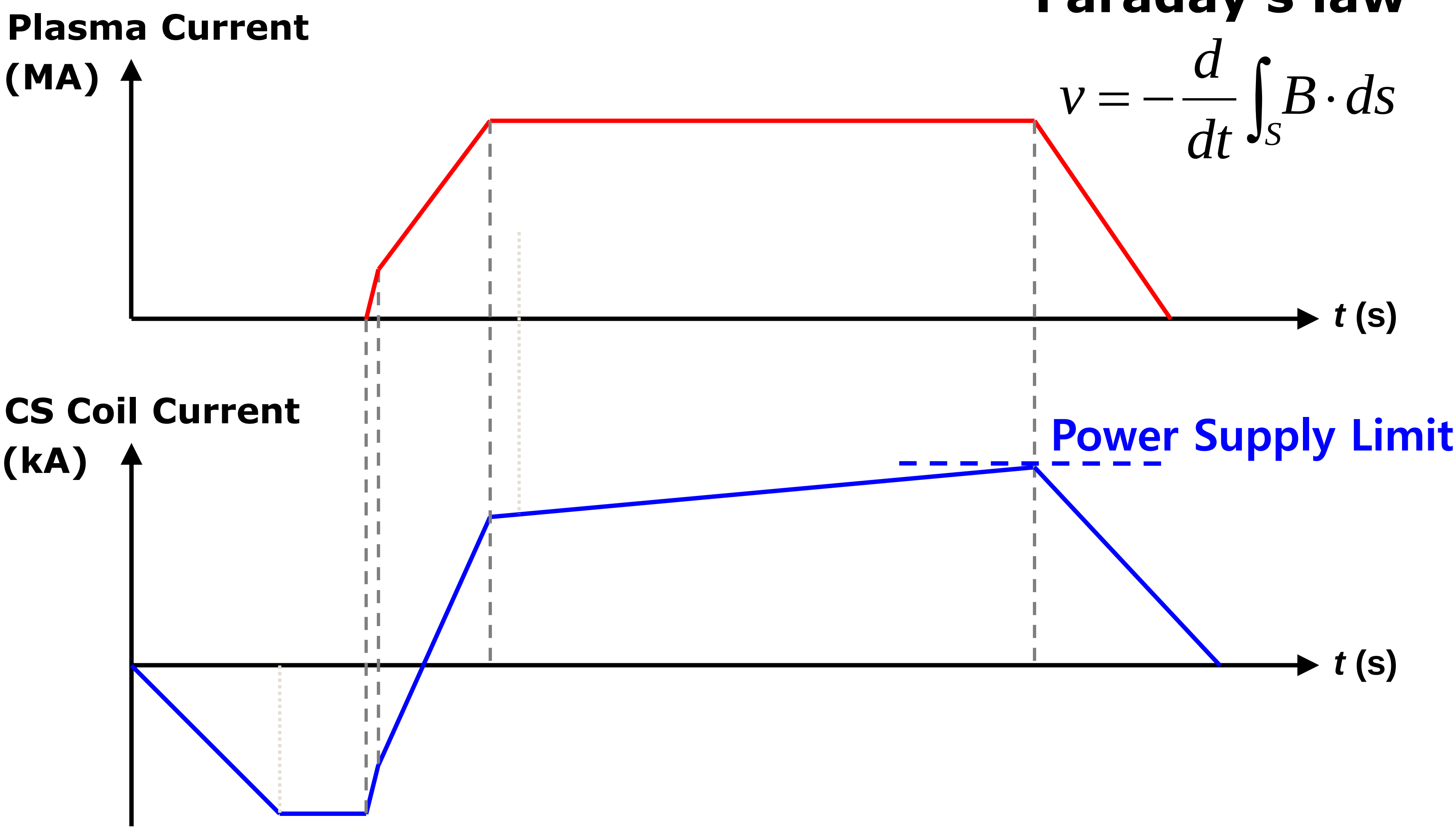
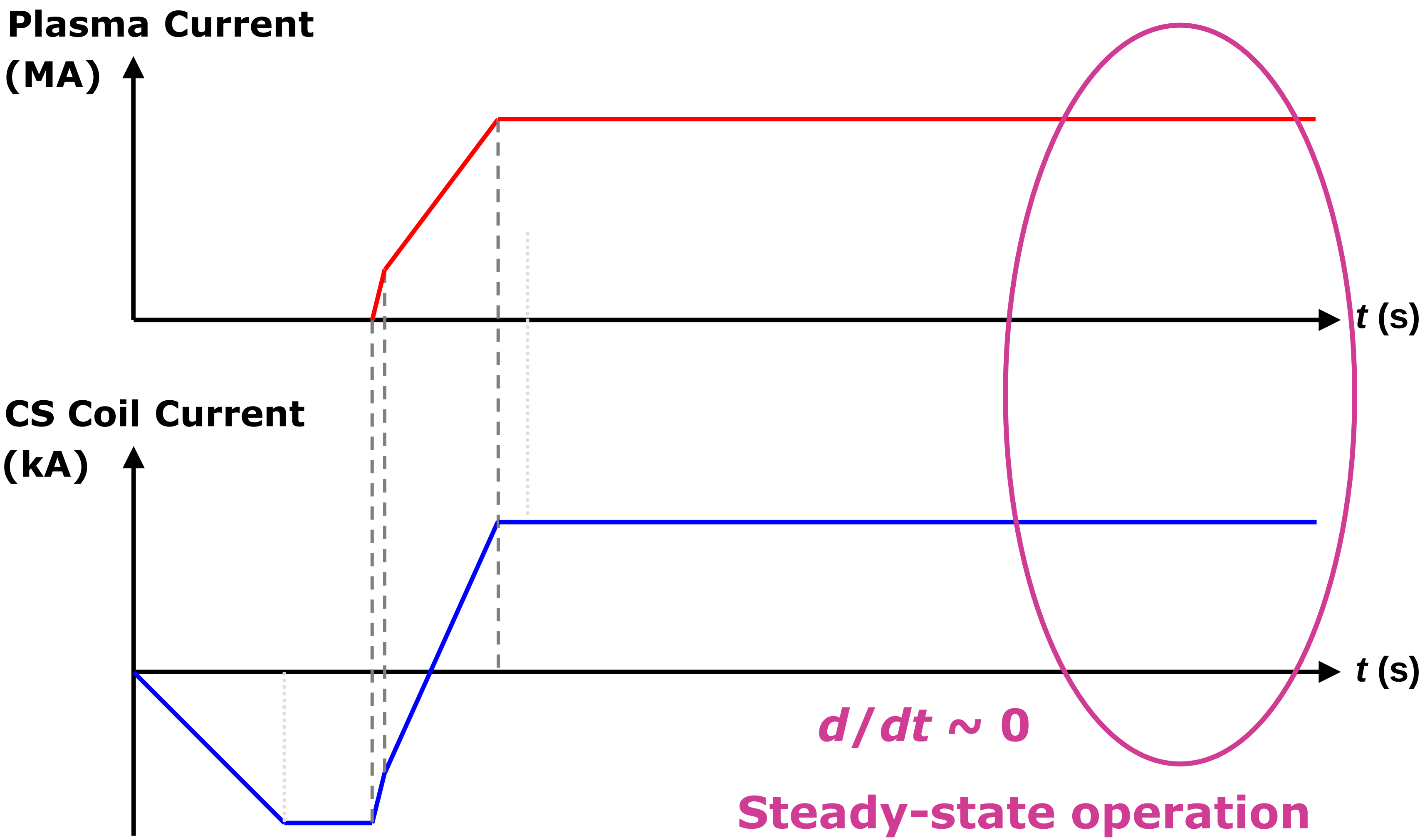


Inherent drawback of Tokamak!

Steady-state operation



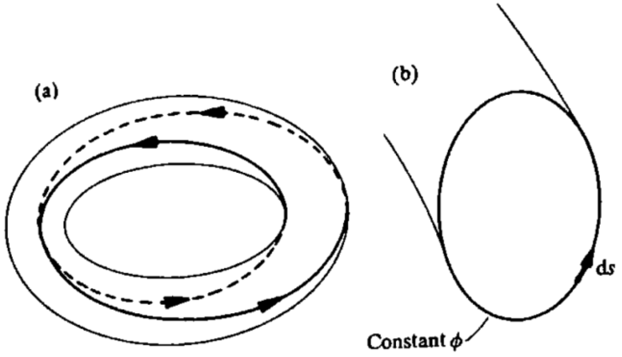
Steady-state operation by external current drive

Safety factor q

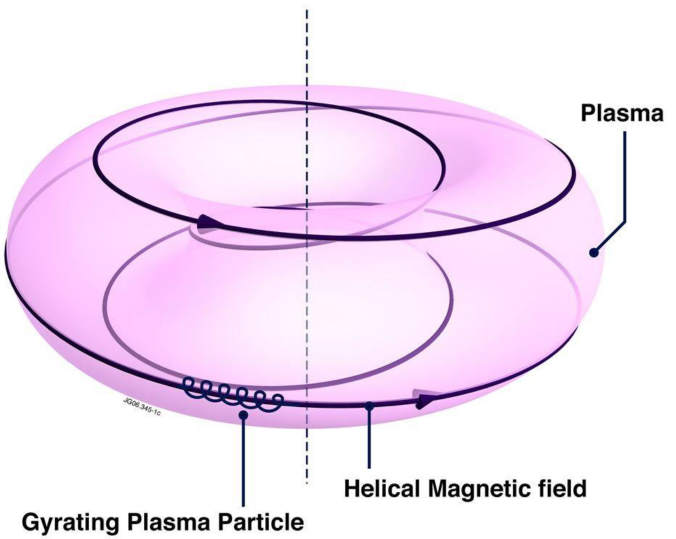
- The safety factor, labeled q, is the ratio of the times a particular magnetic field line travels around a toroidal confinement area's "long way" (toroidally) to the "short way" (poloidally). It plays in determining stability.

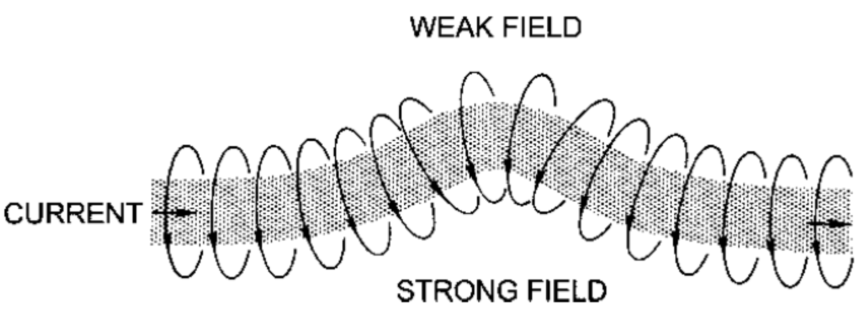
$$q = \frac{d\phi}{2\pi} = \frac{1}{2\pi}\oint \frac{1}{R}\frac{B_t}{B_p}ds = \frac{r}{R}\frac{B_t}{B_p}$$

Number of toroidal orbits per poloidal orbit



- Kruscal-Shafranov limit: $q > 1$ for kink-stability

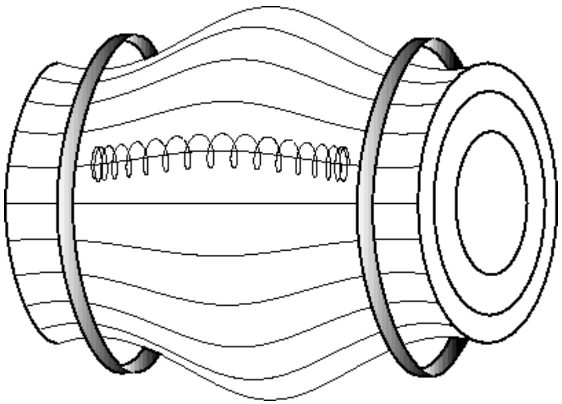


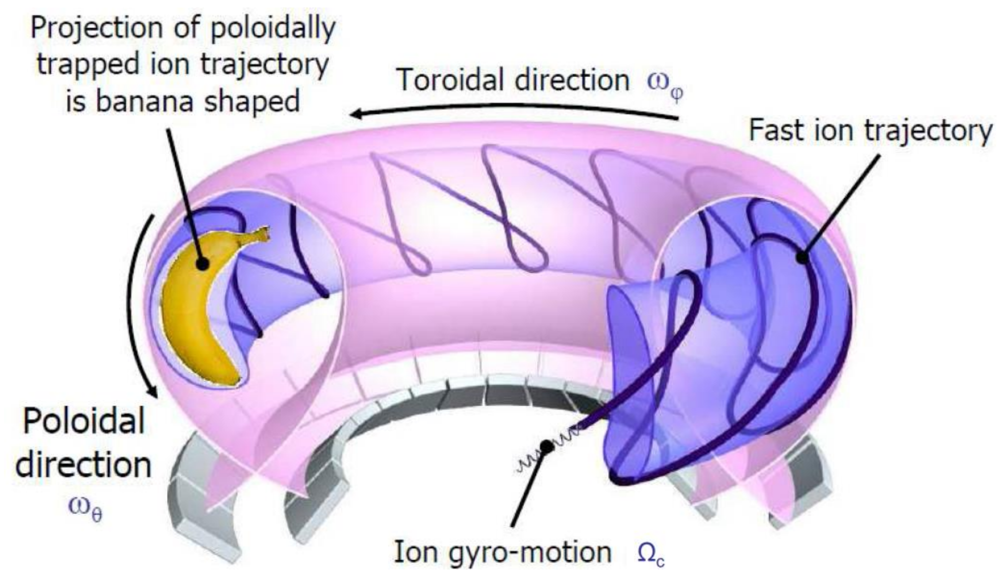


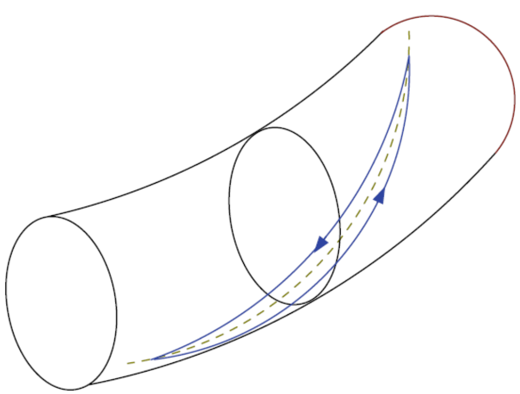
Banana orbits: mirroring effect

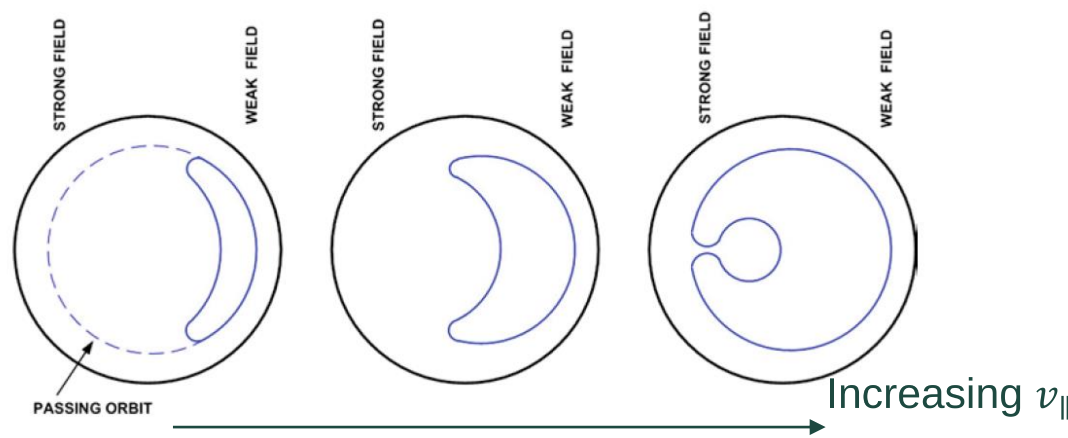
- Ideally, particles travel along helical field lines on a magnetic surface and never leave it. However, magnetic mirroring prevents this (banana orbit).

$$\mu = IA = \frac{q\omega_c}{2\pi} \cdot \pi r_L^2 \sim B \cdot r_L^2$$



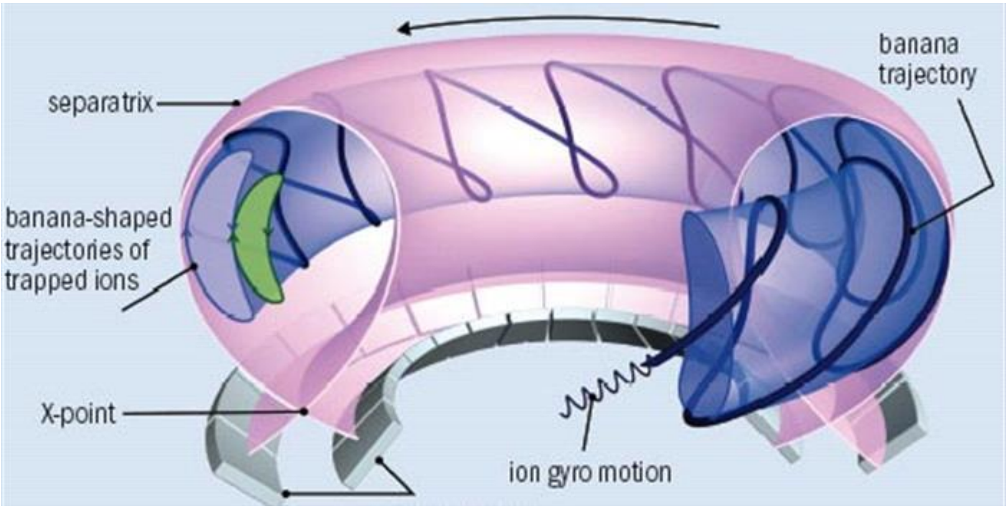


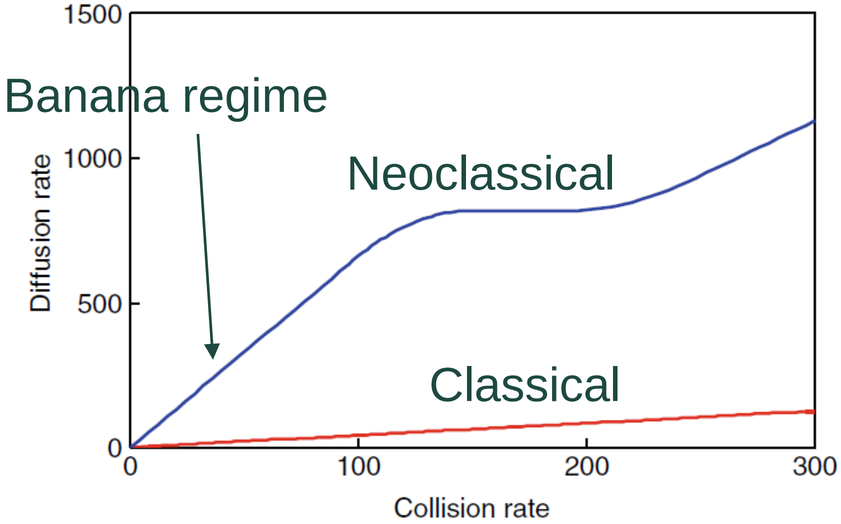




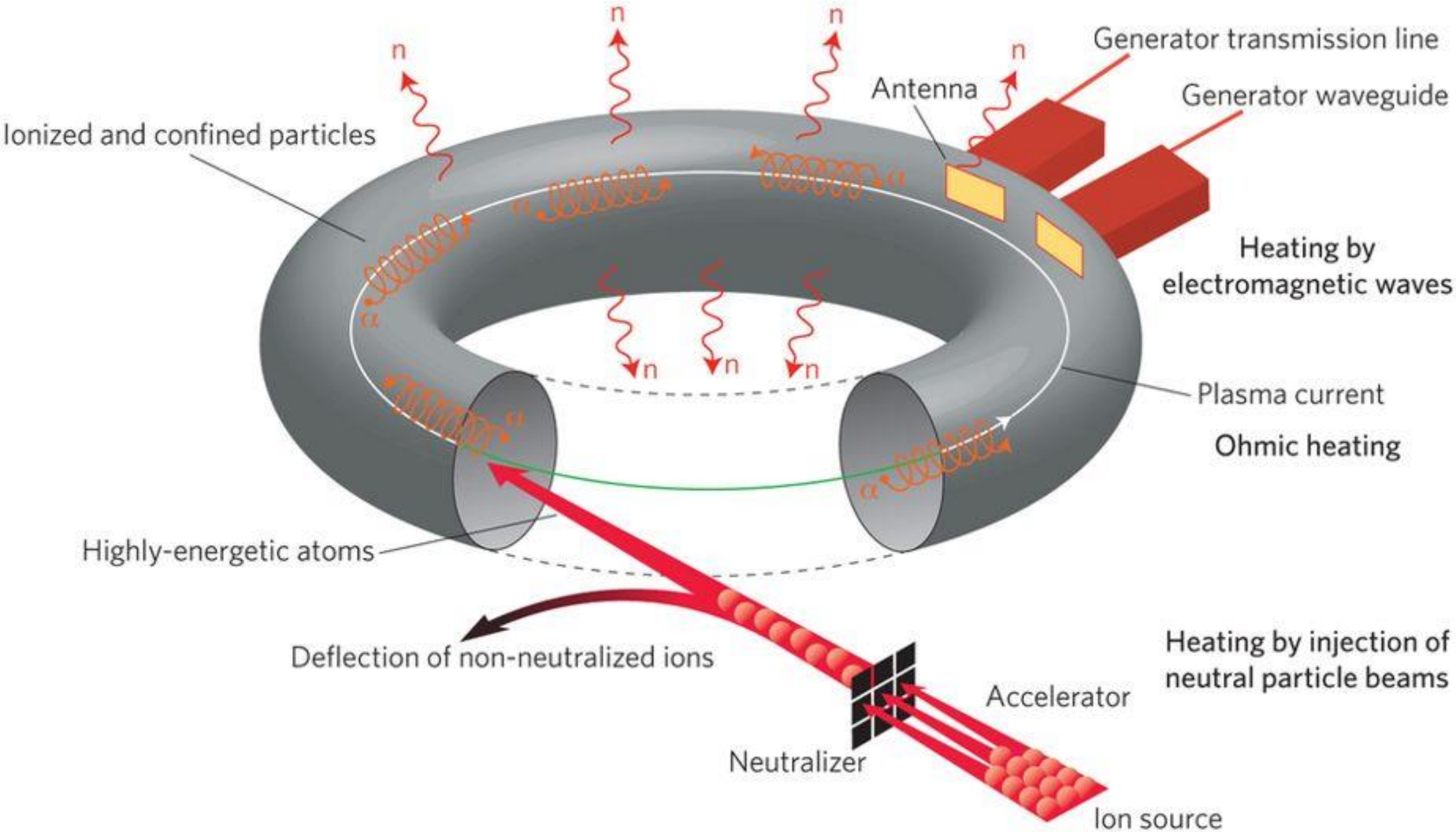
Neoclassical diffusion

- When an ion makes a collision, instead of jumping from one Larmor orbit to an adjacent one, it jumps from one banana orbit to the next; and banana orbits are much wider. Instead of the very slow rate of “classical” diffusion, the rate of plasma transport across the magnetic field is much faster in a torus than in a straight cylinder.
- It turns out that the banana width is approximately the Larmor radius of an ion calculated with B_p instead of B_t.



