USE OF CAD MODELS IN ESFR-SMART EU PROJECT

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Abstract

As part of the Horizon 2020 European Union programme, research and development is under process on the European Sodium Fast Reactor in the framework of the European Sodium Fast Reactor Safety Measures Assessment and Research Tools (ESFR-SMART) project. In this project, a large commercial pool type sodium-cooled fast reactor is under development which requires state of the art research tools. One of the new approaches is the use of Computer Aided Design (CAD) software in which a 3D CAD model was developed, based on open literature, and has already proven its usefulness in many ways during the project. But the possibilities are only scratching the surface. As it is mainly a design tool, it has been used mostly to create the 3D design of the whole reactor system with its sub-systems. Through this process, the visualization of the project gave an unprecedented ease to the understanding of different concepts for project members, allowed to improve communication between the partners and finally helped to decrease the time needed for the development of the reactor system. In particular, this ease of visualization made it possible to assess new design ideas and whether they fit the existing space around the primary system of the ESFR. The CAD model serves as a basis for accurate physical measurements as well as to provide data on different physical properties such as material volumes, surfaces areas, etc. Next, this feature of the model has been used already in the project to provide information for the core catcher design's criticality calculation as well as data about sodium volume to facilitate the reactor pit preliminary design. Among further possibilities of the model is time saving by providing already available input information for other research tools and system codes. For instance, detailed geometrical data can be provided for thermal hydraulic CFD (e.g. OpenFOAM) or neutronics Monte Carlo (e.g. Serpent) codes. Furthermore, the model serves as a common base for any kind of design change to keep track of the latest version of the design which helps documenting the project, providing instant access to the needed information. In addition, the CAD software employs built-in modules which provide greater visualization by making available the creation of videos of the reactor for demonstration purposes or even to use other technologies such as 3D printing to present the work on the project to the other researchers or to public. These possibilities show the originality and usefulness of a 3D CAD model and the new dimensions for future research activities.

I. INTRODUCTION

Research and development is under process on the European Sodium Fast Reactor in the framework of the European Sodium Fast Reactor Safety Measures Assessment and Research Tools (ESFR-SMART) project [1]. The subject of this EU project is a 3600MW_{Th} (1500MW_e), pool type sodium-cooled fast reactor. In order to organise the work and to visualise the reactor design concepts, a Computer Aided Design (CAD) model is being developed. Computer Aided Design is a computational tool which serves the purpose of developing, visualising, optimising and analysing different designs and concepts [2]. The CAD model being developed for the ESFR reactor can be used in multiple ways to help the research project and to provide information for various tasks and has already been a key player in providing multiple benefits for the design process.

The paper is focused on applications of the model and its potentials. First, due to the 3D product visualization, the time for product development is greatly reduced by the improved communication between involved parties in the development process as it facilitates the understanding of the preliminary design concept. Second, the model offers a common source of information regarding to exact measurements of the system components and provides input information for simulation tools. Finally, it has also been used to analyse the possibility of 3D printing. These utilization methods are described in more detail in this paper.

II. DESIGN VISUALIZATION

As a first step to modelling the ESFR system, relevant information was gathered from CP-ESFR [3] and EFR EU projects [4] as well as French ASTRID reactor research program [5]. Based on this information, a preliminary design of the reactor primary system, secondary circuits and decay heat removal systems was established for the ESFR-SMART project.

Having this initial design, there is a source for further design development and a mean to test whether new amendment ideas fit into the available space envelop without major modification on the whole system. In addition, the 3D visualization with different colour codes helps to understand where the different system elements are and how they relate to each other. A visualization example can be seen in Figure 1, which demonstrates the designed elements of the ESFR.

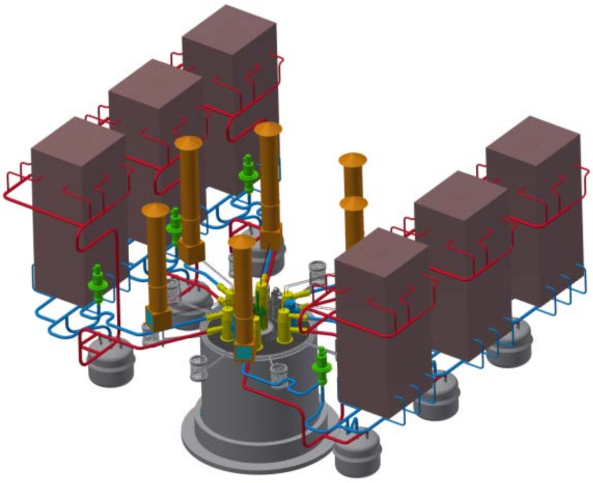


Figure 1: ESFR components overview

These coloured 3D figures help greatly the design iteration process by providing an unprecedented ease to understand how the different elements are interconnected.

