Imperial College London

Jeremy Chittenden

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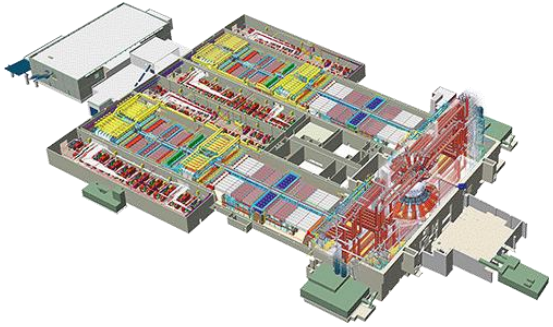
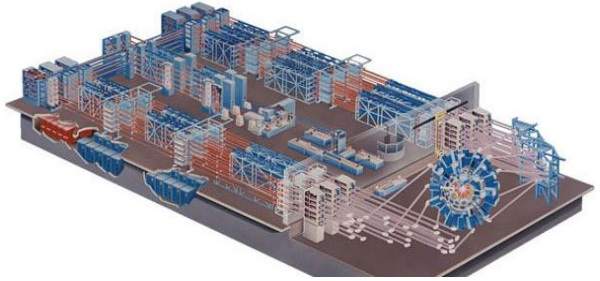
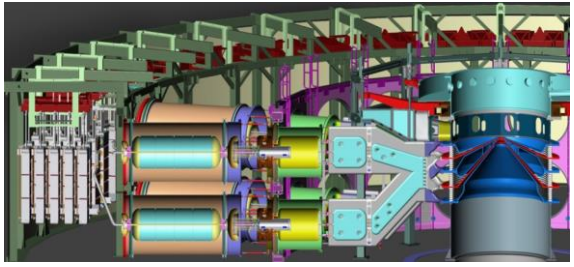
Centre for Inertial Fusion Studies

Imperial College

Theory, simulation and experiments in Inertial Confinement Fusion and fundamental Plasma Science







Fusion Energy APPG, June 27th 2023

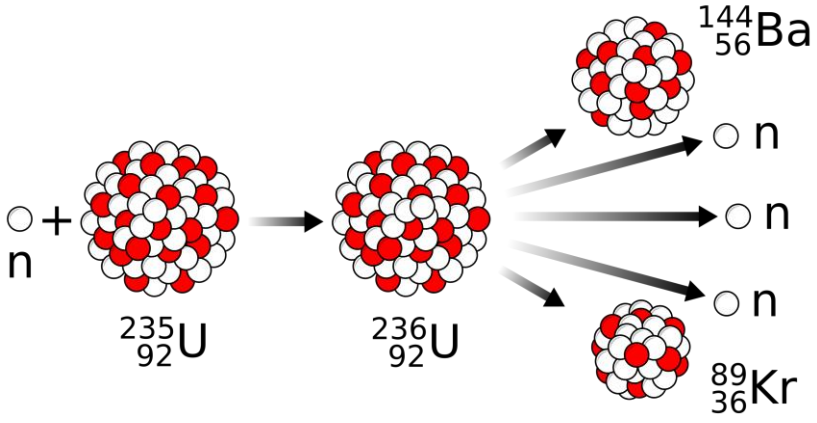
Fusion seeks to replace our reliance on fossil fuels with the energy source inside our Sun

The main fuel can be extracted from seawater (an almost limitless supply)

Each fusion reaction produces a million times the energy of a chemical reaction (with no CO_2 emissions)

No chain reaction or 'meltdown' and no long-lived radioactive waste

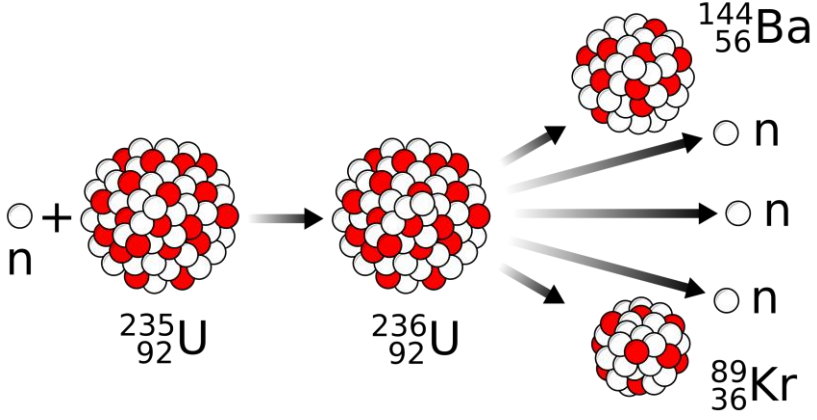
Fission and Fusion are different forms of Nuclear Reactions

