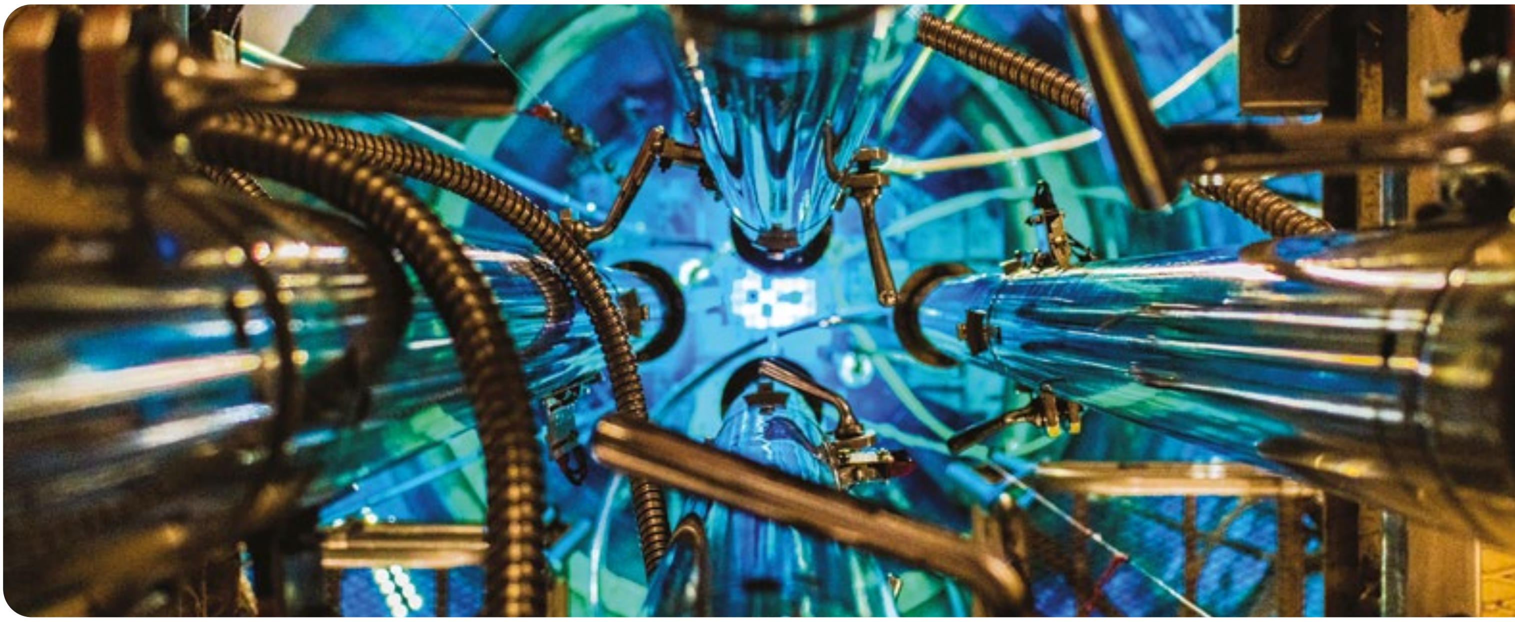
From Accident Simulations to Safer Designs: Accelerating the Deployment of Advanced Nuclear Reactors

Ensuring safety of nuclear reactors under all conditions, including potential accidents, is a cornerstone of their design and operation. Researchers from STFC Daresbury Laboratory have used the power of ARCHER2, the UK's National Supercomputing Service, to significantly improve the modelling of the behaviour of advanced nuclear reactors under extreme accident scenarios.



www.archer2.ac.uk

This ARCHER2 Pioneer Project focused on the High-Temperature Gas-cooled Reactor (HTGR), which is identified by the UK government as a priority advanced reactor technology because of its inherent safety and efficiency. In rare events such as a Loss of Flow Accident (LOFA), where the coolant pumps suddenly stop, heat removal relies solely on buoyancy-driven natural circulation. These events are extremely difficult and often prohibitively expensive to replicate experimentally at full scale, so computer modelling is essential for supporting the assessment of reactor safety.