III. MEASUREMENT AND INPUT INFORMATION PROVISION FOR SIMULATION TOOLS

One further advantage of having the CAD model being developed is that information regarding to the geometry of the system or system elements can be quickly and easily obtained in either 2D or in 3D format for preparing the models for different simulation tools, i.e. MCNP [6], Serpent [7] or OpenFOAM [8].

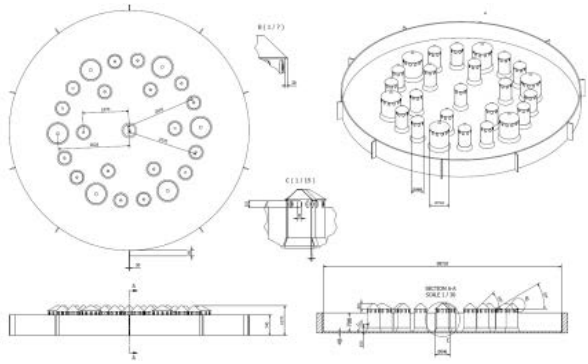
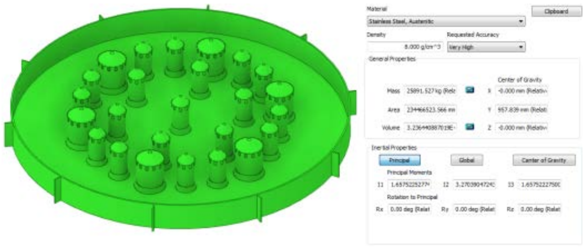


Figure 2: ESFR core catcher working drawing

The 2D format, namely working drawing, can be used when the 3D geometry cannot be used for the actual problem. On these drawings, the components of interest are represented with different 2D views, as it is shown in Figure 2, with all the needed measurements plotted. In this way, it is not necessary to redraw the elements by hand or by a 2D CAD software but the already existing 3D model can be used for the document, speeding up greatly the information exchange process.

Figure 3: Strongback mesh structure for simulation with OpenFOAM

Regarding 3D format, it is possible to provide the exact geometry from the CAD model in the format which directly can be used by the simulation code. For instance, 3D model geometry can be directly fed into OpenFOAM CFD code converting native CAD file into a specific format (such as STL). Figure 3 provides an example to this conversion, where the strongback of the reactor is converted into STL format to create the meshed geometry.



Material: Stainless Steel, Austenitic

Density: 8.000 g/cm^3

Requested Accuracy: Very High

General Properties

Mass: 25891.527 kg (Rela

Area: 234466523.566 mm

Volume: 3.23644088701 9E·

Center of Gravity

X: -0.000 mm (Relativ

Y: 957.839 mm (Relat

Z: -0.000 mm (Relativ

Inertial Properties

Principal Moments

I1: 1.65752252774

I2: 3.27039047240

I3: 1.65752227500

Rotation to Principal

Rx: 0.00 deg (Relat

Ry: 0.00 deg (Relat

Rz: 0.00 deg (Relat

Figure 4: Measurement for core catcher criticality calculations

In addition to geometry information, the model provides many more useful data. By providing the material information to the model, the weight of the elements can be obtained. Surface and volume information can be derived from the model which is essential for accurate thermal hydraulic calculations. For instance, the necessary hydraulic diameter as well as the volume measure for specific elements can be derived. As an illustration, a volume measurement of a core catcher is given in Figure 4. Combined with core volume measurement this data was used to run criticality calculations with the MCNP code in order to assess the potential of anticipated recriticality in accident scenarios with the core meltdown, as an ongoing work within ESFR-SMART project.

