Fusion energy within the next decade?

How private fusion companies accelerate the fusion reactor development

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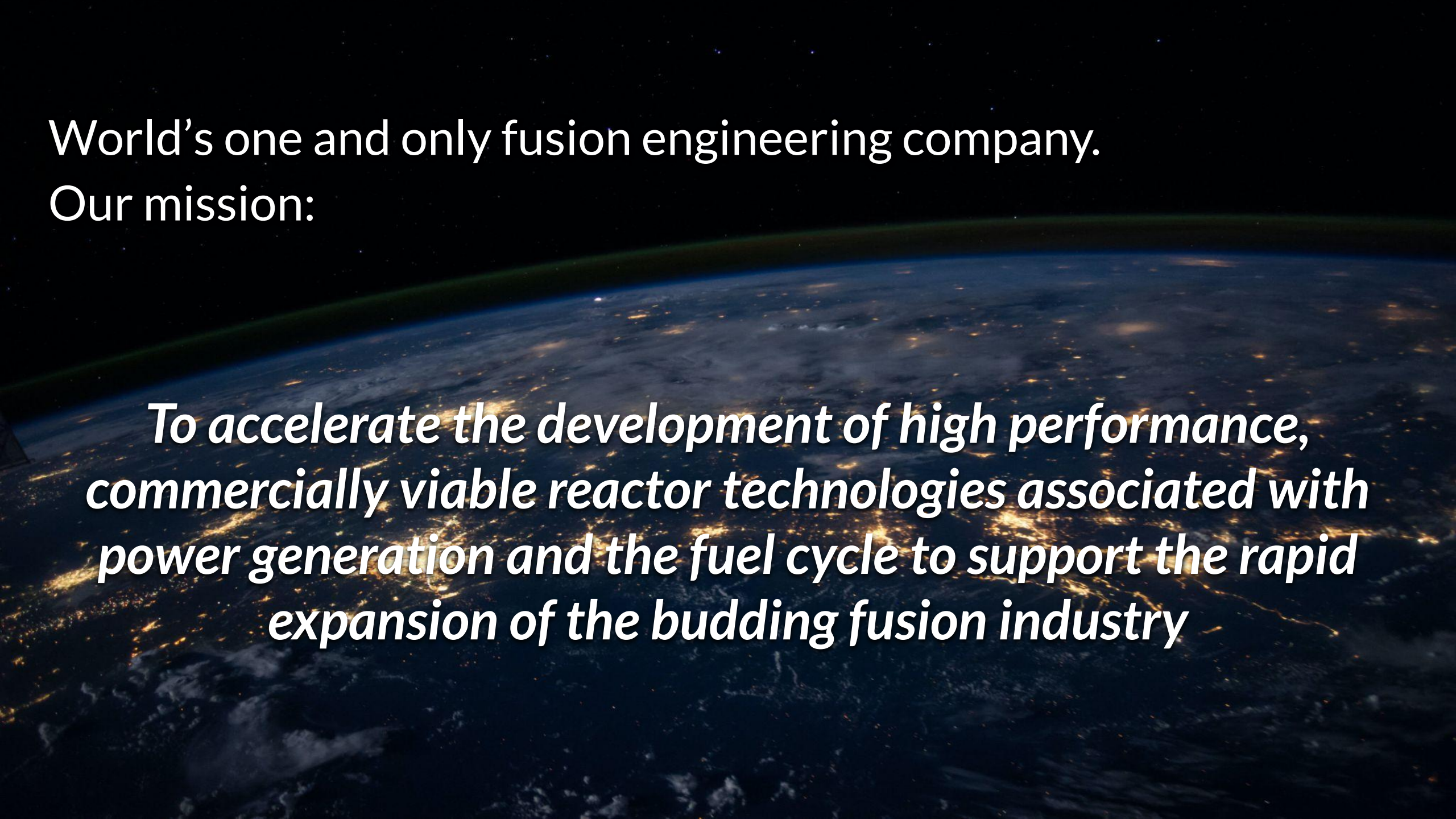
Colin Baus



World’s one and only fusion engineering company.
Our mission:

To accelerate the development of high performance, commercially viable reactor technologies associated with power generation and the fuel cycle to support the rapid expansion of the budding fusion industry

About myself

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Dr. Colin Baus, Head of Plant Technology

- Working in Kyoto, Japan
- PhD in astroparticle physics at KIT (2015 Blümer/Quast/Ulrich)
  - CMS: forward physics, cross section measurement
  - Pierre Auger Observatory: Cosmic rays at highest energies (10^{20} eV)
- Postdoc CERN/KIT
  - Co-author of nuclear and hadronic interaction simulation package *CRMC*
- Moved to Japan and worked in tech for 5 years
  - Chief Quant at SBI (largest online broker)
  - CTO at Obolus (financial cryptography)
- Joined Kyoto Fusioneering early 2021
  - Realised I miss physics and want to do something useful for humanity
  - ~10 people when I joined, now 6 times as many
  - Right place, right time
- Visiting Researcher at Kyoto University

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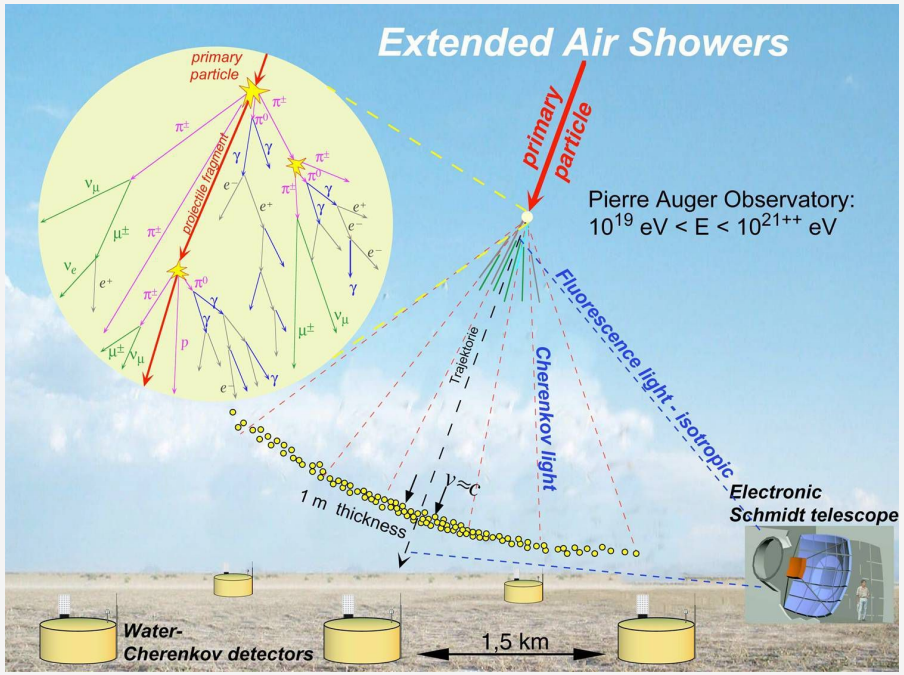
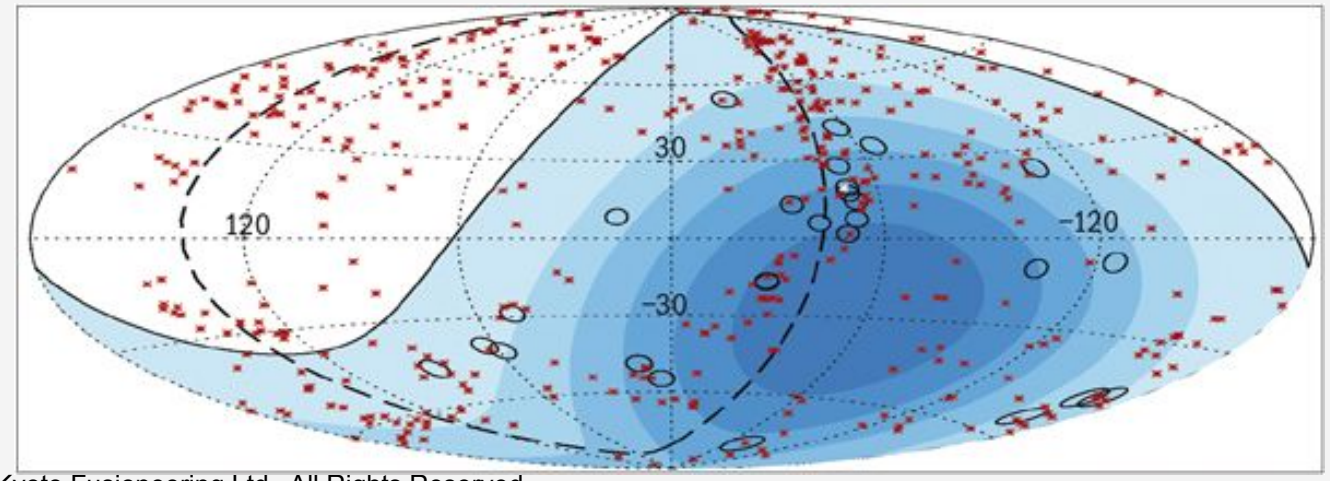
My KSETA past - Pierre Auger Observatory





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My KSETA past - LHC/CMS experiment

