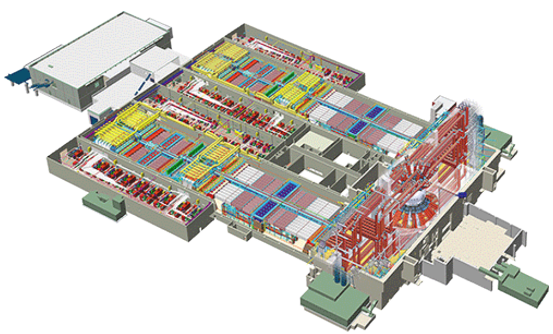
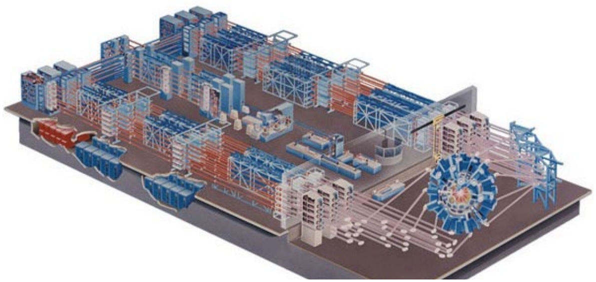
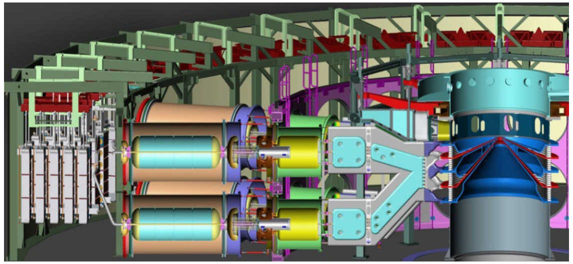
Jeremy Chittenden

Centre for Inertial Fusion Studies

Imperial College







NADM, September 7th 2023

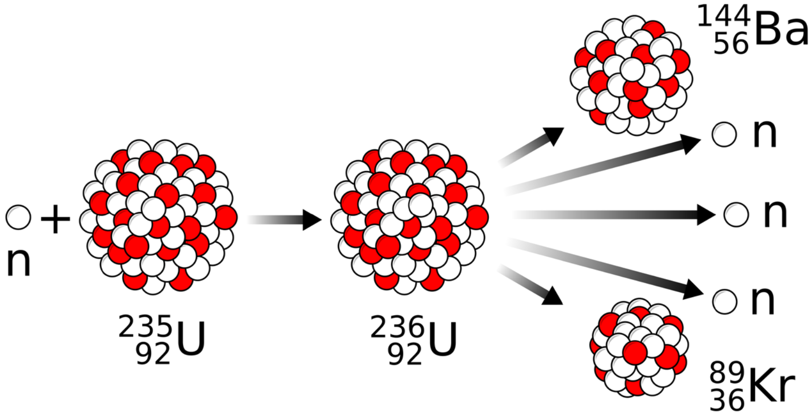
Fusion seeks to replace our reliance on fossil fuels with the energy source inside our Sun

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

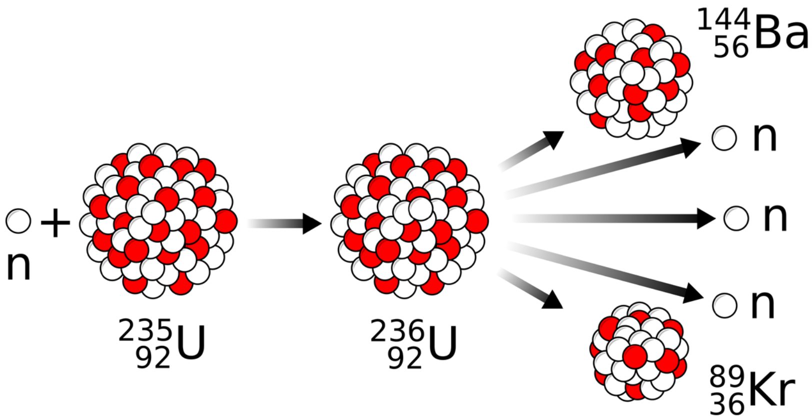
Fission and Fusion are different forms of Nuclear Reactions