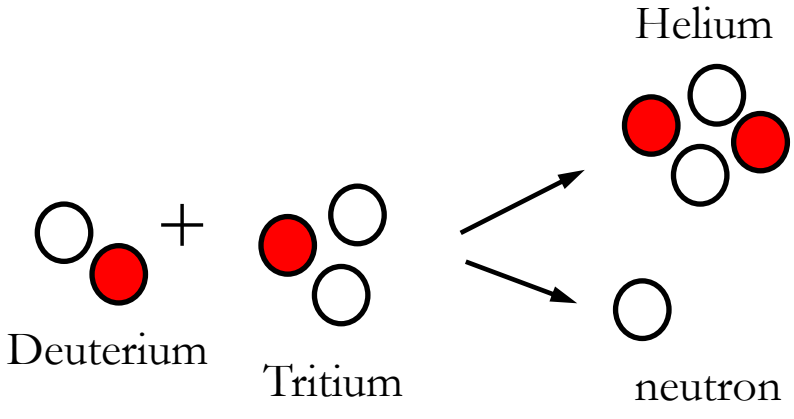


Conventional nuclear reactors use fission reactions to split heavy atoms

A chain reaction as each fission event produces neutrons which initiate further reactions

Fission and Fusion are different forms of Nuclear Reactions





Conventional nuclear reactors use fission reactions to split heavy atoms

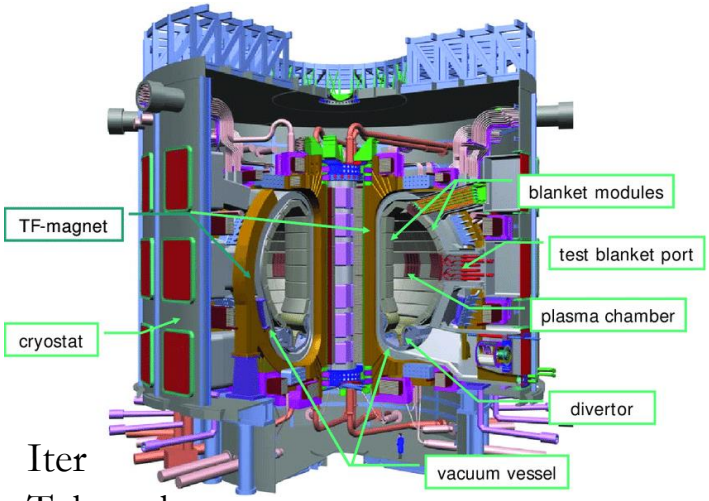
Fusion reactions instead combine light atoms

A chain reaction as each fission event produces neutrons which initiate further reactions

No chain reaction involved but to initiate reactions we must first heat the fuel to around 100 million degrees

Several Different Approaches to Fusion Energy Are Being Explored

Magnetic Fusion Energy

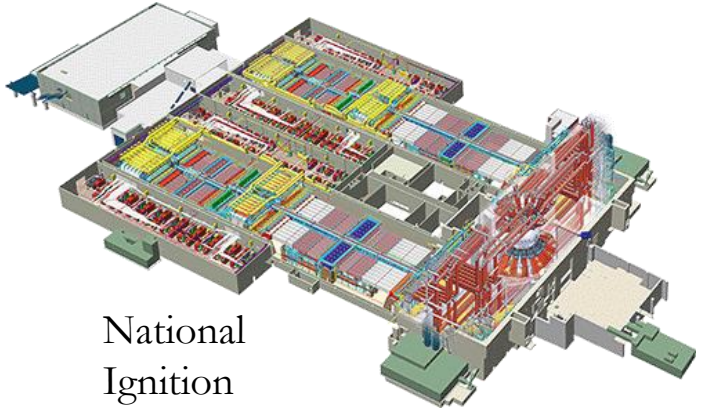


Iter
Tokamak

Steady state
Timescales - minutes or hours
Plasma size - 10m

Many other approaches including hybrid schemes lie between Magnetic and Inertial Fusion Energy

