Nuclear Fusion versus Nuclear Fission

Presentation by John Carr, 12 February 2023, to Ecomodern Society of North America

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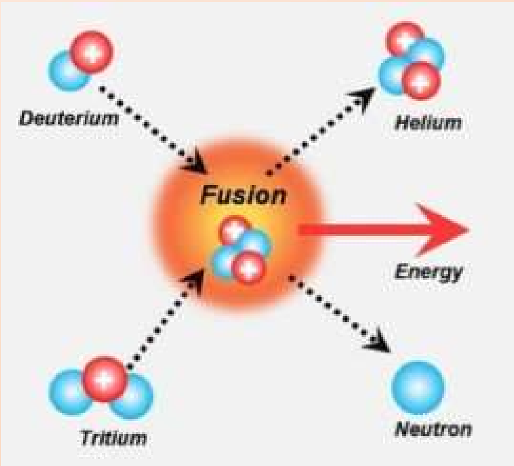
Physics of Fusion and Fission

Fusion

Fusion of deuterium and tritium

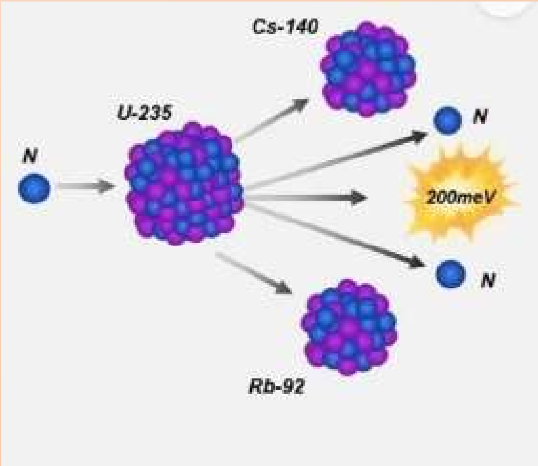
Requires heat to initiate interaction



Fission

Fission of uranium nucleus

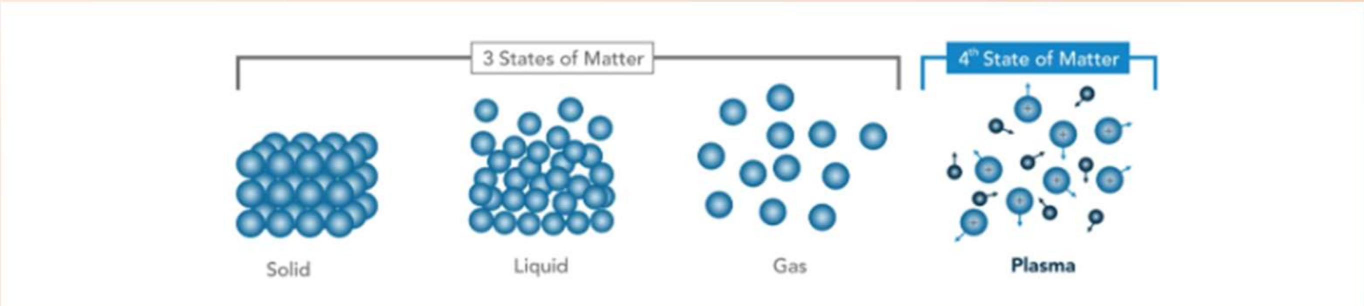
Initiated spontaneously by decays

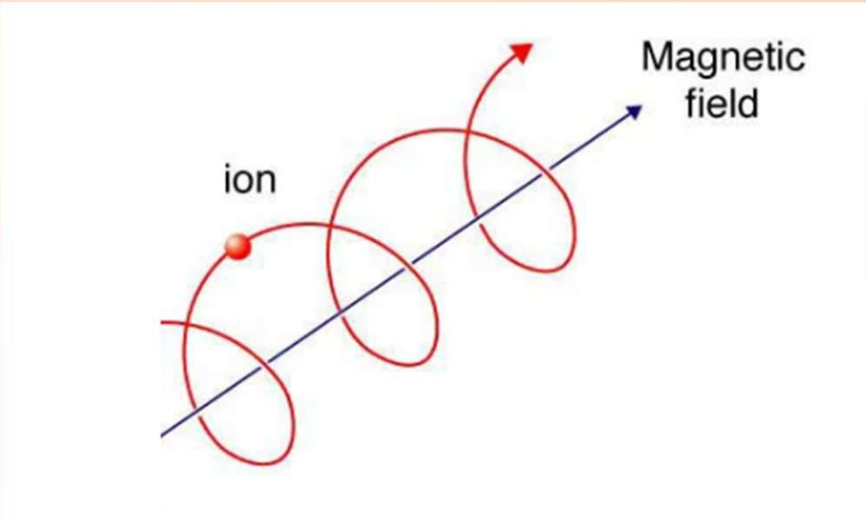


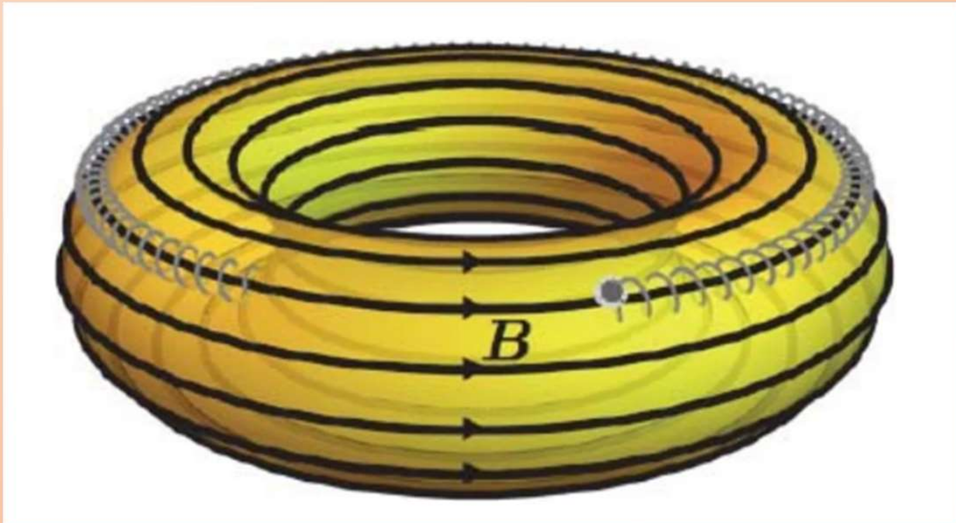
- **Fusion power plant would need to be much more complex than fission power plants.**
- **Also much bigger.**
- **Consequently much more costly.**