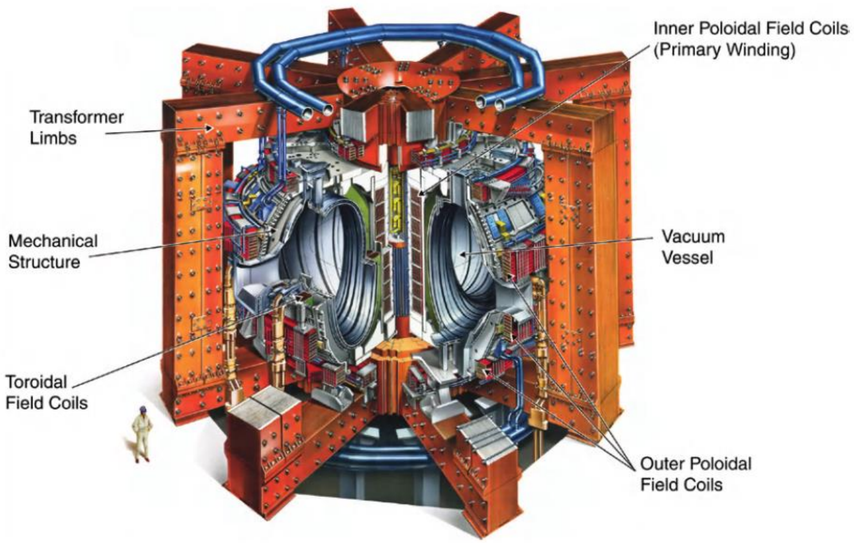


Heating

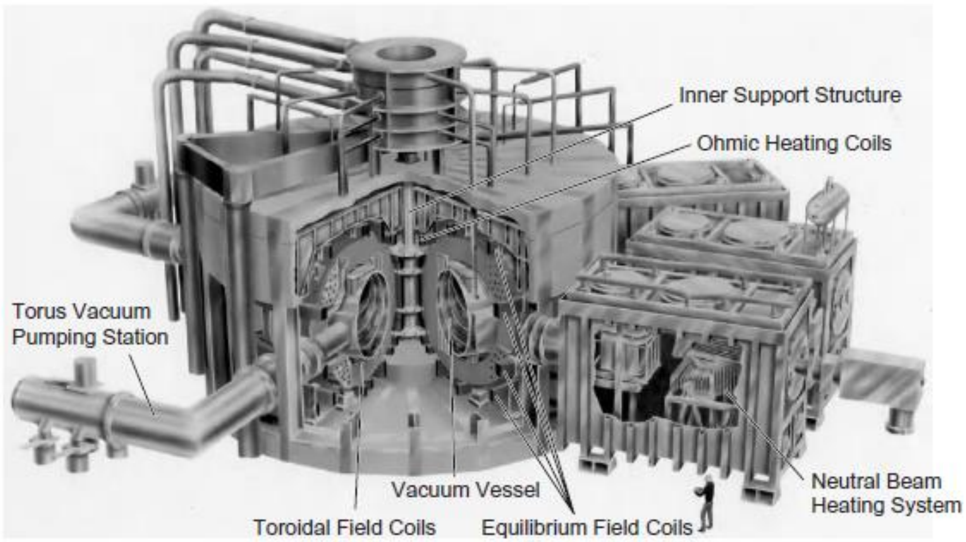

n
n
n
n
Generator transmission line
Antenna
Generator waveguide
Ionized and confined particles
α
Heating by
electromagnetic waves
n
n
n
Plasma current
Ohmic heating
Highly-energetic atoms
Deflection of non-neutralized ions
Heating by injection of
neutral particle beams
Accelerator
Neutralizer
Ion source

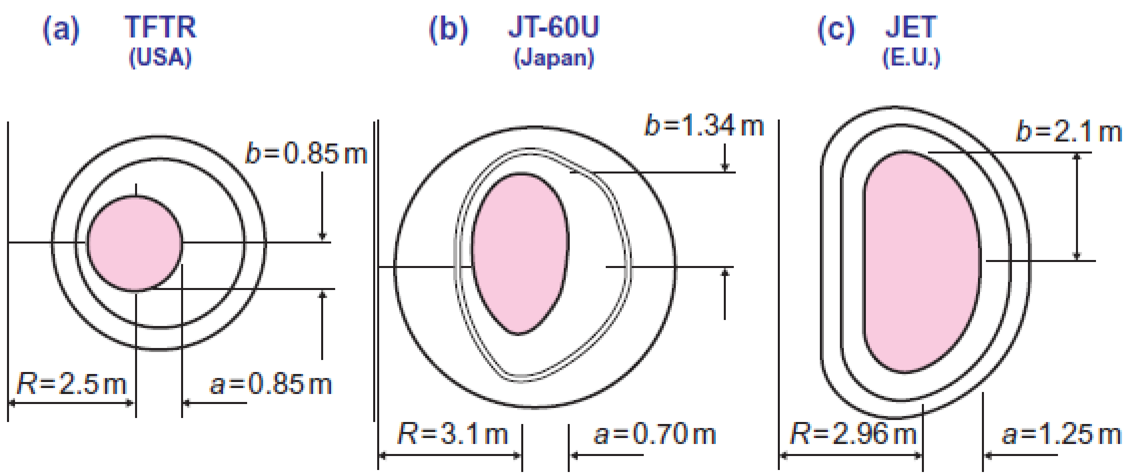
Major tokamak researches

JET (Joint European Torus)



TFTR (Tokamak Fusion Test Reactor)





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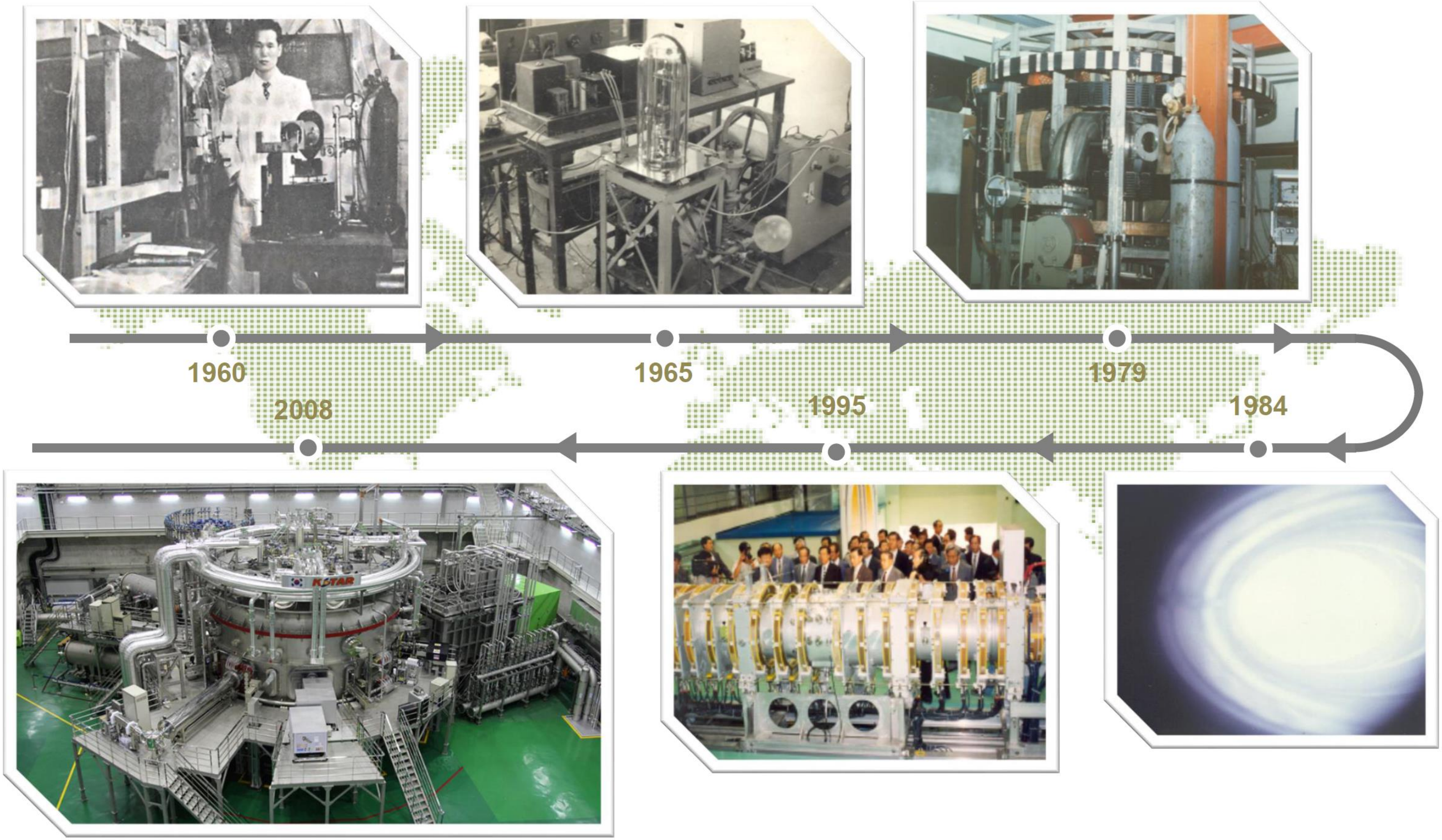
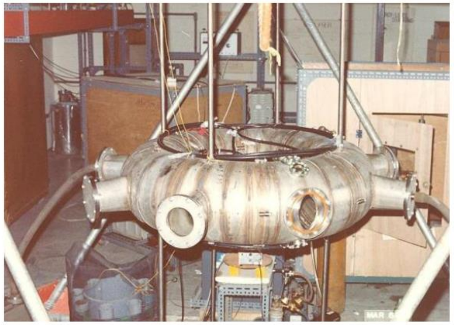
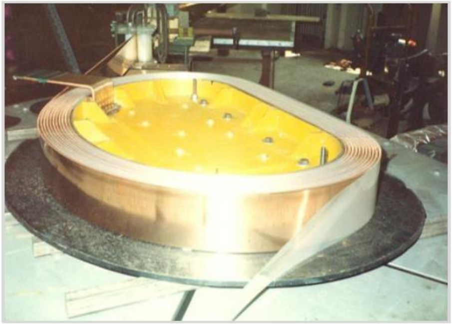
History of fusion researches in Korea

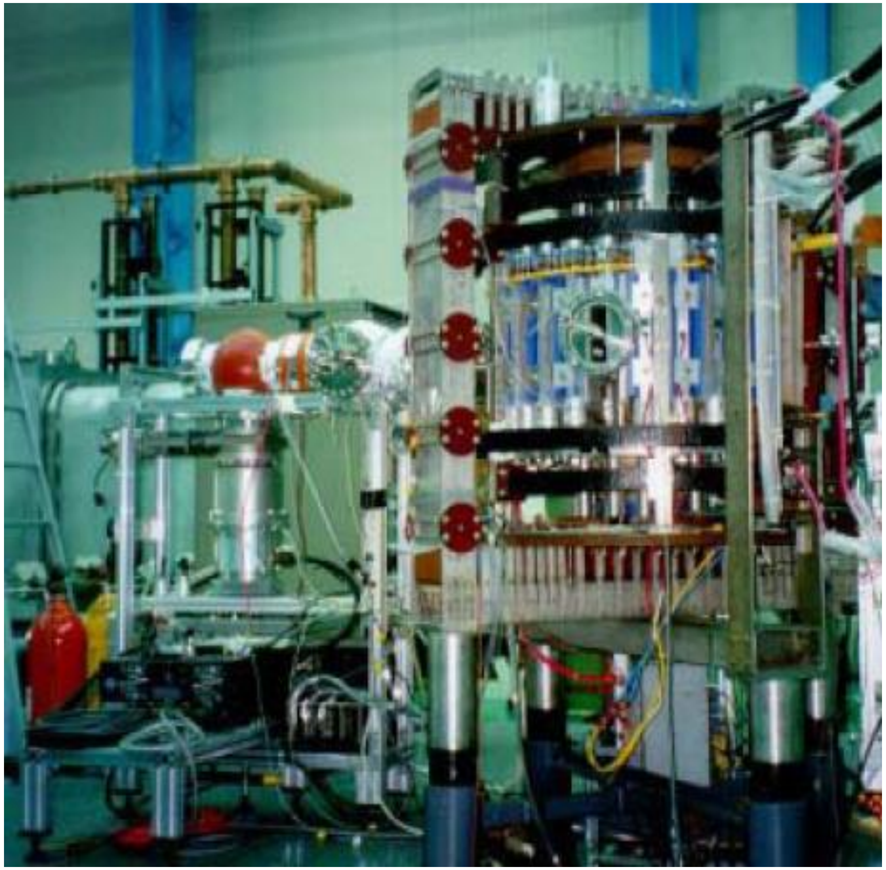


First Tokamak: SNUT-79

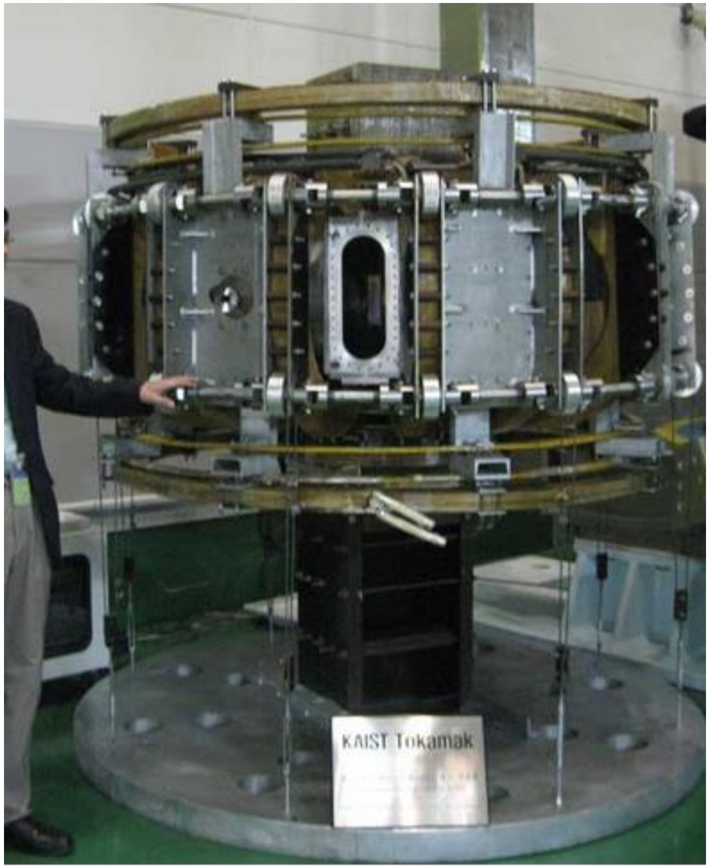




Other tokamaks



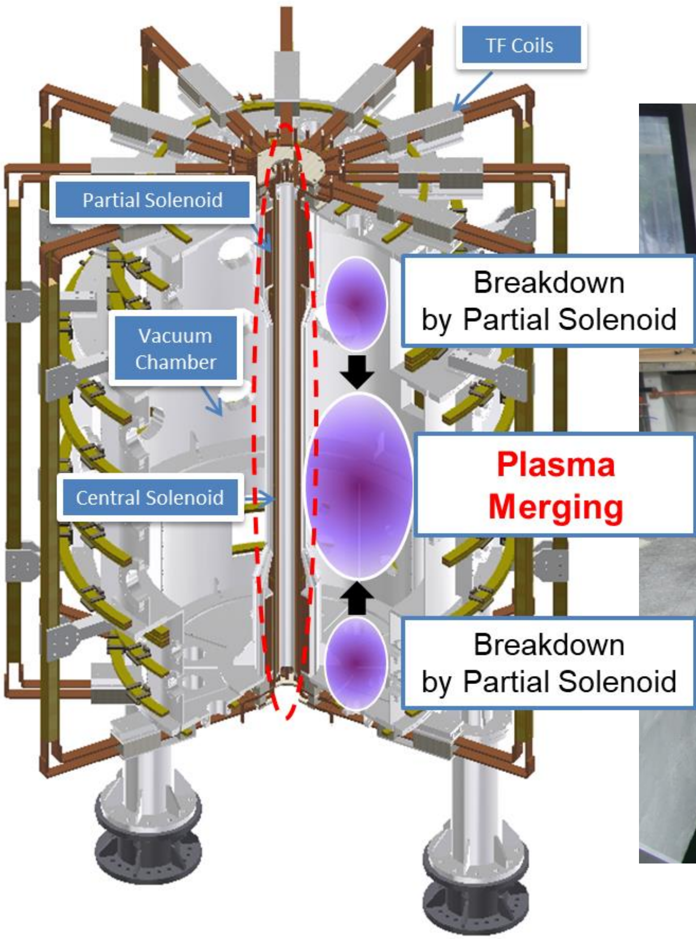
KT-1 (KAERI, 1985)



