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GO-VIKING

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Insights from Stakeholder Outreach

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Summary

Report on industry needs and regulatory expectations in terms of tools and methods for FIV analysis

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D1.1: Stakeholders' outreach

Report on industry needs and regulatory expectations in terms of tools and methods for FIV analysis

Version N°1
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Summary

One of the two goals of WP1 is to identify industry needs and regulatory expectations in terms of tools and methods for the analysis of FIV phenomena in NPPs. To do that, a stakeholders' workshop was organized by EDF in collaboration with IRSN. The workshop took place on the 16th February 2023 at EDF Lab Chatou: 14 stakeholders and institutions from Europe and North America attended the event and presented their relevant topics on FIV. This deliverable details and discusses the content of the presentations and aims at identifying the links with GO-VIKING goals.

Keywords

GO-VIKING WP1, stakeholders' workshop, FIV, FSI, CFD, industrial needs.

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1. Introduction

The GO-VIKING project focuses on Fluid-Induced Vibration (FIV) phenomena in Nuclear Power Plants (NPPs). The goal of the project is to build experimental and numerical databases on relevant configurations, to be used to assess and develop numerical methods for FIV. More specifically, FIV in fuel rods and fuel assemblies (FAs) and FIV in steam generators (SGs) will be studied. For the former configuration, a dedicated work package (WP2) is planned to perform new experimental campaigns and to simulate them with different CFD approaches and different CFD-structure coupling methods. For the SG configuration, new experimental campaigns in both single and two-phase flow are planned within two dedicated work-packages (WP3 and WP4); also in this case, single and two-phase CFD simulations of the experimental campaigns will be carried out following different CFD approaches and CFD-structure coupling methods.

Since one of the goals of GO-VIKING is to propose best practice guidelines for FIV analysis in accordance with the needs of the stakeholders, the organization of a stakeholders' workshop was one of the two deliverables of WP1, the other one being dedicated to the literature review. Such workshop was aimed at gathering international nuclear stakeholders to collect their needs and expectations in terms of FIV in NPPs, beside expected and relevant potential outcomes from GO-VIKING. We decided to restrict the invitation to nuclear utilities, nuclear vendors, nuclear safety organizations and Technical Safety Organizations (TSOs), thus omitting all labs and universities involved in R&D in order to focus on the industrial aspects.

The workshop organization process consisted in inviting many institutions by sending them an email presenting the GO-VIKING project and the plan of organizing the stakeholders' workshop. The invitation detailed the goals of the workshop together with the expected contribution by the participants. The contribution by the participants was not restricted to FAs and SGs, the presentation of other FIV issues encountered in NPPs was considered welcome, too. The possibility of declaring confidential information provided in the presentations was given to all participants. Only the participations with a contributed presentation were accepted, requests of participation without a formal presentation were refused for the sake of an open discussion among the participants.

The following utilities accepted to contribute: EDF (France), EDF UK (UK), TVO (Finland), Vattenfall and Uniper Energy (Sweden, involving 3 nuclear power plants), EPRI (USA). The following vendors accepted to contribute: Framatome (France-Germany) and Westinghouse (USA). The following safety authorities and TSOs accepted to contribute: CNSC (Canada), GRS (Germany), IRSN (France), NRC (USA).

The present document provides an overview of the information shared by the participants in their presentations. One chapter is dedicated to FIV in FAs, one to FIV in SGs and one to FIV in other NPPs components. Moreover, a chapter is dedicated to the content of the presentations given by the safety authorities and TSOs. The agenda of the workshop is provided in appendix 1 and the presentations given by the participants are provided in a separate directory.

No specific references are included in the text of this document, since all the contained information is taken from the proceedings of the GO-VIKING stakeholders' workshop, which is available in a separate folder linked to the present document.

2. FIV in fuel assemblies

2.1 Overview

Vendors (Framatome and Westinghouse) presented their approaches, numerical methods and tools, state of the art and future challenges in terms of FA design, optimization, licensing and operation. A utility (EDF UK) presented FIV issues of FAs in advanced gas-cooled reactors (AGRs). This chapter summarizes the information shared in the frame of these presentations.

