SUCCESS STORY | PRINCETON UNIVERSITY: ITER FUSION ENERGY

SPEEDING THE PATH TO FUSION ENERGY WITH DEEP LEARNING

Stylized illustration of a Tokamak generating clean energy powered by nuclear fusion

NVIDIA

Deep learning used to predict disruptions in a tokamak fusion reactor, paving the way to clean energy.

POWERING EARTH FOR MILLIONS OF YEARS

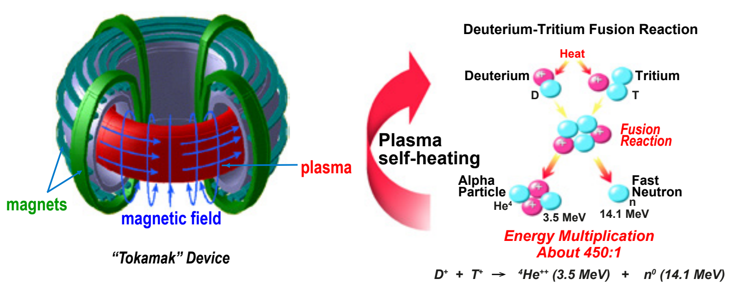


Illustration of a magnetic fusion device and thermonuclear fusion reaction
Source: Princeton University

One of the greatest challenges of our time is finding sustainable clean energy sources to power our future here on Earth. Scientists today believe that fusion is the key to that future. Imagine the ability to harness a small sun within an energy reactor. If the promise of fusion can be realized, it has the potential to become our primary energy source for millions of years.

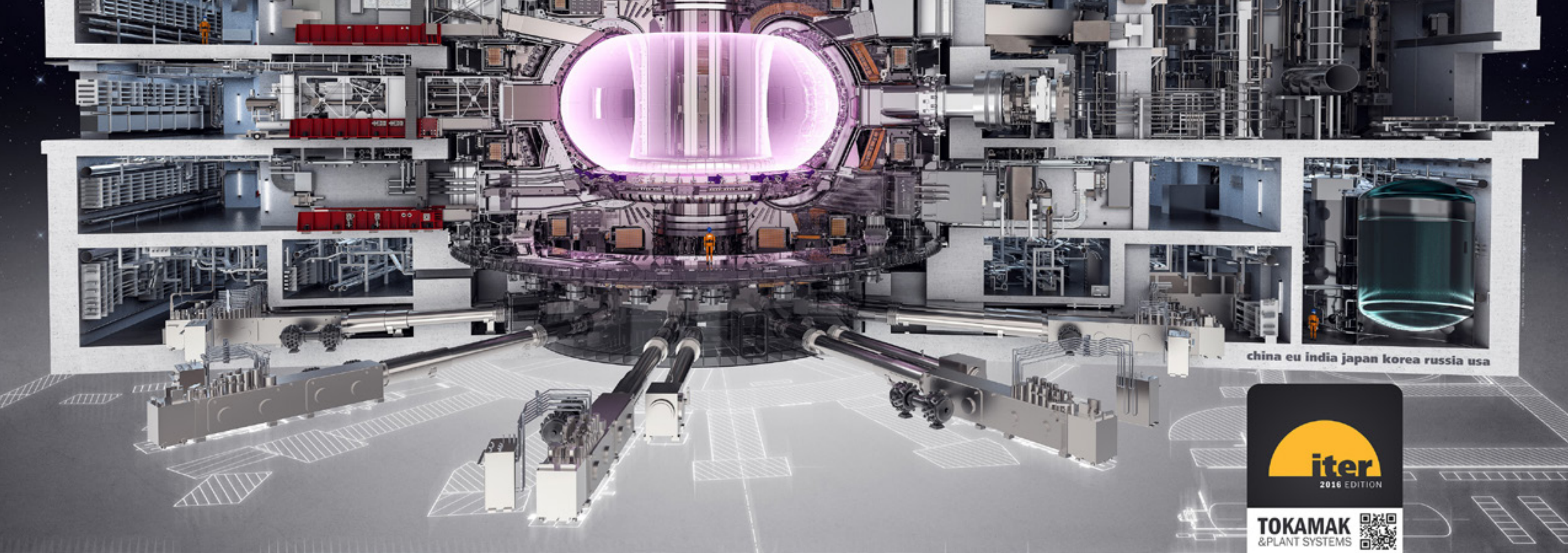
Unlike other forms of energy, fusion is inherently safe because runaway reactions cannot occur. The simplest change in conditions immediately quenches the reaction. Its primary fuel source, deuterium, exists abundantly in the earth's ocean and waste products decay quickly—within 50 years. Most importantly, the energy multiplication factor for fusion is potentially as high as 450 to 1.