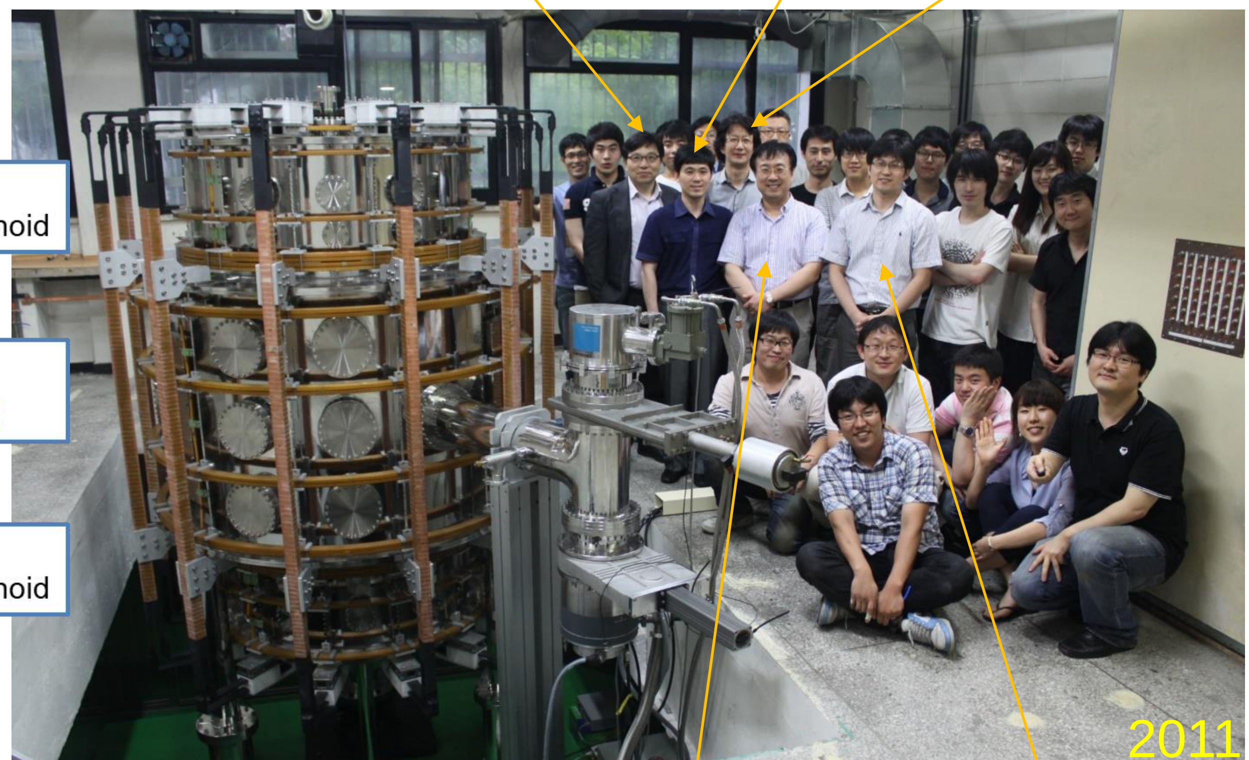
KAIST Tokamak (KAIST, 1991)

VEST: 1st spherical tokamak in Korea (Since 2011)

- VEST (Versatile Experiment Spherical Torus): 1st spherical tokamak in Korea (since 2011) dedicated to basic researches on a compact, high-β ST with elongated chamber in partial solenoid configuration



Prof. Hwang Prof. Na Prof. Hahm



Prof. Kim Prof. Chung

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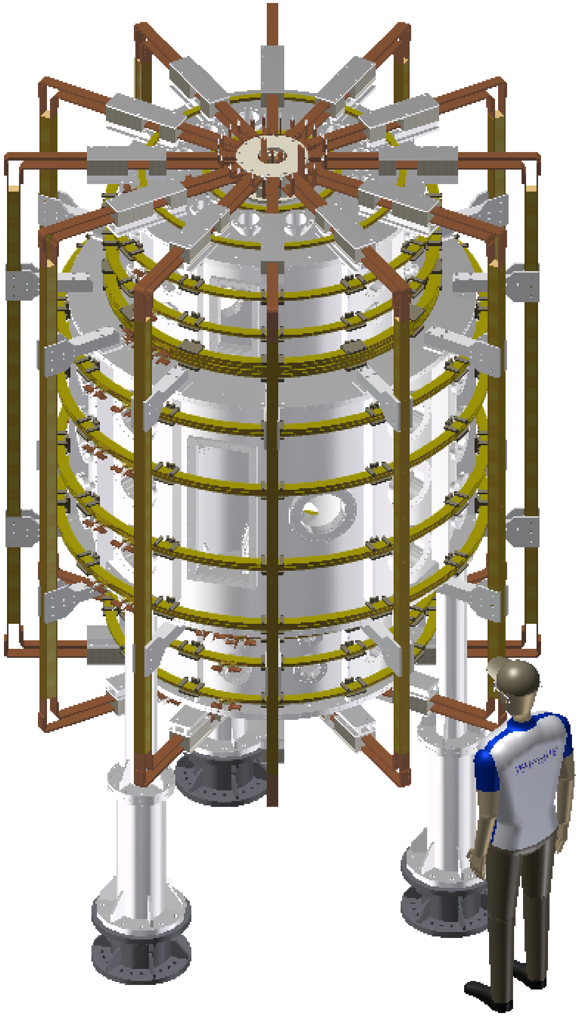
VEST: 1st spherical tokamak in Korea (Since 2011)



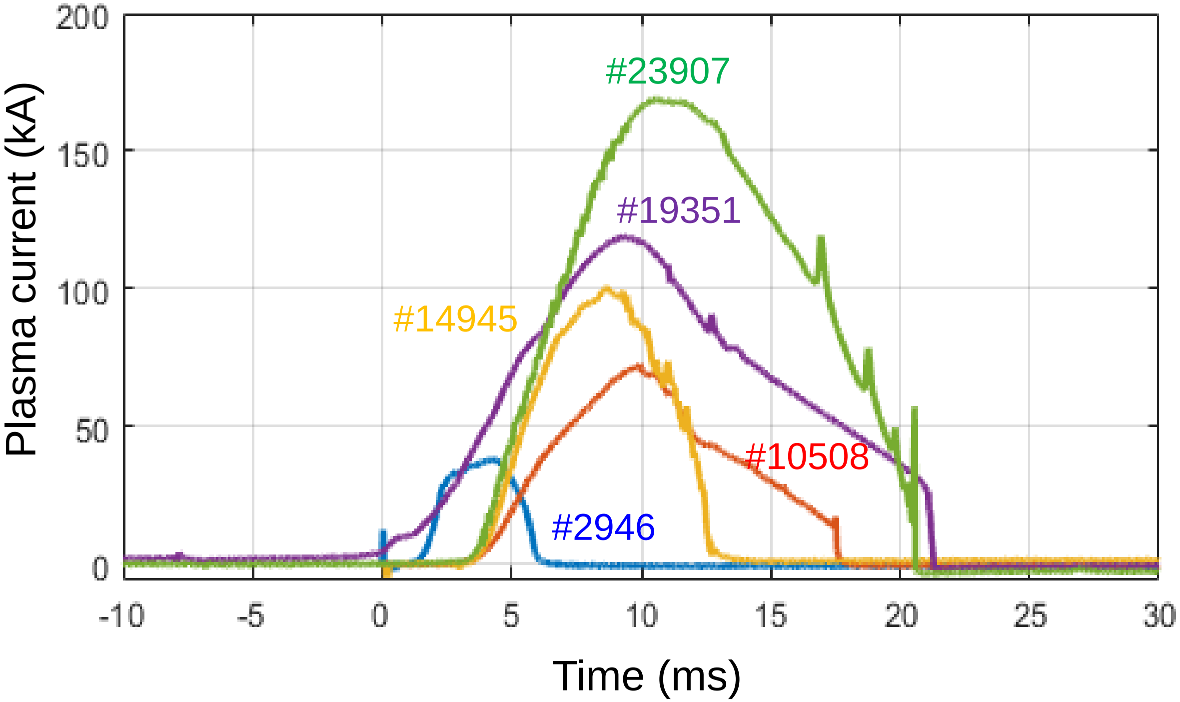
- The first and only ST device in Korea
  - Basic research on a compact, high-β ST (Spherical Torus)
  - Study on innovative start-up, non-inductive H&CD, high β, disruption, energetic particle, innovative divertor concept, etc

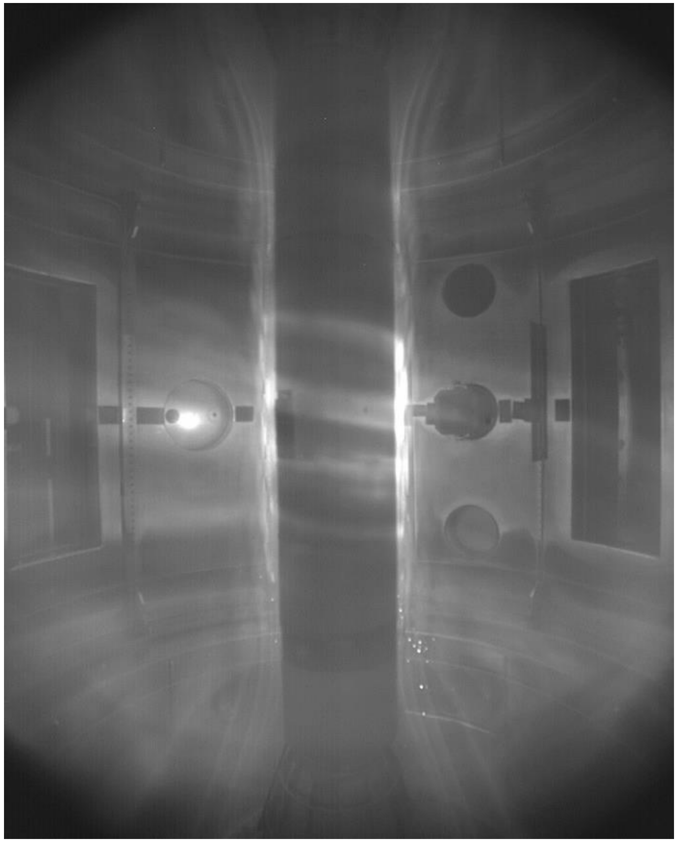
- Specifications

	Present (2019)	Future
Toroidal B Field	**0.05 – 0.19 T**	<0.3 T
Major Radius	**0.45 m**	0.4 m
Minor Radius	**0.33 m**	0.3 m
Aspect Ratio	**>1.36**	>1.33
Plasma Current	**<170 kA**	<300 kA
H & CD (ECH, NBI, LHFW)	**ECH (7.9GHz, 3kW) ECH (2.45GHz, 15kW) NBI (15keV, 600kW) LHFW (500MHz, 10kW)**	ECH (2.45GHz, 30kW) NBI (20keV, 1.2MW) LHFW (500MHz,200kW)

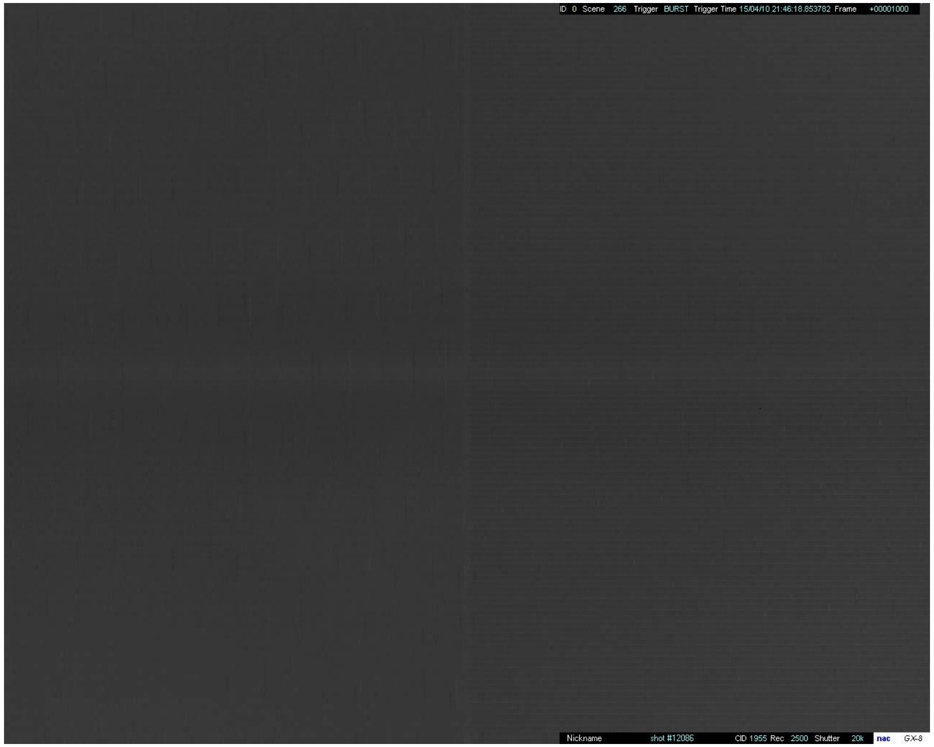
History of VEST discharges

- #2946: First plasma (Jan. 2013)
- #10508: Hydrogen glow discharge cleaning (Nov. 2014)
- #14945: Boronization with He GDC (Mar. 2016)
- #19351: Slower ramp-up and diverted plasma (May 2018)
- #23907 : Higher TF discharge (Oct. 2019)





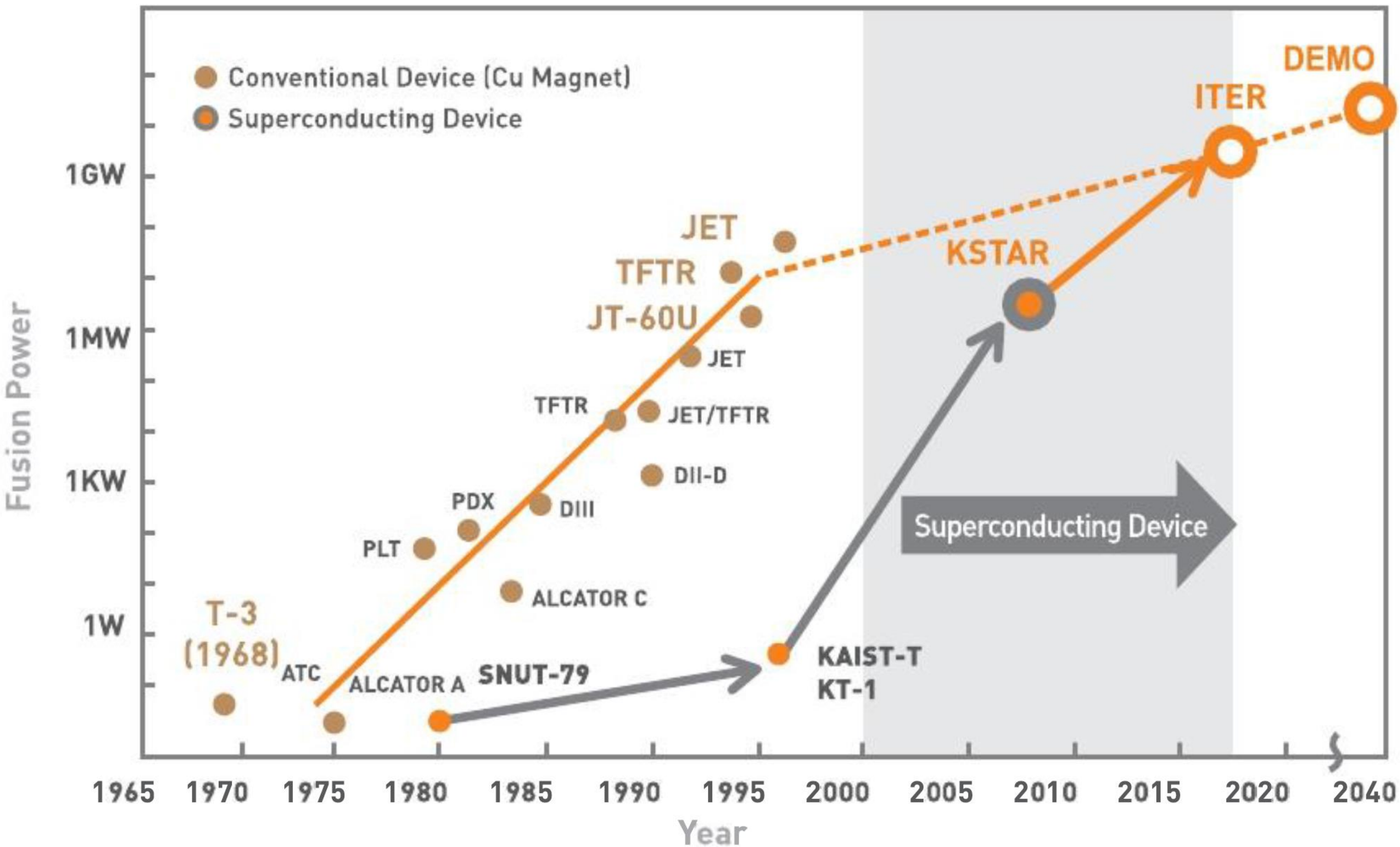
History of VEST discharges



↑ Helicity injection

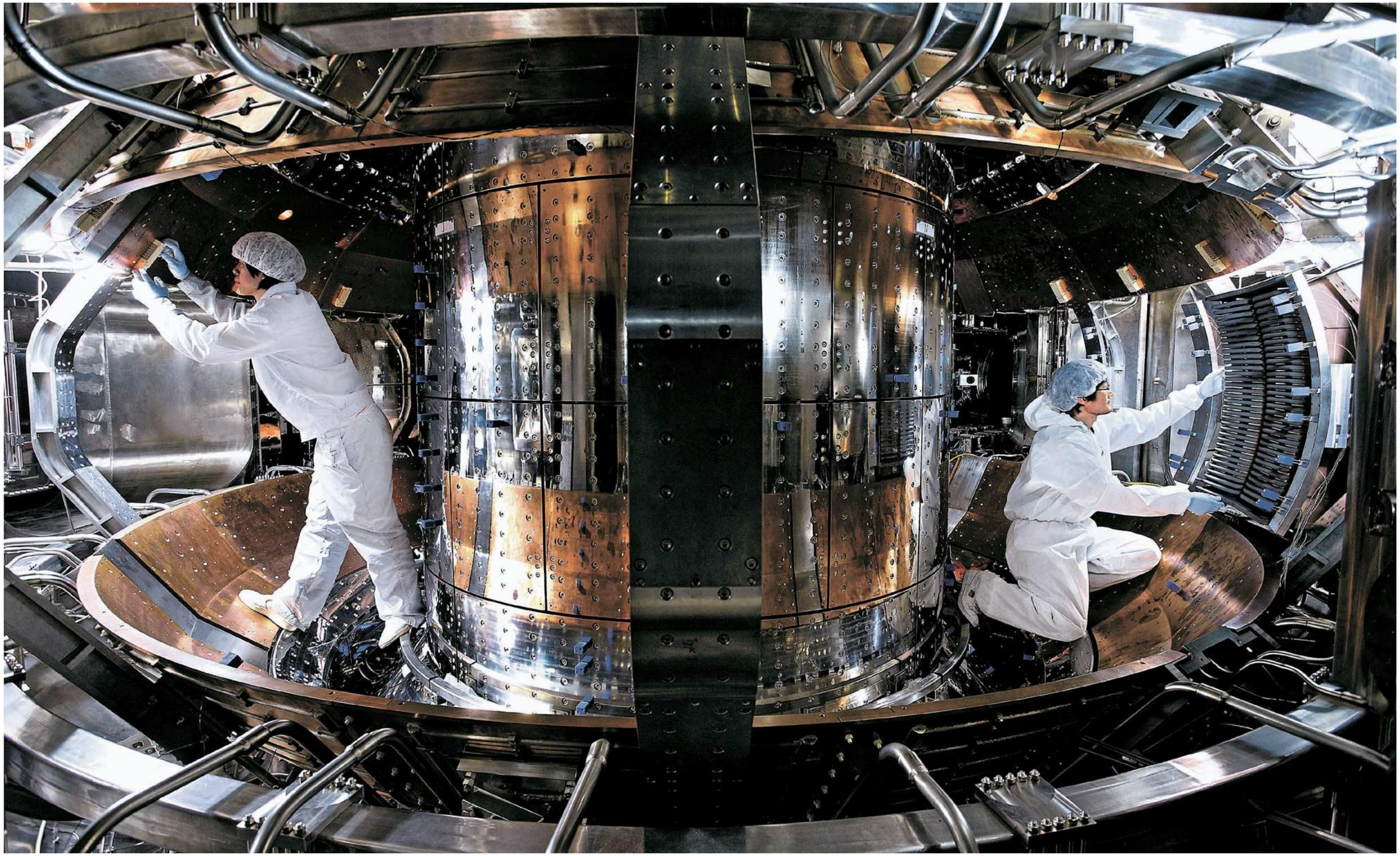
← Diverted plasma (#21193)

Initiation of KSTAR project based on 'Mid-entry strategy'



KSTAR

- Korea Superconducting Tokamak Advanced Research
- R_0 = 1.8 m, a = 0.5 m, 2008-today