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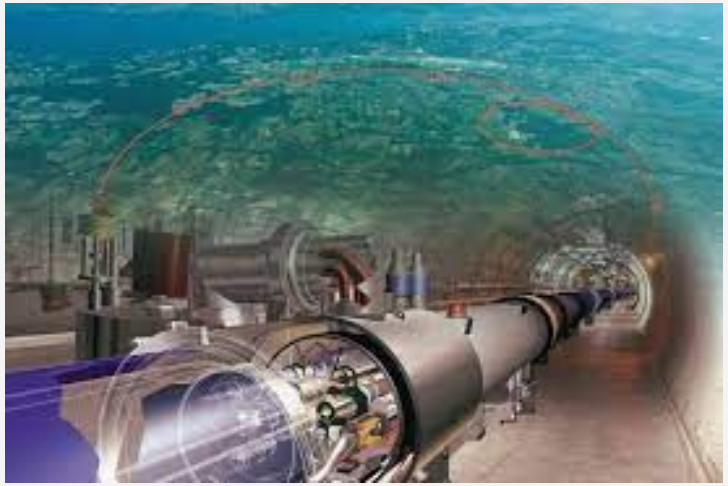

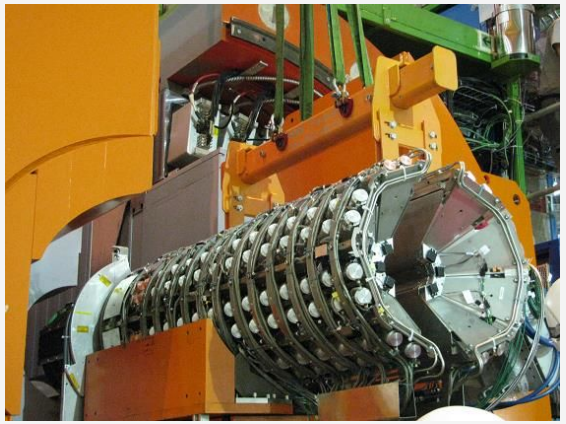

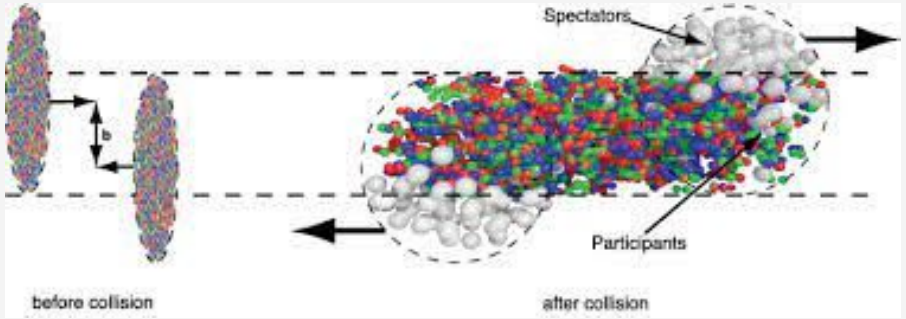

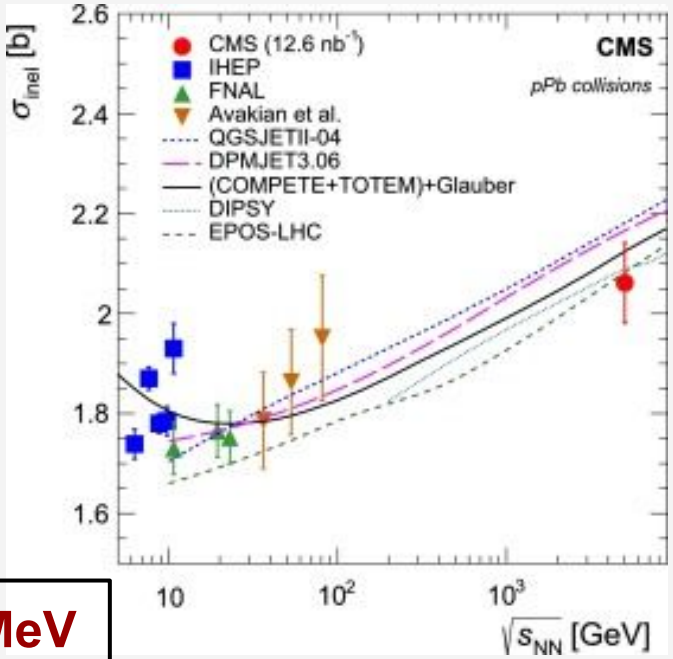

I am downgrading in energy PeV → TeV → MeV

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Company Profile

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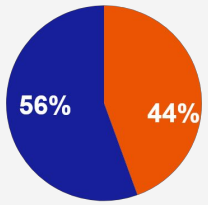
Established: October 2019

Funding (VC): ¥1.73B JPY (~$17M USD)

My team:

Academic Background



Japan Atomic Energy Agency
Nuclear Science Research Institute

The University of Manchester

Mitsubishi Heavy Industry

原子力エンジニアリング株式会社
NUCLEAR ENGINEERING Co.,Ltd.

Kyoto University

National Composites Centre

KIT Karlsruher Institut für Technologie

Mitsubishi Chemical

JGC

iter

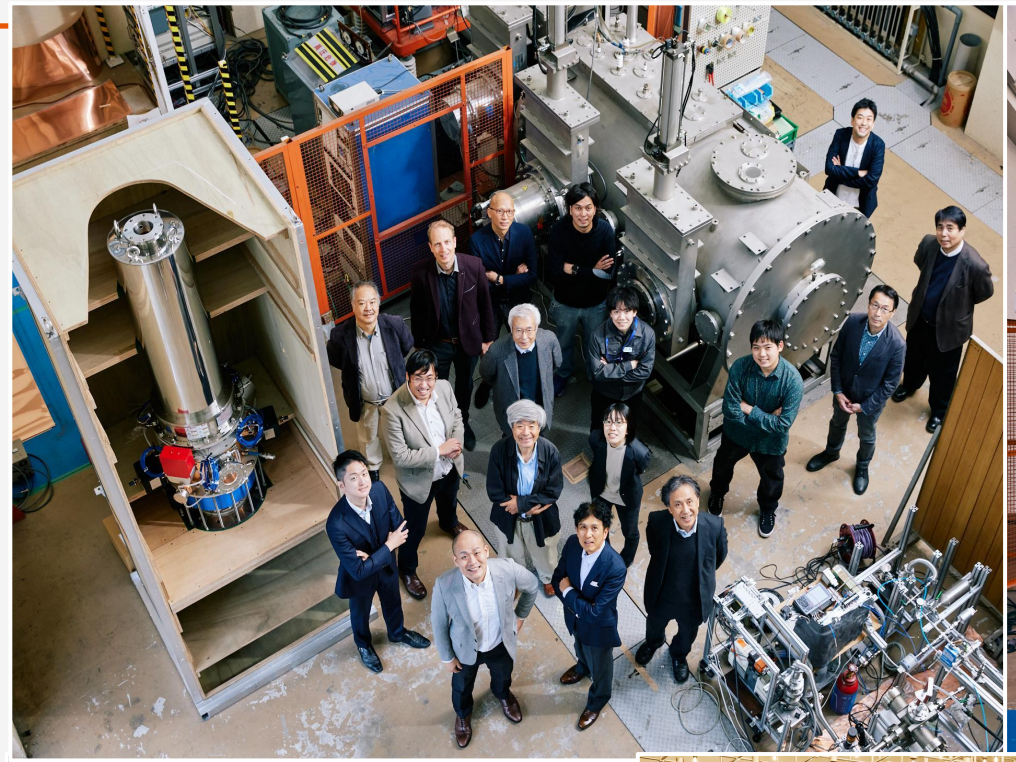
Locations: Kyoto (Laboratory)

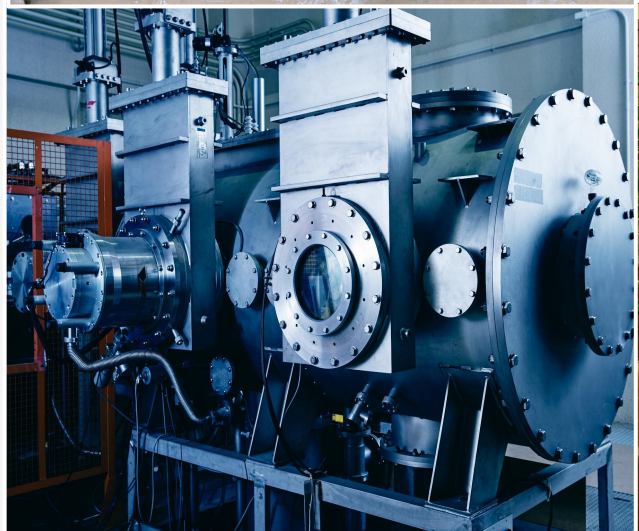
Tokyo (Business HQ)

Reading (UK HQ)

Delaware (US office)

Company size: ~60 staff (incl. part-time)





ISO 9001 2015 CERTIFIED

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Key features of fusion energy: 4-for-net-zero

The fusion reaction does not produce greenhouse emissions

No limit of primary fuels from the sea

No risk of runaway nuclear reaction causing meltdown

No high-level radioactive waste

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Fusion development has been led by huge projects in public sector

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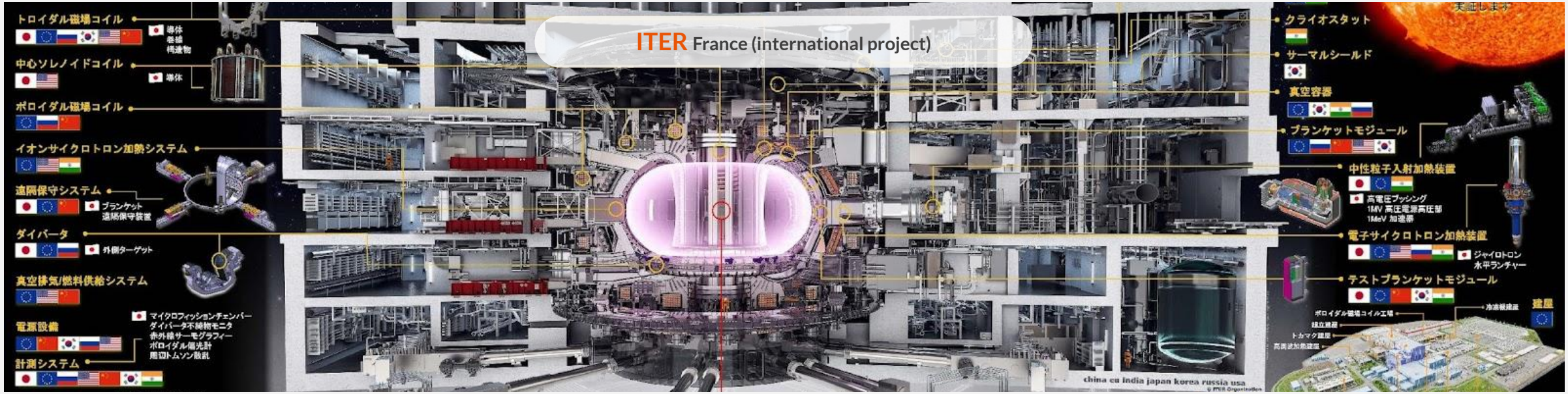

ITER France (international project)

Joint European Torus UK

National Ignition Facility U.S.