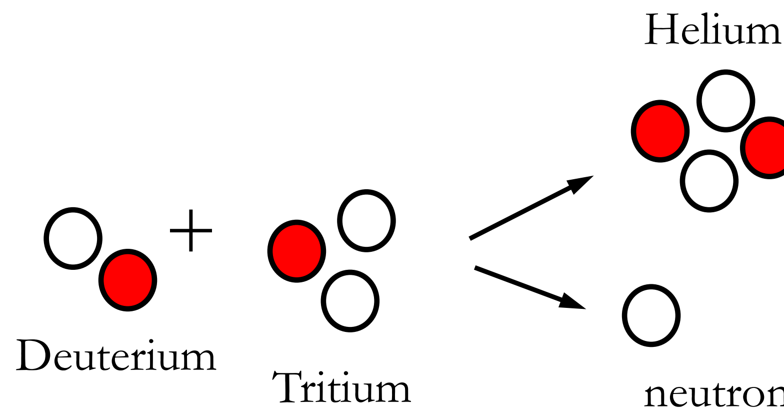


Conventional nuclear reactors use fission reactions to split heavy atoms

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

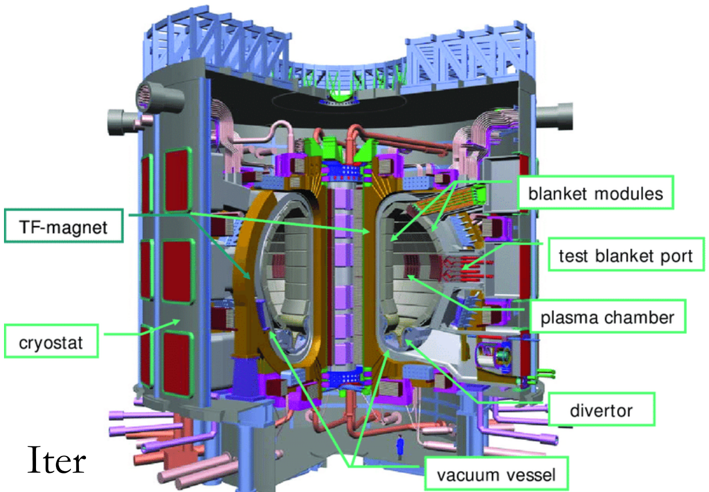
Fusion reactions instead combine light atoms