A specific example of potential area where the model can be used for input information generation is application for the TRACE thermal hydraulic code, which capabilities has been extended in PSI [8] for treating of sodium coolant and, in particular, for modelling of transient accident behaviour of SFR. In Figures 5, 6 and 7, an example of this use is provided. In Figure 5, the primary system is shown after it has been divided up to axial and radial layers corresponding to the actual TRACE model set up. The elements formed after the division of the primary system, which are called nodes, represent a piece of the reactor with its surface, volume and porosity information.

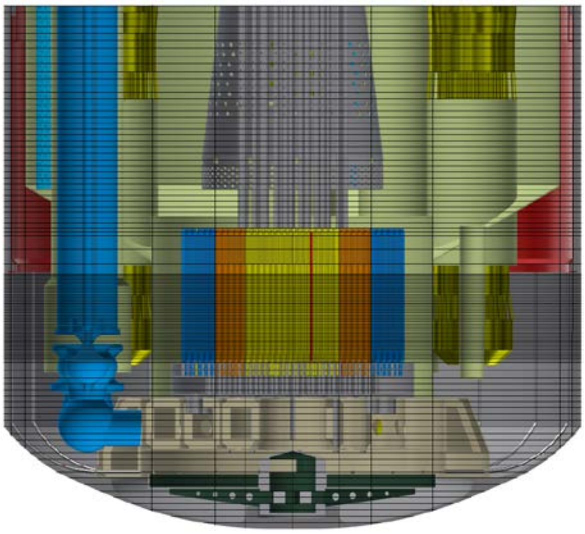


Figure 5: Primary system subdivision in TRACE model

In Figure 6, one axial slice is shown being taken out from the primary system. On the bottom part of the figure, each of the different element slices can be seen such as the (blue) primary pump, the (yellow) intermediate heat exchangers, the (green) redan, (red) vessel cooling system unit and (grey) main vessel. On the upper part of the figure, the same slice is shown filled with sodium (grey).

As the axial layer is further divided into the actual node, which is the division on the azimuthal direction, Figure 7 is obtained. The components can also be seen with different colours on the right side of the picture, whereas the same node is shown on the left filled with sodium. After obtaining this node, it is very straightforward to extract and calculate the required information – volume, surface and porosity value, which is the ratio of the sodium volume in the node to total node volume. Applying the above mentioned method the use of average data for system elements in the calculation can be substituted by use of accurate actual input data for all individual nodes aiming more accurate simulations to be performed.

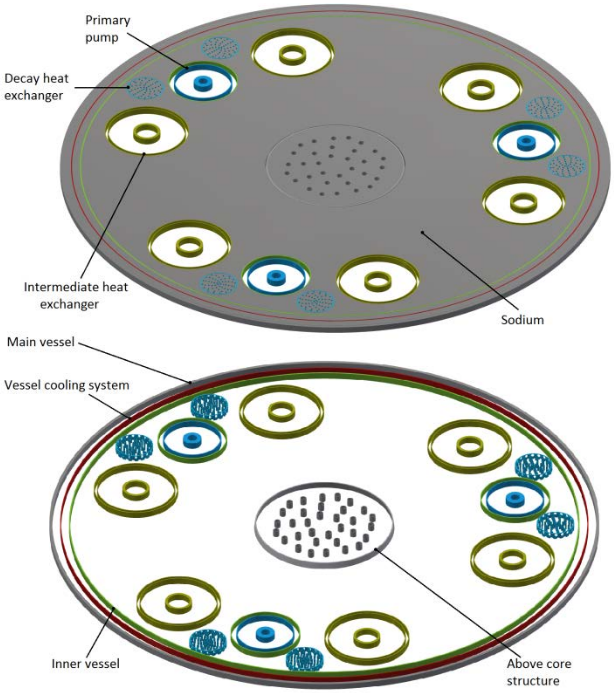


Figure 6: Primary system axial slice in TRACE model

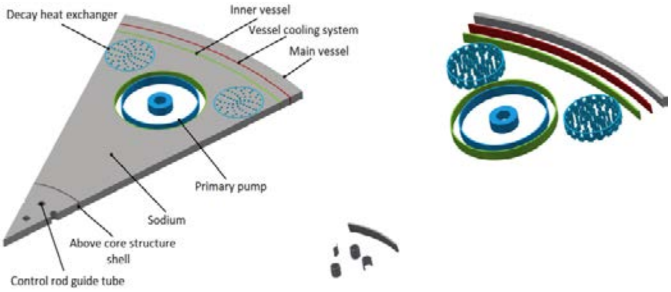


Figure 7: Primary system cells in TRACE model

Another important research project currently being under investigation is to use the CAD model to run different simulations on the model directly within the CAD software. There are various built-in simulation add-ons in most mainstream CAD software, such as the built-in CFD add-on, Finite Element Analysis (FEA), thermal simulation and electromagnetics analysis, just to mention a few possibilities.