Inertial Fusion Energy



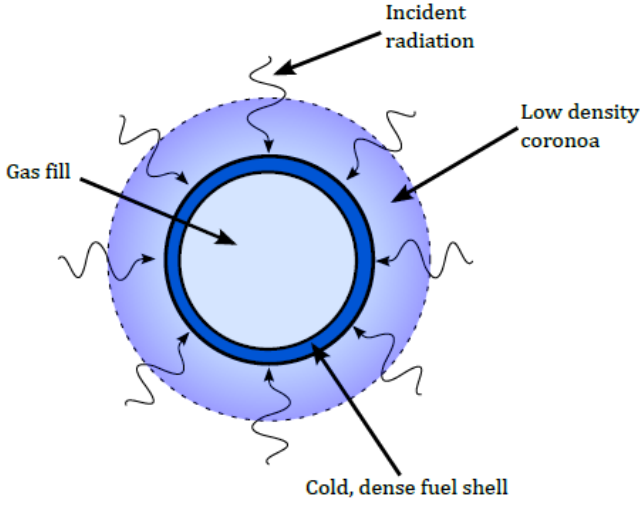
National
Ignition
Facility

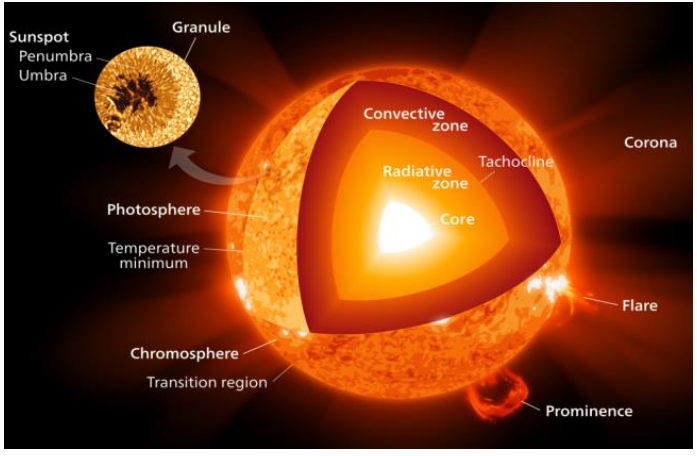
Pulsed
Timescales - billionth of a second
Plasma size - a tenth of a mm
(thickness of human hair)

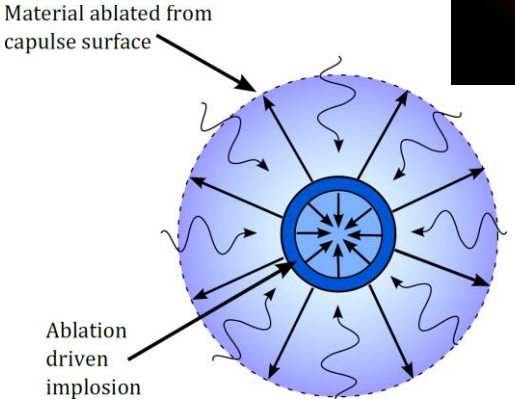
A lot of the underpinning technologies supporting reactor designs are common
however there some are key differences such as 'energy gain' and 'standoff'

Inertial Fusion recreates conditions at the centre of the Sun

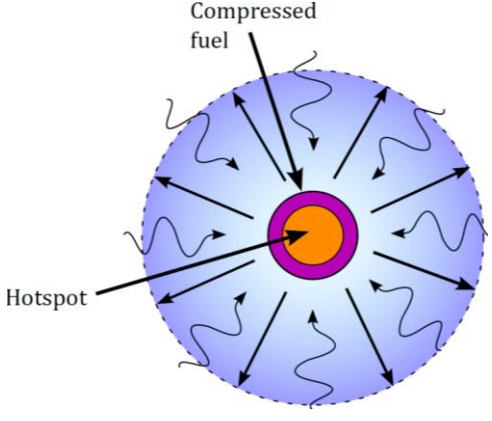
The enormous pressure required are generated by using intense lasers or X-rays to drive a spherical implosion