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

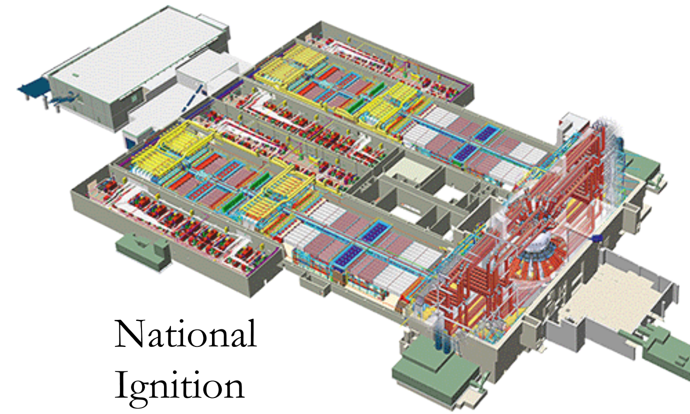
Steady state

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

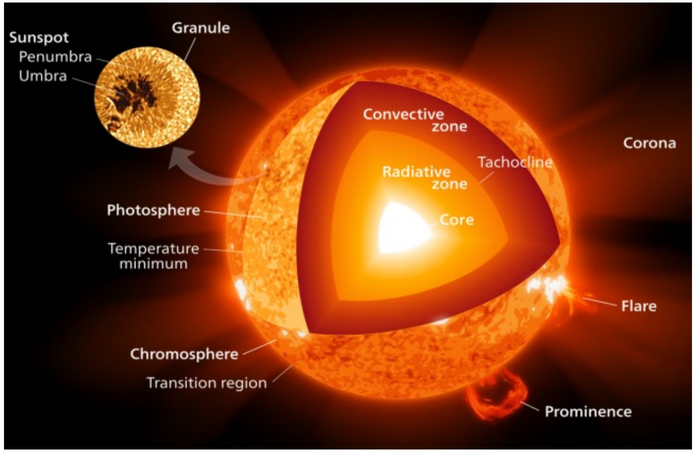
Timescales - billionth of a second

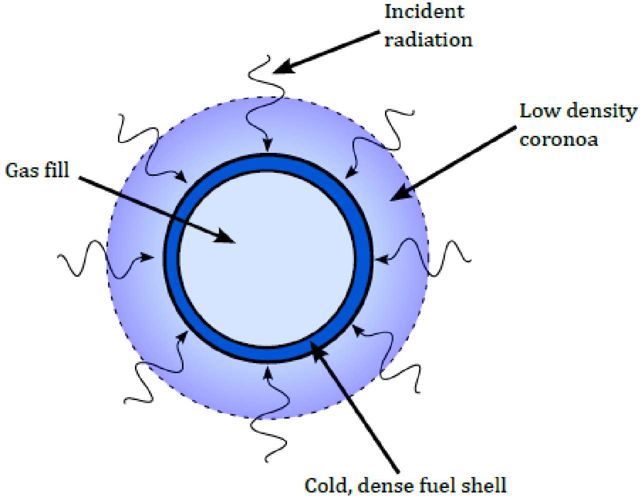
Plasma size - a tenth of a mm (thickness of human hair)

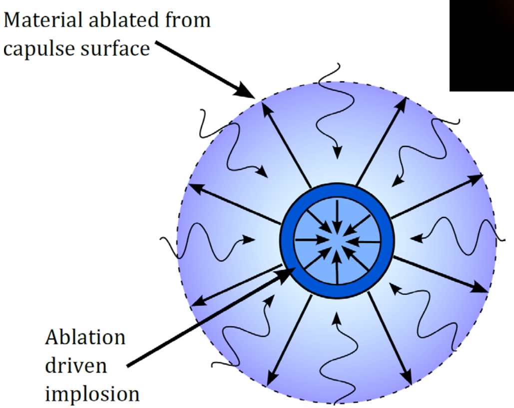
A lot of the underpinning technologies supporting reactor designs are common however there some are key differences such as ‘energy gain’ and ‘standoff’

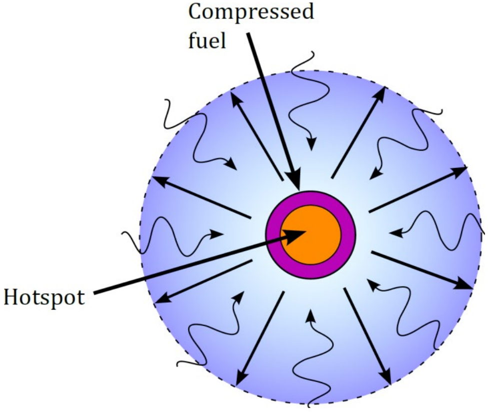
Inertial Fusion recreates conditions at the centre of the Sun

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



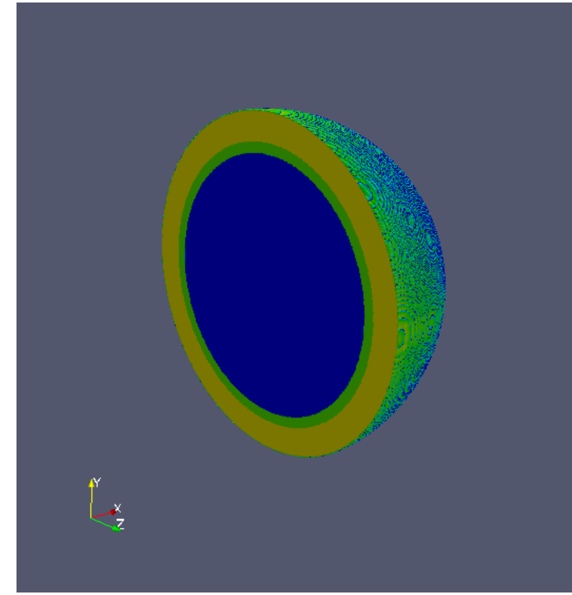






Fusion fuel is encased in a sphere of high density carbon (synthetic diamond) the size of a pepper corn