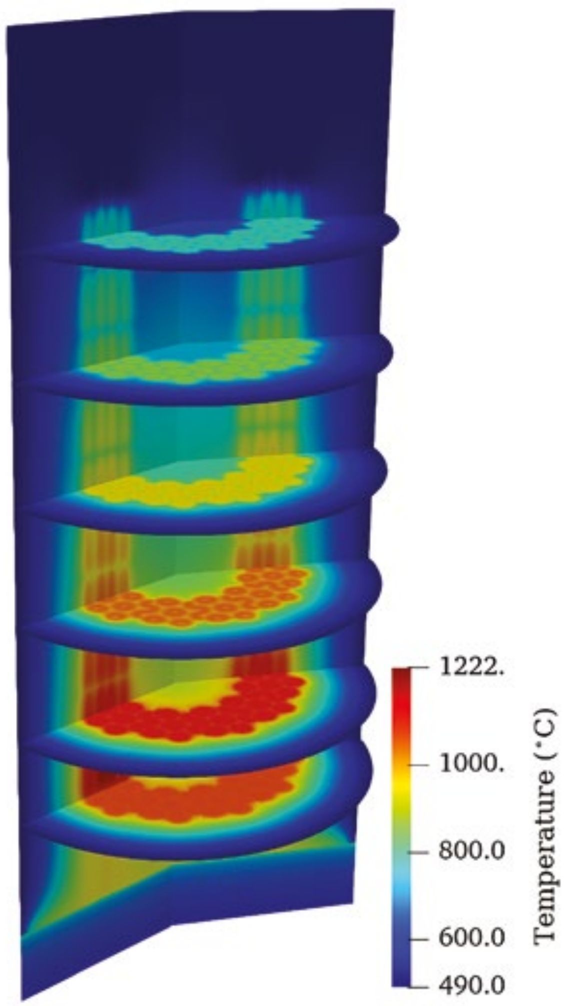


Fig 1: CFD-predicted temperature distribution in an HTGR core during a LOFA transient

Robust safety modelling is essential to deploying new nuclear technologies that can deliver reliable, low-carbon energy. To predict what happens in such situations, engineers use Computational Fluid Dynamics (CFD), a computer modelling approach that simulates fluid motion in three dimensions and heat transfer between the fluid and the surrounding solid parts. These models capture how coolant redistributes, how heat flows through the core, and where temperature 'hot spots' may occur. However, CFD is extremely computationally demanding: to fully simulate a reactor core, even a coarse computational grid description of the core may require billions of calculation points, demanding vast amounts of compute time – even on the UK's most powerful supercomputers. As a result, high-resolution CFD has traditionally been limited to short timescales and/or small geometries, leaving gaps in our understanding of coolant flow and heat removal in long-duration accident transients (rapid, temporary changes in temperature, pressure and flow within the reactor core).

This is where ARCHER2 played a vital role. Using thousands of CPU cores in parallel, the project team performed some of the most detailed CFD simulations yet attempted of an HTGR under LOFA conditions. A full one-twelfth sector of the reactor core was modelled, with nearly one billion cells used in high-resolution simulations. These simulations used 256 ARCHER2 nodes (32,768 cores, ≈ 4.4% of the system) and consumed around 120,000 node-hours (≈ 15.4 million core-hours) of compute time. With this capacity, the team simulated over 1,000 seconds of the reactor's behaviour after onset of LOFA, capturing the critical shift from forced pump-driven cooling to buoyancy-driven natural circulation, and accurately describing the flow and temperature behaviour that maintains safe reactor operation.

Equally importantly, the results provided a vital benchmark for validating more cost-effective engineering modelling tools, such as SubChCFD, a simplified simulation tool developed by the team. SubChCFD uses a far less detailed computational representation (only 6% of the resolution for the aforementioned LOFA simulation), reducing computing costs by a factor of 40 while still capturing the key thermal and flow features observed in the high-resolution CFD. The close agreement between SubChCFD and the full CFD simulations builds confidence in its use as a practical tool for routine reactor safety analysis. With tools like SubChCFD, engineers can perform more widespread and affordable assessment of accident scenarios in advanced reactors, helping regulators and industry gain confidence in new reactor designs.

This work demonstrates how national supercomputing services directly underpin safer, faster deployment of next-generation nuclear energy in the UK. The benefits are far-reaching. First, it accelerates the development of safer, low-carbon nuclear energy by reducing the cost and time needed for safety analysis. Second, it directly supports the UK's ambition to deploy advanced modular reactors, such as HTGRs, to expand nuclear capacity and to decarbonise heavy industry. The insights gained into reactor behaviour under severe accident conditions cannot be obtained experimentally at present, as HTGRs are still under development and reproducing such extreme scenarios in the laboratory would be prohibitively expensive and complex.