Fusion fuel is encased in a sphere of high density carbon (synthetic diamond) the size of a pepper corn



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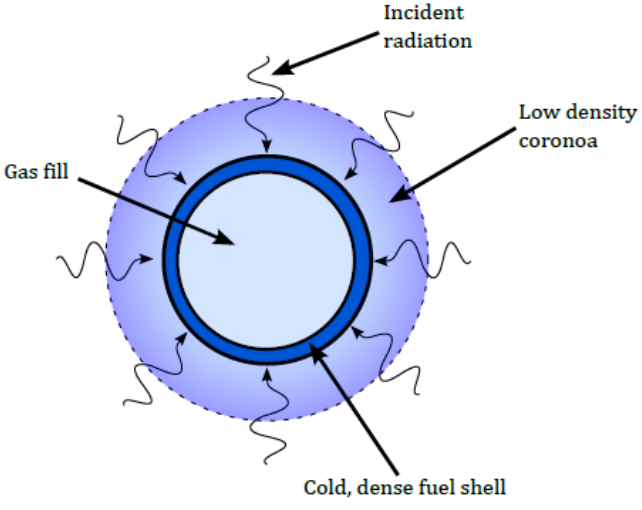

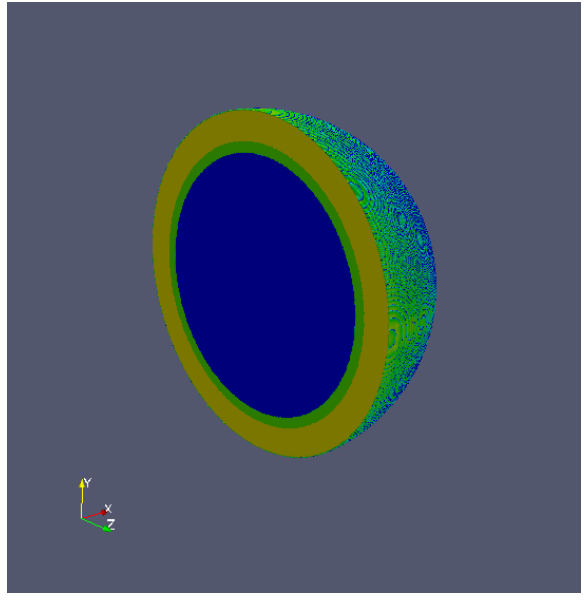

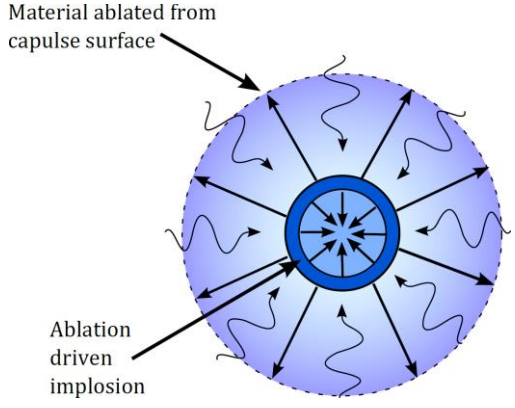

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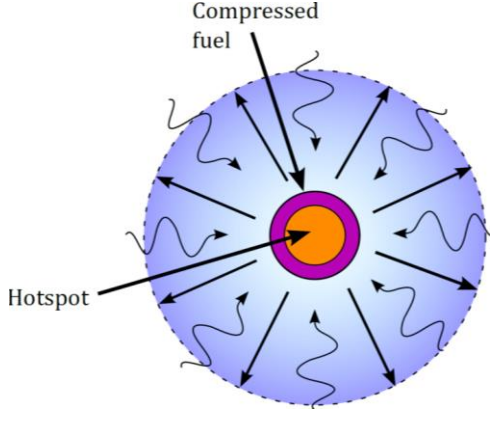

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Demonstration of Ignition, Burn and 'Breakeven'