Grid-to-rod fretting wear is a general FIV issue that concerns FAs, observed above all at the bottom part of the FA. Specific FA designs resulted in further FIV mechanisms, such as self-induced instabilities. Baffle-jetting, resulting in a cross-flow with respect to the FA rods, represents another FIV phenomenon that has been observed in NPPs. Regarding AGRs, wear due to pin-brace interaction was observed in early 1990's in helical rib design, introduced in order to increase fuel/gas heat transfer compared to the original circular ribbed in design. Probably due to the increased induced turbulence, ribs were found to wear and damage in the brace region.

2.2 State of the art of numerical simulations

Full-scale experiments and operating experience represent the historical approaches for FA licensing. Such approaches are expensive and, in the case of the operating experience, long.

Analytical and numerical tools can be applied to turbulence induced vibrations, since this mechanism generally does not require strong FSI coupling. The focus is on the analysis of FIV of single fuel rods (FR). The FR can be modelled through linear mechanical models, meaning that no impact/sliding between FR and spacer grids is taken into account. This in turn results in a limited capability for fretting wear prediction, in particular in the case of gapped fuel rod support. Due to this limitation, the use of non-linear models with the FR being represented by a beam and allowing for modelling of different grid support conditions (gaps, preloads, etc.) is a more appropriate approach, which is followed by Westinghouse (VITRAN) and Framatome. In this case, the impact force and work rate due to the rod motions can be evaluated. Such non-linear beam models have proven to be able to calculate work rate distribution matching the fretting wear distribution observed in NPPs allowing for the improvement of FA designs.

Such structure models must be fed with the turbulence excitation. For this purpose, turbulence reference spectra (obtained by experimental measurements), adjusted to the specific configuration studied, can be employed.

However, the disadvantage of the reference spectral approach is the limited prediction capability in cases where the actual turbulence conditions strongly differ from the reference cases (used to determine the reference spectra).

The more advanced option would be to use CFD to directly obtain the turbulent excitation, to be used as input for the non-linear FR structural model. Scale-resolving approach such as Large Eddy Simulation (LES) in combination with wall functions (as only feasible option) is generally required and can be applied today to simulate different regions of a full-scale FA configuration such as FA spans or inlet zones.

The one-way coupling between LES and non-linear mechanical analysis used by Framatome have proved to lead to reasonable agreement with experimental measurements in terms of vibration modes and RMS amplitudes. The spectra of turbulent fluid forces derived from CFD-LES simulations led to significant improvement of the FIV prediction in cases where traditional approach based on the use of generic turbulent spectra has failed. However, the applicability of LES at the core scale is not yet possible, sub-channel approaches are used for this scale. Generally speaking, the cost (CPU time and memory) required for such CFD simulations remains high when compared to the time scale of the design optimization process. Nevertheless, CFD approach described above can be used for establishing/extending a data base that can successively replace the generic spectra in the analysis of turbulence-induced vibration of fuel rods.

In the case of VITRAN, for each grid span in the fuel rod model, the lumped RMS forces in the 3 directions from CFD are applied, then the lumped forces are modelled as a white noise random signal in a certain frequency range.

2.3 Industry needs, requirements for new numerical tools and Expectations *vs* GO-VIKING

CFD LES is today feasible for reduced-scale models such as FA spans and can be used for one-way coupling in order to calculate turbulence-induced vibration of fuel rods and in turn fretting wear. On the other hand, there are FIV mechanisms that require strong coupling between the fluid and the structure fields: examples are the self-induced excitation, where the FA undergoes resonance under axial flow, and baffle jetting, where a fluid-elastic coupling exists due to cross-flow (see next section dedicated to SGs). Modeling of FA flow-induced instability is still an open field in R&D: some current attempts focus on vibration of bare bundle under pure axial or cross-flow, using URANS combined with linear mechanical models. Larger scales can only be approached by simplified hydraulic models, which can capture only the main flow and, therefore, have no capability for the instability detection.