Magnetic Confinement Fusion

Plasma confined in a system of magnetic fields





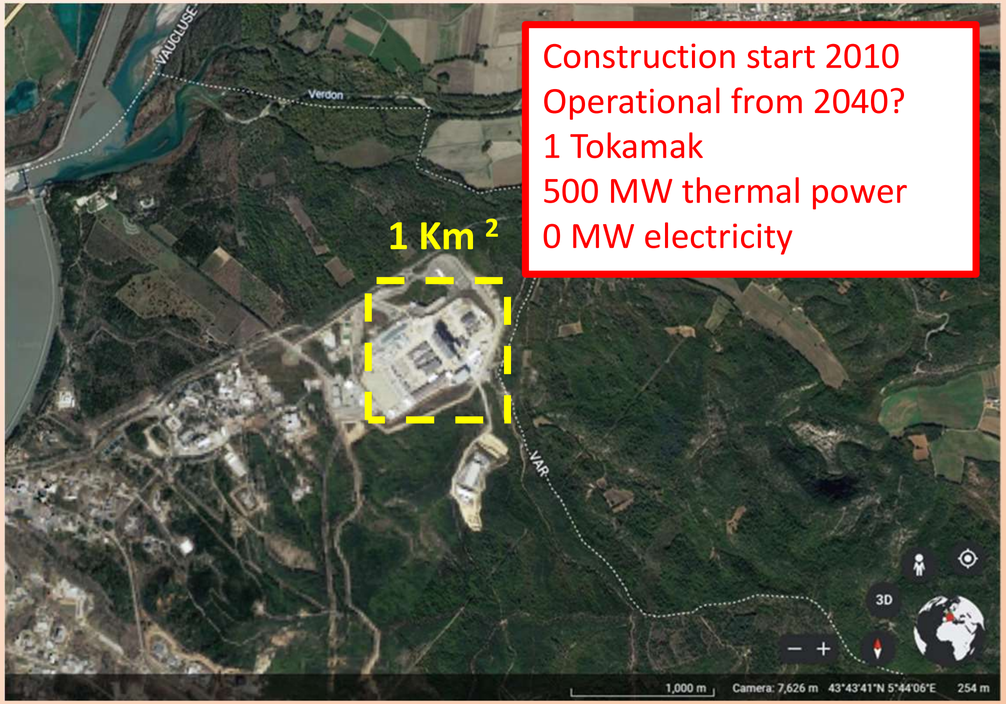


Examples of Current Status

Fusion

ITER, International Thermonuclear Experimental Reactor

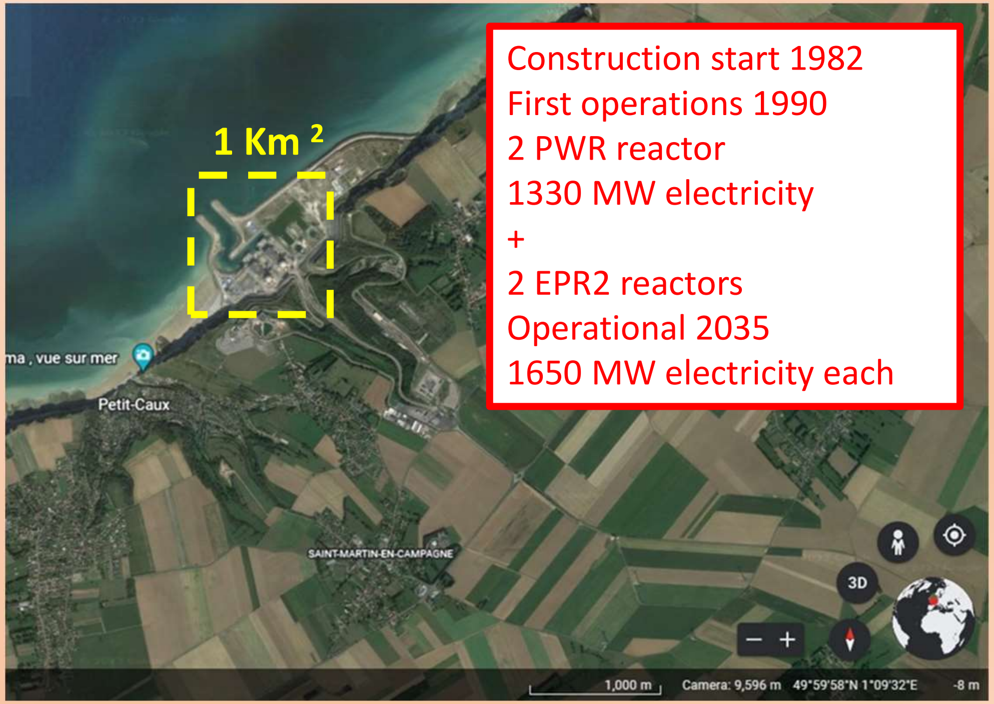
1 Prototype fusion reactor in construction



Fission

Penly, Fission Nuclear Power Plant

2 fission reactors in operation + 2 in planning



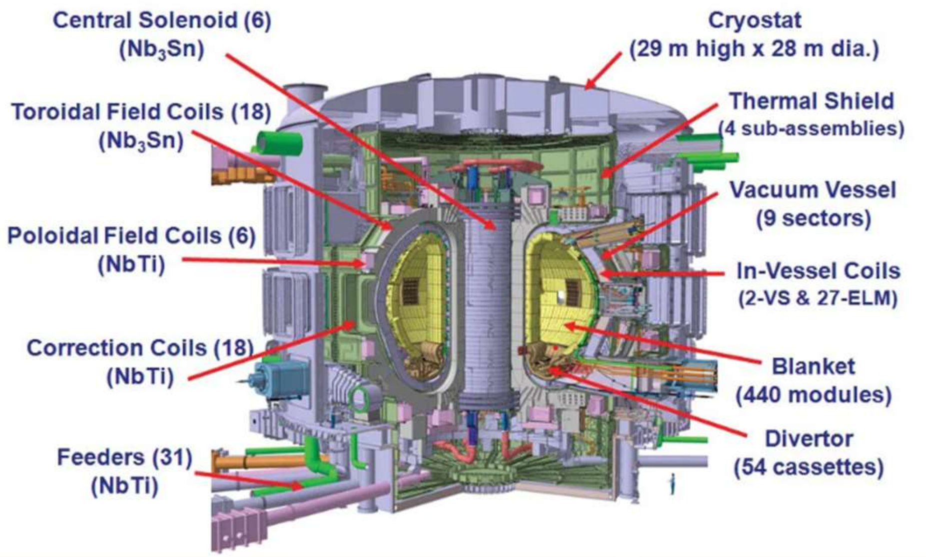
History of Fusion and Fission Development

Year	Fusion	Fission
1930	Physics understood, 1930s	Physics understood, 1930s
1940		First experimental reactor, Chicago Pile-1 1942 First bomb, Trinity 1945
1950	First bomb, Bravo 1954	First commercial power plant, Shippingport 1957
1960		
1970	Many experiments exploring different techniques Eventually Tokamaks emerge as favoured device	200 commercial reactors 1977 Three Mile Island accident, 1979
1980		Chernobyl accident, 1986
1990		416 commercial reactors 1990
2000	First experimental tokamak with fusion reactions, TFTR 1997	
2010	Most global efforts devoted toward ITER	Fukushima accident, 2011
2020		442 commercial reactors 2020
2030	Private fusion companies claim commercial fusion 2030s ????**?**	
2040	First prototype reactor with fusion reactions, ITER, 2040 **?**	
2050		
2060	First prototype power plant, DEMO, 2060- 2080 **???**	

Mainstream Fusion Reactor

- **Magnetic confinement with Tokamak.**
- **Deuterium – tritium fuel.**
- **Tritium hardly exists in nature and world stocks come from CANDU fission reactors.**
- **Tritium must be regenerated in machine.**