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Science & Environment

Breakthrough in nuclear fusion energy announced

13 December 2022 · Comments

Climate change

CBS MORNINGS ›

U.S. announces nuclear fusion energy breakthrough: "One of the most impressive scientific feats of the 21st century"

BY LILIA LUCIANO, CAMILLE C. KNOX
UPDATED ON: DECEMBER 13, 2022 / 11:46 AM / CBS NEWS

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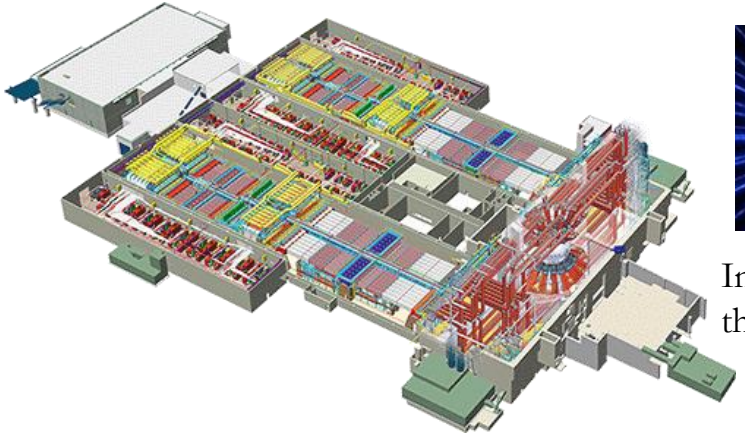
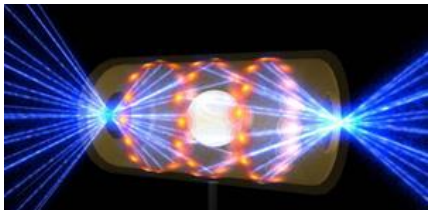
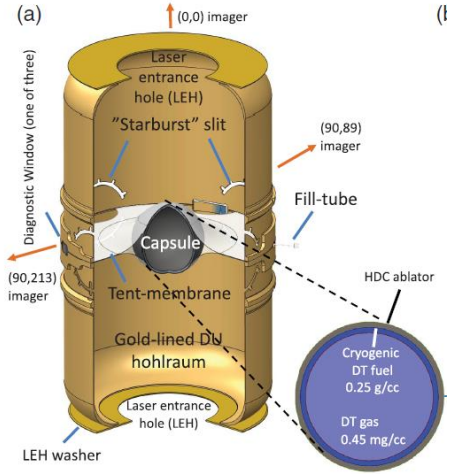
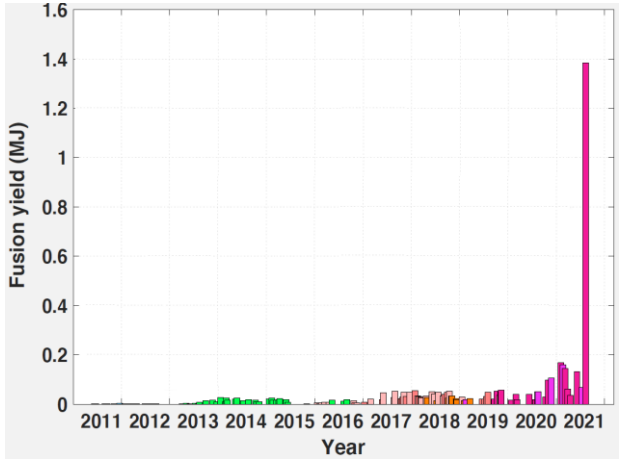




Indirect Drive Inertial Fusion on the National Ignition Facility





August 8th 2021 – First demonstration of a Burning Plasma – 1.3 MJ

December 4th 2022 – First demonstration of net energy gain - 3.15 MJ

Much needs to be done to turn Inertial Fusion into an energy source

It should be stressed that demonstration of energy gain on NIF was a science experiment and was not intended as an efficient means of generating energy

The experiment however proved that 'ignition' works,
this is the key process through which large energies can be generated by Inertial Fusion

To achieve a source of competitively priced energy we need a way to generate still more energy, by producing the same **extraordinary** conditions, repetitively in a much **simpler** and above all **cheaper** system