Generally speaking, the question of CFD validation arises, even for LES, since the direct experimental measurements of fluid (turbulent and fluid-elastic forces) remain a challenge. From this point of view, the results provided by GO-VIKING from the experimental campaigns of WP2 represent a useful CFD-grade database. Within WP2, time-resolved PIV will be available for the cantilever beam experimental campaign, time-averaged LDA will be available for the ALAIN experimental campaign. Moreover, for both campaigns, the vibration response will be measured. The combination of these experimental measurements represents a CFD-grade database that will allow to assess the consistency of CFD results in predicting the fluid forces.

3. FIV in steam generators

3.1 Overview

The Canadian nuclear stakeholders (University of Guelph, Canadian National Laboratories and Canadian Nuclear Safety Commission), utilities (EDF, EPRI) and a vendor (Westinghouse) presented their approaches, numerical methods and tools, operating experience, state of the art and future challenges in terms of SG operation, design, optimization and licensing. This chapter summarizes the information shared in the frame of these presentations.

In the USA, the Steam Generator Management Program (SGMP) was started by EPRI in 1975. Originally, SGMP focused on studying the causes of SG degradation, starting from the early 1990's the focus shifted from causes to managing degradation. Beside reducing operation and maintenance (O&M) costs and providing consulting, the goals of SGMP are to supply tools and guidance, and pursue R&D linked to operational problems for utilities. In terms of SG degradation history in the USA, corrosion-based degradation was the main degradation mechanism before advanced tubing material (690TT and 600TT alloys) and improved chemistry were employed. Such degradation has now been reduced to manageable levels. Currently, wear due to supporting structures and to foreign objects are the main degradation threats. The structure wear is found to represent the main cause of degradations. Tubes are plugged when wear reaches a limit defined in Technical Specifications.

As of 2023, EDF steam generator fleet has reached more than 6000 SG.years of operation. EDF operational experience regarding FIV in SGs is represented by tube fatigue cracking near top tube support plate due to FEI (fluid-elastic instability) and tube wear on supporting elements (anti-vibration bars (AVB) and tube support plates (TSP). Evolutions and improvements have consisted in the development of computational tools for FEI prediction, AVB design change (number and location of AVB sets), in-service examinations and preventive plugging of tubes at risk, TSP design evolution (broached holes), periodic TVI examinations for TSP clogging evaluation (aggravating factor) and chemical cleaning when necessary. The VISCACHE experimental facility, allowing water/freon cross-flow under different configurations (array disposition, number of flexible tubes, …) has been widely employed by EDF to study FIV in SGs tube bundle. Tube/AVB wear phenomenon is found by EDF to occur almost exclusively for the largest U-bend tubes near the center of the bundle, and has been as of 2023 only encountered on original SGs, thanks to the AVB design and manufacturing evolutions that have been implemented on replacement SGs (tube/AVB gap reduction, increased number of AVB sets and evolution of manufacturing processes).

3.2 State of the art of numerical simulations

Westinghouse presented the approach for designing SG, driven by R&D, theory, literature, empirical correlations and constants and analysis methodology/software, as well as by the operating experience. Extensive vibration testing has been employed to identify the vibration mechanisms on small scale U-bend configurations, various tube array patterns and support plate designs: this allowed to identify turbulence, vortex shedding and FEI as the underlying mechanisms for FIV in SGs. The thermalhydraulic analysis in the design stage is realized by the component scale code ATHOS, developed by EPRI. ATHOS is a 3D, ½ symmetric model, retaining porous media approach and allowing for conjugate heat transfer. Around 30,000 cells are used to simulate the entire tube bundle region. ATHOS determines local flow conditions (velocities, density, void fraction) on each tube along the full length. These results are directly used as input for the mechanical analysis. Comparisons have been made with detailed CFD models in local single-phase portions of the tube bundle. EPRI participated in the working group of the TRITON software, a higher resolution (around 1M cells) porous media code based on the commercial CFD code Star-CCM+.