ITER Tokamak

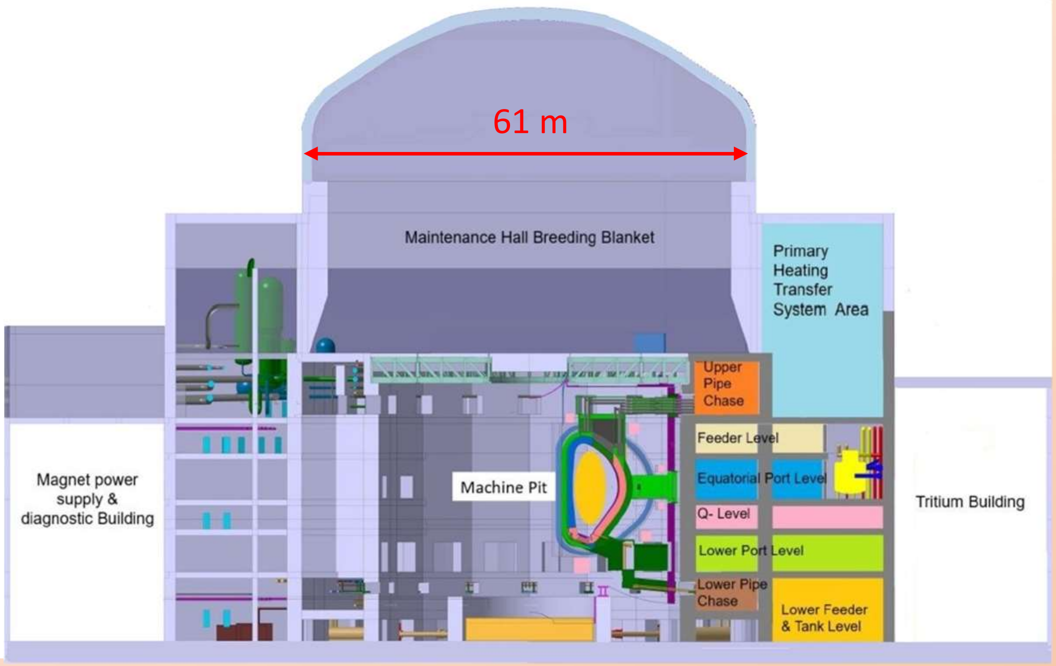


Tokamak fusion power plants have many complex ancillary systems

Fusion and Fission Power Plants

Fusion

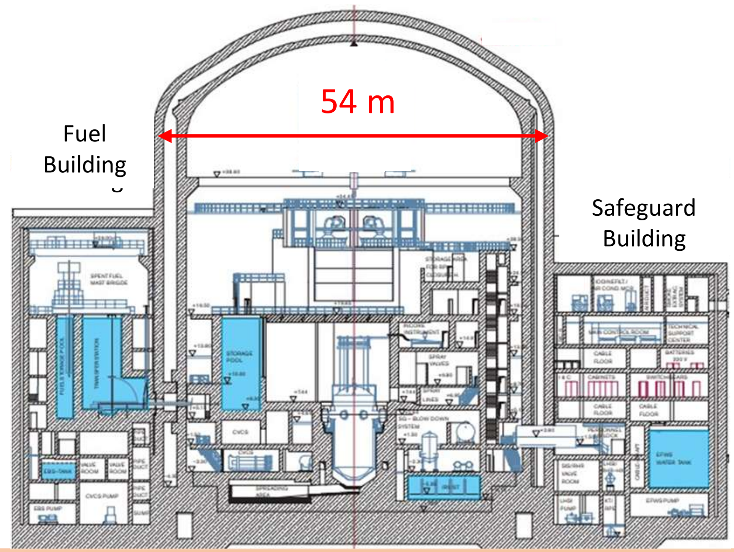
DEMO Fusion Power Plant, 500 MW electricity



EU-DEMO design can only be finalized after ITER success. Operational 2060-2080 ???

