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CASE STUDY · MARLUC SYNOPSIS

Google DeepMind and EPFL: AI plasma control for tokamaks

IMPLEMENTED 2022–2026 · ENERGY AND UTILITIES · GLOBAL · BAND D · PARTLY PROVED

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In 2022 Google DeepMind and the Swiss Plasma Center at EPFL used reinforcement learning to control a real tokamak's plasma. In 2025 DeepMind began working with Commonwealth Fusion Systems on its SPARC machine, which has not yet started operating.

ABOUT THIS SYNOPSIS

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NOTICE WORDING LAST UPDATED 16 NOVEMBER 2026

AT A GLANCE

Frontier case: AI used for a scientific, medical or engineering breakthrough. The transformation is potential and unproven; MarLuc grades what has changed in practice so far.

AI used: Deep reinforcement learning controller and AI-ready plasma simulator for tokamaks.

Implemented: 2022–2026. Grade: band D, Task support, Partly proved.

Headline result, as reported: A learned controller ran a real tokamak's 19 magnetic coils in experiments (Nature, 2022); its use on SPARC is planned, not yet in operation

1 · The case

The facts, as reported by the 5 sources listed at the end. Where a source is silent, the field says "Not reported".

Organisation

Google DeepMind, Swiss Plasma Center at EPFL and Commonwealth Fusion Systems. Research collaboration between Google DeepMind, the Swiss Plasma Center at EPFL (which runs the TCV tokamak in Lausanne) and, from 2025, Commonwealth Fusion Systems, a private fusion company building the SPARC tokamak in Devens, Massachusetts. Google has invested in CFS, per DeepMind. Canvas block: 6. Data and technology. Also 4. Operations and process, 2. Strategy and ambition.

Business challenge

The challenge. By DeepMind's account, fusion research is limited by access to experiments: TCV can sustain a plasma for up to three seconds, then needs 15 minutes to cool down and reset. Existing control systems use separate controllers for each of TCV's 19 magnetic coils, and designing a new plasma configuration takes engineering effort.

How it was addressed. DeepMind and EPFL trained one neural network by reinforcement learning in a plasma simulator, then ran it on TCV without further tuning. It commanded all 19 coils at 10 kHz and produced several plasma shapes, including a stable pair of 'droplets' that had not been held on TCV before. In 2025 DeepMind announced work with CFS on three areas: a fast simulation of SPARC's plasma using its open-source TORAX simulator, searching for efficient operating settings in simulation, and using reinforcement learning to find real-time control strategies, starting with heat exhaust. In October 2026 CFS announced a Department of Energy-funded digital twin project for SPARC that includes DeepMind and aims at an AI co-pilot for the control room. [1] [2] [3] [4] [5]

Who implemented it

Google DeepMind (Model or cloud provider): Developed the reinforcement learning system and the TORAX simulator.
Swiss Plasma Center at EPFL (University or research lab): Ran the TCV tokamak experiments and supplied simulation tools.
Commonwealth Fusion Systems (Industry partner): Fusion company using TORAX for SPARC and leading the 2026 digital twin project.
A research collaboration. Google has invested in CFS, per DeepMind.

Technology (SEAM pillar E)

SEAM types: T5 Custom / fine-tuned models, T9 AI in physical systems. Deployment: Not reported. Vendors and products: Google DeepMind, Reinforcement learning controller for TCV, TORAX plasma simulator.

Where it was built in: The policy was compiled into real-time code and loaded into TCV's digital control system; TORAX is used for pulse planning and simulation at CFS.

What changed

Before: separate engineered controllers for each coil, designed by hand for each plasma shape. After, in experiments: one learned controller for all coils, with the target specified at a high level. At CFS, by DeepMind's account, TORAX is used in daily simulation work for SPARC. Control of SPARC by AI: not yet done, because SPARC is not operating. [1] [2] [3] [4] [5]

What it cost

Not reported

What it saved

Not reported. DeepMind quotes a CFS manager saying TORAX 'saved us countless hours' in setting up and running simulation environments; no hours, cost or schedule figure is published. [1] [2] [3] [4] [5]

Governance and control

In the TCV experiments a conventional controller formed the plasma and control passed to the learned policy at a set handover time; the authors tested compiled policies in an automated benchmark before deployment. Accountable owner, independent assurance and plans for human oversight on SPARC: Not reported.

S2 · Accountable owner · Not reported
Not reported.

A1 · Safe use · Claimed
The authors say compiled policies were tested in an automated benchmark before deployment, so that timing requirements were met. [1]

A2 · Human in the loop · Claimed
Each experiment began with a conventional controller and switched to the learned policy at a set handover time; how humans oversee AI control on SPARC is not reported. [1]

A3 · Monitoring and assurance · Not reported
Not reported.