Currently, efforts are being made to assess the capability of the built-in FEA for application in the modelling of mechanically deformed (perturbed) geometries in different Monte Carlo simulations. In FEA, different temperature distributions, forces and pressure are applied on the analysed nominal body geometry to calculate the resultant stresses, strain, and displacements in different directions. In principle, by using this method, different perturbed reactor core geometries could be accurately modelled and transferred into Monte Carlo neutron physics codes, such as Serpent. The change of multiplication features of the core can be analysed subsequently with respect to nominal conditions, for instance, an accurate subassembly bowing reactivity feedback effect can be simulated and the corresponding reactivity feedback can be assessed. Figure 8 illustrates the above-mentioned analysis presenting a deformed fuel subassembly.

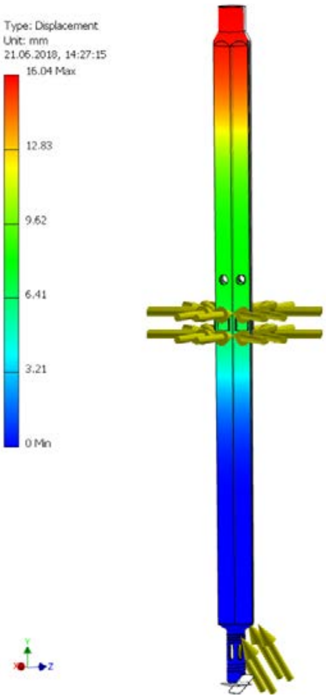


Figure 8: Deformed fuel subassembly

Other major application of the CAD model is related to shielding problem and neutron -photon transport simulation to calculate activation and gamma heating for structural materials [10]. Although this application is currently not in the scope of the ESFR-SMART project it can be considered at later phase of design.

IV. 3D PRINTING APPLICATION

There are other applications of the model which are still in the beginning of their exploration. For example, some tests have been performed for the 3D printing of the model.

There are various ways in which a 3D printed component can be used. As an illustration, a 3D printed part is shown in Figure 9, which was used to test the achievable quality of a specific 3D printing technology serving demonstration purposes.

Figure 9: 3D printed strongback concept

Other future application for the CAD model could be to serve as a base for video creation. There are numerous different CAD software with built-in capability to create a video with different settings which can be used for demonstration purposes for the public or for project members.

V. CONCLUSION

In conclusion, the utilization of the CAD model serves multiple purposes as part of the ESFR-SMART research project. Not only does it help the development of the reactor system itself by providing an easy concept visualization which resulted in better understanding of the design, but also plays a key role in providing geometry and other input information for different simulations and nuclear codes at conceptual design phase. This geometry provision can lead to better simulation results as it represents the actual geometry of the system and not only a simplified version of it. Such a usage was shown for TRACE thermal hydraulic code and the OpenFOAM CFD code.

There are some usage possibilities being explored as well, such as the 3D printing or video creation for demonstration purposes or, perhaps in a more distant future, whole experimental set up printing based on the scaled version of the actual model.

These are few of the current applications of the prepared CAD model for the project. Nevertheless, in the future, more useful applications will arise as the technology evolves and opens up new possibilities.

Acknowledgements

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Nomenclature

3D	three-dimensional
ASTRID	Advanced Sodium Technological Reactor for Industrial Demonstration
CAD	Computer Aided Design
CFD	Computational Fluid Dynamics
CP ESFR	Collaborative Project for a European Sodium Fast Reactor
EFR	European Fast Reactor
ESFR-SMART	European Sodium Fast Reactor Safety Measures Assessment and Research Tools
FEA	Finite Element Analysis
SFR	Sodium-cooled Fast Reactor
TRACE	TRAC/RELAP Advanced Computational Engine

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