Science and Technology Facilities Council
Scientific Computing

STFC Scientists to help power a new generation of energy production

Nuclear power, as a low-carbon energy source, provides a reliable and consistent supply of electricity without directly producing greenhouse gas emissions. It plays a crucial role in the UK's strategy to achieve its Net Zero target by 2050, contributing significantly to reducing the nation's carbon footprint and ensuring energy security. It will provide the UK with more energy independence, reducing its reliance on supplies from other parts of the world.

The Science and Technology Facilities Council (STFC) was called in to provide specialist computational development expertise for an important project concerning the next generation of nuclear reactor design. The project is a collaboration between EDF, one of the UK's main electricity providers, and STFC Scientific Computing. It has been funded by EDF.

The Challenge

The high-temperature gas-cooled reactor (HTGR), or very-high-temperature reactor (VHTR), have been selected by the UK government as priorities for our nation's next nuclear systems. The UK has a long history and experience of operating gas-cooled rectors, and the UK Government sees HTGRs as an important contributor to the Net Zero 2050 target[1].

The new generation of nuclear reactors, termed 'Gen IV', are much more challenging to design and operate as they use helium as a coolant rather than carbon dioxide, making them more efficient in terms of energy and hydrogen production.

Hydrogen is considered an increasingly important energy source for the nation's future. It will be used to generate electricity, used in industrial applications, and to heat homes and businesses. It should help to make electricity cheaper, more resilient to power cuts, and have a positive impact on the UK economy.

The main issue with this new generation of nuclear reactors is that they operate at temperatures that can reach 950°C, making design, build, operation, and safety measures even more critical.

The successful deployment of HTGR technology requires an in-depth understanding of its reactor physics, particularly the coolant flow dynamics and heat transfer processes within the reactor core, as well as their impacts on the reactor efficiency and structural integrity.

Achieving this relies on thermal-hydraulic analyses, which are currently limited by the lack of simulation tools capable of providing high-fidelity simulations of the entire reactor behaviour.

Traditional simulation tools, such as system codes and subchannel codes, have been used in thermal-hydraulic analyses of nuclear reactors for more than half a century. However, they provide only limited insight into complex 3-D phenomena that happen within the reactor system.

Advanced traditional Computational Fluid Dynamics (CFD) methods, whilst capable of resolving 3-D physics in as much detail as required by first principle physical laws, are slow and extremely costly for large-scale applications, and sometimes too demanding for the current generation of supercomputers.

[1] world-nuclear-news.org/Articles/UK-government-unveils-GBP60-million-for-HTGR-resea

Our Approach

STFC Scientific Computing researchers have developed a method called Subchannel CFD (SubChCFD) to bring in some 3-D features from more advanced and modern modelling techniques. This enables the modelling of the next generation complex advanced gas-cooled reactors for large-scale electricity, and potentially hydrogen production, via electrochemical or thermochemical processes.

In fact, STFC Senior Computational Scientist Dr Bo Liu was the first developer of this modelling technique, using EDF's open-source CFD software code_saturne. With this background, he brings a unique set of skills as well as speed to the research for EDF in the UK.

Using SubChCFD developed by Dr Liu, the computational cost for modelling the Gen IV reactors can be reduced by 2 or even 3 orders of magnitude (100 – 1000 times less). This means that the modelling can be applied to real-world engineering scenarios for the new reactors at a critical point, since the HTGRs have only been in the design phase since 2023.

STFC Scientific Computing has previous experience of modelling and testing for other types of reactor, including several types of fission reactors, such as the Advanced Gas-cooled Reactor (AGR) – like the one at Hinckley Point B; Pressurised Water Reactor (PWR) – at Hinckley Point C, and at Sizewell C in the future; and Super-critical Water Reactor (SCWR); focusing on modelling what happens when the fuel assembly gets affected by high temperatures.