JT 60SA Japan

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Shifting gears: public and private support stronger than ever

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Substantial change as well as progress has been made in recent years in government fusion strategy.

Former British PM Boris Johnson outlined a **"Ten Point Plan for a Green Industrial Revolution"** (Nov 2020)

"Aims to build the commercially viable fusion energy plant in the UK by 2040"

15 sites are shortlisted for the UK fusion energy plant (June 2021)

Within 20 years?

White House Fusion Summit revealed **"Bold Decadal Vision for Commercial Fusion Energy"** (Mar 2022)

"Accelerate the viability of commercial fusion energy in coordination with the private sector"

NASEM "Have a viable design by 2028 and initial pilot plant operation in 2035~2040"

Within 15 years?

The rise of private enterprises has changed the game.

Commonwealth Fusion Systems "**Power an electrictrical grid by 2030**". Fundraised over $2.2 B from private investors, incl. Bill Gates.

In 8 years?

TAE technologies will "**Commercialise fusion by 2030**" with over $1.8B incl. Google

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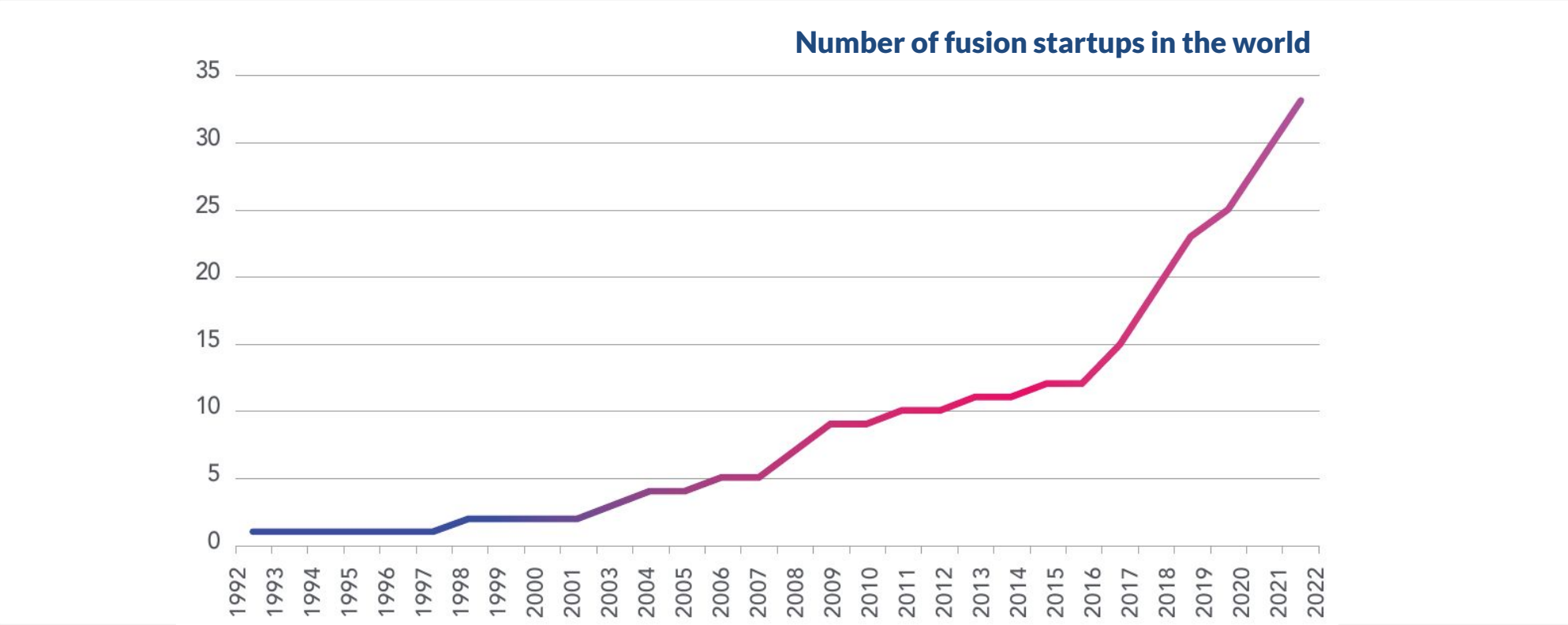
Drastic growth in the number of private fusion developers

- The number of private fusion companies has grown steadily since 2000, then accelerated over the last decade - over 50% of new companies have been established in the last 5 years
- **$4.8+ billion total invested** in private fusion companies as of June 2022



Accelerated growth of the number of players in the fusion industry

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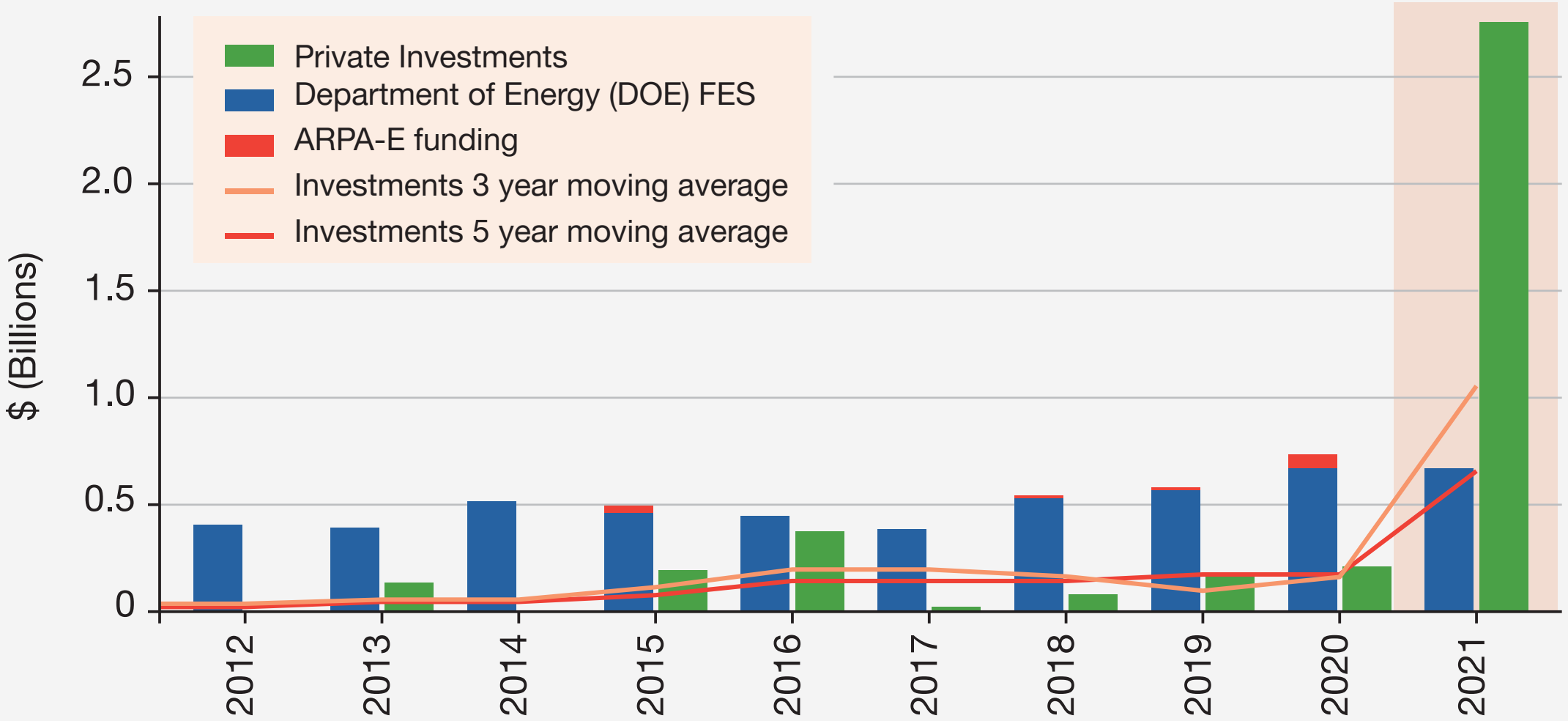
Fusion Industry Association, "The global fusion industry in 2022" (2022)

A new dawn for fusion energy

In 2021, private funding surpassed public funding in the US for the first time.



