The UK National Program R&D on Digital Nuclear Reactor Design

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INTRODUCTION

The United Kingdom has recently consolidated their way into the nuclear renaissance by the definition for the construction of two new reactor blocks at the Hinkley Point site. However, building of reactors of a new generation can only be a part of a nuclear renaissance. Another essential part is developing the required workforce and the required tools. These two objectives can go partly hand in hand when the development of new, advanced tools is linked between Universities and industrial partners. To support nuclear development within the country, the government has announced in November 2016 the Nuclear R&D and Innovation programme with a volume of ~£20m covering following themes:

1. Advanced Fuels
2. Digital Reactor Design
3. Safety and security
4. Recycle and waste management
5. Manufacturing & materials [1]

The tender specification for digital reactor design [2, 3] covers the scope of work for the initial phase of a five-year programme of R&D on digital reactor design in the following areas:

- Work package 1:
  - Virtual Engineering
  - Modelling and Simulation
- Work package 2:
  - Thermal Hydraulics Model Development
  - UK National Nuclear Thermal Hydraulic Facility Specification

The work package one of digital reactor design has in the currently confirmed first two years a volume of ~£2.8m.

THE DIGITAL NUCLEAR REACTOR DESIGN - VIRTUAL ENGINEERING, MODELLING AND SIMULATION

The detailed tender document requested detailed outputs for both sub-topics of work package 1 as well as integration and coordination between the virtual engineering and the modelling and simulation programmes.

Virtual Engineering Capability

Identify and develop solutions to deliver a Nuclear Virtual Engineering Capability that incorporates virtual engineering and associated technologies from high-tech industries to enhance nuclear design and development programmes.

Specific outputs are:

- the establishment of a network of existing UK wide facilities for virtual engineering which enables face-to-face and remote collaboration between researchers in academia, national laboratories and industry.
- demonstration of core capabilities in:
  - virtual engineering between remote sites,
  - dealing with uncertainty in simulation and,
  - integration of Computer Aided Design (CAD) and simulation for reactor systems.
- a strategy for the management of nuclear security and safety assurance within the digital environments.

Modelling and Simulation

Develop multi-scale and multi-physics models to simulate the through-life performance of nuclear reactor structural components, and develop a capability to improve the fidelity of reactor simulations by integrating radiation modelling codes with CAD models of reactor components.

Specific outputs are:

- innovative validated multi-scale and multi-physics models to predict the through-life structural performance of key reactor components.
- integrated radiation modelling codes and CAD models of reactor components. [3]

The tender has been awarded to the proposal of a consortium around Amec Foster Wheeler Nuclear UK Limited with the partners University of Liverpool including the Virtual Engineering Centre, National Nuclear Laboratory, Hartree Centre – STFC, Rolls-Royce, EDF Energy, University of Cambridge, and Imperial College. Their proposal consists of 10 scientific work packages and the management. The general idea of the project can be summarized by:

"It's about bringing industry and academia together to demonstrate and transfer innovative digital techniques like virtual engineering and improved multi-scale, multi-physics

modelling and simulation technologies to boost their application as key for the success of the nuclear renaissance in the UK. The project will have significant influence on economic operation of the new light water reactors as well as on development and design of highly innovative future reactor systems".

Detailed Work Plan

The project consists of several parallel, but interlinked work streams. A close look identifies three major topics:

- content definition
- developing the required digital surrounding
- demonstration and dissemination

The initiation phase starts with a series of workshops to define requirements of virtual engineering (VE) capability for nuclear applications. The key rationale behind this work package is to listen to the demand of the industry to avoid to go too far into cutting edge research in the moment and to find the right balance between industrial demand and applicability on the one hand and innovation and new technology on the other hand. It will lead to a formal definition and documentation of the diverse requirements of the nuclear community, agreement on taxonomies, mapping of requirements against time and definition of derived requirements will be produced.