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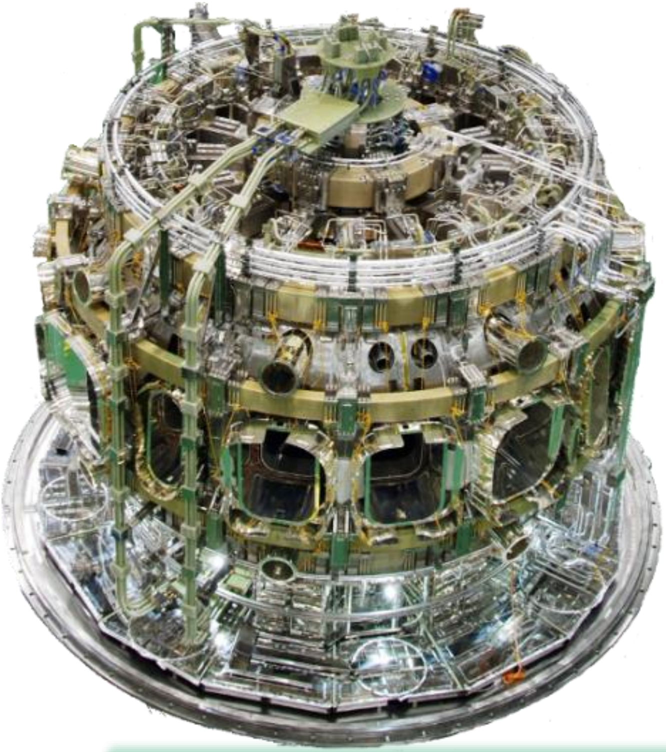
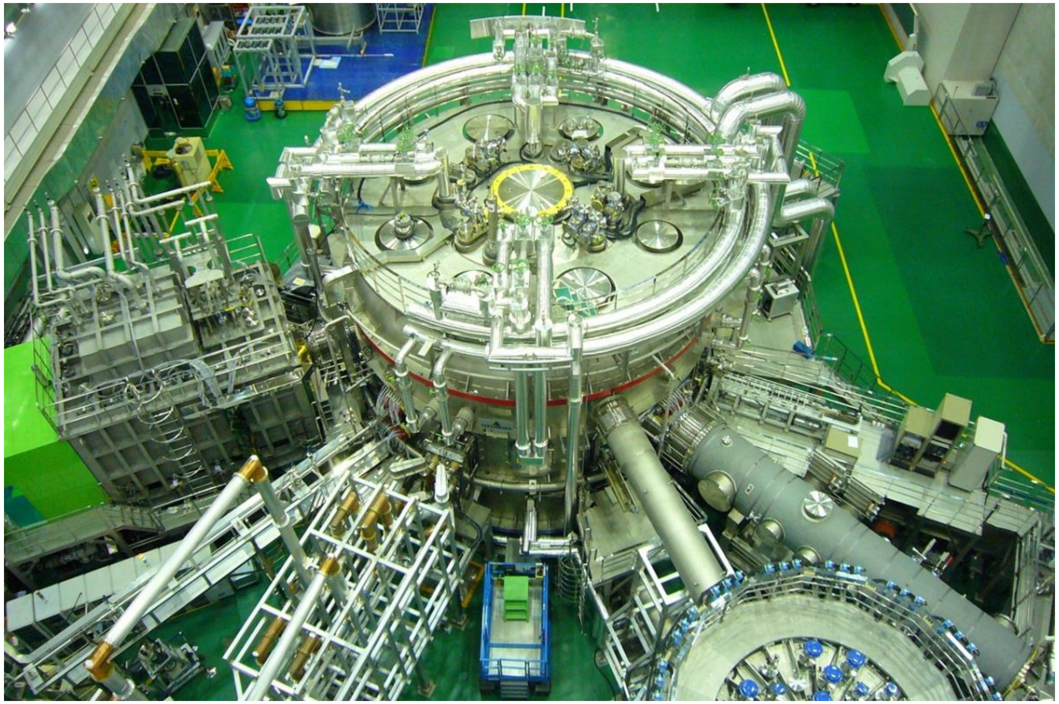
KSTAR

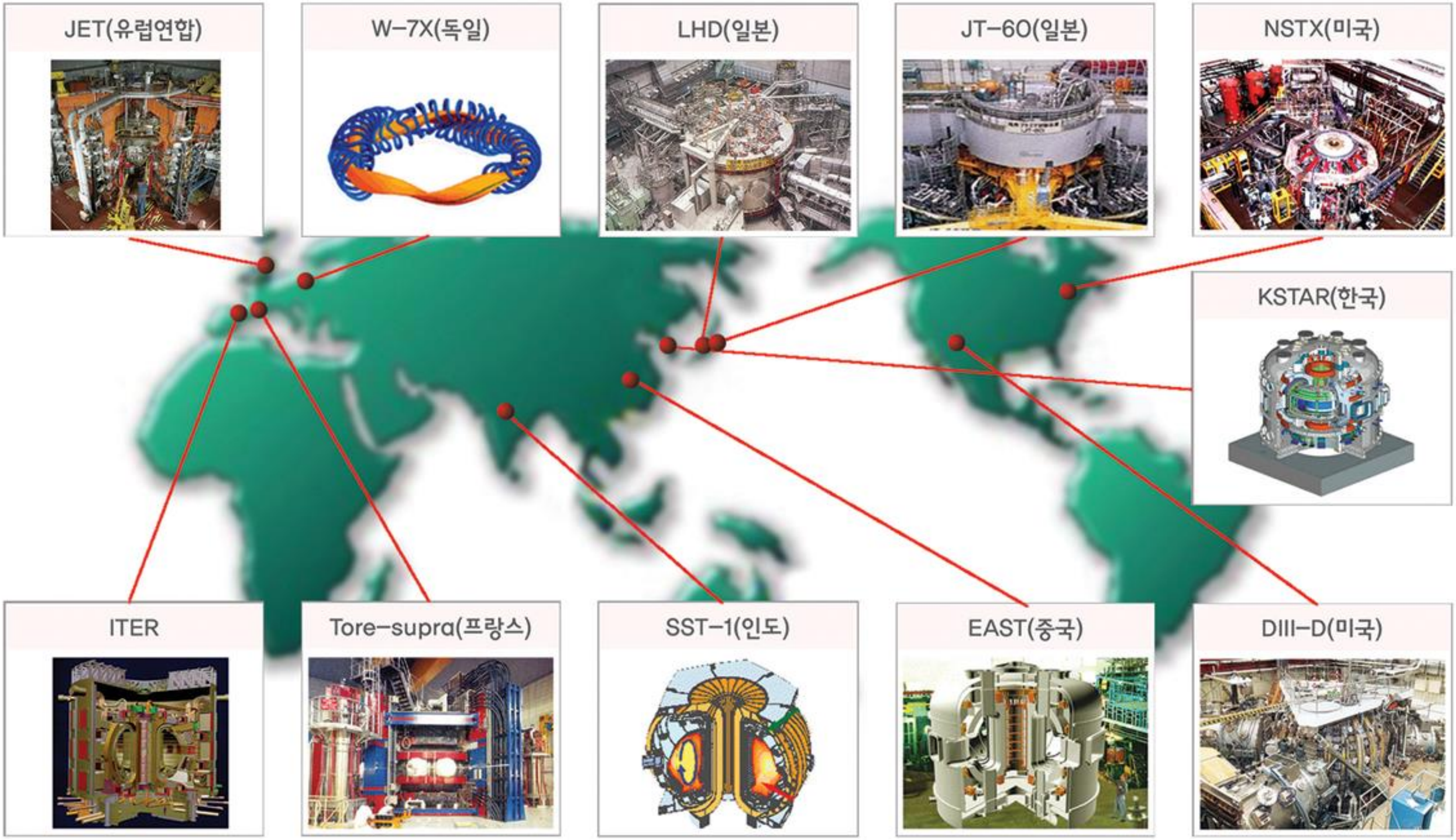
- **K**orea **S**uperconducting **T**okamak **A**dvanced **R**esearch
  - ITER 사양의 초전도자석을 사용한 최초의 초전도 토카막 장치
  - 상용핵융합로급의 플라즈마 성능 달성 가능한 장치





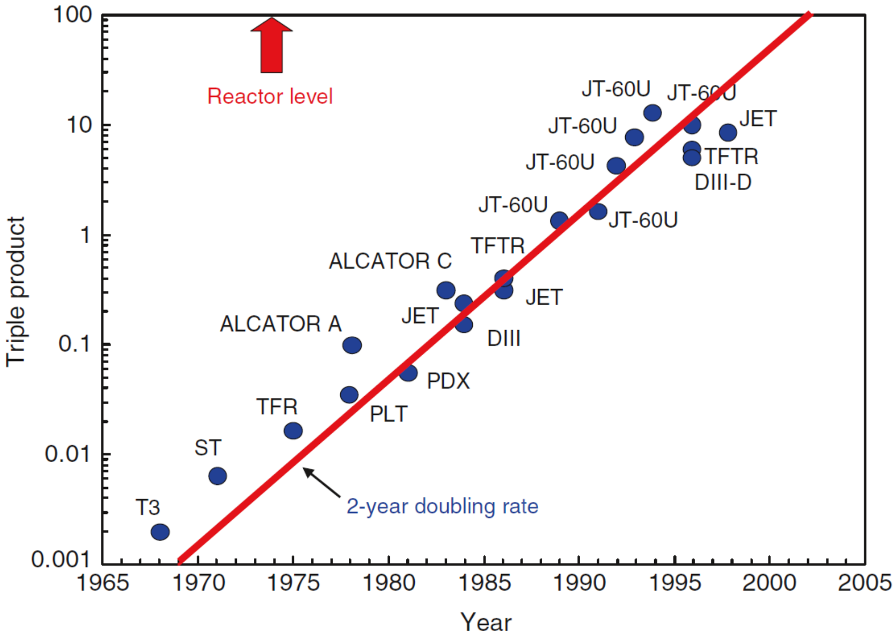
- 토카막 핵융합로를 가기 위한 최적의 플라즈마 성능을 장시간 유지하는 것을 목표로 함

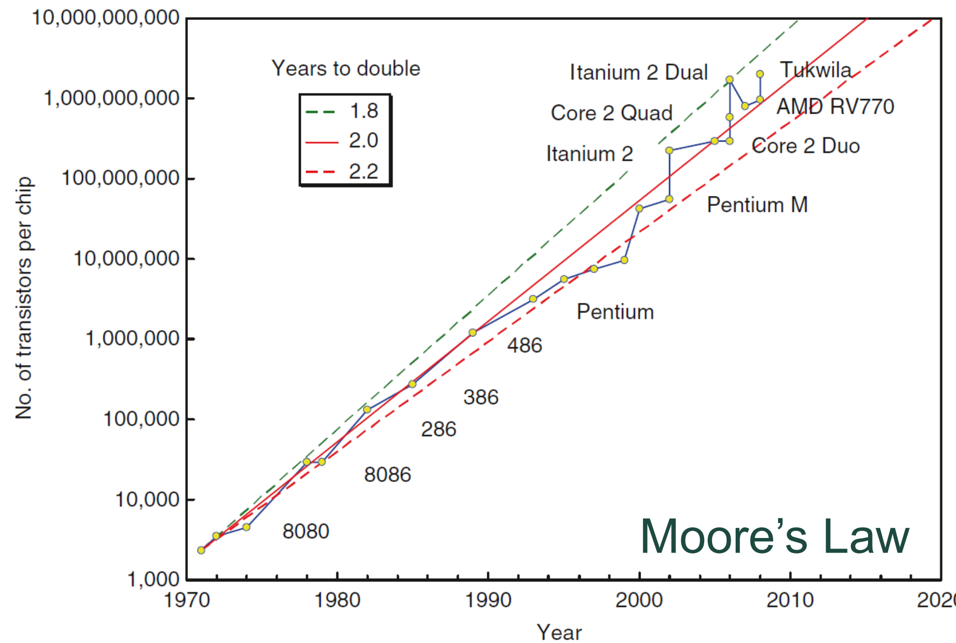
Large tokamaks in the world



Increase of the triple product $nT\tau$ with year

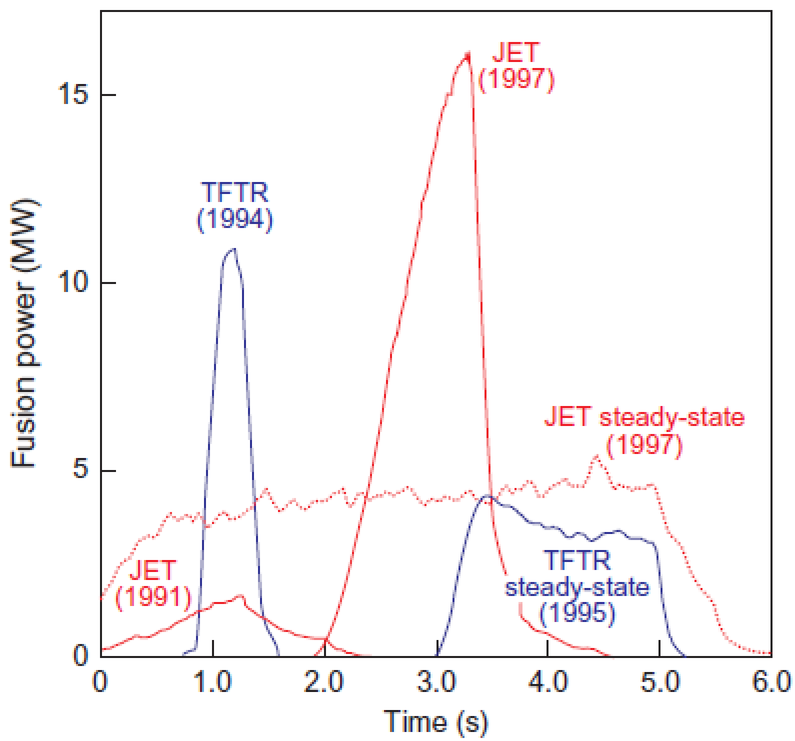
- A controlled fusion reaction requires holding together for a long enough time a plasma that is hot enough and dense enough.
- Over the years, over 200 tokamaks have been built, and the value of $nT\tau$ achieved in each has been calculated.
- Most of this increase has come from the confinement time.

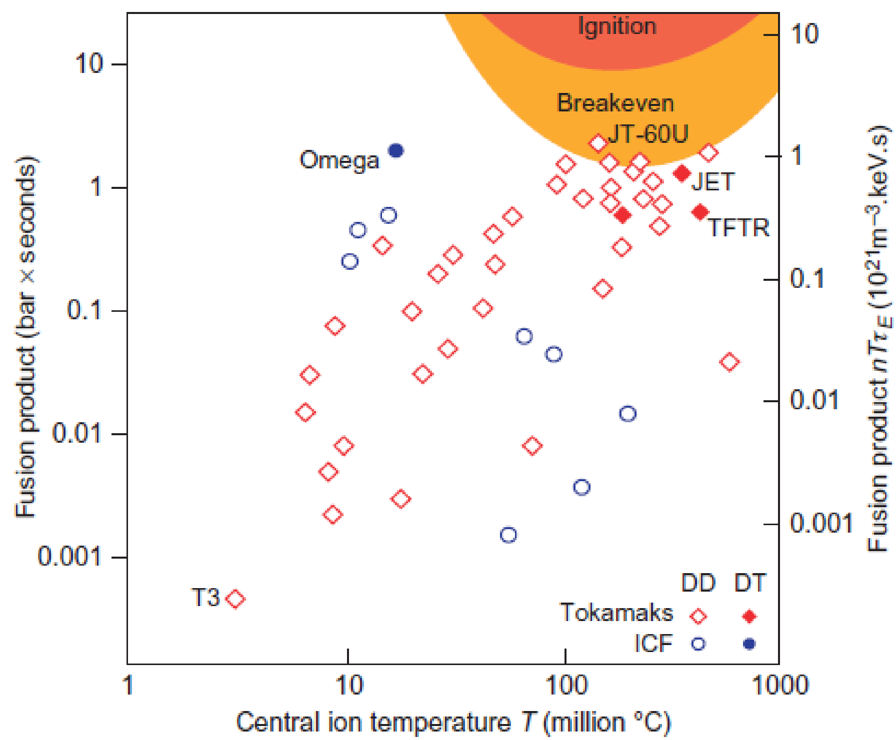




Tritium operation (1997)

- In tritium experiments performed at JET in 1997, the fusion output reaches a record value of about 16 MW, lasting for a few seconds. This was still not a self-sustaining fusion reaction because it had more than 20 MW of external heating.
- When various transient effects are taken into account, the calculated ratio of the nuclear fusion power to the effective input power is close to 1—the long-sought conditions of breakeven.





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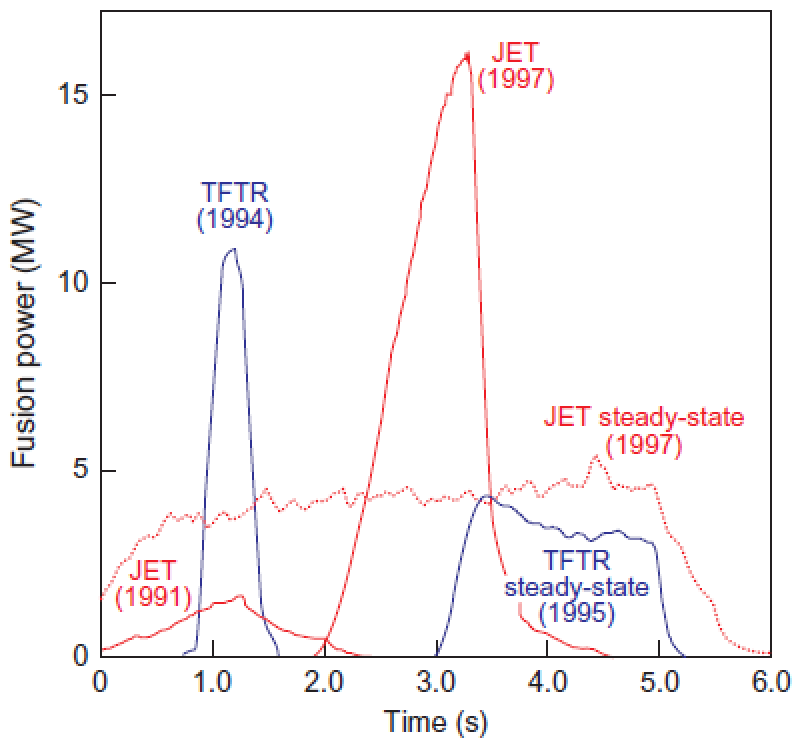
Tritium operation (2022)

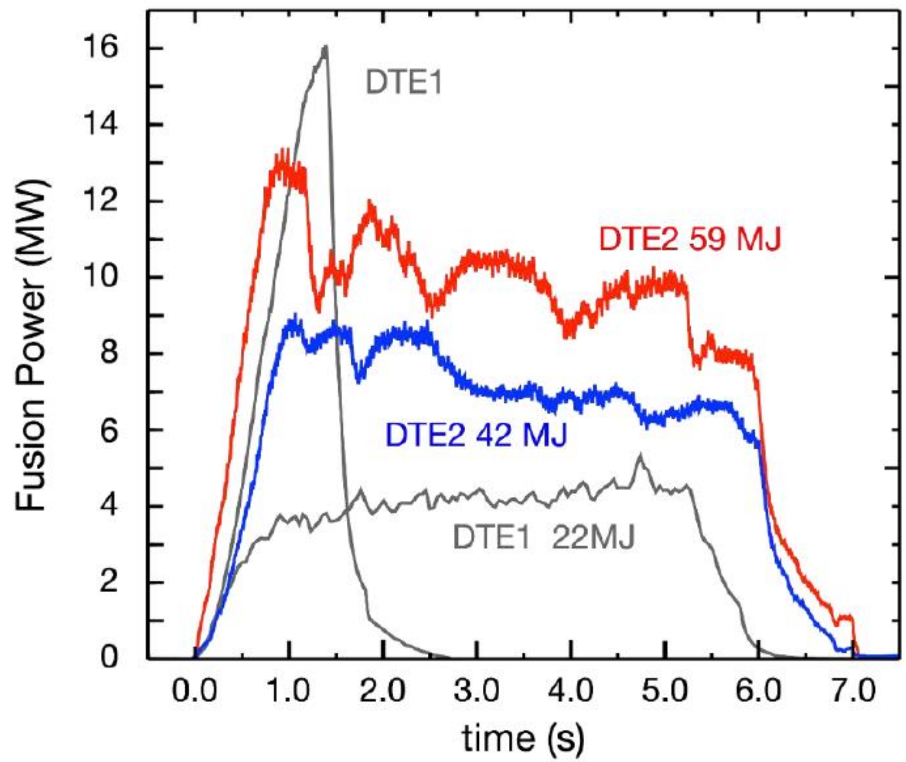
Nature | Vol 602 | 17 February 2022 | **371**

NEWS | 09 February 2022

Nuclear-fusion reactor smashes energy record

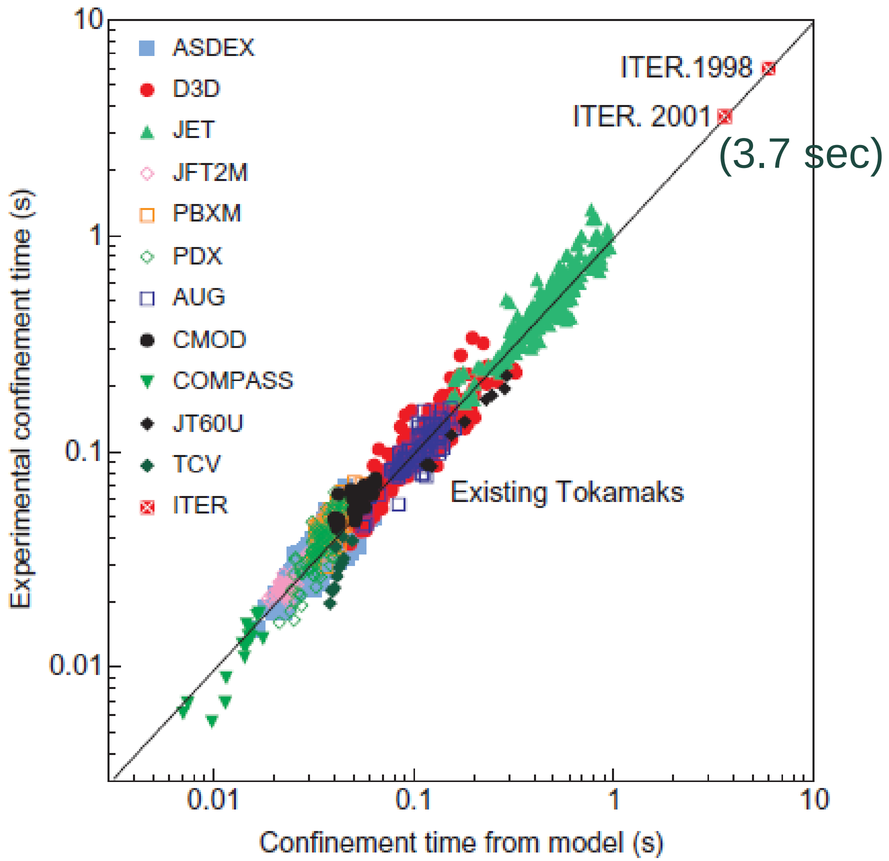
The experimental Joint European Torus has doubled the record for the amount of energy made from fusing atoms — the process that powers the Sun.