Credit: Sam Wurzel (U.S. DoE – ARPA-E)

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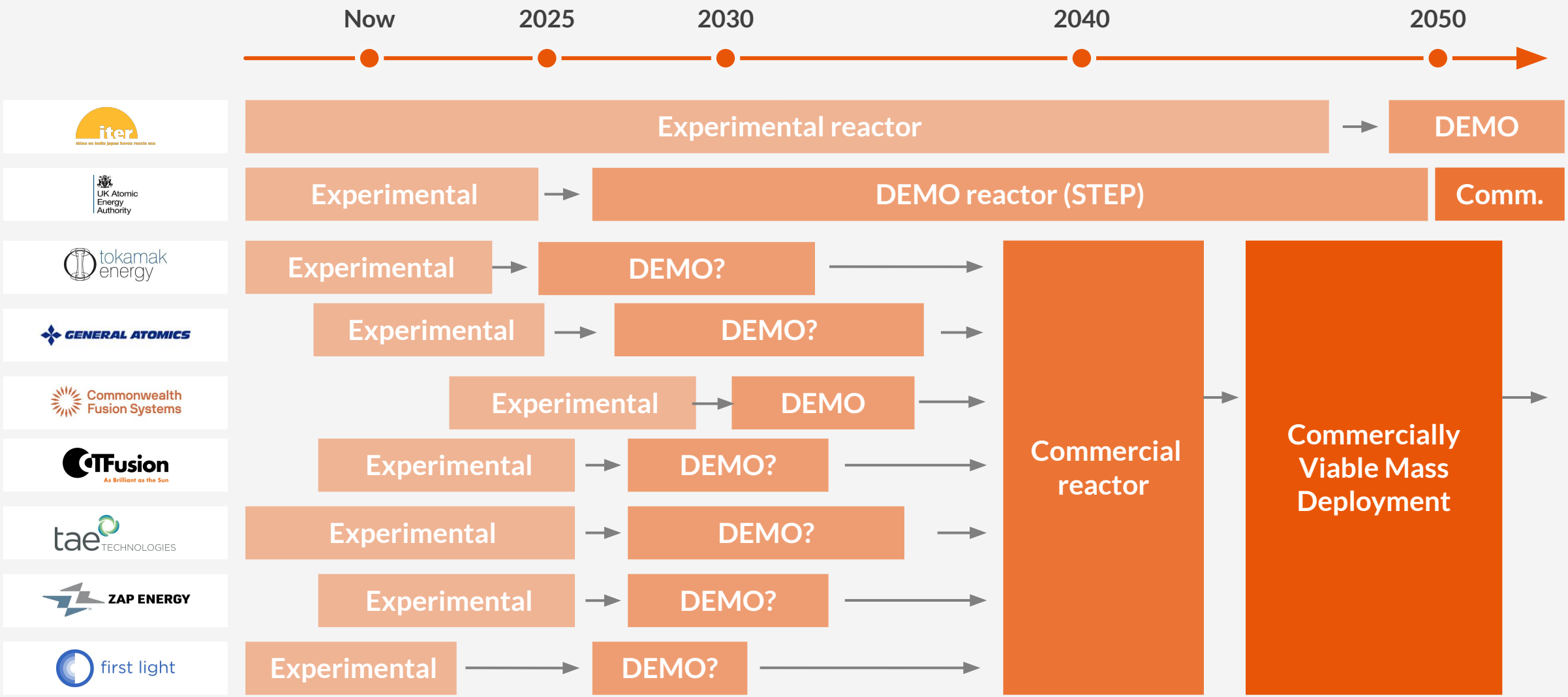
Fusion reactor market: a snapshot of the road ahead



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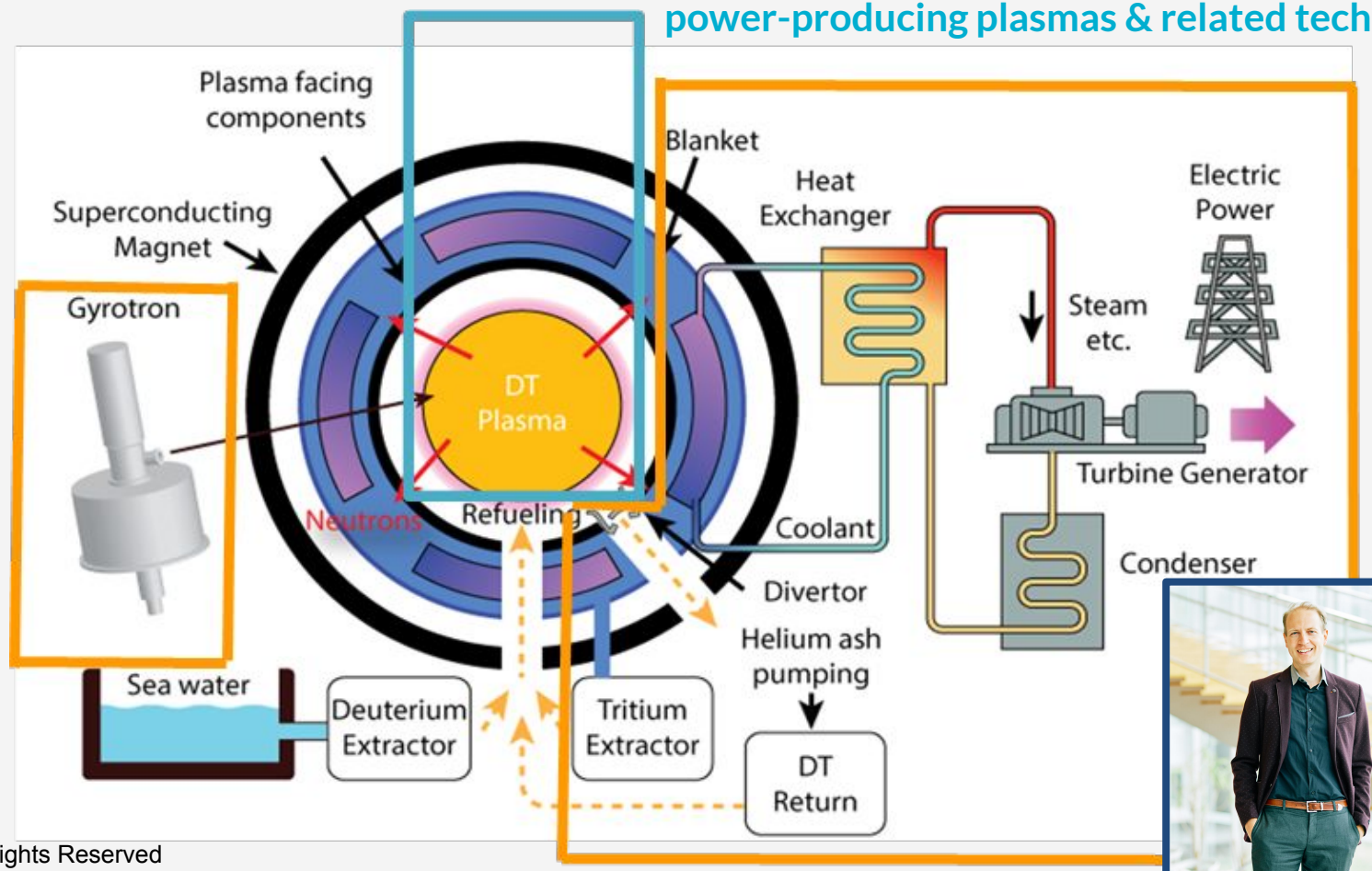
Our technology

Kyoto Fusioneering is the only company completely focused on developing *critical path* fusion reactor technologies in the world

Fusion developers around the world are working on power-producing plasmas & related technologies



Kyoto Fusioneering is focused on reactor technologies and engineering.

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Inside of a fusion reactor

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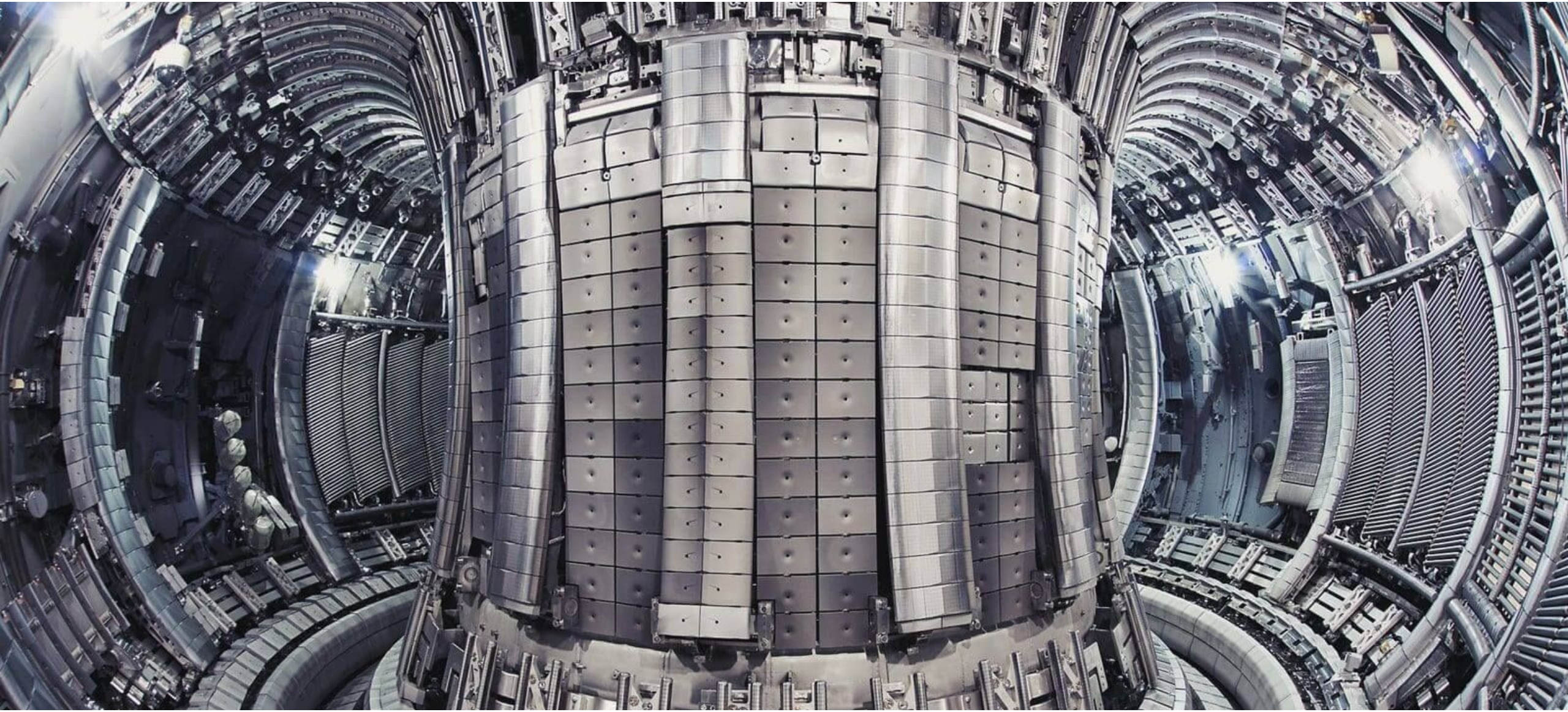
Picture from IDOM