Experimental correlations are extensively used in the design process, to determine FIV empirical constants, lift coefficients, instability constants, added mass, damping, etc. Conservative inputs (in terms, for example, of plant power, plugging ratio, …) and parameters (damping) are used for the numerical analysis. Moreover, a conservative criterion is used for FEI, i.e. a stability ratio lower than the theoretical value of 1.

In Canada, the R&D activity on SG vibrations have led to the development of several modeling methods. The first step was to focus on FIV in single phase flow: the flow across the tube bundle was modeled through mono-dimensional channels around the tubes, where the area and flow velocity of the segments were written as the sum of a constant value plus a perturbation value generated by the tube motion. Coupling the fluid model to a structural beam model allowed to obtain consistent results in terms of prediction of fluid-elastic instability (FEI), for different array dispositions. The same approach was then applied to two-phase bubbly flow, modeling a slip ratio between the phases: the calculated slip ratio and critical velocity for FEI were found to agree with experimental results. 3D CFD was also tested: a URANS drift-flux approach was applied for bubbly flow and provided consistent results in terms of critical velocity for FEI. A numerical model to simulate the different possible support conditions provided by TSPs and AVBs was developed and applied to the tube beam model.

3.3 Industry needs, requirements for new numerical tools and expectations vs GO-VIKING

The CFD two-phase simulations realized by the Canadian stakeholders are limited to bubbly flow, no attempt of simulating higher void fraction (closer to prototypical SG conditions) flow regimes has been made: GO-VIKING is meant to generate experimental CFD-grade results in cross-flow for void fraction corresponding to so-called intermittent flow (occurring for gas flow rates higher than in bubbly flow), that will allow to assess the consistency of CFD simulation for flow regimes different from bubbly flow. Moreover, several two-phase CFD approaches to model intermittent flow will be retained by the different participants, which will allow to understand strengths, weaknesses and necessary developments of so-called “all-regime-CFD” approaches for SG application.

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EDF develops the Neptune_CFD code, which allows for fluid-structure interaction simulations in two-phase flow. EDF interest in GO-VIKING is motivated by the possibility of improving their CFD codes in terms of turbulence modeling in tube bundle configurations and of validating two-phase and vibration results. From this point of view, GO-VIKING is expected to provide CFD-grade validation data in terms of two-phase flow and vibrations behaviors (measured simultaneously) for different configurations.

Experimental measurements in the tube bundle flow field represent an identified beneficial aspect from GO-VIKING also for current component scale codes. Since most of current SG codes use porous media, empirical correlations are used to model the flow resistance and the validation of the obtained results is very important. Moreover, void fraction measurements will be quite beneficial in validating SG thermalhydraulics codes. Measurements of the turbulence loading for a wide range of void fractions, velocities and flow directions are also identified as beneficial aspects. Other industrial expectations consist in the study of tube interaction with supporting structures, in obtaining work rate and wear coefficient measurements, since understanding wear mechanisms is considered an important aspect for next generation of SG design.

The development of SG FIV standards and guidelines for industries is seen as a potential outcome of GO-VIKING.

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4. FIV in other configurations

Beside FAs and SGs FIV issues, other problems linked to FIV were reported by the participants. These issues will not be tackled in Go-Viking but reporting them may open other discussions and widen the project impact. The different examples show the ability of CFD to contribute in understanding and solving few practical issues.

4.1 Water/steam lines

Water and steam line vibrations were reported to represent an issue sometimes encountered in PWR and BWR NPPs. Such vibrations are often found to be caused by acoustic modes of the line being close to the structural mode.

The pump pressure pulsation, given by the impeller, seemed to be the cause of one of such vibration issues observed in a water feed line: since the pump pressure pulsation was found to coincide with the vibration frequency of the line, the pumps are supposed to excite the acoustic modes and in turn the structure modes. CFD simulations of the pressure fluctuations generated by the pumps were run in support of this analysis.