Empirical scaling

- Data from many tokamaks over a wide range of different conditions are analyzed using statistical methods to determine the dependence of quantities like energy confinement time on parameters that include the current, heating power, magnetic field, and plasma dimensions.



International collaboration

"All the News That's Fit to Print"

The New York Times

Late Edition

Weather: Rain likely today, strong easterly winds; rain ending late tonight. Partly cloudy and warmer tomorrow. Temperatures: today 43-47, tonight 40-45; yesterday 38-62. Details, page C30.

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Text of the Joint U.S.-Soviet Statement: 'Greater Understanding Achieved'

Special to The New York Times

GENEVA, Nov. 21 — Following is the text of the joint Soviet-American statement at the end of the summit meeting today, as made public by the White House:

By mutual agreement, the President of the United States, Ronald Reagan, and the General Secretary of the Central, Committee of the Communist Party of the Soviet Union, Mikhail S. Gorbachev, met in Geneva Nov. 19-21. Attending the meeting on the U.S. side were Secretary of State George P. Shultz; chief of staff, Donald T. Regan; Assistant to the President, Robert C. McFarlane; Ambassador to the U.S.S.R., Arthur A. Hartman; special adviser to the President and the Secretary of State for Arms Control, Paul H. Nitze; Assistant Sec-

In this connection the two sides have confirmed the importance of an ongoing dialogue, reflecting their strong desire to seek common ground on existing problems.

They agreed to meet again in the nearest future. The General Secretary accepted an invitation by the President of the United States to visit the United States of America, and the President of the United States accepted an invitation by the General Secretary of the Central Committee of the C.P.S.U. to visit the Soviet Union. Arrangements for the timing of the visits will be agreed upon through diplomatic channels.

In their meetings, agreement was reached on a number of specific issues. Areas of agreement are registered on the following pages.

Security

ple of 50 percent reductions in the nuclear arms of the U.S. and the U.S.S.R. appropriately applied, we well as the idea of an interim I.N.F. agreement.

During the negotiation of these agreements, effective measures for verification of compliance with obligations assumed will be agreed upon.

Risk Reduction Centers

The sides agreed to study the question at the expert level of centers to reduce nuclear risk taking into account the issues and developments in the Geneva negotiations. They took satisfaction in such recent steps in this direction as the modernization of the Soviet-U.S. hot line.

Nuclear Nonproliferation

General Secretary Gorbachev and President Reagan reaffirmed the commitment of the U.S.S.R. and the U.S. to the Treaty on the Nonproliferation of Nuclear Weapons and their interest in strengthening together with other countries the nonproliferation regime, and in further enhancing the effectiveness of the treaty, inter alia by enlarging its membership.

The U.S.S.R. and the U.S. reaffirm their commitment, assumed by them under the Treaty on the Nonproliferation of Nuclear Weapons, to pursue negotiations in good faith on matters of nuclear arms limitation and disarmament in accordance with Article VI of the treaty.

The two sides plan to continue to promote the strengthening of the International Atomic Energy Agency and to support the activities of the agency in implementing safeguards as well as in promoting the peaceful uses of nuclear energy.

They view positively the practice of regular Soviet-U.S. consultations on nonproliferation of nuclear weapons, which have been businesslike and constructive, and express their intent to continue this practice in the future.

Chemical Weapons

In the context of discussing security problems, the two sides reaffirmed that they are in favor of a general and complete prohibition of chemical weapons and the destruction of existing stockpiles of such weapons. They agreed to accelerate efforts to conclude an effective and verifiable international convention on this matter.

The two sides agreed to intensify bilateral discussions on the level of experts on all aspects of such a chemical weapons ban, including the question of verification. They agreed to initiate a dialogue on preventing the proliferation of chemical weapons.

Mutual Basic Force Reduction

The two sides emphasized the importance they attach to the Vienna (M.B.F.R.) negotiations and expressed their willingness to work for positive results.

C.D.E.

Attaching great importance to the Stockholm Conference on Confidence and Security Building Measures and Disarmament in Europe and noting the progress made there, the two sides stated their intention to facilitate, together with the other participating states, an early and successful completion of the work of the conference. To this end, they reaffirmed the need for a document which would include mutually acceptable confidence and security building measures and gave concrete expression and effort to the principle of nonuse of force.

Process of Dialogue

President Reagan and General Secretary Gorbachev agreed on the need to place on a regular basis and intensify dialogue at various levels. Along with meetings between the leaders of the two countries, this envisages regular meetings between the U.S.S.R. Minister of Foreign Affairs and the U.S. Secretary of State, as well as between the heads of other ministries and agencies. They agree that the recent visits of the heads of ministries and departments in such fields as agriculture, housing and protection of the environment have been useful.

Recognizing that exchanges of views on regional issues on the expert level have proven useful, they agreed to continue such exchanges on a regular basis.

The sides intend to expand the programs of bilateral cultural, educational and scientific-technical exchanges, and also to develop trade and economic ties. The President of the United States and the General Secretary of the Central Committee of the C.P.S.U. attended the signing of the Agreement on Contacts and Exchanges in Scientific, Educational and Cultural Fields.

They agreed on the importance of resolving humanitarian cases in the spirit of cooperation.

They believe that there should be greater understanding among our peoples and that to this end they will encourage greater travel and people-to-people contact.

Northern Pacific Air Sa

— a global task — through joint research and practical measures. In accordance with the existing U.S.-Soviet agreement in this area, consultations will be held next year in Moscow and Washington on specific programs of cooperation.

Exchange Initiatives

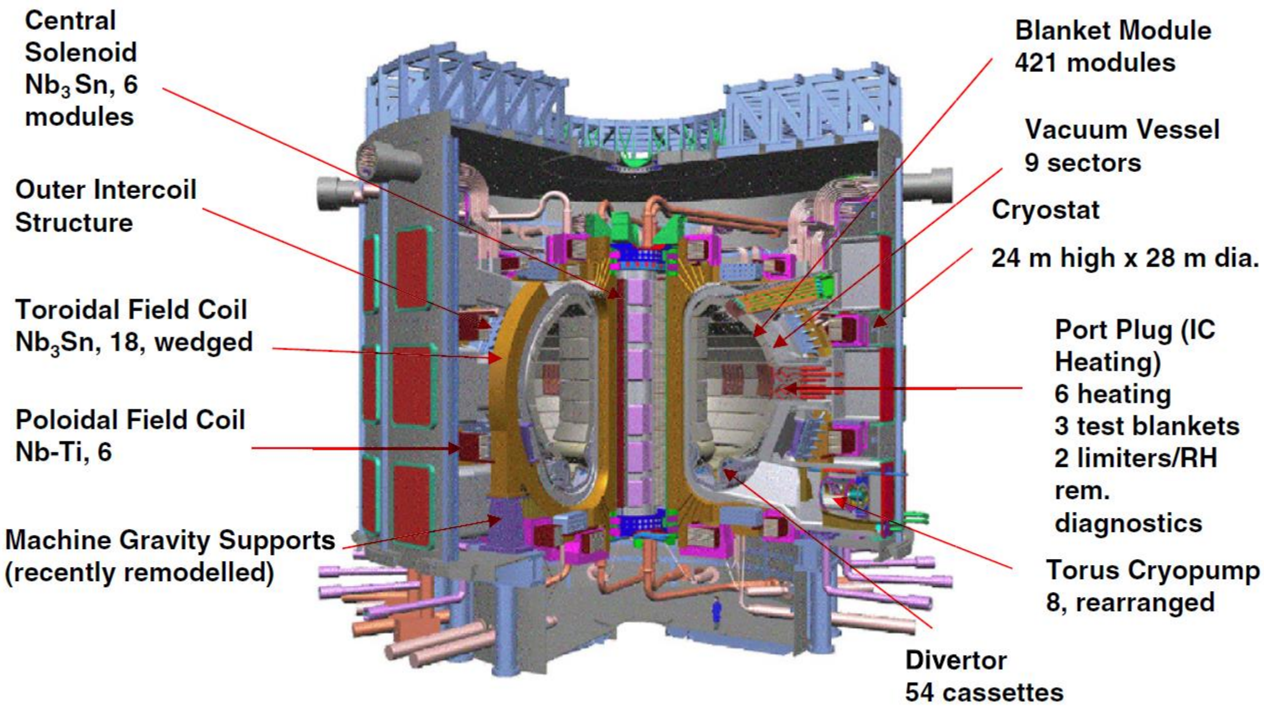
The two leaders agreed on the utility of broadening exchanges and contacts including some of their new forms in a number of scientific, educational, medical and sports fields (inter alia, cooperation in the development of educational exchanges and software for elementary and secondary school instruction; measures to promote Russian language studies in the United States and English language studies in the U.S.S.R.; the annual exchange of professors to conduct special courses in history, culture and economics at the relevant departments of Soviet and American institutions of higher education; mutual allocation of scholarships for the best students in the

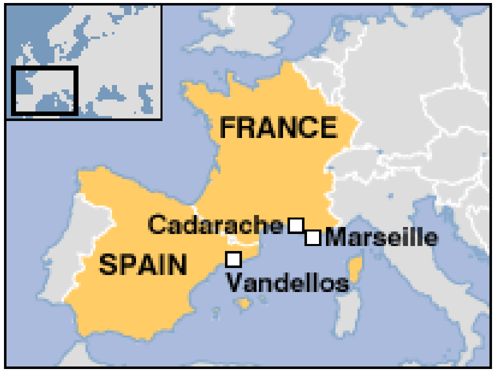
Fusion Research

The two leaders emphasized the potential importance of the work aimed at utilizing controlled thermonuclear fusion for peaceful purposes and, in this connection, advocated the widest practicable development of international cooperation in obtaining this source of energy, which is essentialy inexhaustible, for the benefit for all mankind.

ITER

- International Thermonuclear Experimental Reactor, “The way” in Latin.
  - 핵융합 발전 가능성을 과학 및 공학적으로 검증하는 것을 목표로 삼고 있음





- 인류 역사상 세계에서 가장 큰 국제공동프로젝트

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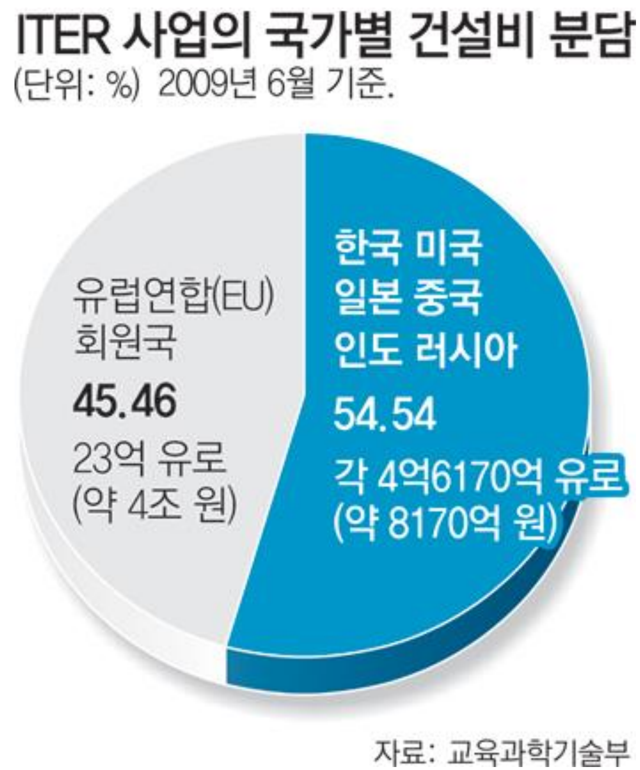
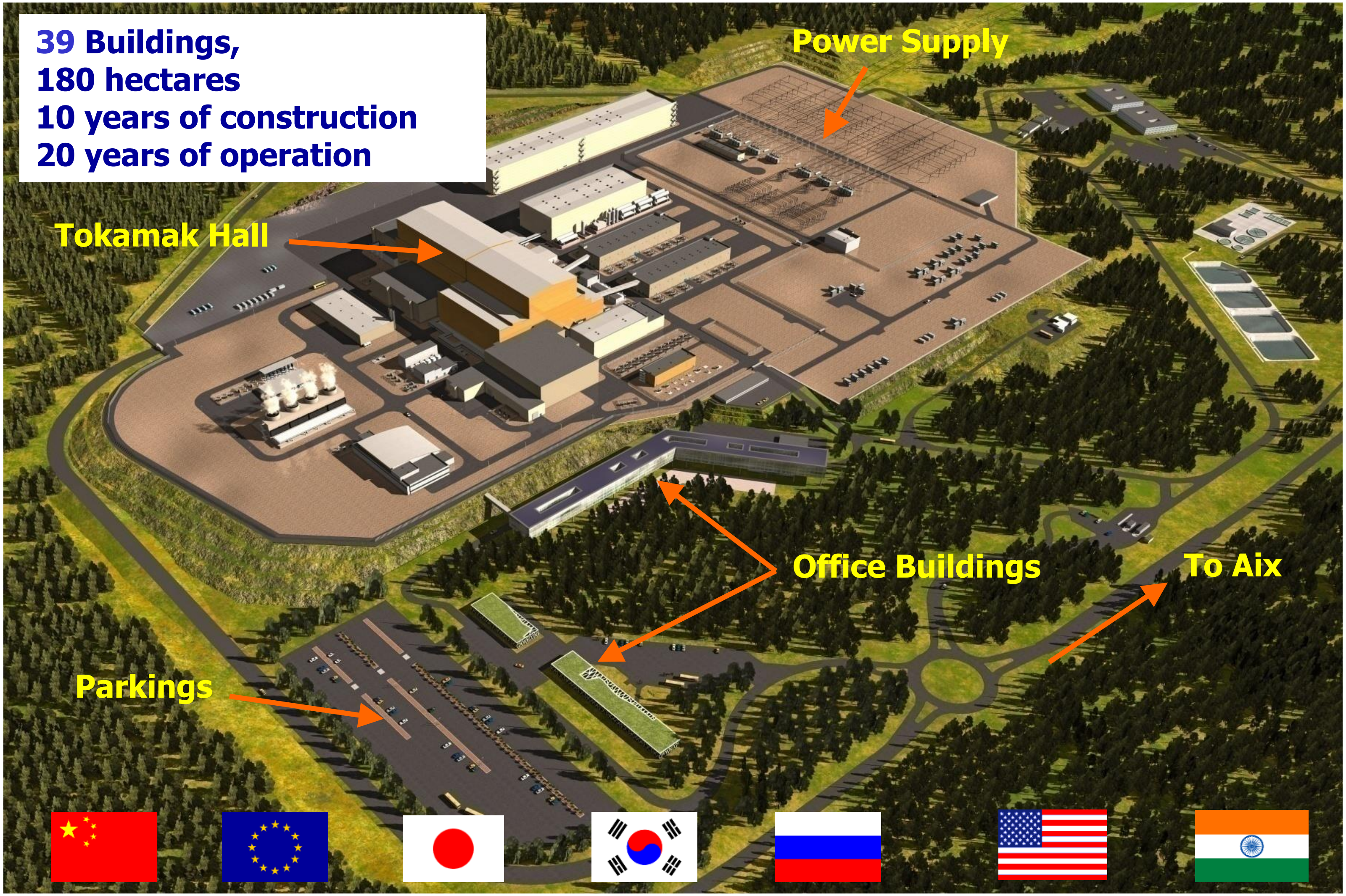
ITER

http://blog.naver.com/science_u



ITER


39 Buildings,
180 hectares
10 years of construction
20 years of operation
Power Supply
Tokamak Hall
Office Buildings
To Aix
Parkings

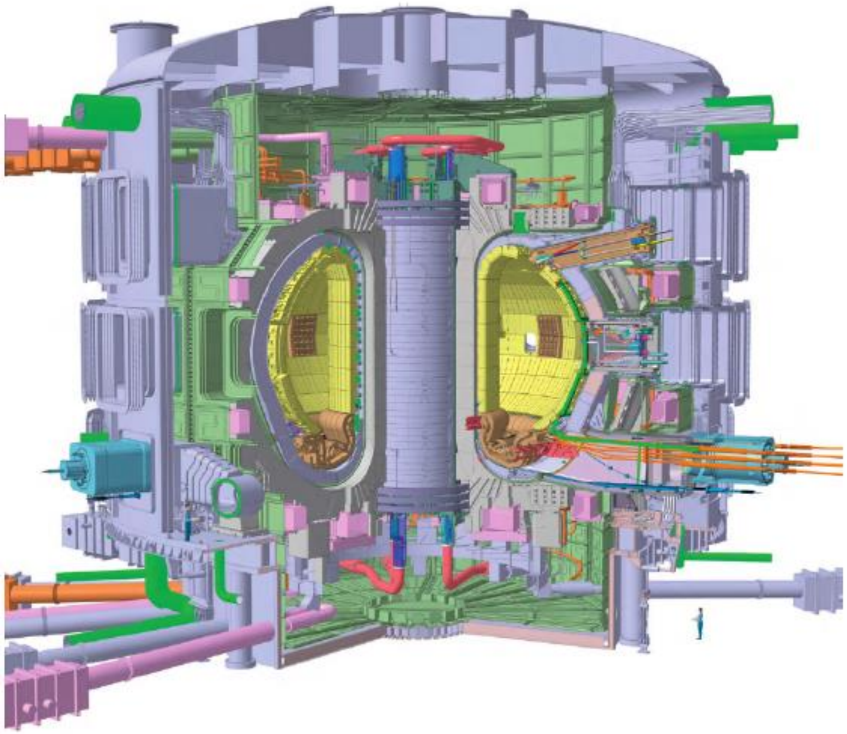
ITER

Tokamak Complex
(28 August 2014)