Breeding Blanket

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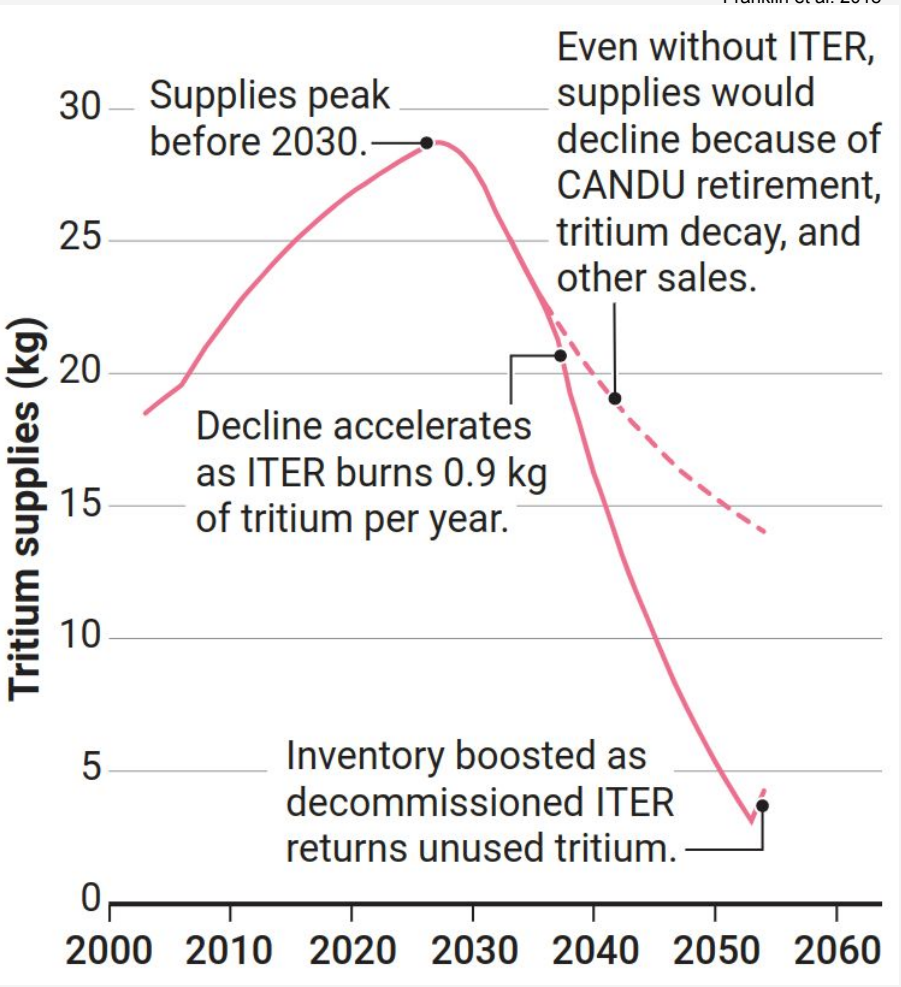
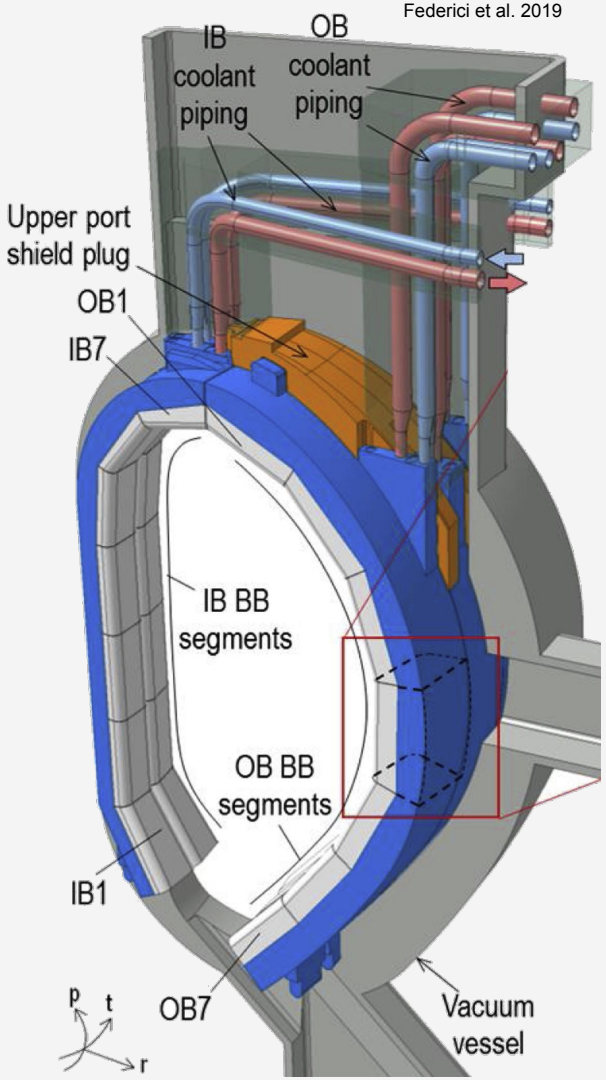
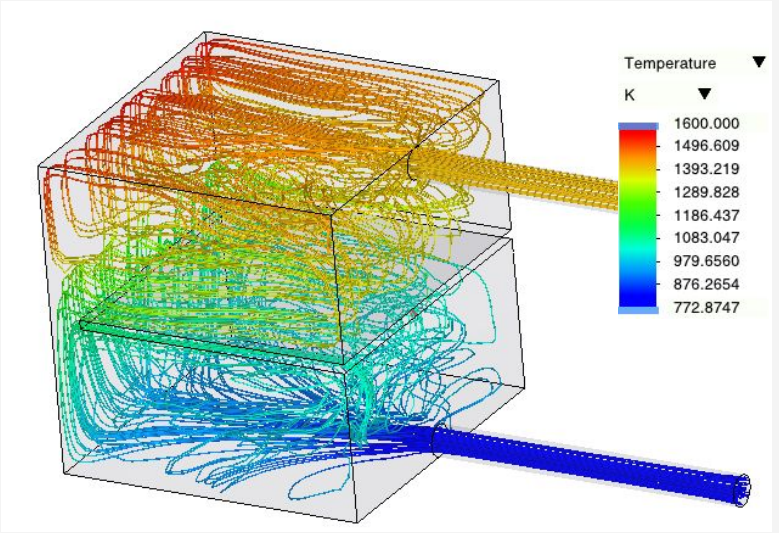
Magic that makes fuel from fuel: Tritium Breeding Ratio TBR>1 (hopefully 1.1)

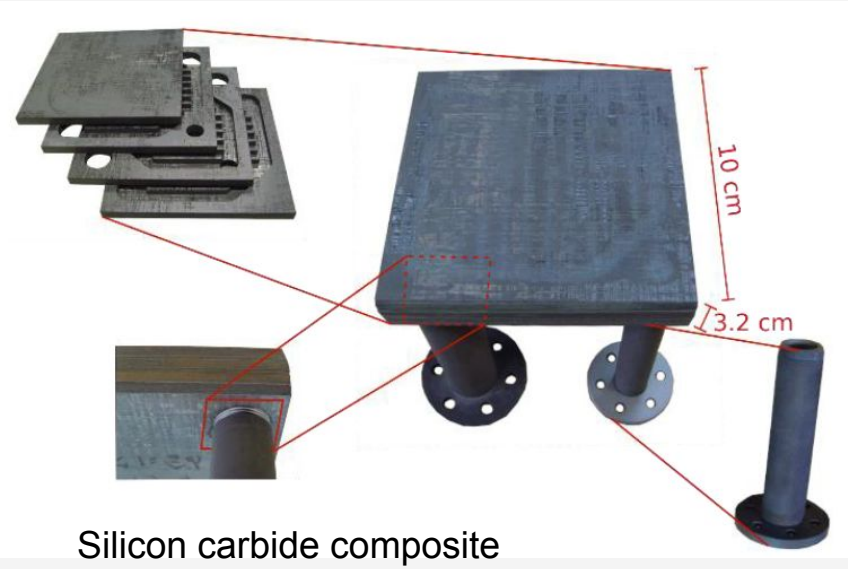
Franklin et al. 2018



Federici et al. 2019







Silicon carbide composite
(heat and radiation resistant)