A comparable intention is behind the capability mapping package. The current state-of-the-art for multi-site working, integrated modelling and VE in the nuclear industry will be reviewed, in order to define the starting point for developing the capability to meet the requirements. This will lead to a report including a plan for development of the VE capability and future UK methods development activities. Last but not least, it will help to identify the future potential partners for integrative and wider follow up proposal.

Both work packages will provide the basis to define the use cases and pilot projects which will be produced to demonstrate the opportunities and advantages of the application of a virtual engineering environment for different kinds of 'customers', applying nuclear simulation technologies in academia, national institutions, regulatory bodies and industry. 'Challenge problems' will be defined to target future capability developments within the pathway to a future integrated nuclear digital environment (INDE) [4]. Further use cases may be iterated further during the project as the INDE develops and evolves.

The general design of the architecture of the digital environment will be defined based on the outputs of the content definition work packages. The backbone architecture will provide a baseline for any modifications/amendments needed in the future. It has to be assessed against a range of use cases and will be a prototype environment which will support a future INDE. The architecture and software of a distributed system will be based on the already existing virtual engineering center (VEC) of University of Liverpool. It will follow the structure used on other programmes to provide an ability to allow stakeholders to join their models together via a common interface to investigate performance and integration issues without having to release their IP. The proposed high-level architecture (HLA) is a general purpose architecture for distributed computer simulation systems. The interaction between simulations is managed by a run-time infrastructure (RTI).

Different software tools will be integrated by the VEC, including an interface to the UK nuclear analysis, and tools of other project partners partly based on the source codes and party as licensed executables where nuclear software is proprietary. The high performance computation lab of STFC Daresbury will provide expert technical support on implementing capabilities on the Daresbury HPC, in order to demonstrate how project partners can access this UK computing facility for VE.

Following the tender document, a key point will be the demonstration of the integration of radiation modelling codes with CAD models of reactor components. A strategy will be developed to incorporate this capability within the digital environment, to enhance the capability to perform straight through shielding/dosimetry calculations using interlinked components. This capability will be demonstrated through solution of example problems in close interaction between the partners.

Due to the approach using distributed computing and remote access, strong emphasis will be put on the development of a security strategy and a safety assurance roadmap to develop procedures and techniques necessary to assure all concerned parties that the data and information being passed between collaborators is held, transmitted and processed with appropriate security. This has to be accompanied with the infrastructure safety to assure that the regulator might accept as suitable for the evaluation of the proposed safety case for nuclear systems.

Demonstration will be done via different use cases selected before besides the required use case to develop, exercise and test a multi-scale, multi-physics calculation for through-life performance analysis of reactor components, through CAD models, core simulation, radiation transport for dosimetry, stress analysis and structural integrity analysis. This will be based on a demonstration on the structural integrity of graphite bricks in Advanced Gas-cooled Reactors involving multiple inter-dependent assessment tools and while avoiding the traditional complex and fraught movement of data.

A key factor for the success will be dissemination and supply chain/user engagement to assure that the developed virtual environment will be used and seen as innovative and promising tool for the users.

A dialogue will be established with interested parties including a wide range of representatives from the nuclear industry, academia and government facilities, incorporating regular meetings of a users group, with emphasis on linking

representatives of national facilities with representatives of the nuclear industry and academia. Virtual links to international partners will be developed, including related programmes (NURESIM, CASL). The dissemination will be supported by the development of a roadmap for future steps in modelling and simulation development to assure a strong progress in the development of the modelling and simulation tools itself within a future phase of the program to support the nuclear renaissance with state of the art software tools when the first reactors are put into operation.

CONCLUSIONS

The United Kingdom has announced Nuclear R&D and Innovation programme with a volume of ~£20m end of 2016. Digital Nuclear Reactor DESIGN - Virtual Engineering, Modelling and Simulation are a key point of this program which has been awarded to a consortium around Amec Foster Wheeler Nuclear UK Limited and the main partner University of Liverpool including the Virtual Engineering Centre.

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