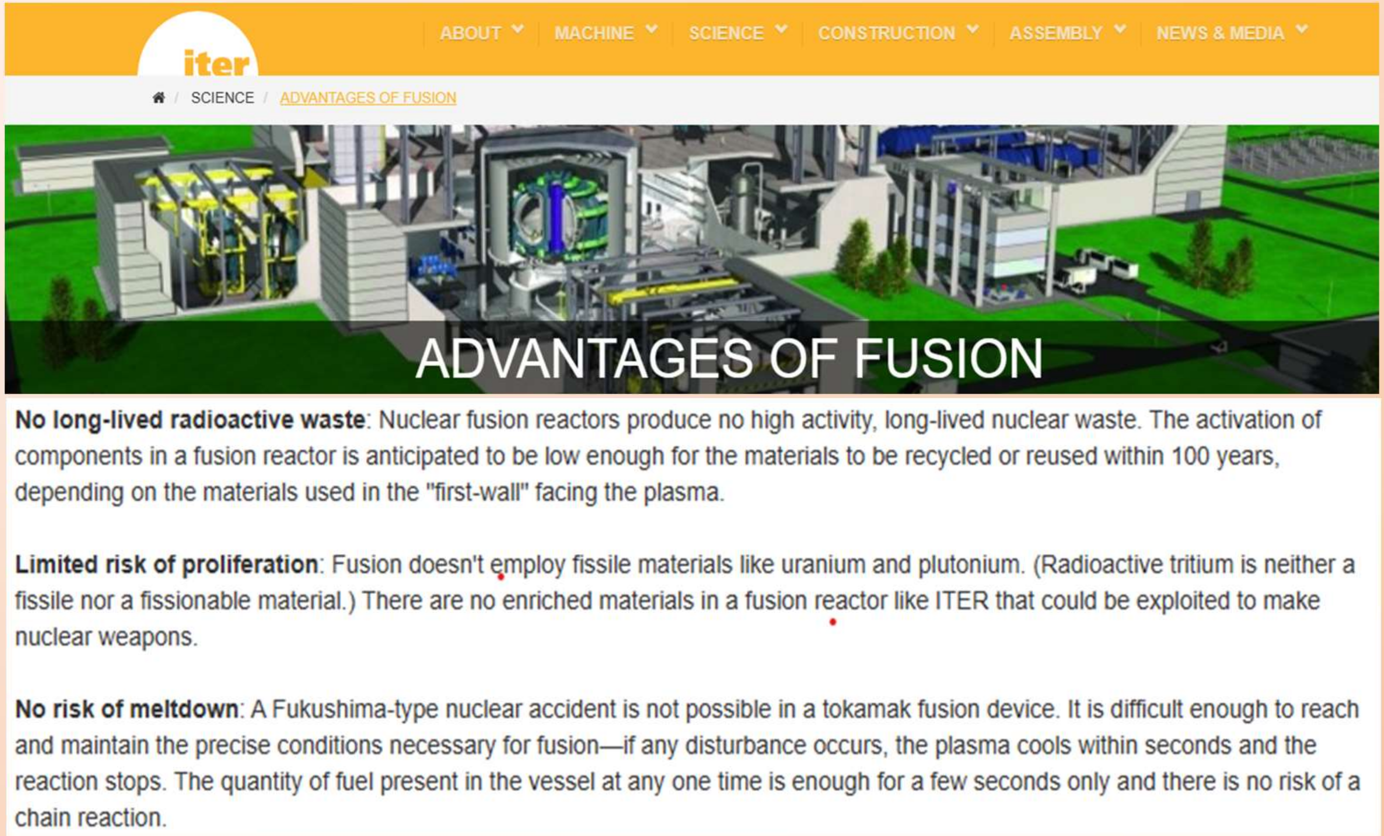
Fission

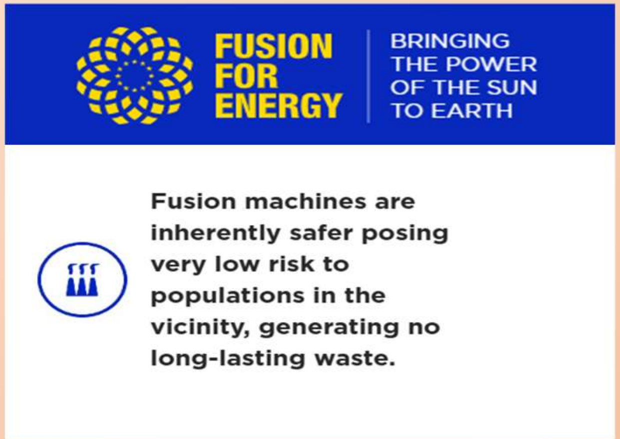
EPR2 Reactor, 1650 MW Electricity

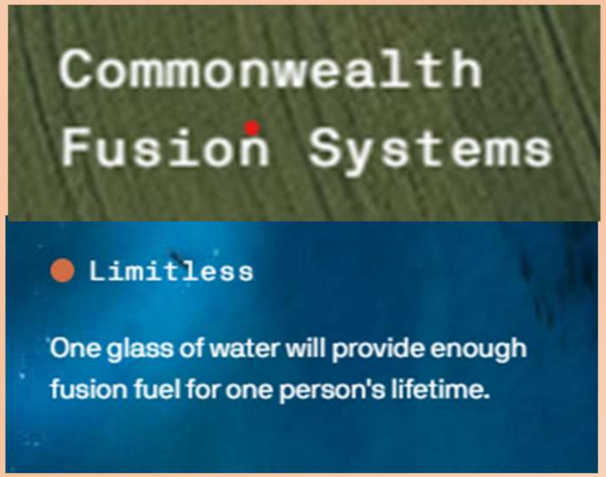


New nuclear construction program in France. 14 new reactors operational between 2035-2050

Fusion Propaganda







It is important to counter the anti-fission implications.

Pros and Cons of Fusion and Fission

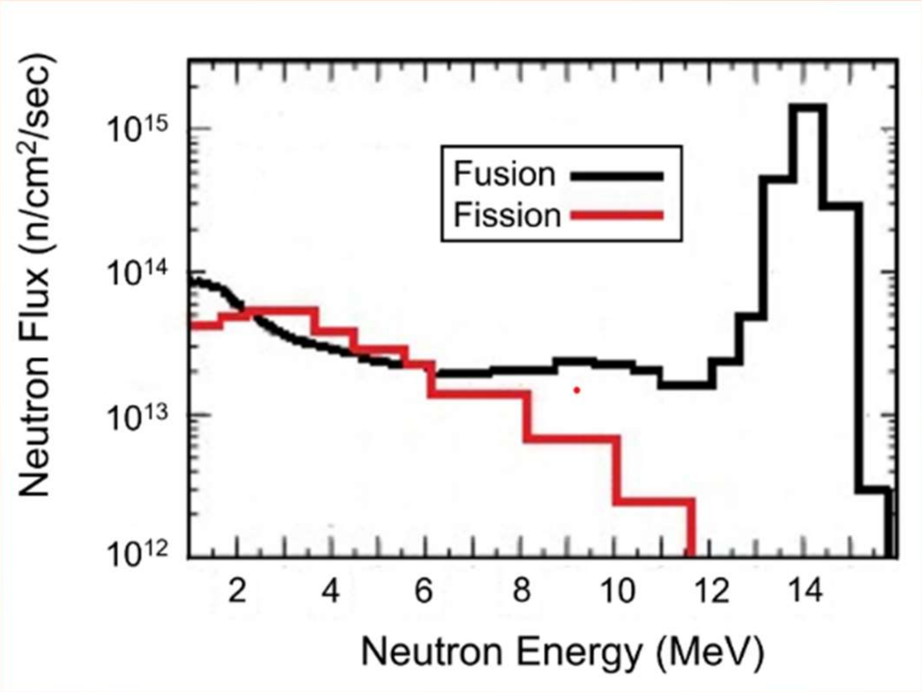
	Fusion	Fission
Status	Research for 70 yrs	Operational for 70 yrs
Reliability	**Major doubt**	>80% of time
Carbon Emissions	None	None
Fuel availability	**Tritium scarce**	Uranium abundant
Radioactive waste	Mostly short lifetime	Partly Long lifetime
Safety	Complex systems	**Historic accidents**
Cost *	**$22000/KW**	$6000/KW

* Impossible to give accurate costs for fusion because no complete power plant design exists

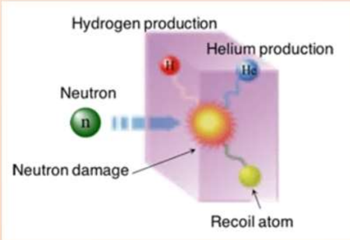
Ultimately, cost of power generation system will decide which is used.

Radiation Damage and Neutron Activation

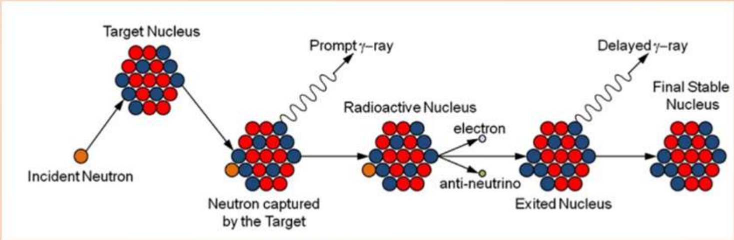
- **Neutron flux in fusion reactor is higher than in fission reactor for same power.**
- **Neutron energy is much higher.**



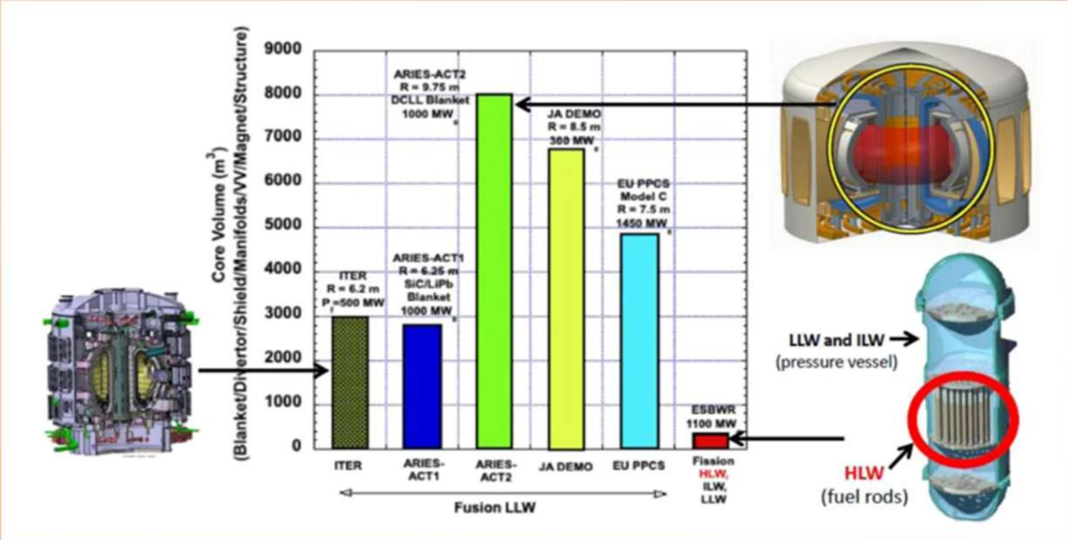
Radiation damage



Neutron activation



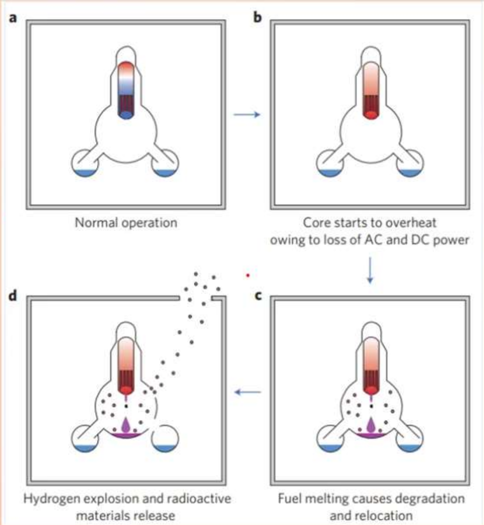
Higher volumes of radioactive waste from fusion reactor



Safety

Analysis of safety risks essential but complicated activity with numerous aspects.