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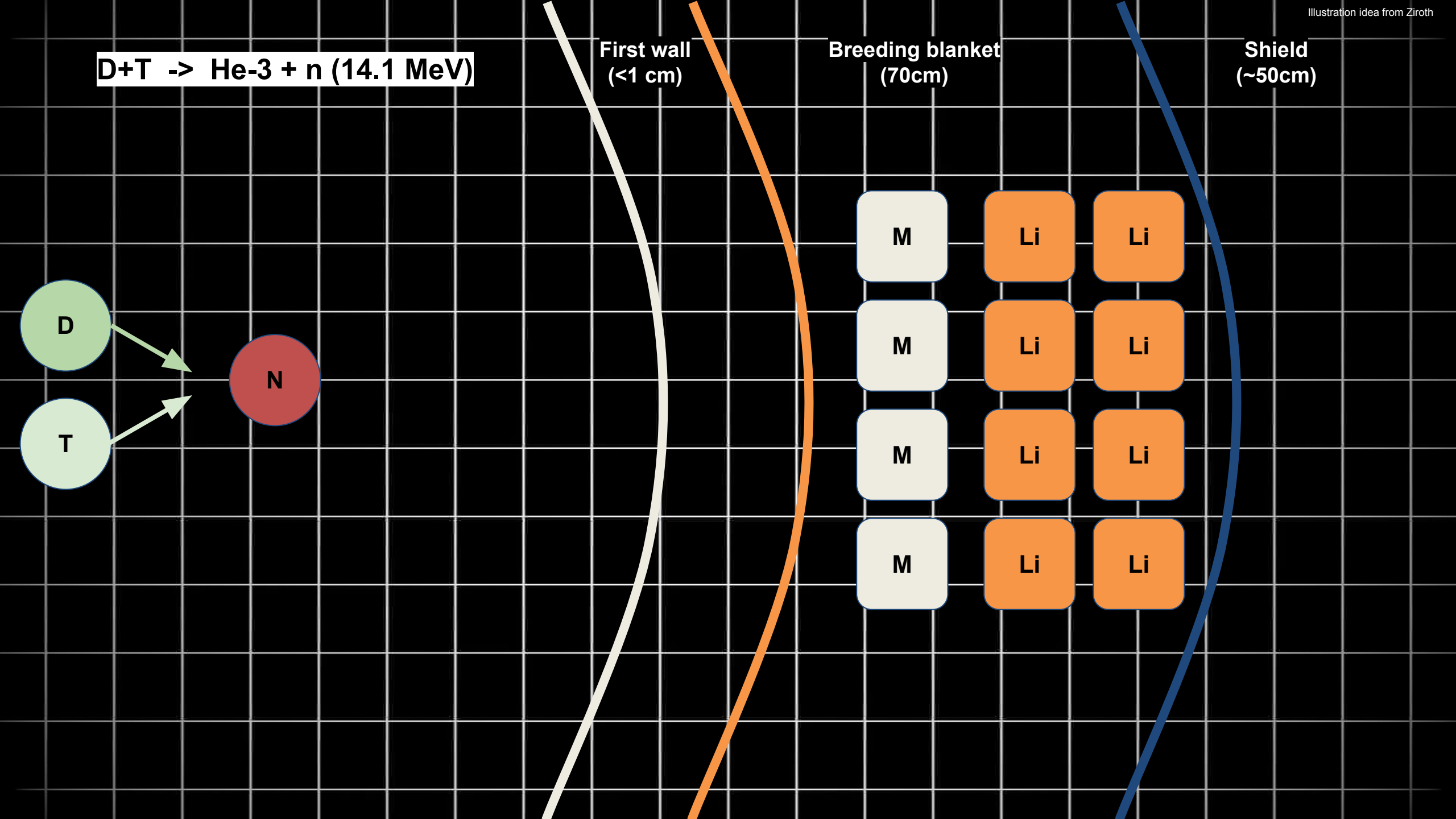
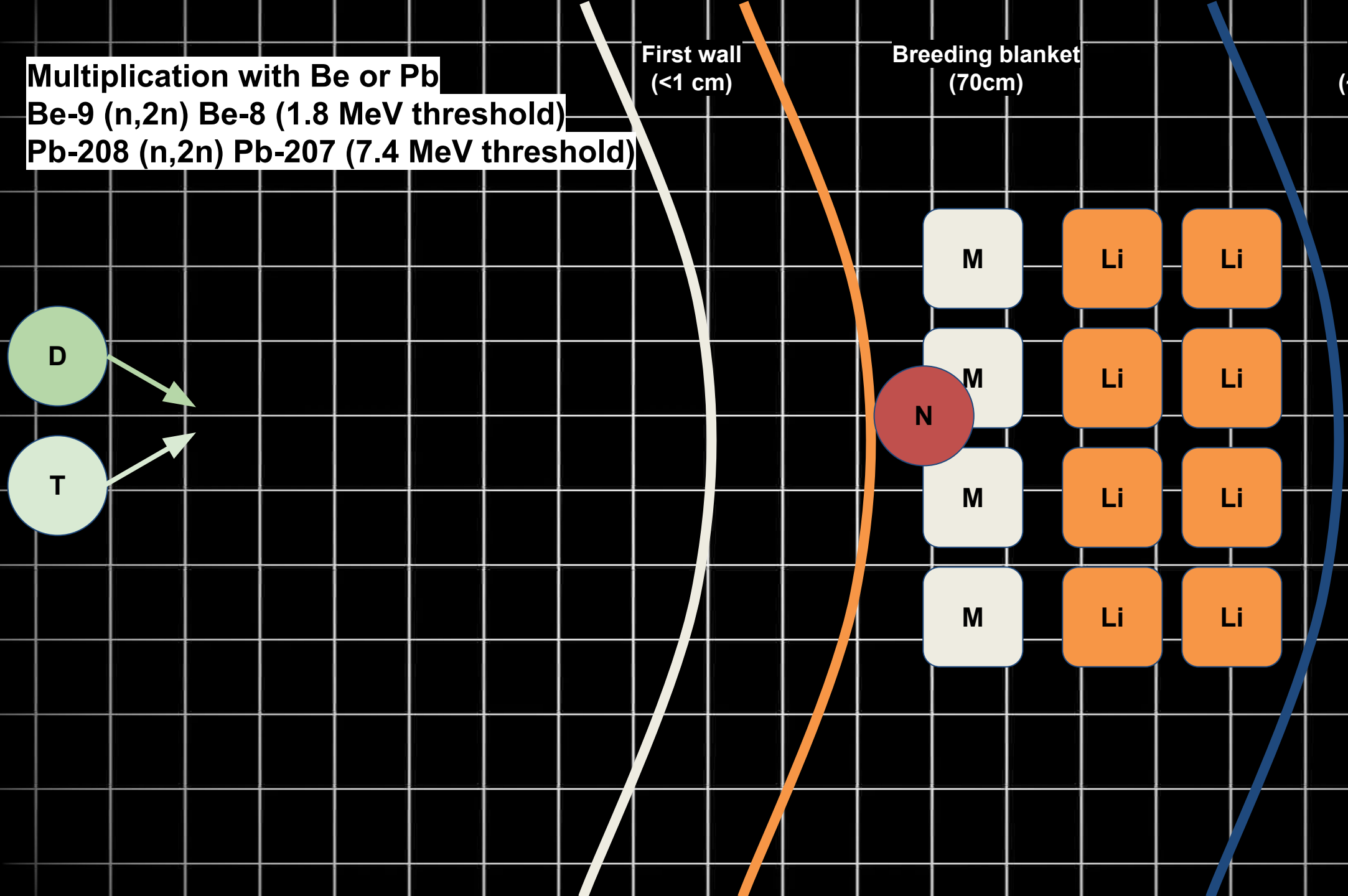
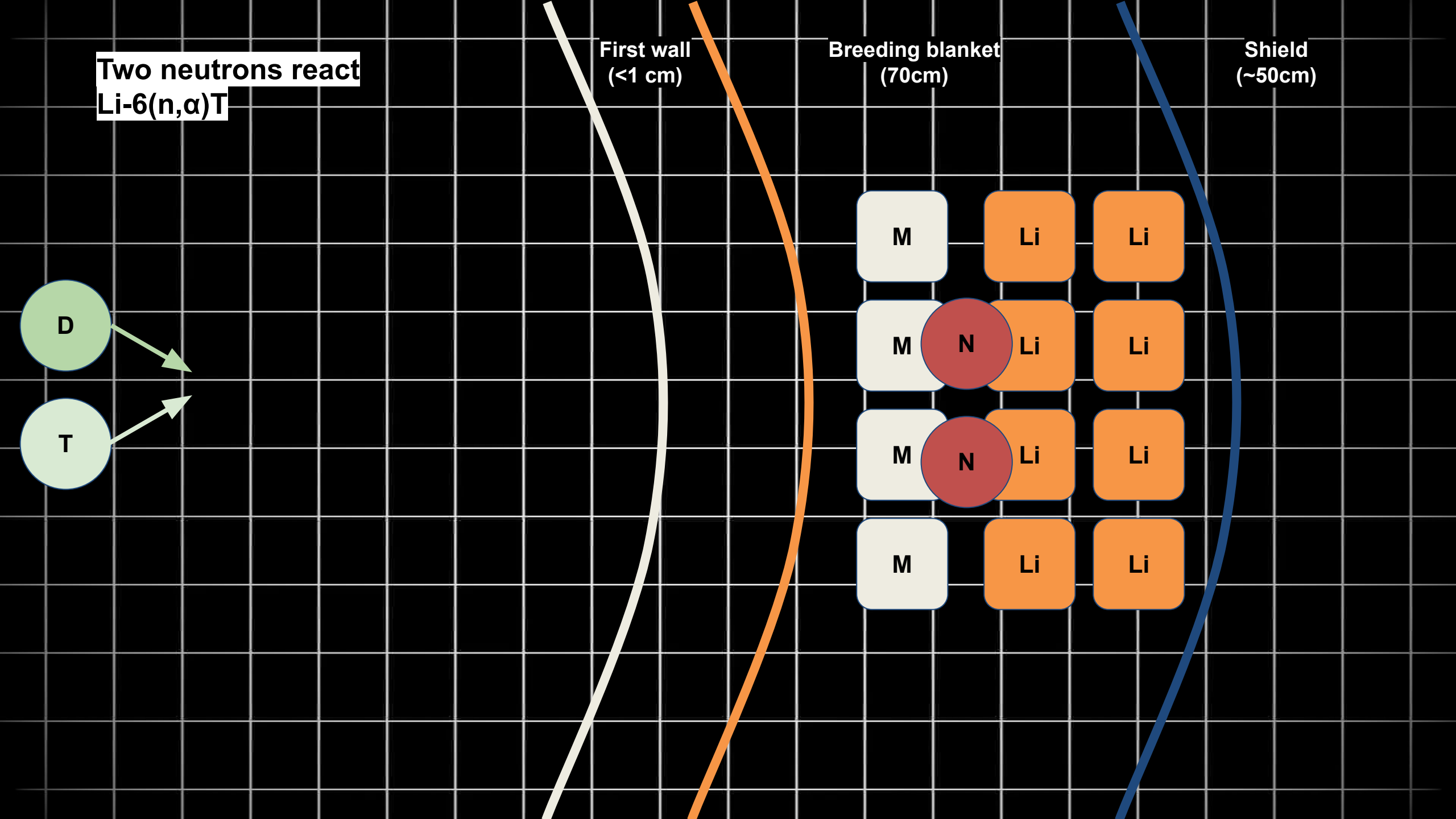
Illustration idea from Ziroth