A4 · Vendor AI · Not reported
Not reported.

A5 · Agent controls · Claimed
The policy outputs voltage commands to the magnetic coils within limits set in its training objectives; the paper says it can include physical and operational constraints. [1]

A6 · Standards and regulation · Not reported
Not reported.

What worked, what did not, what is unproven

WORKED

– The learned controller held and shaped plasma on a real tokamak in experiments, including configurations such as 'snowflake' and 'droplets' (Nature, 2022).

– It ran without tuning on the machine after training, which the authors say shows a simulator of this kind can support controllers for future devices.

– DeepMind and CFS say TORAX is in daily use at CFS for planning SPARC operations.

DID NOT

– The authors say they cannot predict how the approach performs on other kinds of devices.

– No AI controller has yet been reported running SPARC, which has not started operating.

– No independent evaluation of TORAX's value to CFS is published; the account comes from DeepMind and a CFS manager.

UNPROVEN

– Whether learned control works on SPARC and on future power plants, and whether it beats conventional control there.

– Whether AI changes the cost or timeline of commercial fusion power.

– Whether TORAX predictions match SPARC's behaviour; CFS and DeepMind say they will validate it against past data and when SPARC runs.

Timeline

Feb 2022 Nature paper published: a deep reinforcement learning controller, trained in simulation, shapes and holds plasma on the TCV tokamak in Lausanne [1]

May 2024 DeepMind releases TORAX, an open-source plasma simulator [2]

Oct 2025 DeepMind and Commonwealth Fusion Systems announce a research partnership on the SPARC tokamak [3]

Oct 2026 CFS announces a US Department of Energy Genesis Mission award to build an AI digital twin of SPARC, with Google DeepMind among the partners [4]

Nov 2026 CFS says it is still assembling SPARC and expects to turn it on in 2027 [5]

2 · Grade and SEAM assessment

MarLuc's opinion, made on the evidence above. How cases are graded: marluc.co.uk/case-studies/how-we-rate

Level of change and impact

Claimed: A. Grade: D, Task support. Proof: Partly proved. Route: Model-led.

Task support (Level 1, band D), claimed as transformational (band A). Experiments and simulation work now use AI. Fusion is not yet commercial and SPARC is not operating, so the transformation is potential and unproven.

Graded D, claimed A. A learned controller has run a real tokamak in experiments, and CFS says it uses DeepMind's simulator every day. Fusion power is not yet commercial and SPARC has not started operating, so no plant, utility or customer works differently. A transformation of fusion control is potential and unproven.

The SEAM view and lessons learnt

A research result became a working tool in two steps: a peer-reviewed demonstration on a shared machine, then a partner whose own engineers now use the simulator. The transferable idea for any engineering team is to train and test in simulation, keep the conventional controller as the starting point, and hand over control at a defined moment. What is still missing is evidence on the target machine, which has not yet been switched on.

1. Test learned controllers in simulation first, then on hardware with a conventional fallback.
2. Separate what a paper proves from what a partnership plans.
3. Wait for results on the real machine before claiming a change in how the work is done.

Evidence

Score 2 of 4. Mixed: the 2022 experiments are in a peer-reviewed paper by the research team itself; the later CFS work rests on company announcements.

Evaluation method. Peer-reviewed paper (Nature, 2022) by the research team and company announcements (DeepMind and CFS); no independent evaluation of the later work.

Sources disagree. None found between the sources. DeepMind's 2025 post says Google has invested in CFS, so the partners are financially linked.

3 · Original sources

Read these in full. To challenge a fact or a grade, use the contact form at marluc.co.uk or the link on https://marluc.co.uk/case-studies/deepmind-epfl-tcv-plasma-control

[1] Nature: Magnetic control of tokamak plasmas through deep reinforcement learning
https://www.nature.com/articles/s41586-021-04301-9

[2] Google DeepMind: Accelerating fusion science through learned plasma control
https://deepmind.google/blog/accelerating-fusion-science-through-learned-plasma-control/

[3] Google DeepMind: Bringing AI to the next generation of fusion energy
https://deepmind.google/blog/bringing-ai-to-the-next-generation-of-fusion-energy/

[4] Commonwealth Fusion Systems: CFS to lead AI-enabled digital twin fusion project in second phase of Genesis Mission
https://cfs.energy/news-and-media/commonwealth-fusion-systems-to-lead-ai-enabled-digital-twin-fusion-project-in-second-phase-of-genesis-mission/

[5] Commonwealth Fusion Systems: How CFS will rev up our SPARC tokamak for its Q>1 fusion moment
https://blog.cfs.energy/how-cfs-will-rev-up-our-sparc-tokamak-for-its-q1-fusion-moment/

Google DeepMind, Swiss Plasma Center at EPFL and Commonwealth Fusion Systems website: https://deepmind.google

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