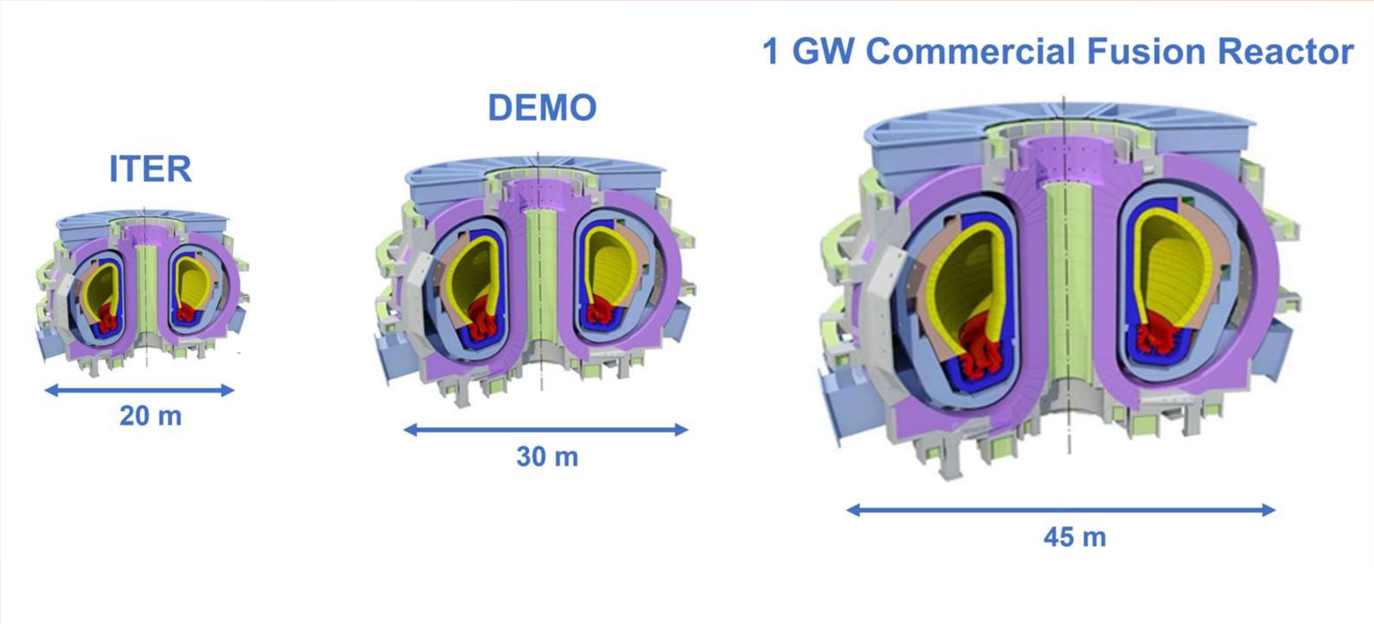
Hydrogen explosions after coolant loss are biggest dangers for both fusion and fission reactors



ITER assembly has been on hold since January 2021
because of concerns raised by the French Nuclear Safety Authority (ASN)

Physical Size

Fusion



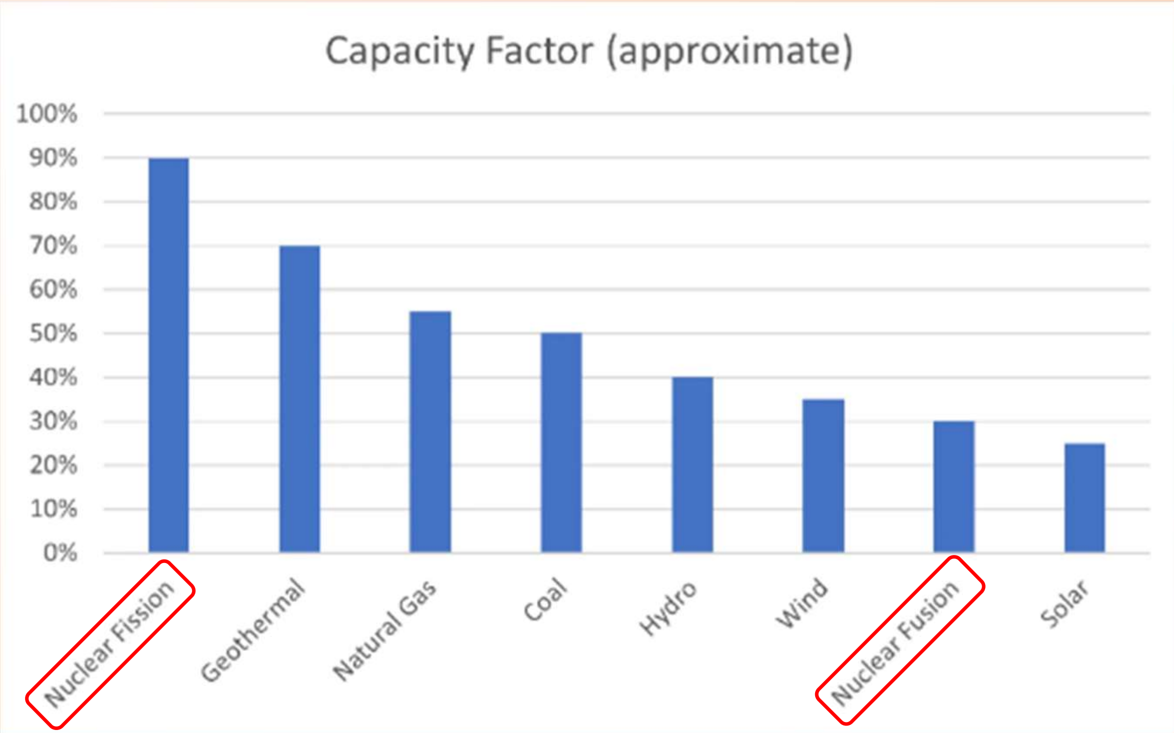
Fission

Fusion Reactor "cores" must be enormous compared to fission reactor cores. because of low energy density of fusion reactions in plasma.