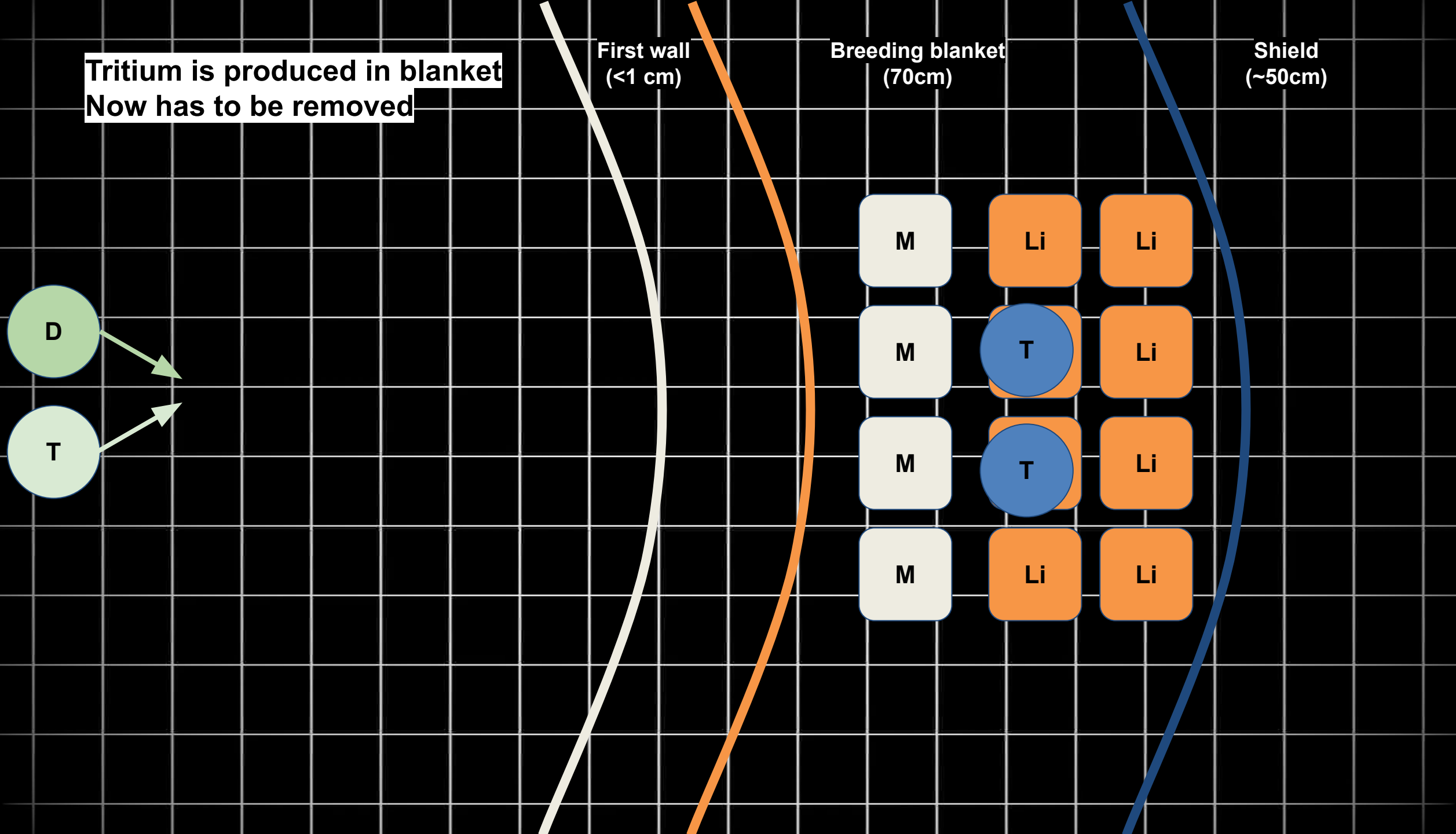


Multiplication with Be or Pb
Be-9 (n,2n) Be-8 (1.8 MeV threshold)
Pb-208 (n,2n) Pb-207 (7.4 MeV threshold)




Two neutrons react
Li-6(n,α)T
First wall
(<1 cm)
Breeding blanket
(70cm)
Shield
(~50cm)
D
T
M
Li
Li
M
N
Li
Li
M
N
Li
Li
M
Li
Li

Tritium is produced in blanket
Now has to be removed



UNITY: taking the fusion industry into the era of industrialisation

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- **Nobody has tested a fusion power generation system:**
  - All players focus solely on the plasma physics & reactor; nobody has tested power system for fusion energy.
- **Nobody has demonstrated heat extraction from a blanket, even at lab scale:**
  - Not planned for ITER, but urgently needed for the private sector and upcoming DEMOs;
  - Material challenge for fusion environment with liquid metal/molten salt are significant.
- **Nobody has demonstrated high-temperature power cycle from liquid metal/molten salt:**
  - High-temp (~1,000 °C) heat extraction from liquid metal/molten not demonstrated;
  - Tritium permeation within the power cycle should not be underestimated.

Beyond lab scale integrated power cycle R&D is urgently needed

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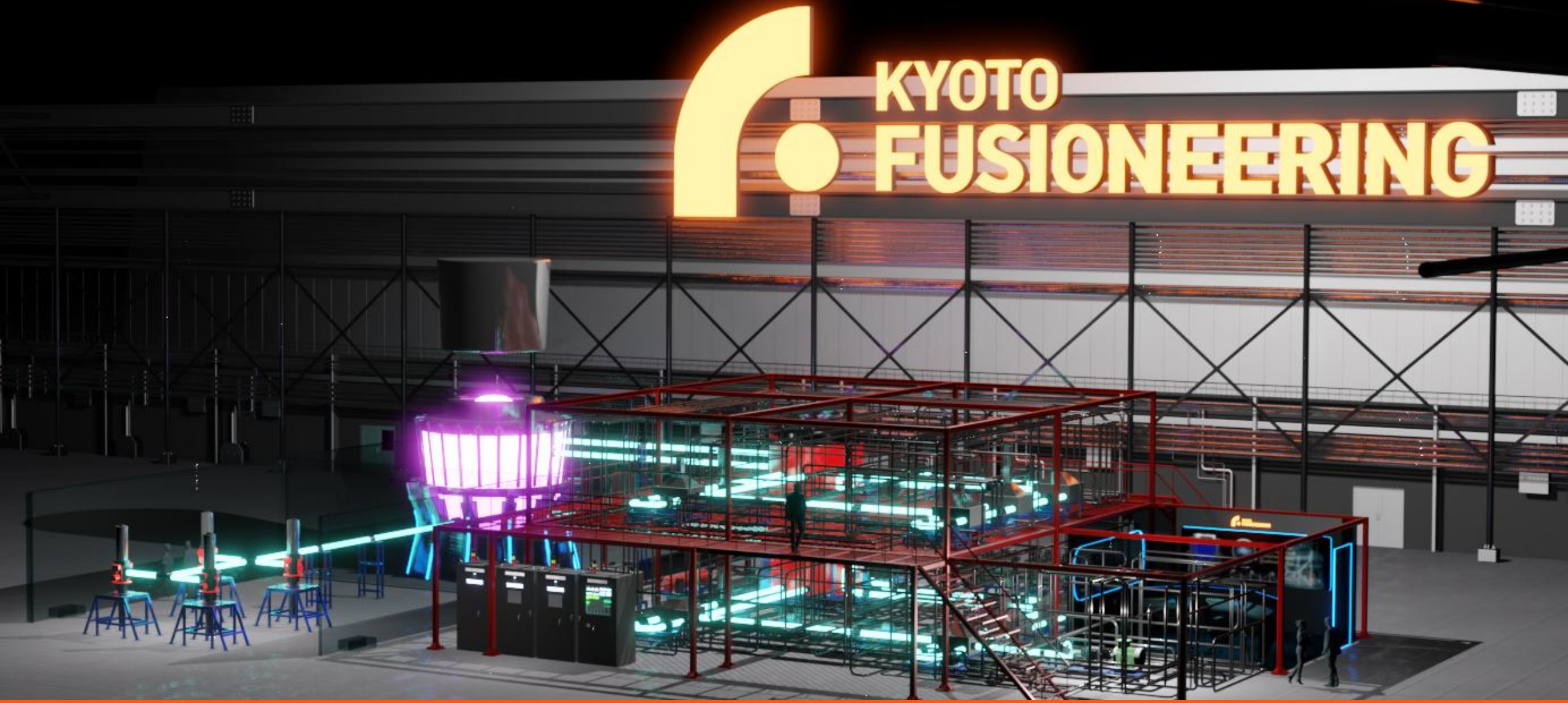


UNITY (UNique Integrated Testing facilitY)

World-first integrated testing facility for fusion power plant equipment.
Electricity generation with fusion relevant technologies planned by 2024.