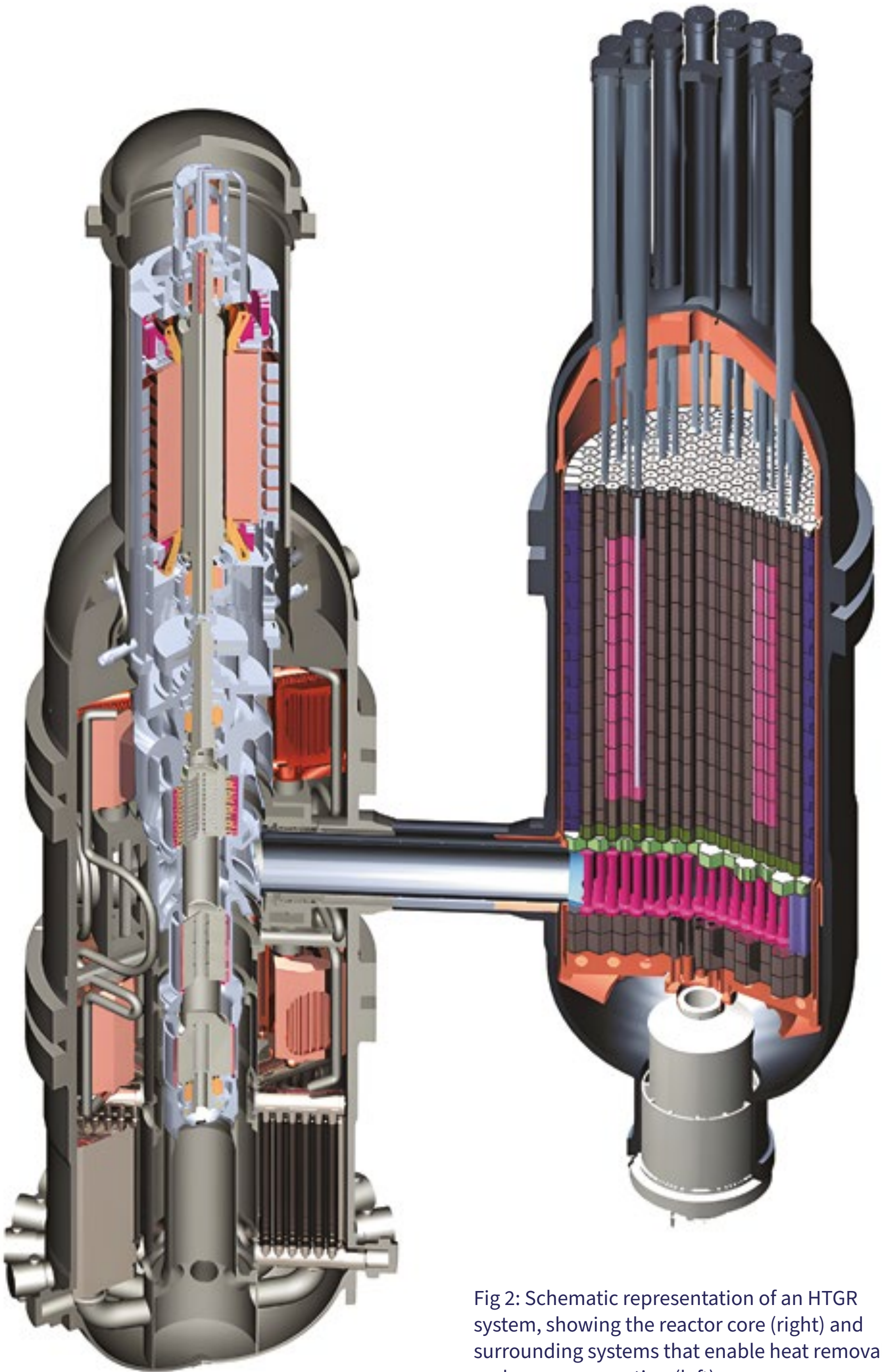
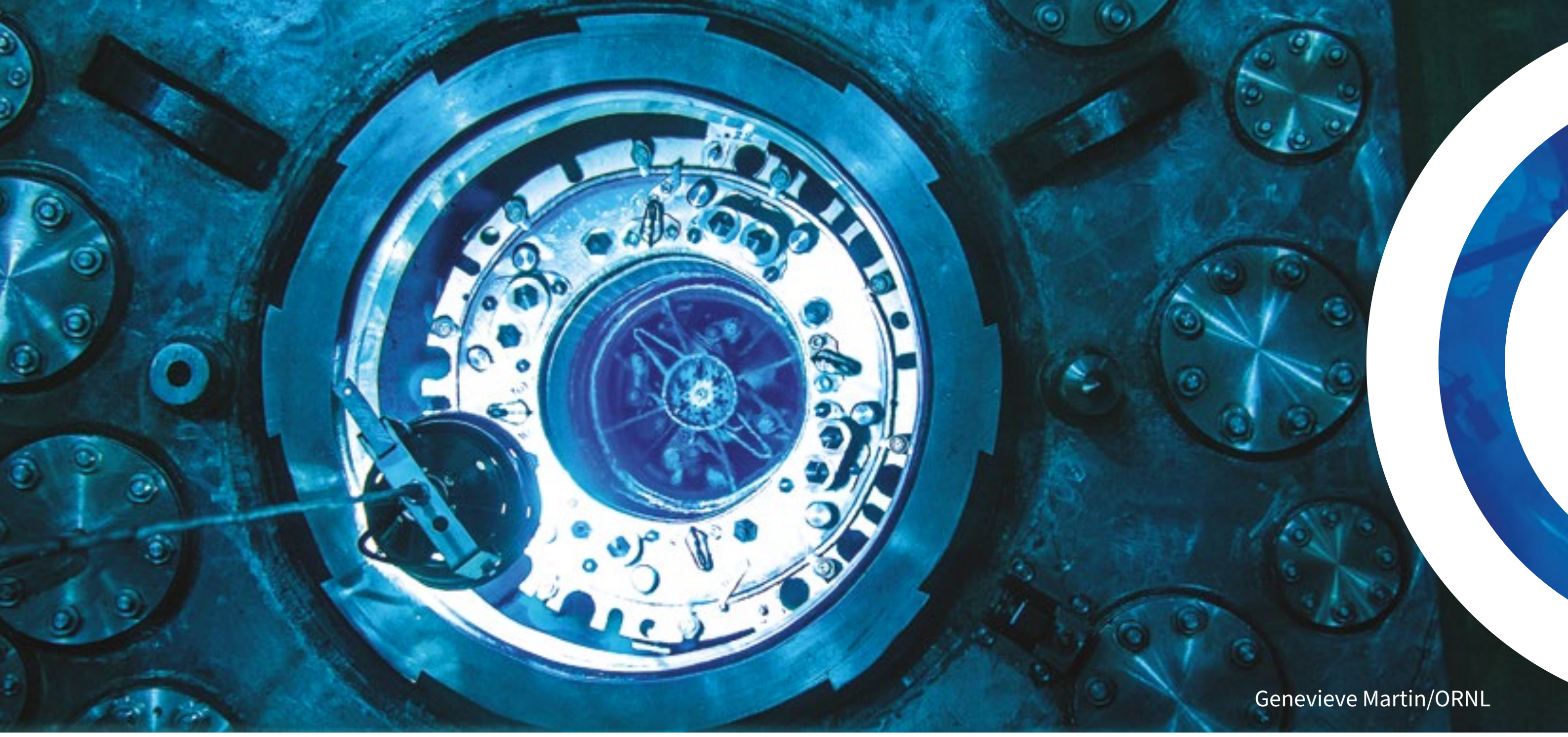


Fig 2: Schematic representation of an HTGR system, showing the reactor core (right) and surrounding systems that enable heat removal and power generation (left)
(Image credit: PD-USGov-DOE).



Genevieve Martin/ORNL

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Journal articles:

Bo Liu, Wei Wang, Charles Moulinec, Stefano Rolfo, Marion Samler, Ehimen Iyamabo, Constantinos Katsamis, and Marc Chevalier. "Development of a Cost-Effective Simulation Tool for Loss of Flow Accident Transients in High-Temperature Gas-cooled Reactors." arXiv preprint arXiv:2503.12467 (2025).

About ARCHER2

ARCHER2 is the UK's National Supercomputing Service, a world class advanced computing resource for UK researchers. ARCHER2 is provided by UKRI, EPCC, HPE and the University of Edinburgh. ARCHER2 is the latest in a series of National Supercomputing Services provided to UK researchers.

More ARCHER2 case studies can be found at:
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This project was an **ARCHER2 Pioneer Project**, awarded by UKRI to conduct computationally intensive modelling, simulation and calculations to deliver ambitious and pioneering projects.