A broad range of approaches to Inertial Fusion Energy are now being explored,
including laser direct drive, projectile driven inertial fusion and magnetic-inertial fusion schemes, through national and international programs, private venture funding and public-private partnerships

The UK is well positioned to exploit its expertise in Inertial Fusion

PHYSICAL REVIEW LETTERS **129,** 075001 (2022)

Editors' Suggestion | Featured in Physics

Lawson Criterion for Ignition Exceeded in an Inertial Fusion Experiment

H. Abu-Shawareb *et al.*[*]
(Indirect Drive ICF Collaboration)

[1]*General Atomics, San Diego, California 92186, USA*
[2]*Lawrence Livermore National Laboratory, P.O. Box 808, Livermore, California 94551-0808, USA*
[3]*Massachusetts Institute of Technology, Cambridge, Massachusetts 02139, USA*
[4]*Polymath Research Inc., 827 Bonde Court, Pleasanton, California, USA 94566*
[5]*Los Alamos National Laboratory, Mail Stop F663, Los Alamos, New Mexico 87545, USA*
[6]*Nevada National Security Site, 232 Energy Way, North Las Vegas, Nevada 89030, USA*
[7]*Sandia National Laboratories, P.O. Box 5800 Albuquerque, New Mexico 87123, USA*
[8]*Imperial College London, Plasma Physics, South Kensington Campus, London, SW7 2AZ, United Kingdom*
[9]*Luxel Corporation, P.O. Box 1879, 60 Saltspring Drive, Friday Harbor, Washington 8250, USA*
[10]*Laboratory for Laser Energetics, University of Rochester, Rochester, New York 14623, USA*
[11]*University of California at Berkeley, Department of Nuclear Engineering, 4165 Etcheverry Hall, Berkeley, California 94720-1730, USA*
[12]*Lawrence Berkeley National Laboratory, 1 Cyclotron Road, Berkeley, California 94720, USA*
[13]*Gryphon Technologies, 303 Lindbergh Avenue, Livermore, California 94551, USA*
[14]*Princeton Plasma Physics Laboratory, 100 Stellarator Road, Princeton, New Jersey 08540, USA*
[15]*CEA/DAM/DIF, 91297 Arpajon cedex, France*
[16]*National Nuclear Security Administration, Office of Defense Programs, United States Department of Energy, Washington, D.C. 20585, USA*
[17]*SLAC National Accelerator Laboratory, Menlo Park, California 94025, USA*
[18]*University of New Mexico, Department of Nuclear Engineering, MSC01 1120, 1 University of New Mexico, Albuquerque, New Mexico 87131-0001, USA*
[19]*University of Michigan, Climate & Space Research Building, 2455 Hayward Street, Ann Arbor, Michigan 48109-2143, USA*
[20]*Kentech Instruments Ltd., Isis Building, Howbery Park, Wallingford, Oxfordshire OX10 8BD, United Kingdom*
[21]*Atomic Weapons Establishment, Aldermaston RG7 4PR, United Kingdom*
[22]*Department of Physics, Clarendon Lab, University of Oxford, Parks Road, Oxford OX1 3PU, United Kingdom*
[23]*Spectral Sciences Inc., 4 Fourth Avenue, Burlington, Massachusetts 01803-3304, USA*
[24]*Fraunhofer Institute for Laser Technology ILT, 52066 Aachen, Germany*
[25]*RWTH Aachen University, 52066 Aachen, Germany*
[26]*Optical Sciences Centre, Department of Physics and Astronomy, Swinburne University of Technology, Hawthorn, Victoria 3122, Australia*
[27]*United States Naval Research Laboratory, Plasma Physics Division, 4555 Overlook Avenue SW, Washington, D.C. 20375, USA*
[28]*Washington State University, Office of Research, P.O. Box 641060, Pullman, Washington 99164-1060, USA*
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[30]*University of Nevada at Reno, Department of Physics, MS 0220, 1664. Virginia Street, Reno, Nevada 89557, USA*
[31]*Université of Paris-Saclay, CEA, LMCE, 91680 Bruyères-le-Châtel, France*

While Inertial Fusion is a predominantly US program at the moment the UK and France are acknowledged as major contributors to the achievement of ignition.