Benefits

STFC Scientific Computing's work is critical to EDF's work on the Gen IV reactors. The modelling is transforming the design phase, as it can be applied to simulate the entire reactor core rather than one small element of it, making for more global and performant engineering and design. In addition, the lighter computational load means that results can be produced in a reasonable timescale (days rather than weeks) and a more cost-effective way.

Using traditional high-fidelity models, it can take weeks or even months to simulate a small part of the reactor on the current generation of supercomputers, at far from industrial scale.

> **"Our modelling software can perform simulations 100 to 1,000 times faster than conventional CFD methods, and can even be used to simulate a full reactor core. By contrast, using traditional CFD alone to simulate a full reactor at industrial scale is computationally infeasible with the existing hardware available."**
>
> **Dr Bo Liu**
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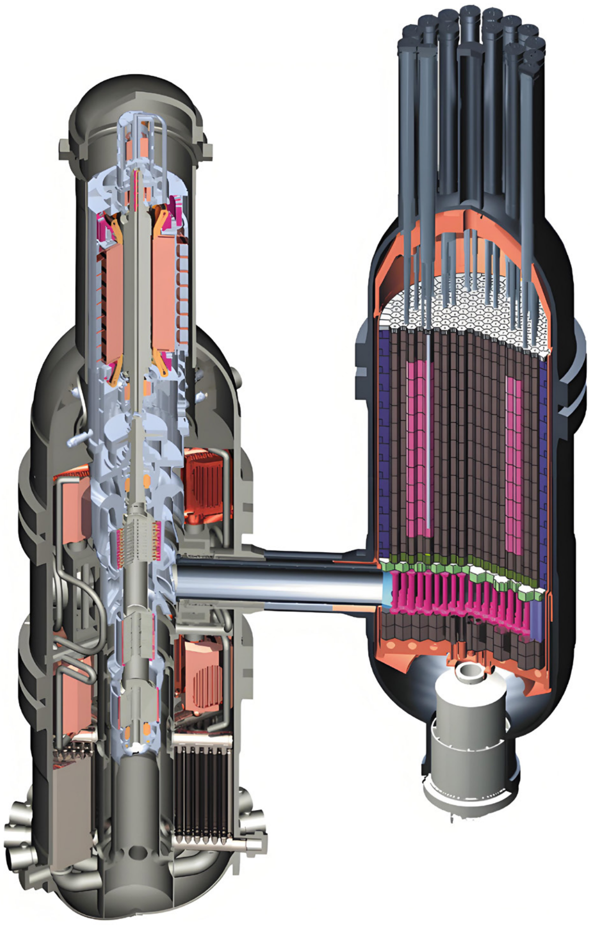
> Senior Computational Scientist, STFC Scientific Computing



The Future

The STFC Scientific Computing team is continuing to improve and hone its modelling work for gas-cooled nuclear reactors. The team is currently working on more advanced modelling, which take the simulations beyond normal operating and design conditions into accident conditions, which are more challenging, but clearly more realistic.

EDF plans to integrate STFC's work as an official module in the CFD software code_saturne. This module is still in a heavy development stage to account for more physics being required, and is maintained by Dr Bo Liu.

The Gen IV new type of nuclear reactor could be built by 2040, and EDF is working with several collaborators to investigate a variety of designs, before establishing which organisations would cover the build phase of the reactors.

Image credit: PD-USGov-DOE

SubChCFD is built on EDF's open-source multi-purpose massively parallel CFD software code_saturne (code-saturne.org/cms/web/), which provides user-friendly graphic and text interfaces, making it easily accessible to users.

STFC Scientific Computing has made the SubChCFD model open source, so that it is available to other researchers in the science field, to help move science forwards for the whole community.

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For more information:

Development of Subchannel CFD for Prismatic HTGR Fuel Assemblies

epubs.stfc.ac.uk/work/60343935

Development of a Cost-Effective Simulation Tool for Loss of Flow Accident Transients in High-Temperature Gas-cooled Reactors

arxiv.org/abs/2503.12467

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