ITER

June 19, 2017

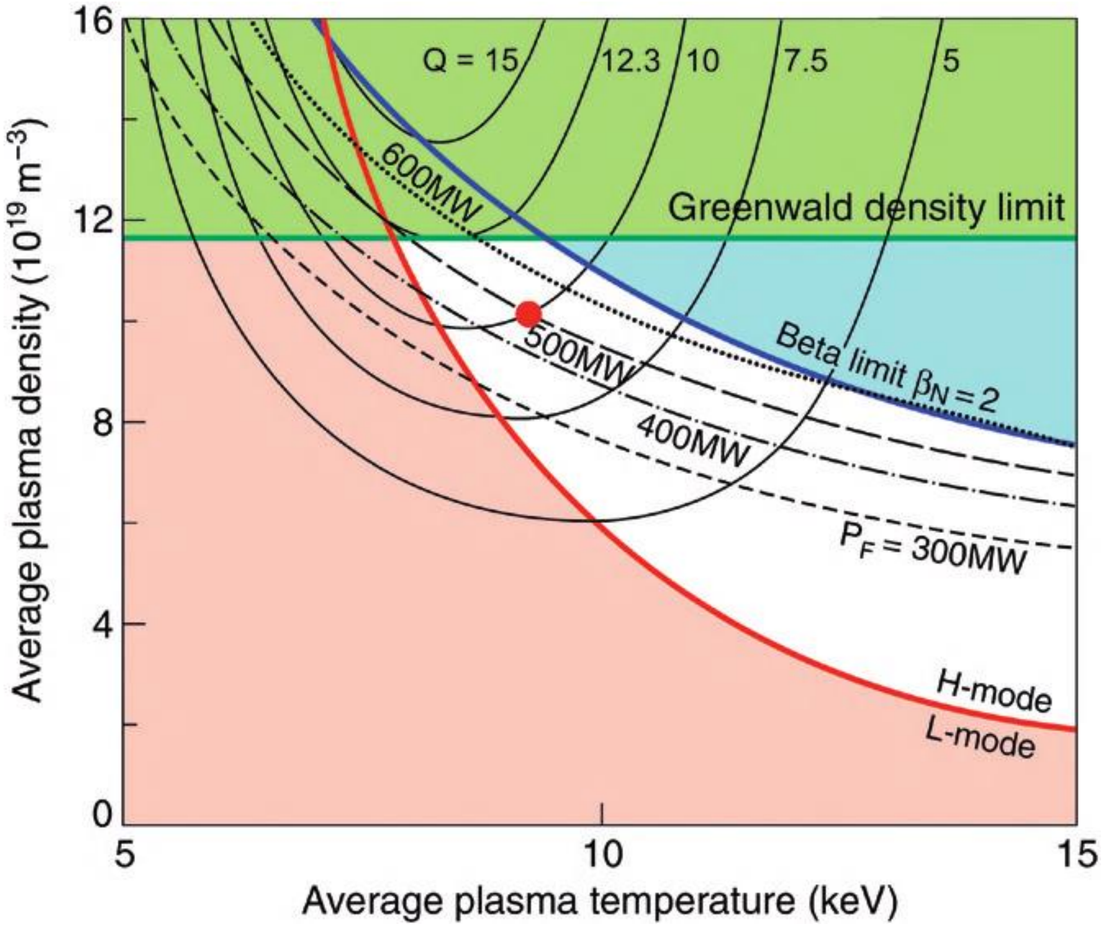
ITER parameters



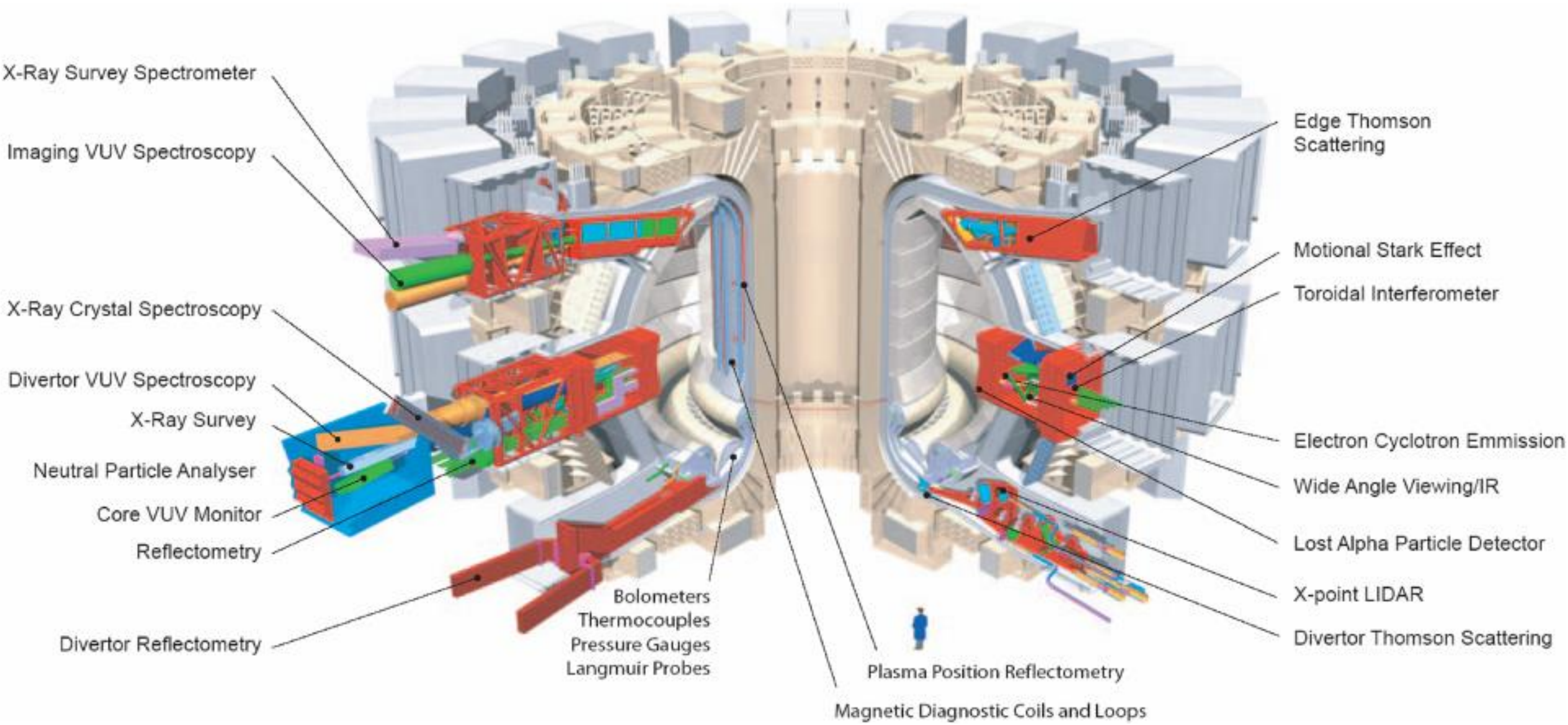
Parameter		1998 Proposal	2001 Proposal	2011 Baseline	Units
Plasma major radius	R	8.14	6.2	6.2	m
Plasma minor radius	a	2.8	2.0	2.0	m
Plasma volume	V	2000	870	870	m^3
Toroidal magnetic field (at plasma axis)	B	5.68	5.3	5.3	T
Plasma current	I	21	15	15	MA
Safety factor	q	3	3	3	
Vertical elongation	κ	1.6	1.8	1.8	
Average plasma/ magnetic pressure	β	2.2–3.0	2.5	2.5	%
Normalized beta	β_N		1.77	2	
Average electron density	n_e	0.98	1	1	$10^{20} m^{-3}$
Average ion temperature	T_i	13	8	9.2	keV
Energy confinement time	τ_E	5.9	3.7	3.7	s
Energy multiplication factor	Q	Ignition	10	10	
Fusion power	P_F	1500	500	500	MW
Alpha particle heating	P_α	300	80	100	MW
External heating power at Q	P_{ext}	0	50	50	MW
Planned external heating power		100	73	73	MW

ITER operating space

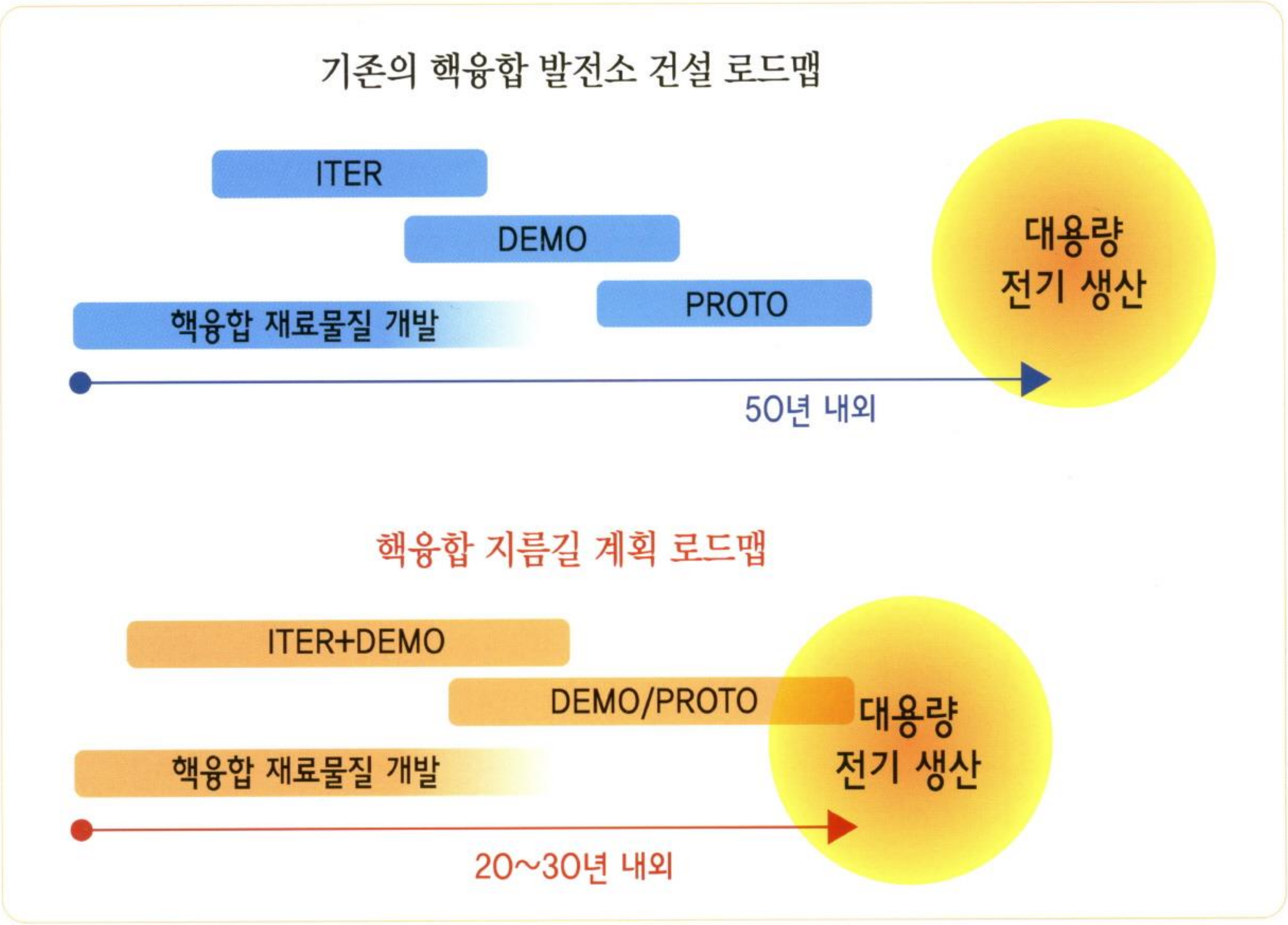
- ITER's goal is to achieve Q = 10, i.e., 500 MW of fusion power with 50 MW of external heating power.



ITER diagnostics



Fast track approach

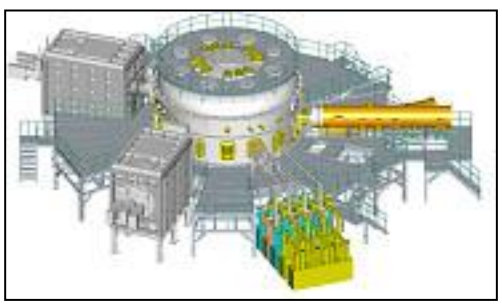


Fusion energy development plan

Scientific feasibility	→	Technical feasibility	→	Demonstration power plant	→	Commercial power plant
JET, TFTR		ITER		DEMO		

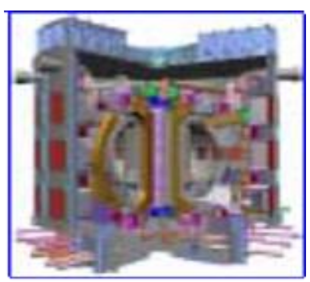
2007년 이후
KSTAR

- 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

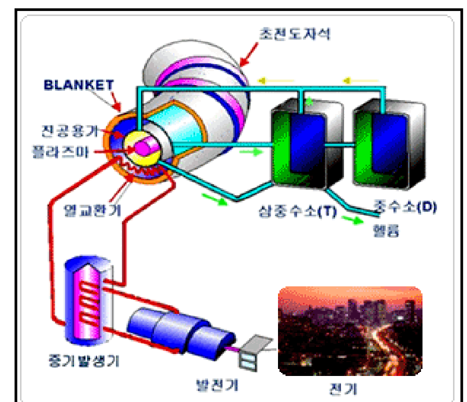
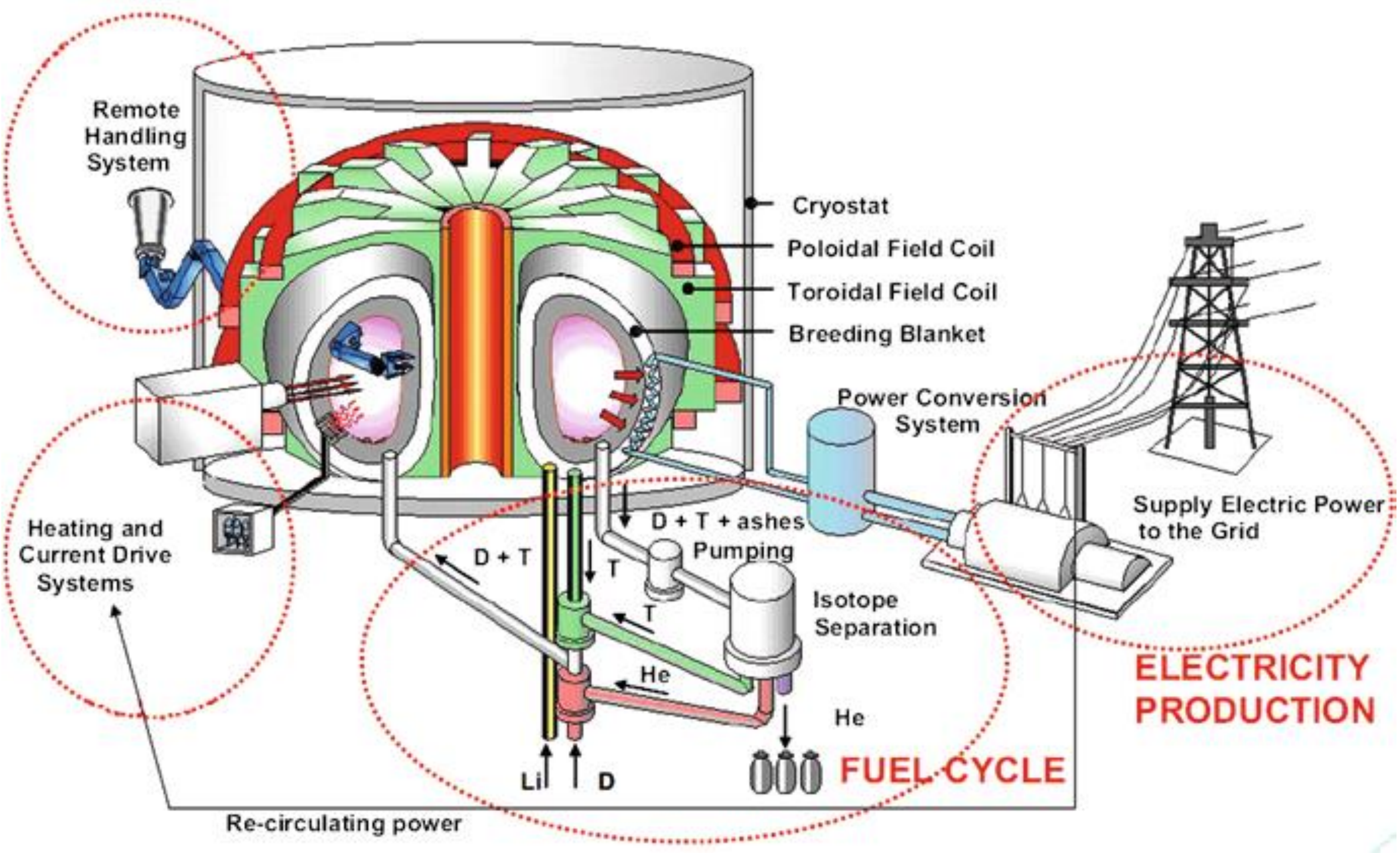


그림 15. 핵융합발전의 원리

Fusion power plant

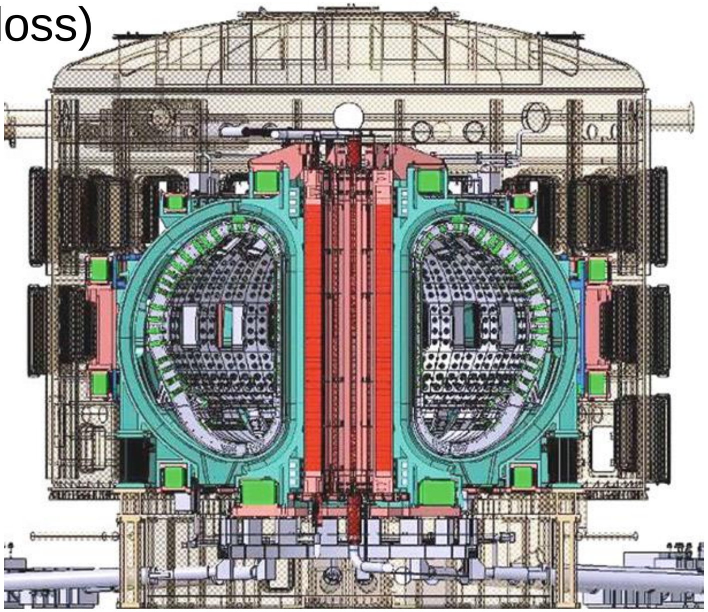


Engineering issues: First wall

- The first walls (plasma facing components, PFCs) have to withstand a tremendous amount of heat from the plasma and yet must not contaminate the plasma and be compatible with the fusion products that impinge on them.
- The first-wall material must not absorb tritium and must have a low atomic number, take high temperatures, and be resistant to erosion, sputtering, and neutron damage.
- CFC (carbon fiber composite): light, strong, high melting point, but tritium absorption (formation of hydrocarbon)
- Tungsten: high melting point, but high-Z (radiation loss)
- Beryllium: Low-Z, but low melting point

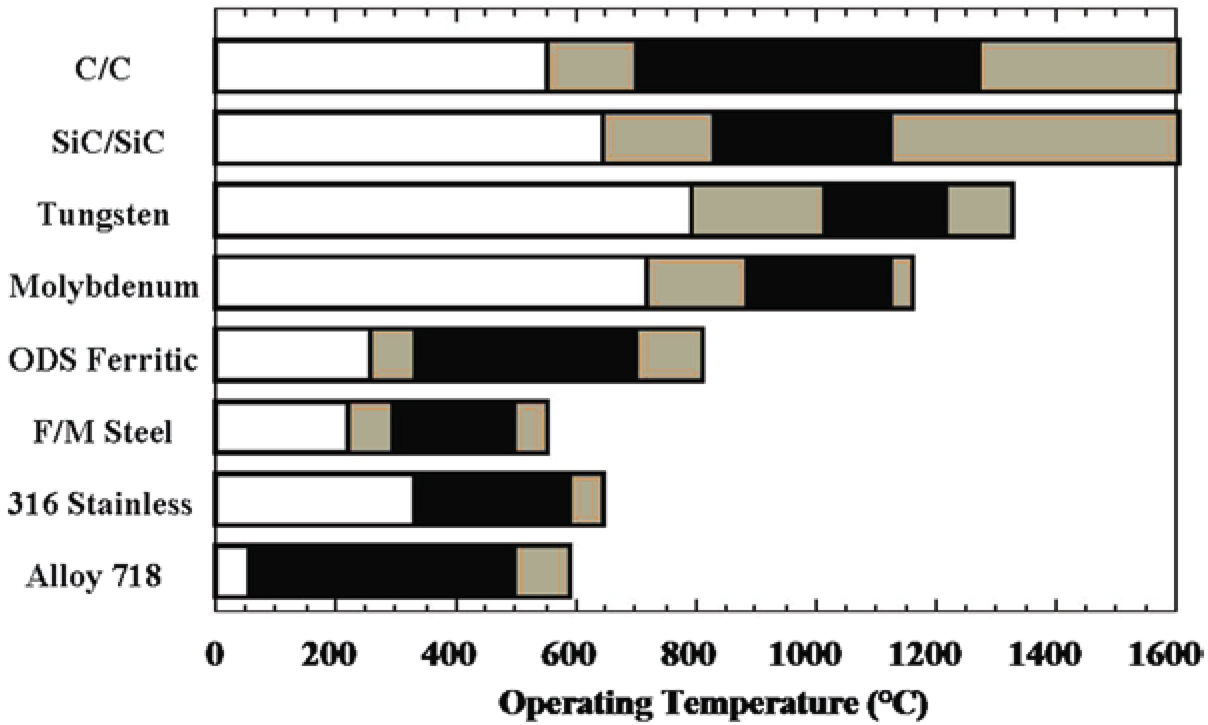
Loads on the first wall

	ITER	DEMO	Reactor	Units
Fusion power	0.5	2.5	5	GW
Heat flux	0.3	0.5	0.5	MW/m^2
Neutron load	0.78	<2	2	MW/m^2
Neutron load in life	0.07	8	15	$MW\text{-}years/m^2$
Neutron damage	<3	80	150	dpa