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UK universities are World leading in the science supporting and have trained a significant fraction of US Inertial Fusion scientists

Our strong interactions with the US program provide the UK with collaborative access to multi-billion dollar experimental facilities at US national laboratories

The UK has World leading capabilities in Theory and Simulation, Plasma Diagnostic Techniques and High Power Laser technology

Imperial College London

Jeremy Chittenden

CIFS

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Imperial College

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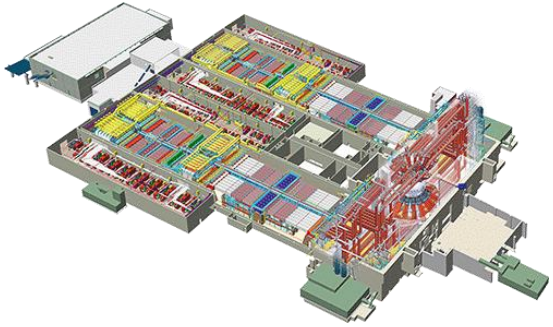

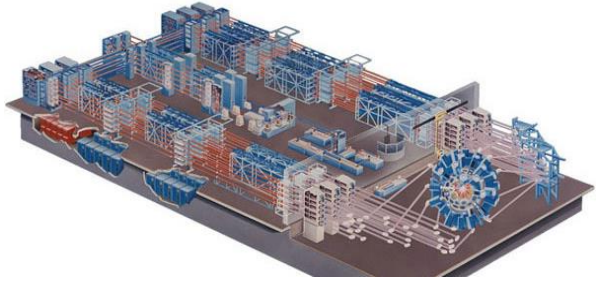

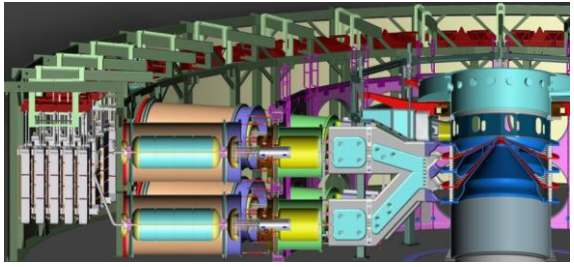

Fusion Energy APPG, June 27th 2023

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Back up slides

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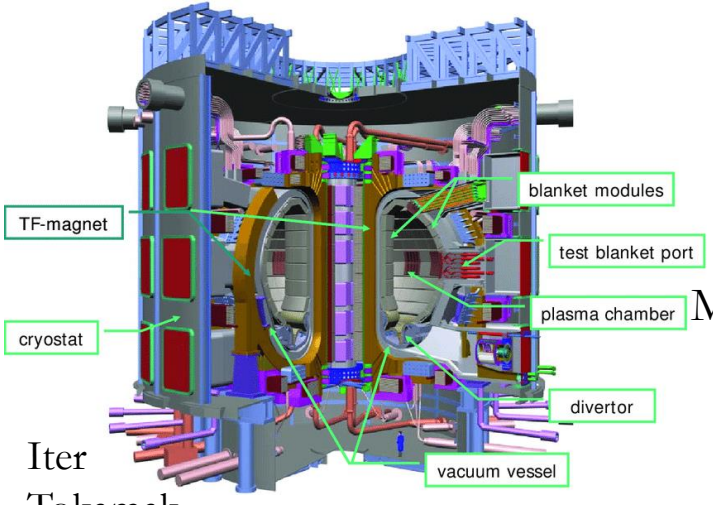
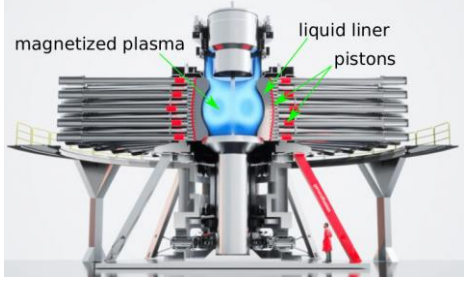