Reliability / Availability

Fusion Power Plants will have large downtime due to:

- **breakdowns of complex systems**
- **extensive scheduled maintenance to replace radiation damaged components**

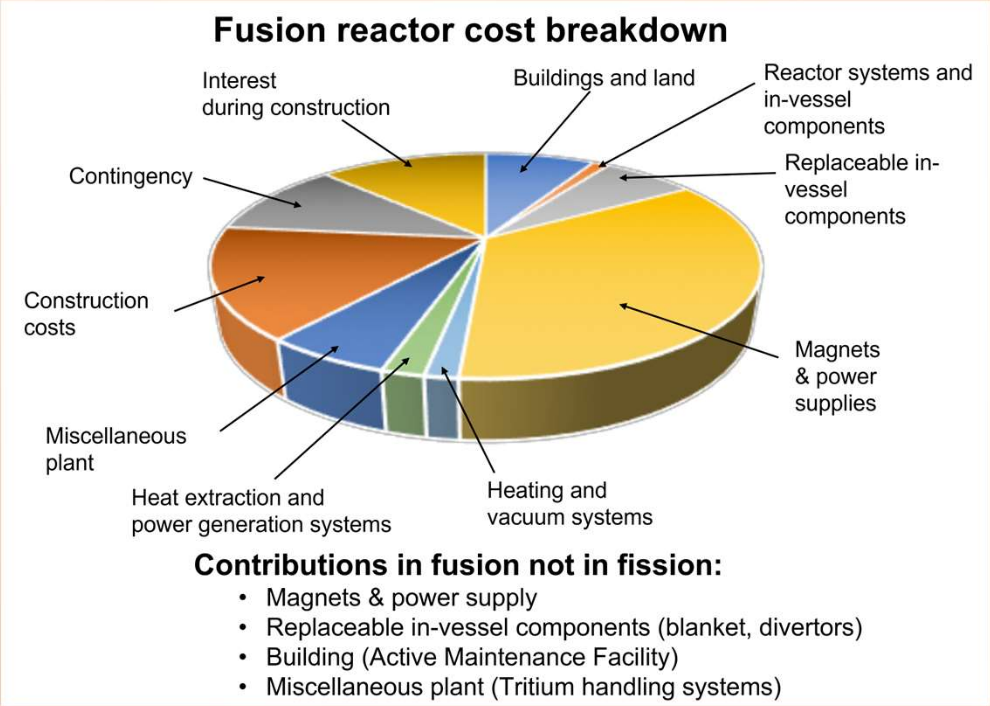


Fusion 30%
Fission 90%

Fission 3 times higher capacity factor

Costs of Fusion

- **Construction costs: factor 4 more than fission**
- **Availability: factor 3 less than fission**
- **Operational costs larger because of extra complexity and more maintenance.**

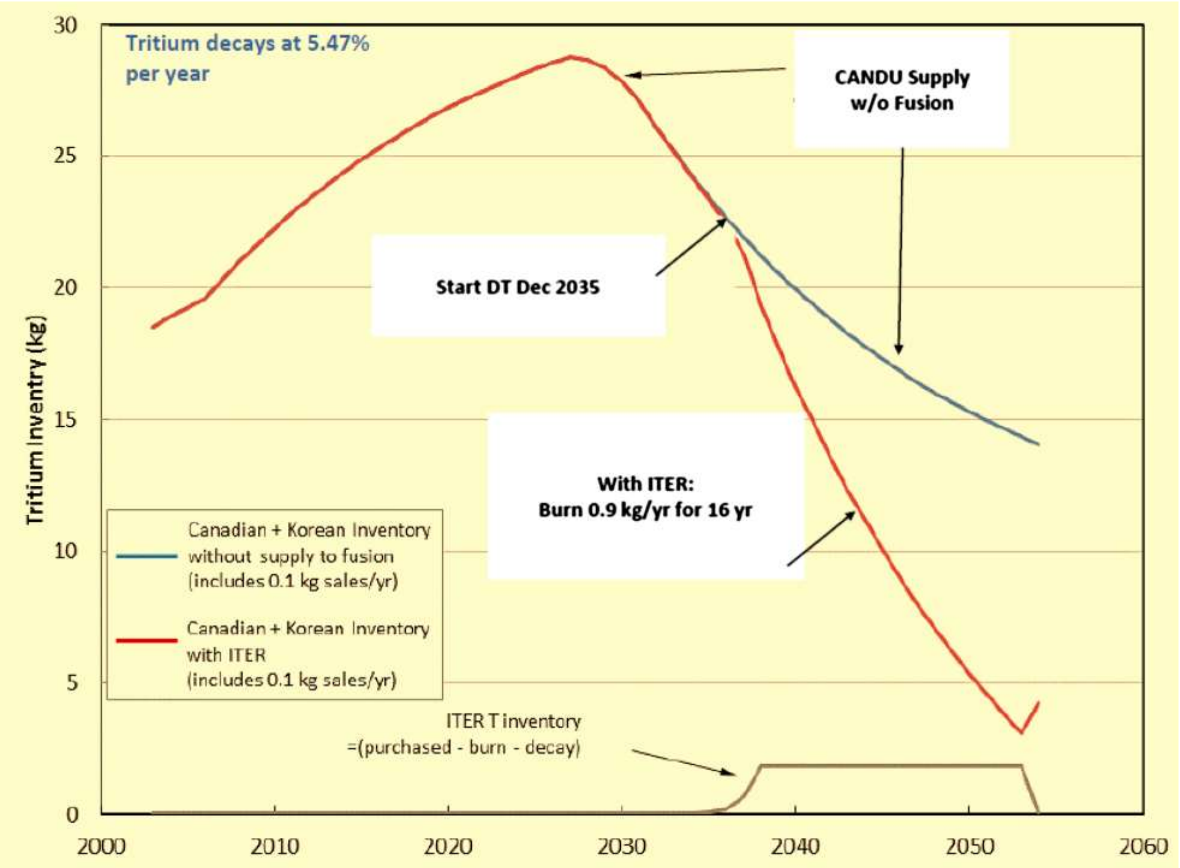


Conclusion is that the costs of a mainstream fusion power plant are unknown at the present time but certainly will be much higher than fission by more than a factor 10.

Show-Stoppers for Mainstream Fusion

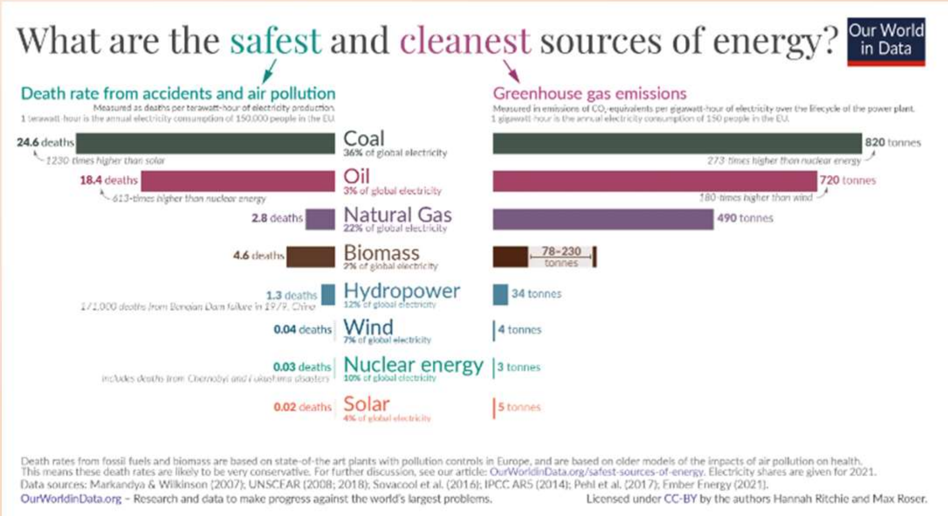
- **Lack of tritium fuel**
- **No suitable materials**
- **Impossible Size**

ITER will use up nearly all global tritium fuel stocks



Why bother with Fusion rather than Fission?

Only reason for fusion power plants would be public opposition to fission power plants.
Fission is one of the safest and cleanest sources of energy.