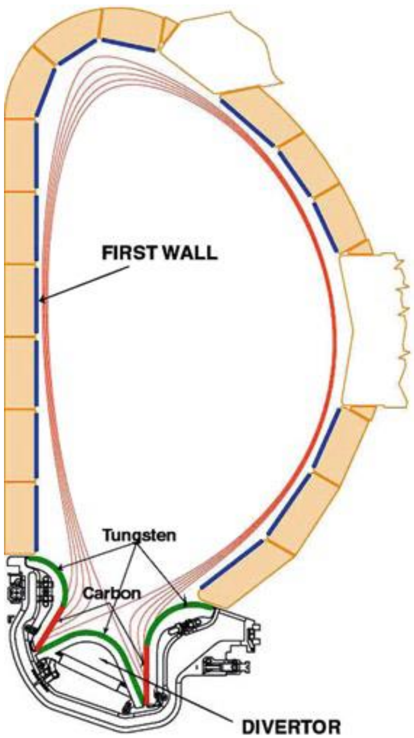
Engineering issues: First wall

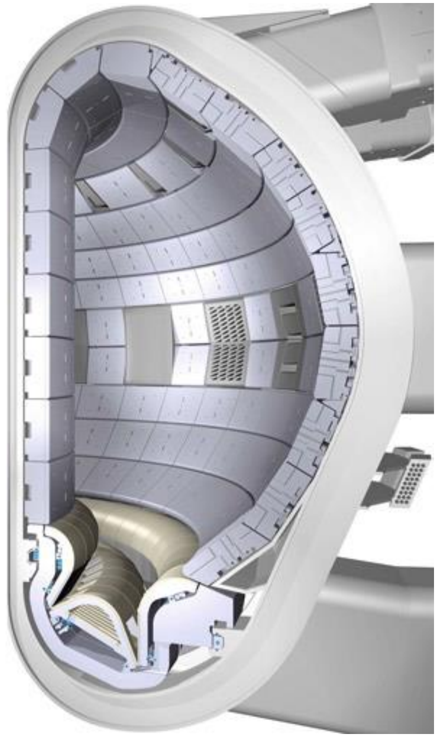
- Silicon carbide (SiC) is a promising material that has been studied extensively in the laboratory but does not have a known method for manufacturing in large quantities.
- Temperature range of various wall materials under irradiation (the swelling and fracture effects caused by neutrons are included)

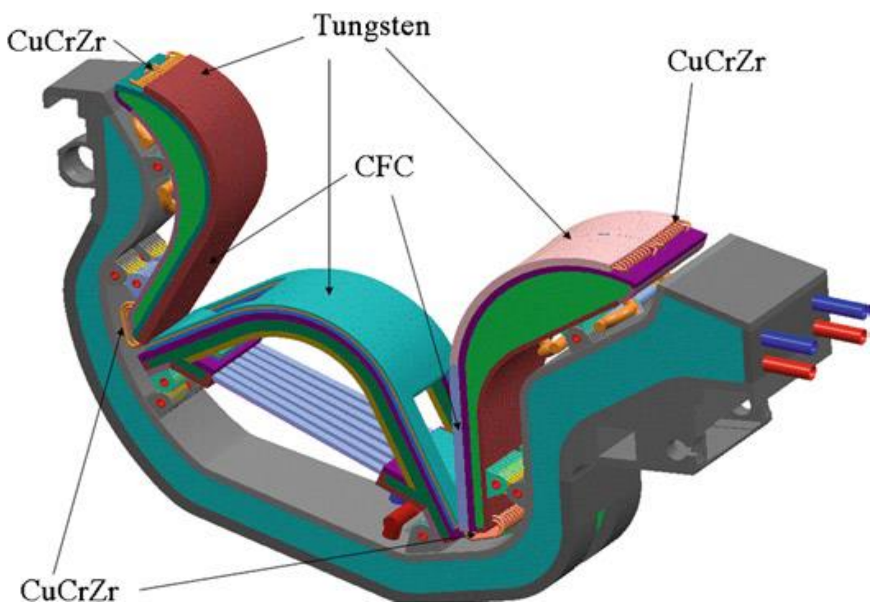


Engineering issues: Divertor

- Sixty percent of the plasma exhaust is designed to go into the “divertor,” thus sparing the first wall from the major part of the heat load.
- The heat load on the divertor surfaces is huge, some 20 MW/m^2, so the cooling system is an important part of the design.
- Water-cooled for ITER, He-cooled for reactors.

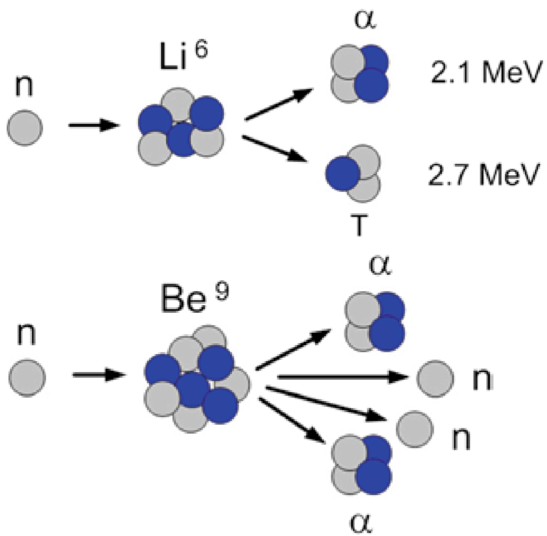






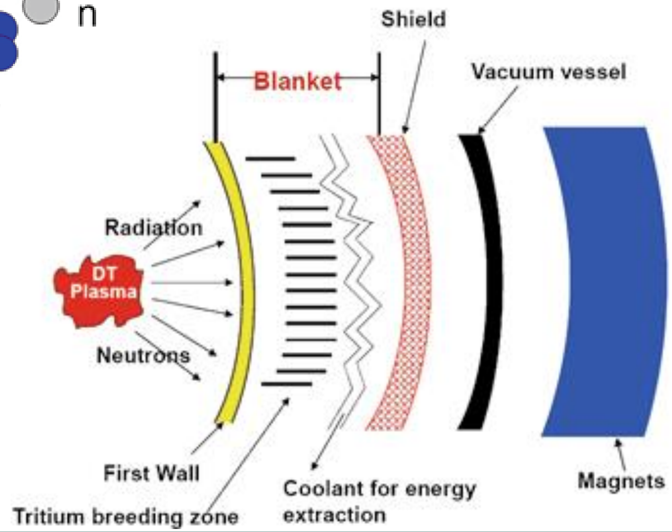
Engineering issues: Blanket

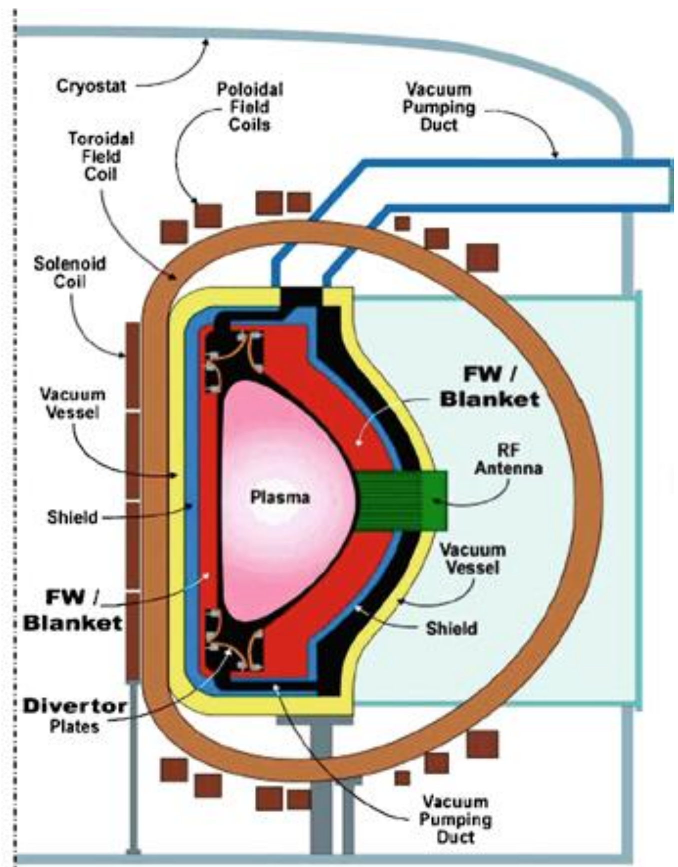
- Three major purposes of a blanket: (1) capture the neutrons generated by fusion and convert their energy into heat, (2) produce the tritium to fuel the DT reaction, and (3) shield the superconducting magnets from the neutrons.



T breeder

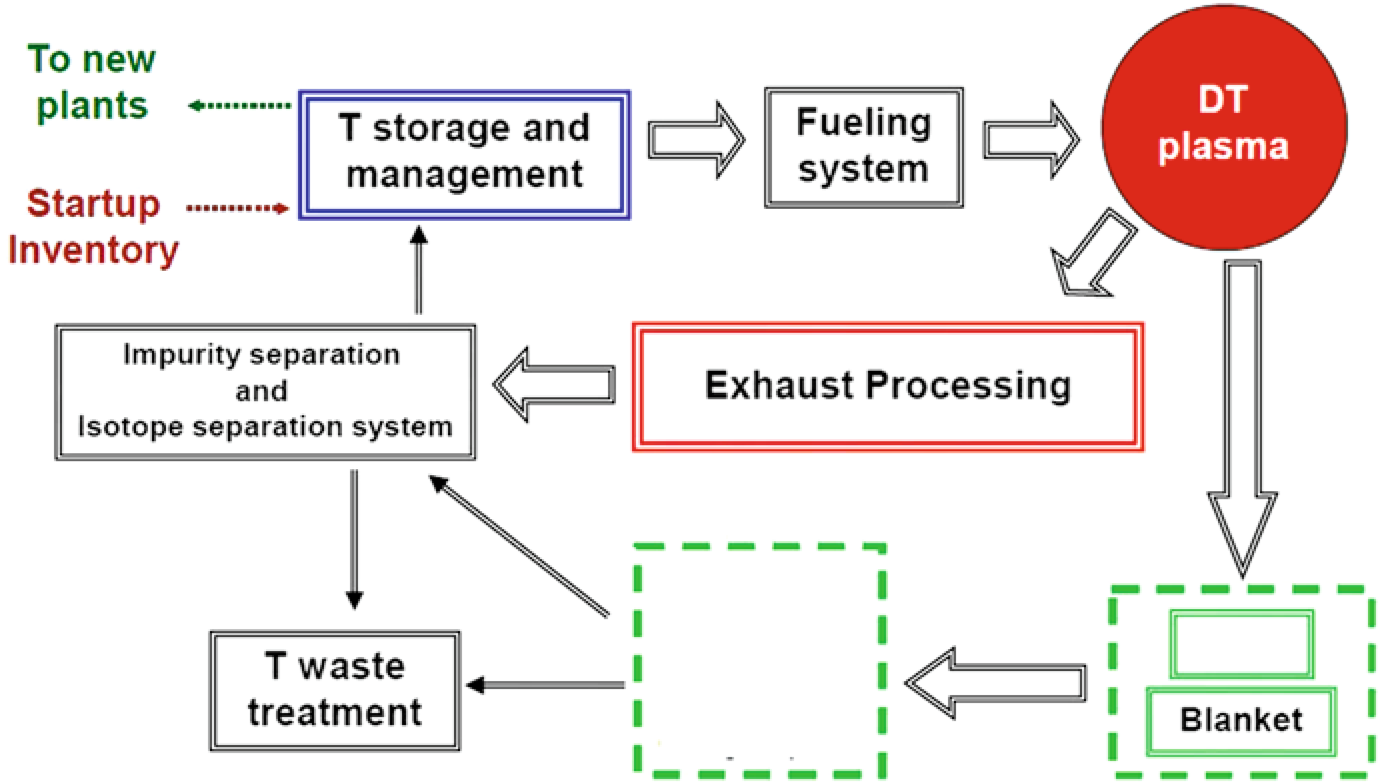
n multiplier





Engineering issues: Tritium fuel cycle

- Tritium leaves the tokamak in two paths – either through the vacuum pumps, including those pumping the divertor, or through the first wall (FW) and the blanket.
- Fueling is done by injecting frozen pellets of tritium and deuterium at sufficient velocity to reach the center of the plasma.



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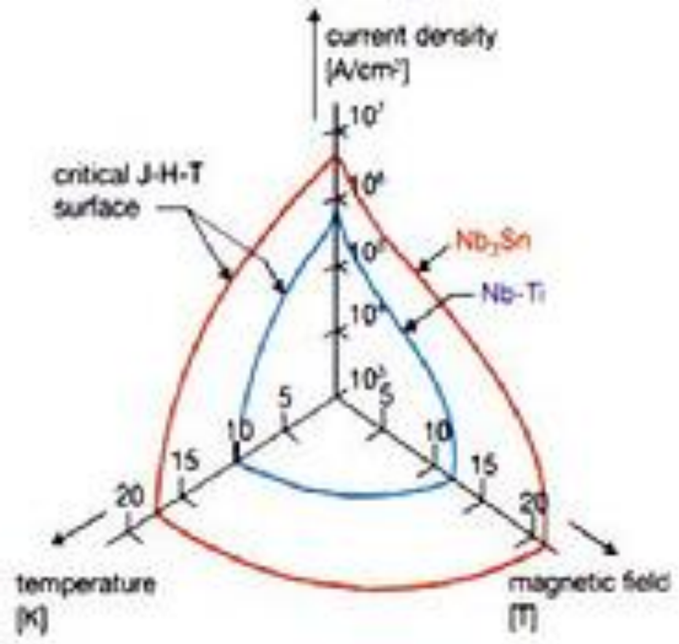
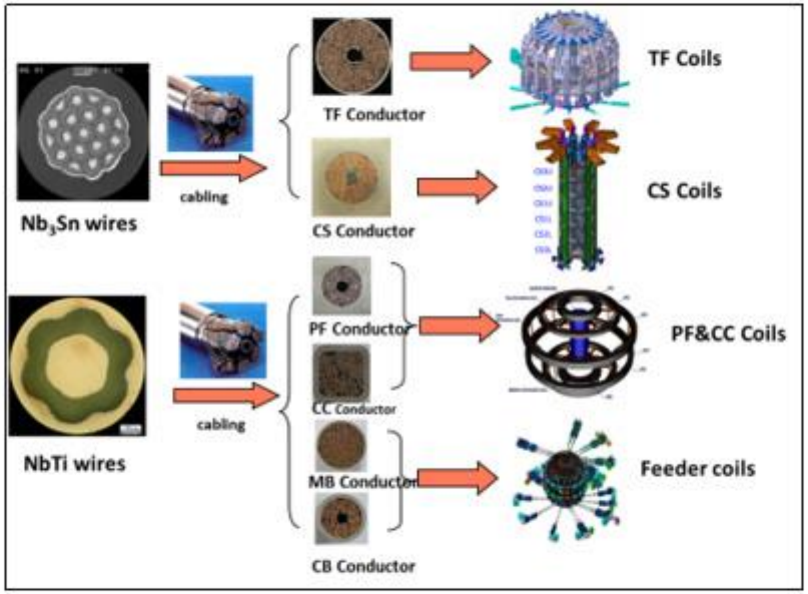
Engineering issues: Superconducting magnets

- Superconductors have zero resistivity, and once the current has been started in them, it will keep going almost forever.
- Superconductors (NbTi and Nb_3Sn) have to be cooled below 4.2 K with liquid helium. A cryogenic plant has to be built to supply the liquid helium, and the magnet coils (and hence the whole machine) have to be enclosed in a cryostat to insulate them from room temperature.
- High-temperature superconductors (> 77K) need to be developed.





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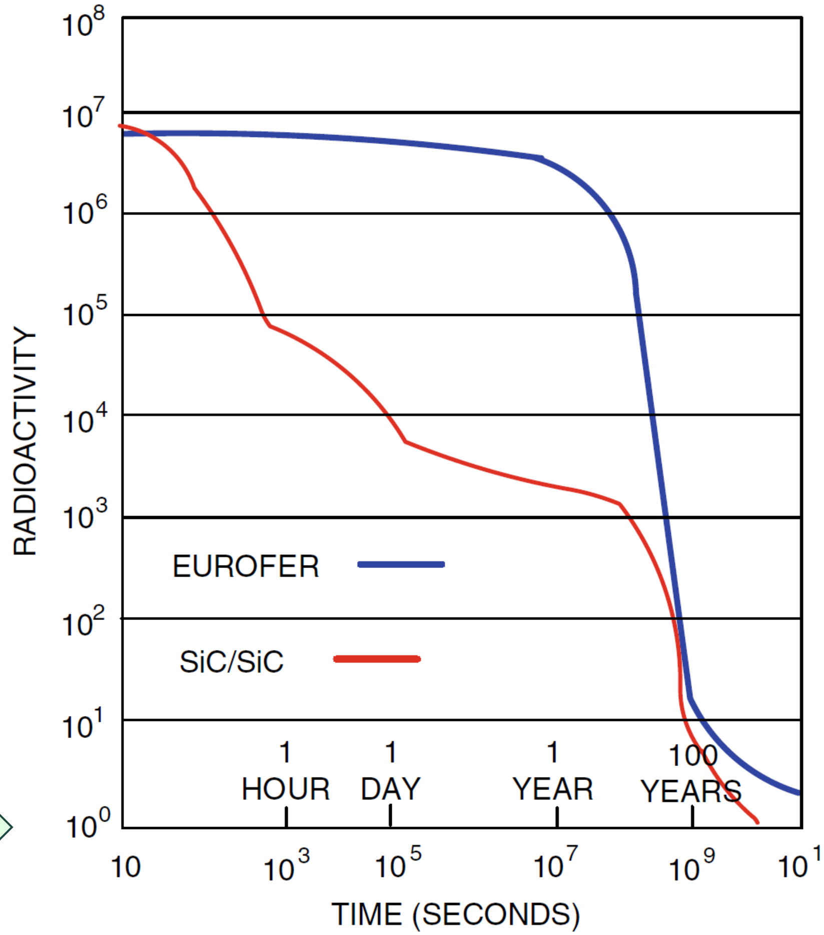
Engineering issues: Structural material

- Aside from materials exposed to plasma and large heat fluxes, structural materials have a low activation characteristic by neutron irradiation.
- Two Reduced Activation Ferritic Martensitic (RAFM) Steels have been designed: Eurofer (in Europe) and F82H (in Japan).
- These steels have only short-lived radioactivity and, unlike fission products, are nonvolatile and can be re-used after storage for 50–100 years. The amount of swelling under neutron bombardment is much smaller than for ordinary stainless steel.