Inertial Fusion recreates conditions at the centre of the Sun



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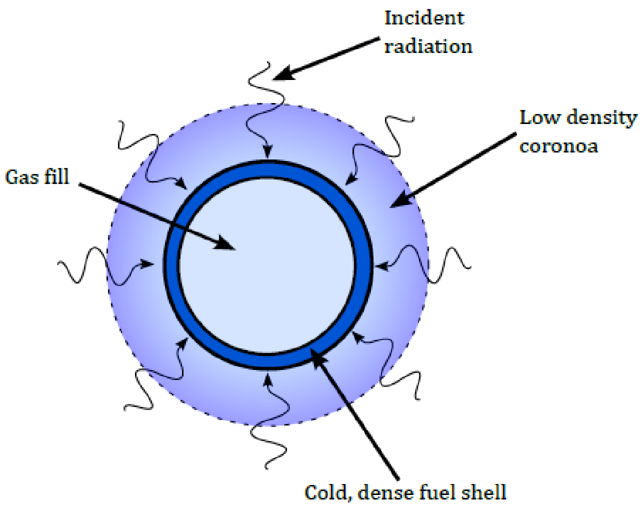

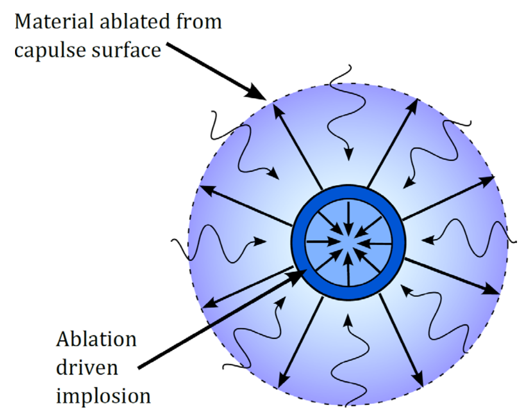

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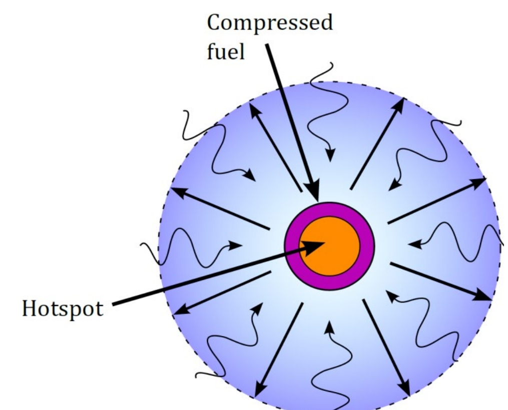

Demonstration of Ignition, Burn and 'Breakeven'