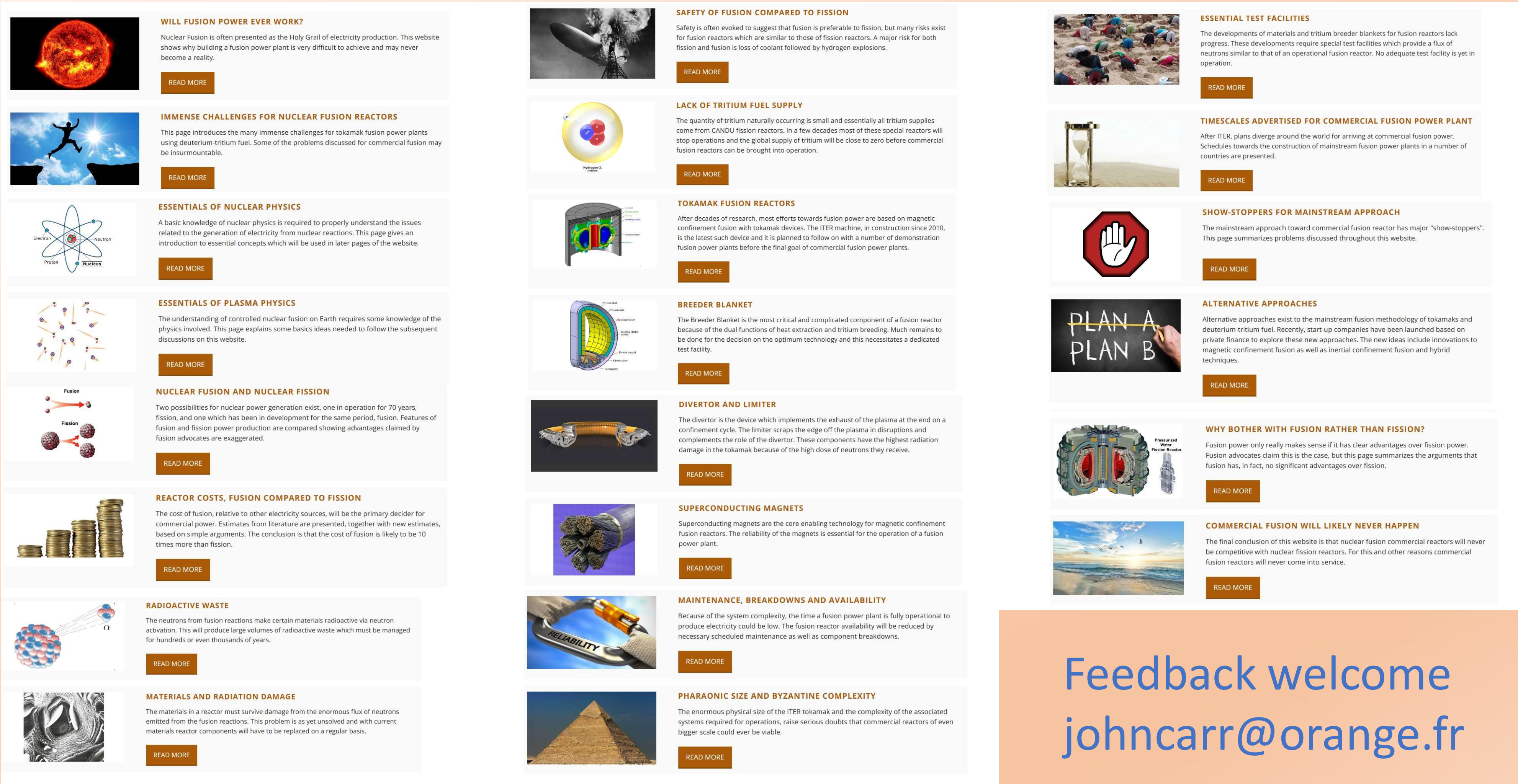
Even if all the difficulties can be overcome, fusion would have no significant advantages over fission and would cost 10 times more.

We should work to ensure that fusion advocates do not distort the truth.

Website: Climate and Hope

https://www.climate-and-hope.net/

Website: Nuclear Fusion Pages



WILL FUSION POWER EVER WORK?

Nuclear Fusion is often presented as the Holy Grail of electricity production. This website shows why building a fusion power plant is very difficult to achieve and may never become a reality.

READ MORE

IMMENSE CHALLENGES FOR NUCLEAR FUSION REACTORS

This page introduces the many immense challenges for tokamak fusion power plants using deuterium-tritium fuel. Some of the problems discussed for commercial fusion may be insurmountable.

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ESSENTIALS OF NUCLEAR PHYSICS

A basic knowledge of nuclear physics is required to properly understand the issues related to the generation of electricity from nuclear reactions. This page gives an introduction to essential concepts which will be used in later pages of the website.

READ MORE

ESSENTIALS OF PLASMA PHYSICS

The understanding of controlled nuclear fusion on Earth requires some knowledge of the physics involved. This page explains some basics ideas needed to follow the subsequent discussions on this website.

READ MORE

NUCLEAR FUSION AND NUCLEAR FISSION

Two possibilities for nuclear power generation exist, one in operation for 70 years, fission, and one which has been in development for the same period, fusion. Features of fusion and fission power production are compared showing advantages claimed by fusion advocates are exaggerated.

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REACTOR COSTS, FUSION COMPARED TO FISSION

The cost of fusion, relative to other electricity sources, will be the primary decider for commercial power. Estimates from literature are presented, together with new estimates, based on simple arguments. The conclusion is that the cost of fusion is likely to be 10 times more than fission.

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RADIOACTIVE WASTE

The neutrons from fusion reactions make certain materials radioactive via neutron activation. This will produce large volumes of radioactive waste which must be managed for hundreds or even thousands of years.

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MATERIALS AND RADIATION DAMAGE

The materials in a reactor must survive damage from the enormous flux of neutrons emitted from the fusion reactions. This problem is as yet unsolved and with current materials reactor components will have to be replaced on a regular basis.

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SAFETY OF FUSION COMPARED TO FISSION

Safety is often evoked to suggest that fusion is preferable to fission, but many risks exist for fusion reactors which are similar to those of fission reactors. A major risk for both fission and fusion is loss of coolant followed by hydrogen explosions.

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LACK OF TRITIUM FUEL SUPPLY

The quantity of tritium naturally occurring is small and essentially all tritium supplies come from CANDU fission reactors. In a few decades most of these special reactors will stop operations and the global supply of tritium will be close to zero before commercial fusion reactors can be brought into operation.

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TOKAMAK FUSION REACTORS

After decades of research, most efforts towards fusion power are based on magnetic confinement fusion with tokamak devices. The ITER machine, in construction since 2010, is the latest such device and it is planned to follow on with a number of demonstration fusion power plants before the final goal of commercial fusion power plants.

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BREEDER BLANKET

The Breeder Blanket is the most critical and complicated component of a fusion reactor because of the dual functions of heat extraction and tritium breeding. Much remains to be done for the decision on the optimum technology and this necessitates a dedicated test facility.

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DIVERTOR AND LIMITER

The divertor is the device which implements the exhaust of the plasma at the end on a confinement cycle. The limiter scraps the edge off the plasma in disruptions and complements the role of the divertor. These components have the highest radiation damage in the tokamak because of the high dose of neutrons they receive.

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SUPERCONDUCTING MAGNETS

Superconducting magnets are the core enabling technology for magnetic confinement fusion reactors. The reliability of the magnets is essential for the operation of a fusion power plant.

READ MORE

MAINTENANCE, BREAKDOWNS AND AVAILABILITY

Because of the system complexity, the time a fusion power plant is fully operational to produce electricity could be low. The fusion reactor availability will be reduced by necessary scheduled maintenance as well as component breakdowns.

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PHARAONIC SIZE AND BYZANTINE COMPLEXITY

The enormous physical size of the ITER tokamak and the complexity of the associated systems required for operations, raise serious doubts that commercial reactors of even bigger scale could ever be viable.