Iter
Tokamak

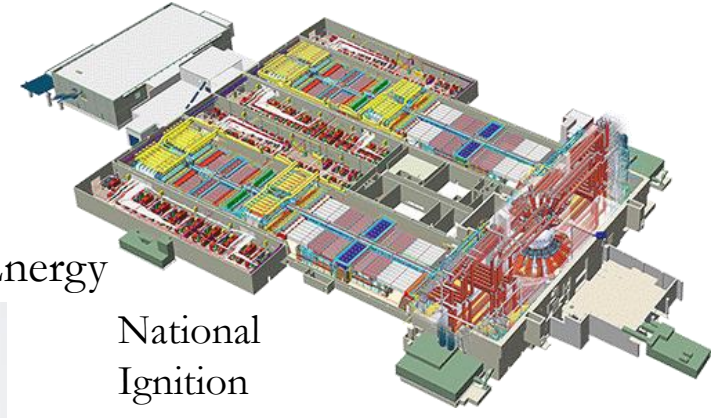
Steady state
Timescales - minutes or hours
Plasma size - 10m

Magneto-Inertial Fusion Energy



Pulsed
Timescales - millionth or thousandth of a second
Plasma size - 10cm - 1m

Inertial Fusion Energy



National
Ignition
Facility

Pulsed
Timescales - billionth of a second
Plasma size - a tenth of a mm
(thickness of human hair)

The UK has considerable expertise in Magnetic, Inertial and Magneto-Inertial Fusion

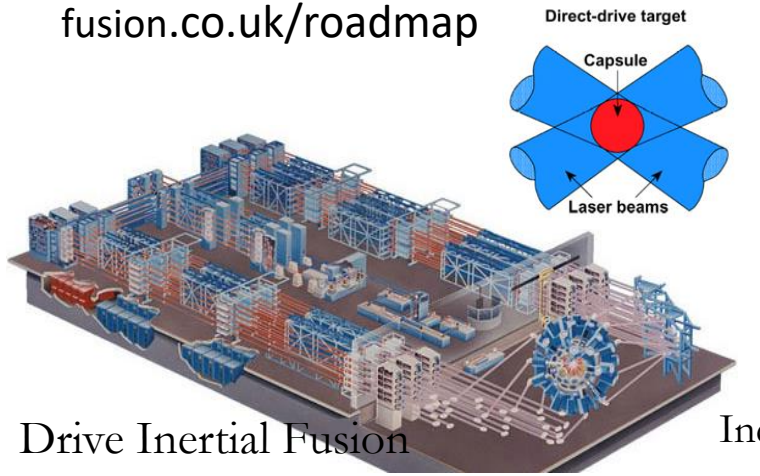
Imperial College London

CIFS

The UK Inertial Fusion Roadmap

The UK Inertial Fusion Consortium draws members from all UK groups with research interests in Inertial Fusion. From this, a small group, the Roadmap Committee, was tasked with drafting a 15-year Roadmap. The Roadmap Committee was: R.H.H. Scott (Chair), T.D. Arber, A.R. Bell, J. Chittenden, W.J. Garbett, P.A. Norreys, J. Pasley and N. Woolsey. We also acknowledge the extensive contributions of S. Rose and G. Gregori to the Roadmap. The Roadmap was subsequently revised based on input from the wider UK Inertial Fusion Consortium. The views expressed within this document are personal opinions and do not necessarily represent those of their institutions.

https://www.inertial-fusion.co.uk/roadmap



Drive Inertial Fusion

Commonwealth Fusion Systems
generalfusion
tae TECHNOLOGIES
ZAP ENERGY
HELION
HB11 ENERGY
Tokamak Energy
FOCUSED ENERGY
TYPE ONE ENERGY
first light
MarvelFusion
LPP FUSION
AVALANCHE
MIFTI
nearstar FUSION
SHINE
RENAISSANCE FUSION
HelicityEpace
PrincetonSATELLITE
Princeton Stellarators
Helical Fusion
ELECTRIC FUSION SYSTEMS
EX-Fusion
HORNE TECHNOLOGIES
NK
REALTA FUSION
Xcimer Energy Company
nT-tao
STELLAREX
fuse

https://www.fusionindustryassociation.org/members

Inertial Fusion is a Rapidly Growing part of the Fusion Industry Sector