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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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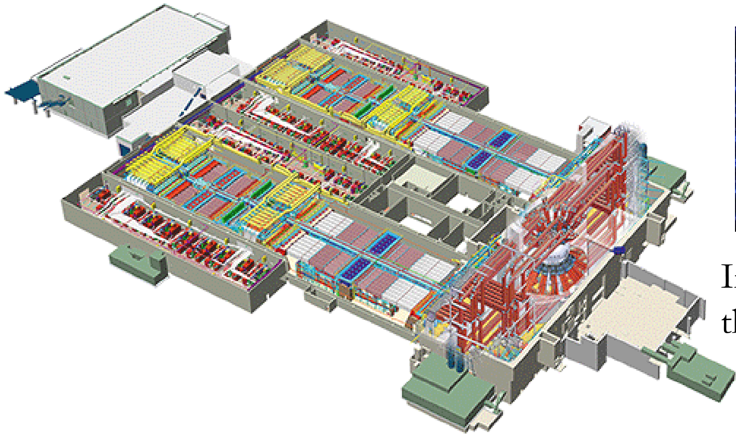
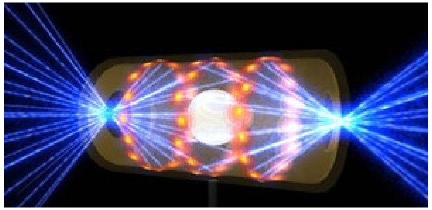
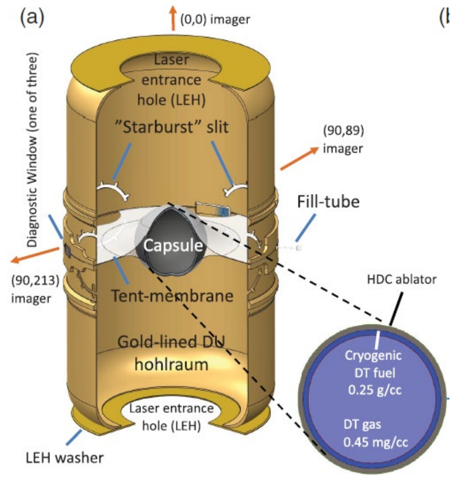
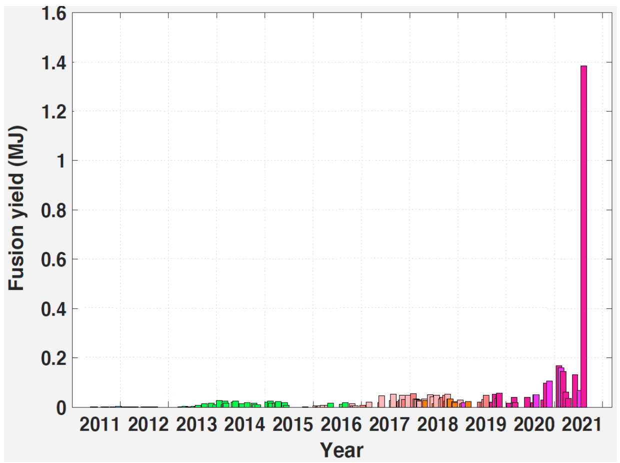




Indirect Drive Inertial Fusion on the National Ignition Facility





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 magneto-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*
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[14]*Princeton Plasma Physics Laboratory, 100 Stellarator Road, Princeton, New Jersey 08540, USA*
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[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*
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[20]*Kentech Instruments Ltd., Isis Building, Howbery Park, Wallingford, Oxfordshire OX10 8BD, United Kingdom*
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[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*
[29]*Laboratoire pour l'utilisation des Lasers Intenses chez École Polytechnique, F-91128 Palaiseau cedex, France*
[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.

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

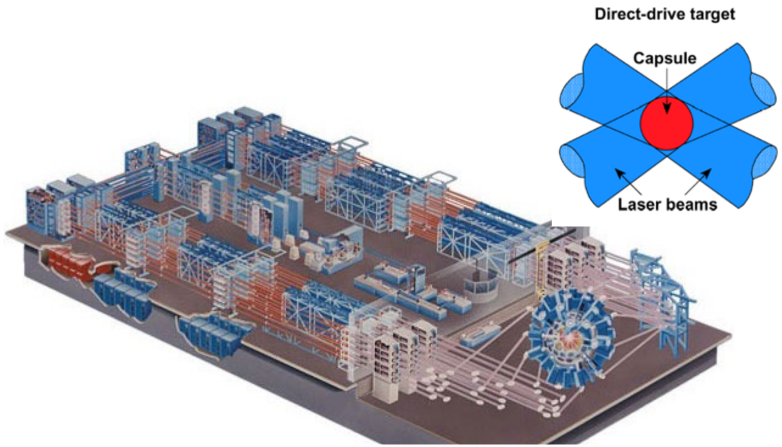
The UK has World leading capabilities in Theory and Simulation, Plasma Diagnostic Techniques and High Power Laser technology

The UK Inertial Fusion Consortium and Roadmap

The UK Inertial Fusion Consortium
is comprised of 85 members from
AWE,
Imperial College London,
Lancaster University,
University of Oxford,
Queens University Belfast,
STFC Rutherford Appleton Laboratory,
University of Strathclyde,
University of Warwick,
First Light Fusion
and University of York.