Researchers at the international ITER facility—the world's largest experimental nuclear fusion reactor—are working to build what will be the first fusion system to produce net energy. ITER will be the first controlled device capable of maintaining fusion reactions for long periods of time. However, sustaining such burning plasma reactions is very challenging because large-scale disruptive events can cause the plasma (a very hot gas of charged particles) to escape confinement and cause serious damage to such multi-billion dollar devices known as "tokamaks." To be successful, ITER must be able to predict, respond to, and minimize or avoid the disruptions that hinder the path to creating a truly sustainable energy source.

CUSTOMER PROFILE

PRINCETON UNIVERSITY

Organization	Industry	Location	Website
Princeton University	Higher Education	Princeton, New Jersey, U.S.A.	www.princeton.edu



Cross-section of the multi-level ITER Tokamak and plant systems, showing the hot plasma torus at center

PRODUCTS

NVIDIA® Tesla® P-100 GPU

Google Tensorflow

Theano

NVIDIA CUDA®

NVIDIA cuDNN

DEEP LEARNING TO IMPROVE PREDICTIONS

To predict and steer fusion reactions to avoid disruption and safely continue to produce power, researchers at Princeton University have developed the advanced machine learning Fusion Recurrent Neural Network (FRNN) predictive code. FRNN uses deep learning methods and has successfully scaled to 200 NVIDIA® Pascal™ P100 GPUs to predict the onset of highly deleterious disruption events under reactor-relevant conditions in magnetically-confined fusion tokamak devices.

Disruptions are large-scale events where the magnetic confinement field is broken, leading to a rapid termination of discharges along with various levels of damage to the physical confining vessel. During disruptions, the machine is subjected to massive thermal and electromagnetic loads as the plasma's thermal energy and current dissipate in less than a millisecond. The damage from even a small number of events makes building a sustainable tokamak fusion reactor impossible. Traditional high performance computing simulations used for prediction are too inaccurate and slow. However, over the past decade traditional machine learning methods have improved to be able to predict the onset of disruptions with around 85% accuracy, 5% false positive rates, and with sufficient time for avoidance of about 30 milliseconds before these events. To deliver the further improvements needed, deep learning convolutional and recurrent neural net capabilities have now been implemented in the FRNN software–with the large database from the Joint European Tokamak (JET) experiment used for training and associated prediction.

“Fusion has the exciting potential to be the future of sustainable clean energy with ITER representing the next major step in this direction. Deep learning predictive capability powered by NVIDIA’s advanced GPU’s is helping accelerate progress toward making this vision a reality in our lifetime.”

Prof. William Tang of Princeton University’s Program in Plasma Physics and the Princeton Plasma Physics Laboratory

The FRNN software, developed with the Google Tensorflow framework, uses deep learning to predict fusion plasma disruption with enough time to minimize damage and downtime–first for today’s powerful thermonuclear fusion experiments such as the Joint European Torus (JET) and eventually for the burning plasma ITER experiment. By training FRNN to detect disruptions using historical, time-dependent, zero-dimensional (point/scalar) diagnostic data from the JET experiment, Princeton researchers can exceed the predictive capability of conventional simulations by achieving 90% accuracy with less than 5% false positive rates. With this, they are well on the path to the key goals of (i) demonstrating the portability of the deep learning software trained on one major experiment such as JET to many other current tokamak facilities and eventually to ITER; and (ii) reacting in a timely way the predictive capability to deliver accuracy and reliability of 95% true positive and less than 5% false positive at 30 milliseconds or more before the onset of disruptions.

POWERING THE FUTURE

ITER is a burning plasma tokamak experiment designed to run at an energy multiplication factor of ten—i.e., if successful, ITER will produce ten times the amount of energy it consumes. Once ignited, the heat captured by the fusion reactions will be sufficient to keep the thermal energy in the required range for the fusion reactions to be sustainable as long as fuel is added. In a commercial power station, the energy produced through this fusion of atoms is absorbed as heat in the walls of the vessel to produce steam and then electricity by turbines and generators.

ITER is no small undertaking. With membership from 7 governments (the European Union, Japan, China, South Korea, India, Russia, and the US) representing over half the world’s population, it’s goal is to conquer one of the great frontiers in science–reproducing on Earth the limitless energy that fuels the Sun and stars.

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