	Chromium (%)	Tungsten (%)	Vanadium (%)	Tantalum (%)	Carbon (%)
Eurofer	7.7	2	0.2	0.04	0.09
F82H	8.9	1	0.2	0.14	0.12

The predicted radioactivity of Eurofer and SiC in a fusion reactor after 25 years of full-power operation



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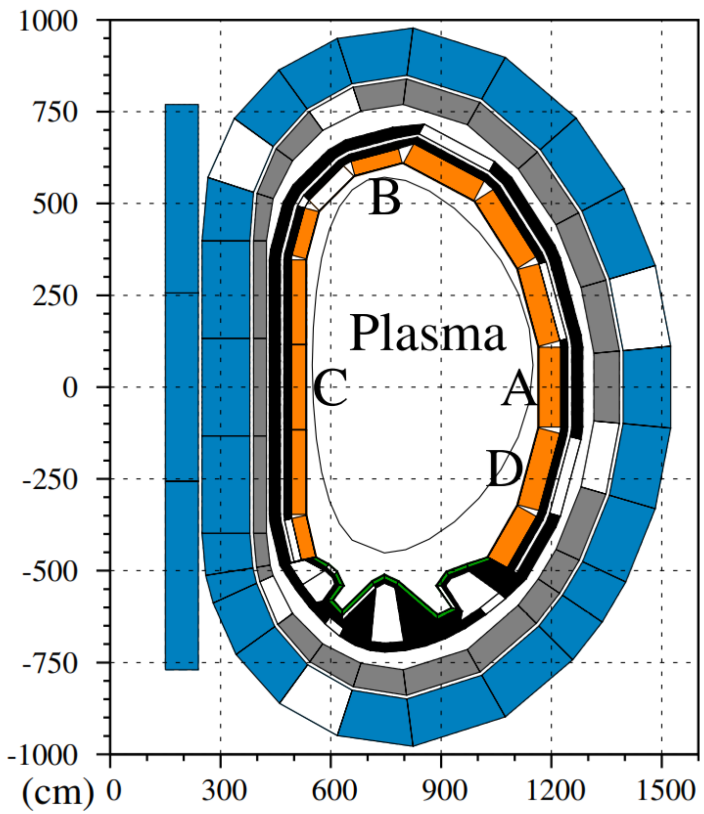
Fission vs. fusion neutrons

- In fusion, the issue of transmutation gas production is likely to be a more significant problem than in fission because of the higher neutron fluxes and higher average neutron energies.



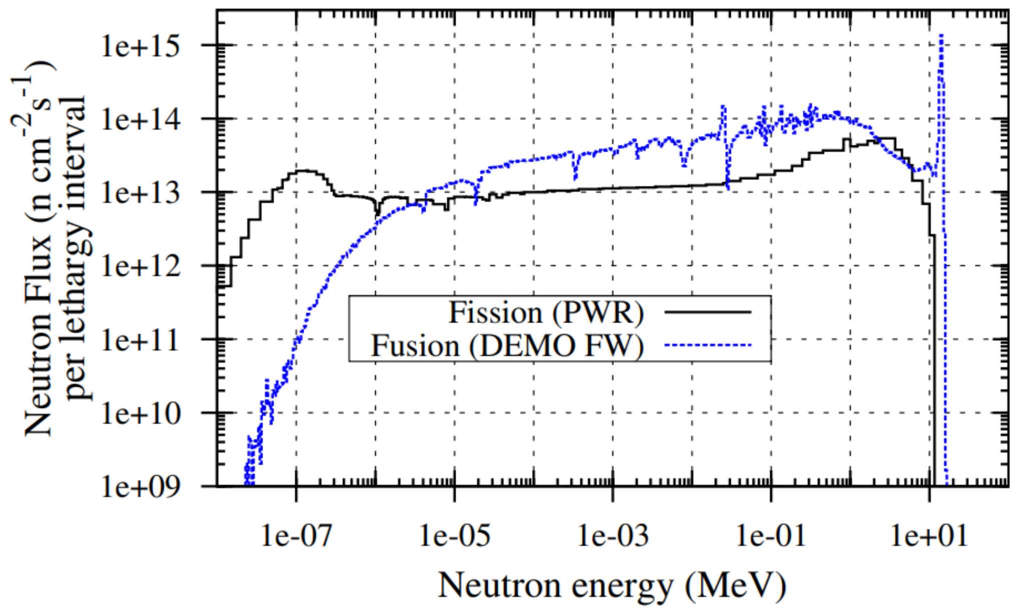


Figure 1. Comparison of the neutron-energy spectra in fission and fusion reactors. For fission the average neutron spectrum in the fuel assembly of a PWR reactor is shown, while the equatorial FW armour spectrum for the DEMO model in figure 2 is representative of fusion.

Nuclear Fusion 52 (2012) 083019

Characteristics of D-T fusion neutrons

- Transmutation and He/H gas production
  - $^{56}Fe(n,\alpha)^{53}Cr$ (threshold energy = 3.7 MeV)

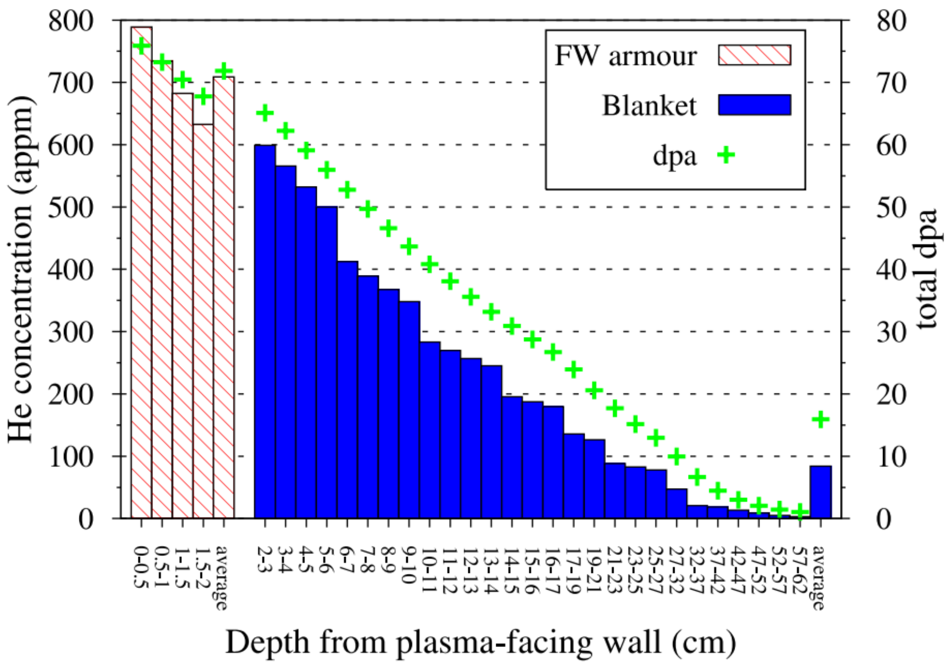


Figure 7. Variation in He concentration in pure Fe after a five-year irradiation as a function of depth (from the plasma) into the FW armour and blanket of DEMO at A in figure 2. The total dpa in pure Fe at each depth after five years is also shown (pluses).

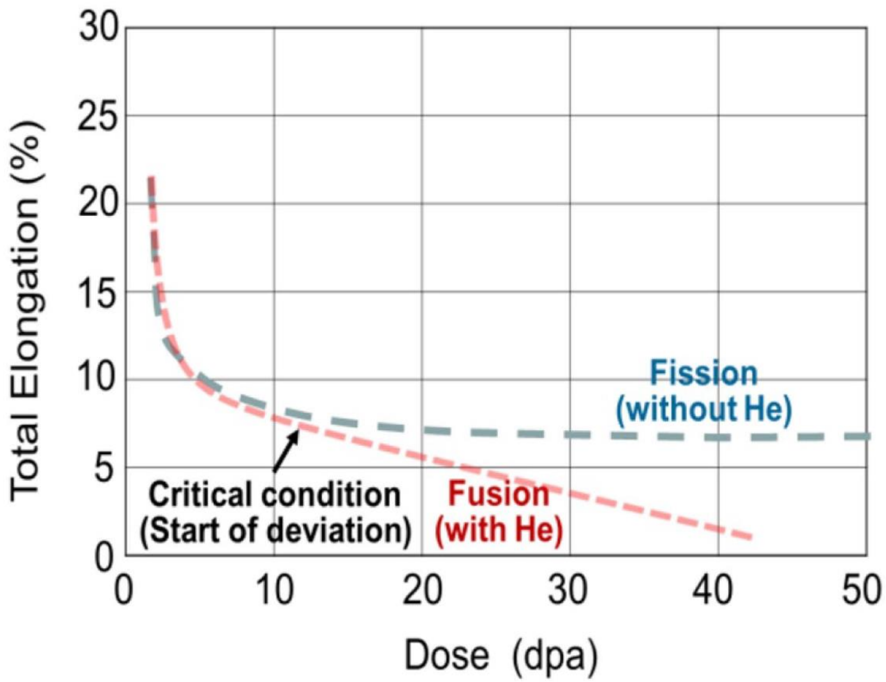


Figure 2. Correlation of DPA and helium production for each neutron facility.

Nuclear Fusion 52 (2012) 083019

Nuclear Fusion 61 (2021) 025001

Neutron damage

- Neutron energy: 14.1 MeV
- Neutron wall loading: 1 MW/m^2 (100 W/cm^2)

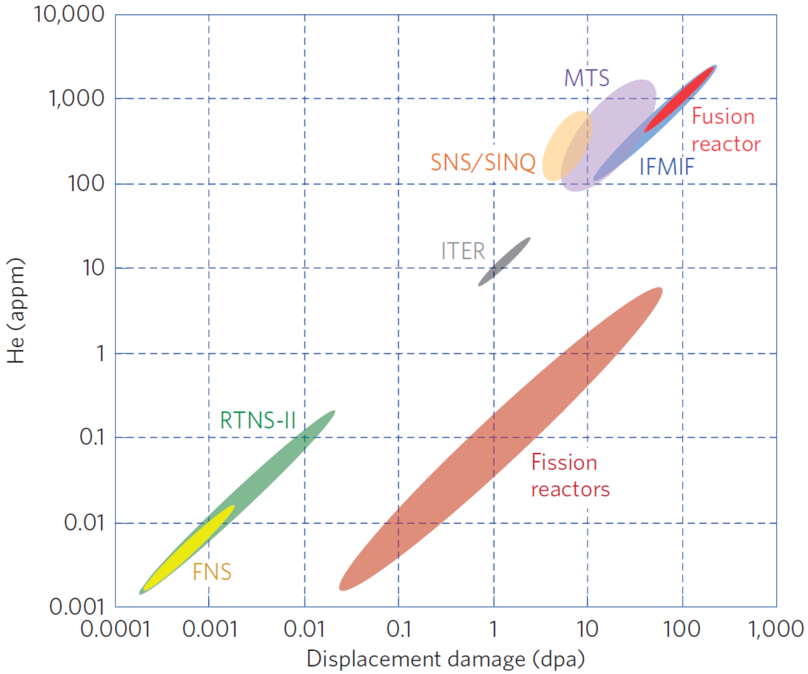
- ITER: 0.75 MW/m^2
- K-DEMO: 3 MW/m^2

→ Neutron flux at first wall: 4.5×10^{13} n/cm^2/s

→ Material damage: ~10 dpa/yr

1 dpa/yr (Fe) = 4.8×10^{12} n/cm^2/s

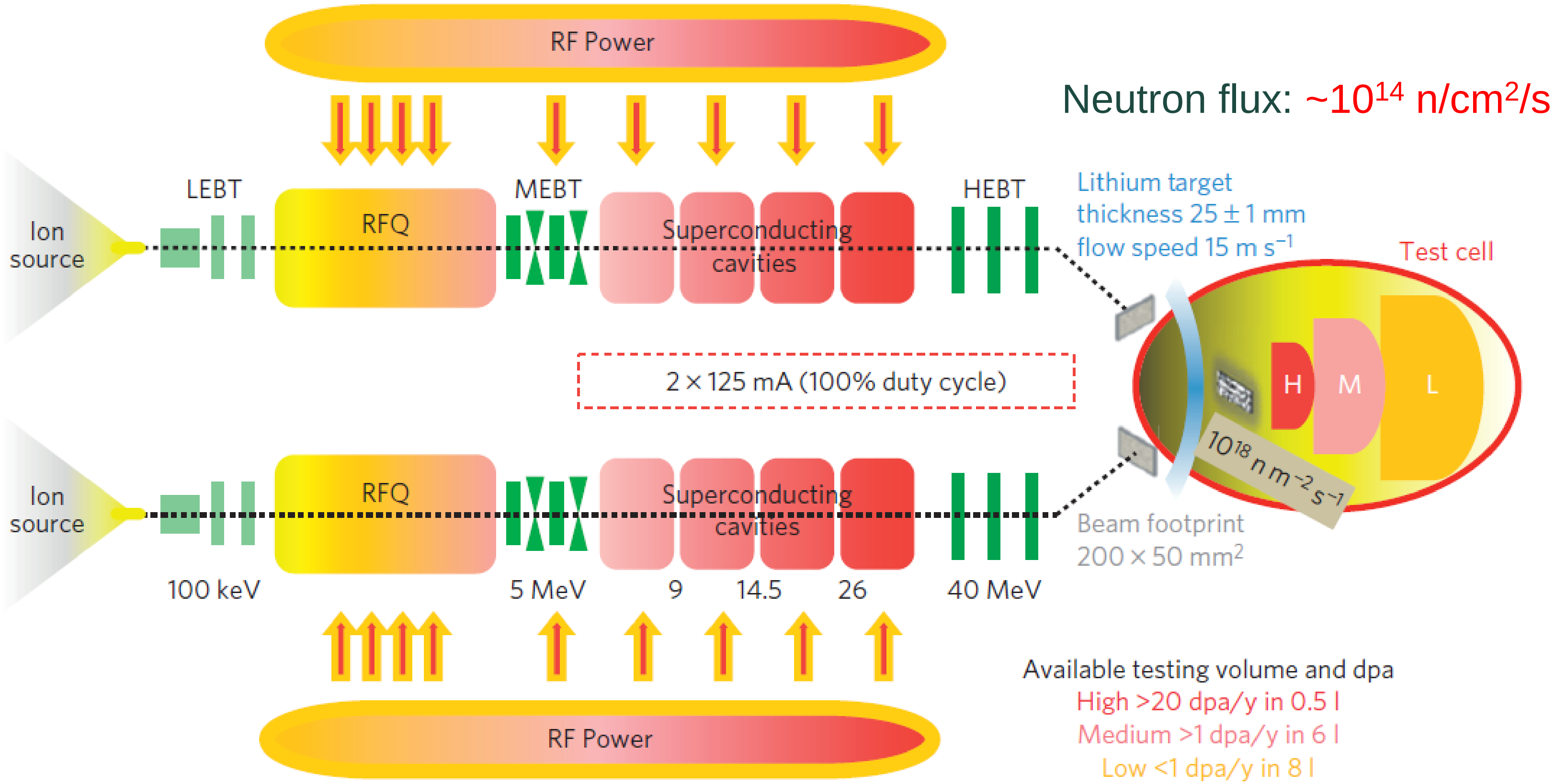
- He production: significant impact on mechanical properties
  - $^{56}Fe(n,\alpha)^{53}Cr$ (threshold energy = 3.7 MeV)
  - 12 appm/dpa (fusion reactors)
  - 0.3 appm/dpa (fission reactors)
  - 70 appm/dpa (spallation sources)



Nature Physics 12 (2016) 424

IFMIF: International Fusion Materials Irradiation Facility

- IFMIF is a large linear accelerator which is designed to produce neutrons with energies matching those that would enter a tokamak blanket. This is done by accelerating to 40 MeV a beam of deuterons onto a target of liquid lithium.



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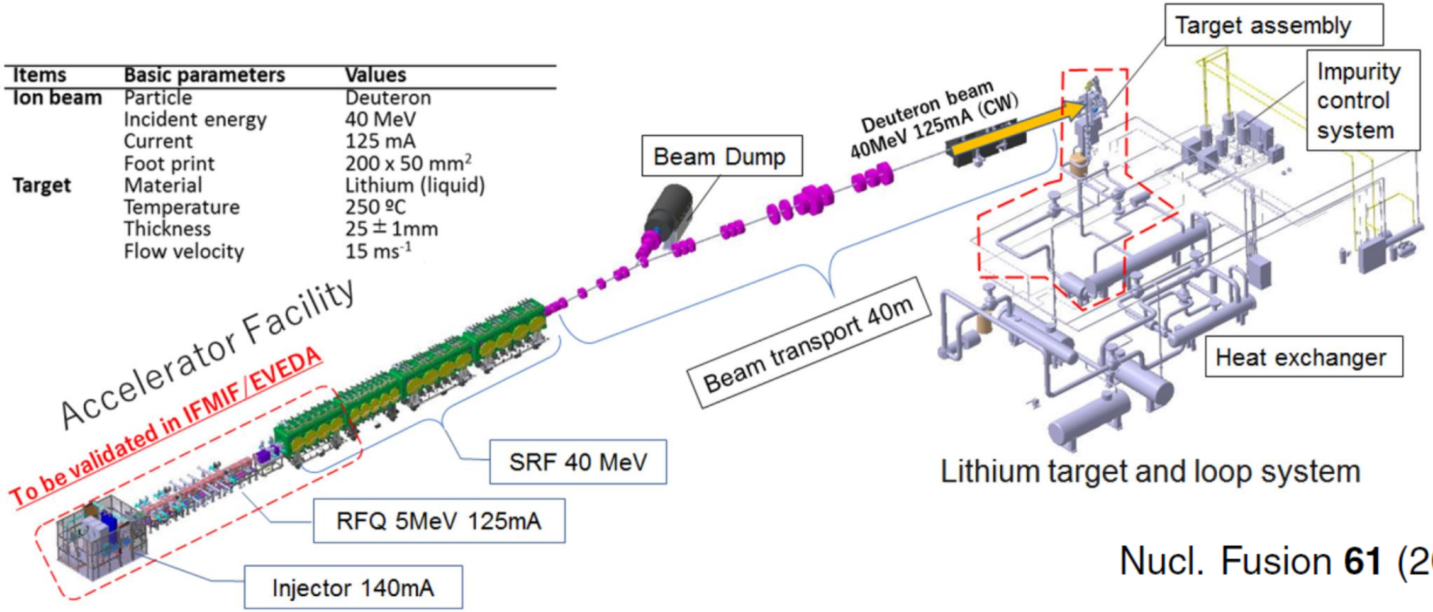
A-FNS (Japan)

Items	Basic parameters	Values
Ion beam	Particle	Deuteron
	Incident energy	40 MeV
	Current	125 mA
	Foot print	200 x 50 mm^2
Target	Material	Lithium (liquid)
	Temperature	250 ºC
	Thickness	25 ± 1mm
	Flow velocity	15 ms^{-1}



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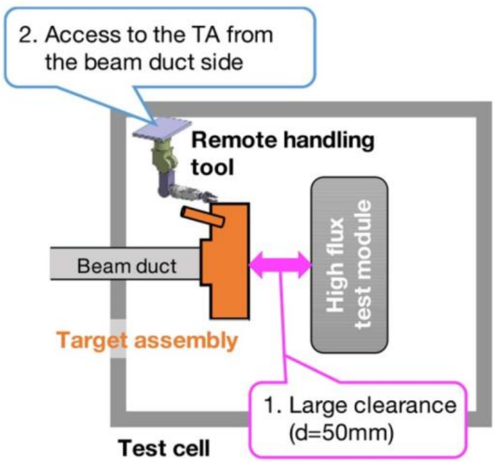

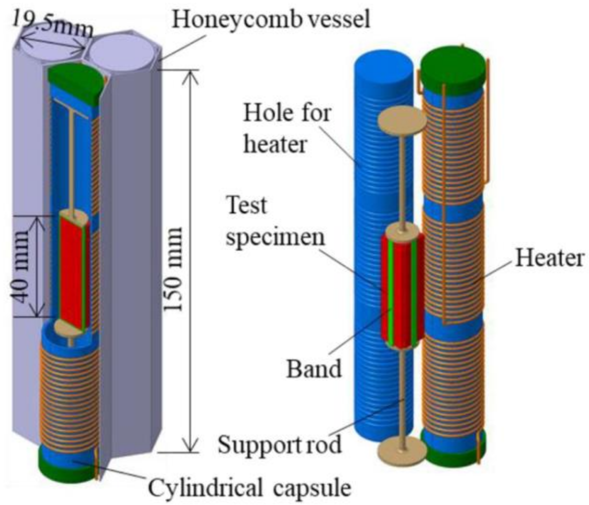

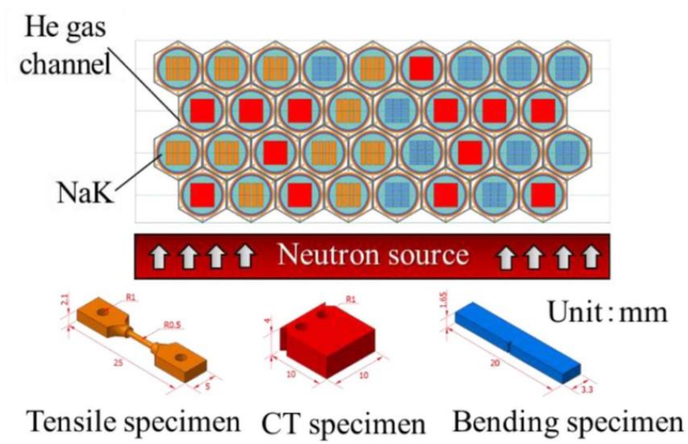

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