In 2022 the consortium published a roadmap outlining plans for growth in research, technology and training
https://www.inertial-fusion.co.uk/roadmap

The consortium aims to leverage on the success of ignition of NIF and to exploit UK expertise in different approaches to inertial fusion such as direct drive fusion, magneto-inertial fusion and impact driven fusion.

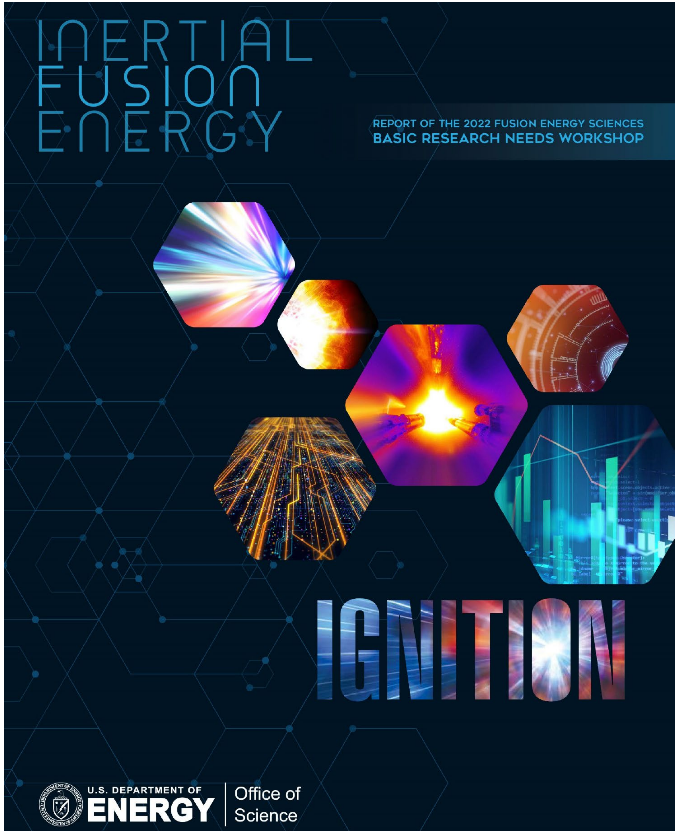


Drive Inertial Fusion

Imperial College London

CIFS

In 2022 the US DoE commissioned an assessment of the research needs for inertial fusion as an energy source



The DOE-sponsored Basic Research Needs (BRN) workshop, held in June 2022, produced a list of Priority Research Opportunities (PROs) to inform future research efforts in the areas constituting the building blocks of an IFE program:

- Target physics
  - Energy coupling
  - Compression and burn
  - Alternate fusion concepts
- Target design
- Driver technologies
- Power systems
- Cross-cutting fields
  - Theory and simulations
  - Machine learning and artificial intelligence
  - Measurement innovation
  - Workforce development
  - Research infrastructure

This led to 10 awards totalling $45 million for the initial phase of an inertial fusion energy program

Increasingly the fusion is being funded through combinations of national and international programs alongside private capital