Abnormal vibrations of the steam line downstream of the steam generator of a PWR were observed in a NPP after a SG replacement. The root cause to the vibration were pressure pulsations created in the steam generation outlet nozzle: a new design of the venturi part of the nozzle allowed to eliminate the problem.

Valves along the lines were also found to be the source of vibrations. High vibration levels were measured after replacement of the main steam stop control valves in a BWR. CFD simulations were run to understand the difference of the flow inside the valve between the original and the replacement valve designs: the results showed that the new design resulted in much higher velocity fluctuations inside and at the outlet of the valve. Therefore, the new valves were in turn replaced by valves adopting the original design, and the vibration issue was solved.

In another BWR, vibrations in the main steam inlet valves and in the main steam line were measured after a power uprate. The former was found to be caused by vortex shedding above the valve cavities exciting acoustic modes. The latter were found to be caused by an unstable flow behavior (shear layer instability) causing pressure peaks in the safety relief valve line. This analysis was conducted through CFD simulations of the steam line network downstream of the RPV.

CFD was reported to be used to analyze the flow inside check-valves of BWR, following the detection of vibration-induced wear on the valve housing. The calculated velocity field around the check valve was found to show a high unstable behavior with large fluctuations close to the valve.

4.2 RPV internals

Wear of thermal sleeves, placed on the RPV top head of PWRs, were reported. The wear in some cases led to a break, causing the sleeve to drop: the ring that remained in the top part creates a risk of blocking the rod cluster control assembly (RCCA). CFD was used to model the dynamic loads on the thermal sleeves in order to understand the cause of wear. The head region of the RPV was simulated, the forces calculated by CFD were then applied to an uncoupled mechanical analysis. The preliminary results show that the RPV upper head flow implies strong loads on thermal sleeves, which generate displacements and stresses that could be linked to the fatigue observed in plants. The central thermal sleeves are more concerned than peripheral ones, but important wear has been observed on peripheral thermal sleeves, which has not been found in the calculation.

A first attempt of CFD simulation was also reported to be applied to the investigation of guide tube wear in PWR. In order to understand the cause of the wear, CFD was applied to a full-scale experimental setup of RCCA in its guide tube: the results showed higher wear in the bottom region of the tube, which is consistent with the operating experience.

CFD-FEM one-way simulations were reported to be used to analyze the vibrations of the core barrel observed in a PWR. The CFD simulation was used to calculate the fluid pressure pulsations, then applied to the structure model.

5. FIV and regulators

Safety authorities (NRC) and TSOs (GRS, IRSN) presented requirements for numerical tools to be used in the frame of the safety demonstration, FIV issue considerations within the national safety requirements, examples of R&D programs and of FIV issues investigated.

5.1 Regulatory requirements for numerical tools

In the USA, the NRC requires that software used in regulatory applications should be developed under the framework of a software quality assurance (SQA) plan and undergo verification & validation (V&V) activities. The specific SQA and V&V activities depend on the safety significance, the complexity, the previous use in regulatory applications and the status of previous approval for the software. Code verification is aimed at verifying the maturity of the development process and of the SQA, and to check that errors or algorithm deficiencies do not provide improper mathematical results. Solution verification is aimed at checking procedural or numerical solution errors. The model validation must ensure that the physical system is accurately modeled and must establish validation criteria to assess modeling results. Importance is also given to quantification of uncertainties (UQ). Sources of uncertainty such as the model structure, the numerical approximations, the inputs and the model parameters must be considered. Regulatory guidelines from NRC exist for different physical applications and define a graded set of guidelines on analysis steps, analytical SQA and V&V, and levels of associated documentation. When followed, these guidelines result in an acceptable practical framework to ensure the effectiveness and efficiency of NRC reviews of submittals containing analysis and results.