What do I do these days?

Involved in all projects on plant technology side

- Half my day for our experimental and simulation work
- Half my day for managing the team (10-15 ppl)
- Half my day for advising (UKAEA/QST + private)

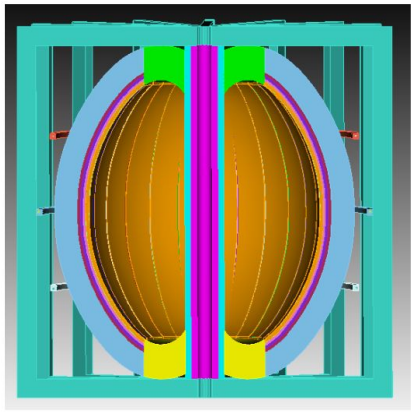
Academic papers and conferences (office at uni)

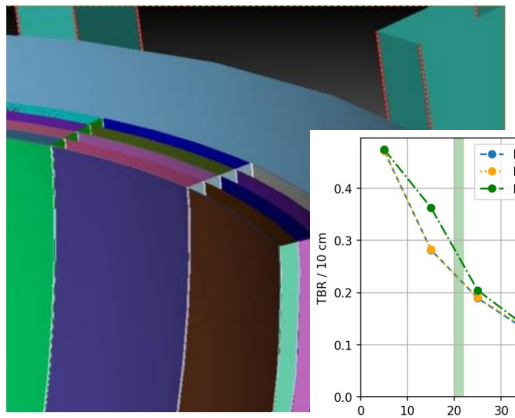
Funding applications (similar to uni but large team)

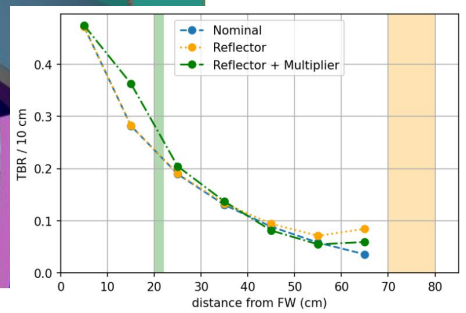
Neutronics simulations (similar to Geant4, nuclear grade)

CFD studies (no expert, supervision)

Chemical engineering calculations (exciting)







Fusion within the next decade?

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- Many private fusion companies promise to have a DEMO plant on the grid by 2040
- Public projects have longer timeline. T. Omae: “ITER has the responsibility to continue running” even if all startups fail, fusion will work eventually
- Many challenges neglected especially regarding the blanket and tritium handling in private companies’ concepts
  - KF can help but still major challenges ahead
  - Even with magnet break-through almost every single component has an unclear path forward and significant R&D is needed

Personal lessons:

- KIT is really famous for fusion
- Do something that could be your hobby and make it your work
- Industry often has no error bars
- Please visit this beautiful country 🇯🇵

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ありがとうございます

(Thank You !)

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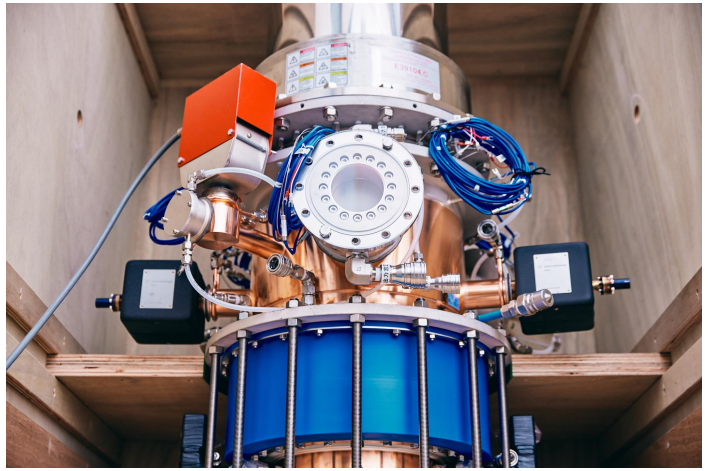
Contact: c.baus+kseta@kyotofusioneering.com
Twitter: @kyotofusioneer
LinkedIn: linkedin.com/company/kyoto-fusioneering/

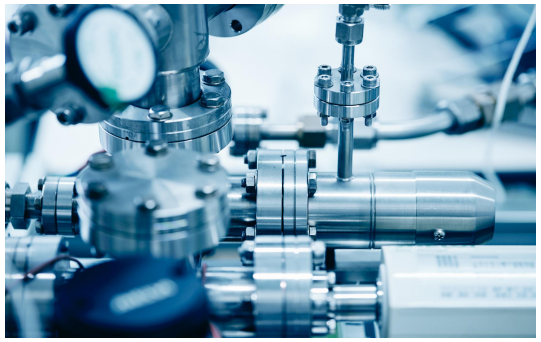
Our Technologies & Capabilities

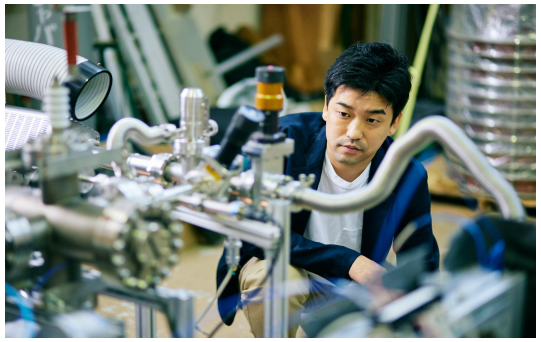
1. **Gyrotrons** for plasma heating
2. **Tritium fuel cycle** technologies, including design and assessment of required tritium systems.
3. **Plasma exhaust systems** (hydrogen isotope separation pump, liquid metal diffusion pump).
4. Advanced **tritium breeding blankets** (focused on: LiPb, Li and FLiBe).
5. **Liquid metal & salt** technologies.
6. **Advanced materials** development, including SiCf/SiC and RAFM steels.
7. **Fusion neutron experimental** testing & neutronics.
8. **Power cycle engineering**, including non-electricity applications (especially H2 and biomass gasification for carbon capture and storage).
9. **General fusion power plant design**.
10. **Commercialization** support (e.g. roadmapping).



Tritium handling (Detail)

- DT reactors require **tritium compatible pumping systems** to sustain a **continuous burning of fusion plasma with fuel recirculation**
- Kyoto Fusioneering Ltd & Kyoto University are developing **three types of pumps** to **evacuate** and **transfer** highly **tritiated gases** for **continuous fuel cycle operation**: as a combined **pump train** (in development with manufacturer, testing finished in 2022).
  1) **Proton Conductor Pump:** selective pumping of H isotopes
  2) **Inorganic Metal Diffusion Pump (Li vapor jet):** replacement for turbomolecular pumps under magnetic fields and/or wet conditions
  3) **Reciprocating Roughing Pump:** suitable for combination with diffusion pump-proton conductor pump.
- Tritium handling facilities, detritiation system scaling, tritium detection devices and diagnostics





Advanced tritium breeding blankets: SCYLLA© (Detail)

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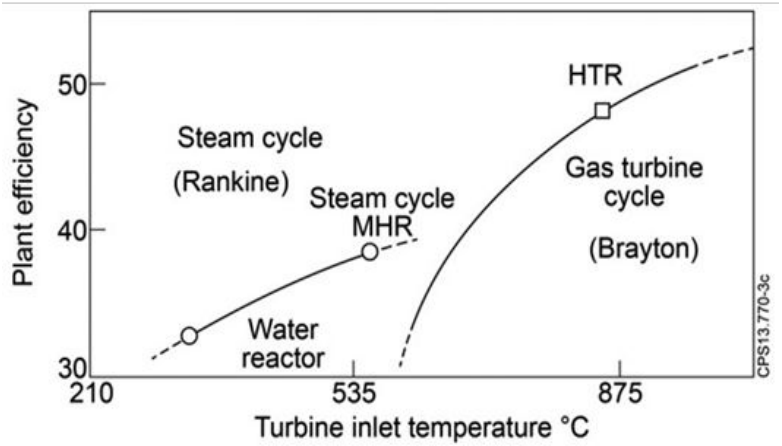
- **Breeding blanket** is on the **critical path** for realisation of a commercial fusion reactor
- Strong influence on **performance, cost, lifetime, waste, operational reliability** (etc)
- For fusion to be a **transformative** energy source, **current designs are not advanced enough**: limited performance (low temperature), complex designs, depend on many difficult-to-procure-or-manufacture materials
- Revivified public & private programmes will see **fusion demonstrators** constructed within the next 5-15 years - some of which will need blanket systems
- The time for development of an advanced blanket is **NOW** … *(not post-ITER)*

Federici et al., 2017



- **> 950°C heat management with advanced materials SiCf/SiC (nuclear-grade)**
- **Innovative tritium separation system**
- **Partnering with Japanese SME**