There are now over 50 fusion start-up companies

https://www.fusionindustryassociation.org/members

And an even larger number of companies working on supporting technologies

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

Imperial College London

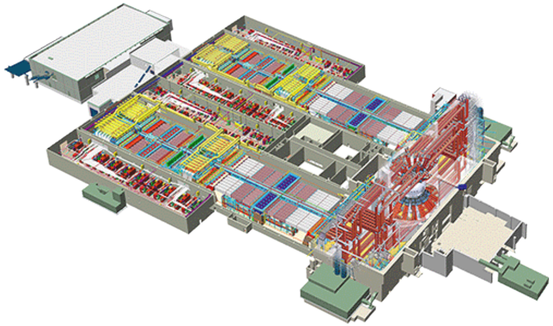
Jeremy Chittenden

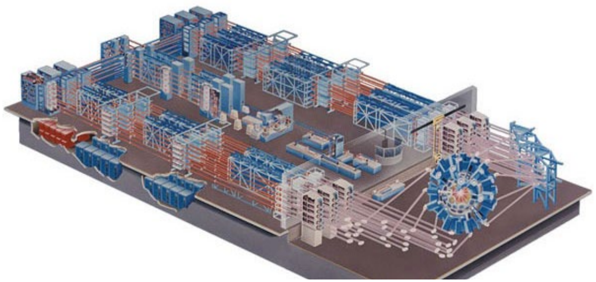
CIFS

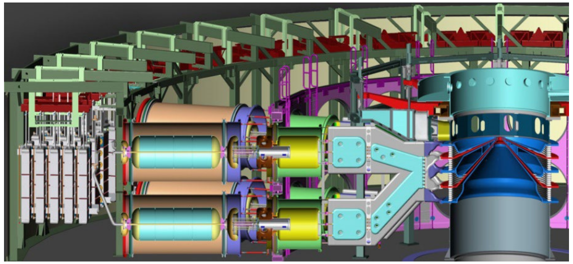
Centre for Inertial Fusion Studies

Imperial College

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







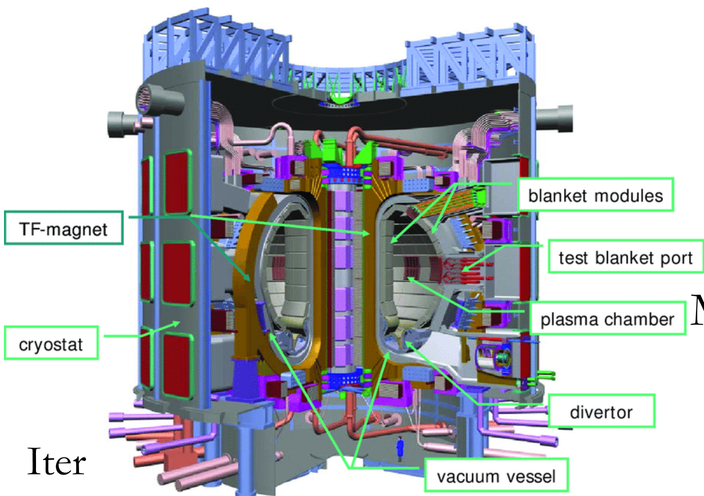
NADM, September 7th 2023

Imperial College London

Several Different Approaches to Fusion Energy Are Being Explored

CIFS

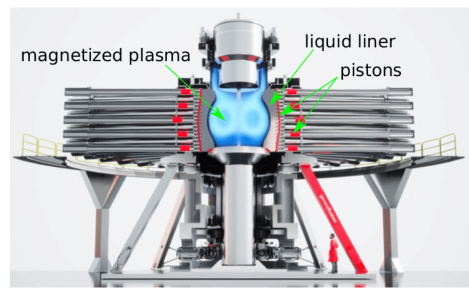
Magnetic Fusion Energy



Iter
Tokamak

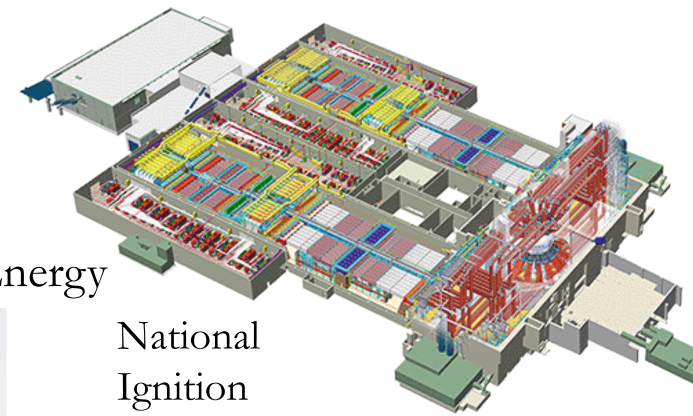
Steady state
Timescales - minutes or hours
Plasma size - 10m

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