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ESSENTIAL TEST FACILITIES

The developments of materials and tritium breeder blankets for fusion reactors lack progress. These developments require special test facilities which provide a flux of neutrons similar to that of an operational fusion reactor. No adequate test facility is yet in operation.

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TIMESCALES ADVERTISED FOR COMMERCIAL FUSION POWER PLANT

After ITER, plans diverge around the world for arriving at commercial fusion power. Schedules towards the construction of mainstream fusion power plants in a number of countries are presented.

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SHOW-STOPPERS FOR MAINSTREAM APPROACH

The mainstream approach toward commercial fusion reactor has major "show-stoppers". This page summarizes problems discussed throughout this website.

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ALTERNATIVE APPROACHES

Alternative approaches exist to the mainstream fusion methodology of tokamaks and deuterium-tritium fuel. Recently, start-up companies have been launched based on private finance to explore these new approaches. The new ideas include innovations to magnetic confinement fusion as well as inertial confinement fusion and hybrid techniques.

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WHY BOTHER WITH FUSION RATHER THAN FISSION?

Fusion power only really makes sense if it has clear advantages over fission power. Fusion advocates claim this is the case, but this page summarizes the arguments that fusion has, in fact, no significant advantages over fission.

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COMMERCIAL FUSION WILL LIKELY NEVER HAPPEN

The final conclusion of this website is that nuclear fusion commercial reactors will never be competitive with nuclear fission reactors. For this and other reasons commercial fusion reactors will never come into service.

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Feedback welcome

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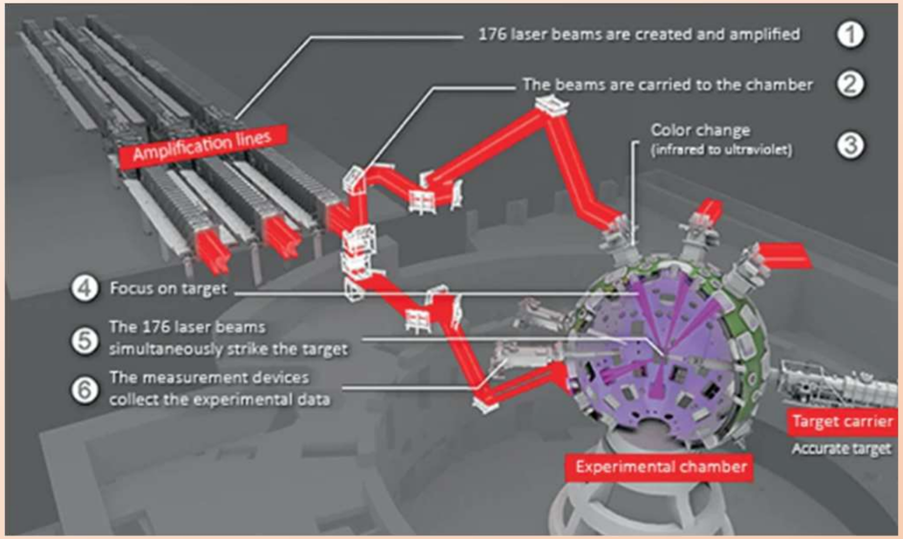
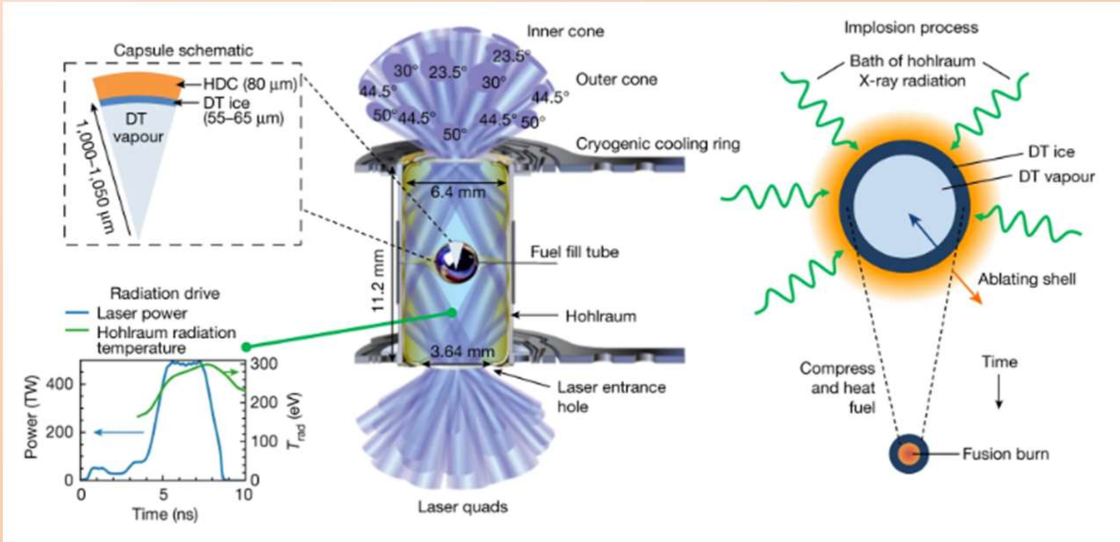
Questions ?

Inertial Confinement Fusion

A system of lasers focus light on a small target pellet with deuterium-tritium fuel which implodes to make fusion reactions





Very complicated and expensive
Not clear how the repetition rate can be fast enough for a power plant

Private Fusion Companies

Company Name and website	Technology	Fuel
Commonwealth Fusion Systems	Compact Tokamak	D-T
TAE Technologies	Field Reversed Config.	p-^{11}B
Helion	Magneto-inertial	D-^{3}He
General Fusion	Magneto-inertial	D-T
Tokamak Energy	Spherical Tokamak	D-T
Zap Energy	Sheared flow Z-Pinch	D-T
ENN	Spherical Tokamak	p-^{11}B

The seven private fusion private companies with funding >$200 million by 2022

Alternative Fuels

Fuel	$k_B T_i$	$k_B T_e$	$\langle \sigma v \rangle$	$p_{\text{fusion}}/p_{\text{brem}}$
D–T	50 keV	42 keV	8.7×10^{-22} m^3/s	139
D–^{3}He	100 keV	73 keV	1.7×10^{-23} m^3/s	6.6
D–D	500 keV	209 keV	2.0×10^{-22} m^3/s	2.9
p–^{11}B	300 keV	137 keV	2.4×10^{-23} m^3/s	0.57

ITER Failure?

The international ITER project is putting all mainstream fusion eggs in one huge, complicated basket. If ITER fails, it will be noticed by politicians everywhere and a restart of a similar fusion project will be impossible. There are many paths by which ITER could fail:

- **Plasma Physics**. The primary goal of ITER is to finally solve the problems with plasma confinement and disruptions. If it fails here, it is unlikely there will ever be a new bigger project with the same role.
- **Technical Fault**. Any number of engineering issues could lead to project failure. One risky decision that has been taken, is to skip power tests of superconducting magnets. After the tokamak is completely assembled a repair of the magnet coils would be impossible without several years of work. Recently, leaks in the partly assembled thermal shields have been discovered and these leaks can now be repaired but would have been impossible after complete tokamak assembly. Possibly other technical gambles have been made.
- **Political collapse.** The multinational structure of ITER is slowly being eroded for numerous reasons. The current funding arrangement ends in 2035 and some significant extension will be needed. This might not happen.
- **Nuclear Regulatory Rejection.** ITER is licensed by the French nuclear safety authority (ASN). Agreement by ASN must be given at certain stages of ITER construction. Between, January-December 2022 ITER construction has been stopped because of objections of ASN. The progress of ITER towards completion depends on ASN approval and safety concerns might halt ITER.