In France, the French legal framework requires that the demonstration of nuclear safety established by the operator of a basic nuclear installation must be, when required, based on "calculation and modelling tools qualified for the fields in which they are used". The qualification of a Scientific Calculation Tool (SCT) must ensure that it is able to calculate the figures of merit with the uncertainties within the intended scope of utilization. The French Safety Authority (ASN) issued the "Guide 28", to specify recommendations and requirements associated to the qualification of calculation and modelling SCTs. It details requirements for V&V and UQ and aims to facilitate the preparation of SCT qualification files by giving the overall structure and the different steps required by ASN to provide the agreement on specific applications. An important highlighted aspect is that the qualification of a SCT is always linked to a specific application: if the application changes or evolves, the qualification must be updated or done again, even if the numerical tool is the same as before.

5.2 Example of FIV in the safety requirements

GRS presented how FIV is considered and mentioned within the German safety requirements. The safety requirements for NPPs, issued by the federal ministry of the environment, nature conservation, nuclear safety and customer protection, do not explicitly mention "FIV", but state that "all events or plant conditions and the associated mechanical […] impacts" shall be considered for the design of the "barriers and retention functions". Moreover, "vibrations" in conjunction with earthquakes and explosions is explicitly mentioned to be considered. At the following lower hierarchical regulatory level, the RSK (German Reactor Safety Commission) guidelines, issued by the advisory bodies, explicitly mention FIV for RPV internals and for pressure waves from explosions. Further decreasing in the regulatory hierarchy, the KTA safety standards, issued by the Nuclear Safety Standards Commission (KTA), also explicitly states FIV: the document "Components if the Reactor Pressure Boundary of Light Water Reactors, Part 2: Design and Analysis" mentions the investigation of mechanical loading coming from long-term influences of vibrational stresses and from vibrations caused by fluid forces and earthquakes. In the document "Design of Reactor Cores of Pressurized Water and Boiling Water Reactors, Part 3: Mechanical and Thermal Design", FIV is mentioned in conjunction with GTRFW and fatigue. In the document "Reactor Pressure Vessel Internals", FIV is mentioned in conjunction with mechanical loads on the RPV internals and FA vibrations due to earthquake. In the document "Component Support Structures", vibrations are required to be considered for fatigue analysis of supports for highly dynamic loads.

5.3 Examples of CFD for FIV

In Germany, the "German CFD network" was established in 2022, with the goal of "development of a CFD-software package for the efficient and accurate simulation of reactor safety relevant fluid flows and heat transfer processes". Two strategic documents have been released in 2021: in the paper "Priorisation of OpenFOAM Development and Validation Activities for the Reactor Cooling Circuit", the FIV numerical simulation with CFD-CSM tools is mentioned. Priorization is given to GTRFW and FA bow. A high priority for FIV analyses and development of coupled CFD-CSM tools is considered.

GRS started CFD FIV numerical analyses in 2015: studies on the implementation and validation of full and reduced order FSI methods have been realized, simple axial and cross-flow geometries relevant for FA and SG have been investigated, and GRS has participated to international FIV activities such as OECD/NEA benchmarks and R&D collaborations such as VIKING. The current challenges, identified by GRS, are the lack of guidelines, the parallel mastering of the fluid and mechanical aspects, the very expensive CPU time, the validation and the uncertainty quantification (UQ). Moreover, the regulatory acceptance is considered as a primary aspect: without this perspective, FSI methods might not be considered by stakeholders.

GRS detailed that the improvement of numerical tools can be achieved by defining best practice guidelines and training, together by the availability of high quality CFD-grade experimental results (or numerical direct numerical simulations (DNS)). Fast running methods or even analytical methods represent a powerful perspective.

IRSN presented a preliminary study of the thermal sleeve break inside a French PWR, based on a CFD analysis. CFD was used to understand the physical phenomena inside the RPV head leading to deterioration: the forces were calculated and then applied to an uncoupled mechanical analysis. The CFD results showed that the RPV upper head flow implies strong loads on the thermal sleeve, which generate displacements and stresses that could be linked to the fatigue observed on plants. The central thermal sleeves are found to be more concerned than peripheral ones, but it has been observed important wear on peripheral thermal sleeves, which has not been found by the calculation. Coupled FSI was mentioned as a possible approach to improve and capture the entire physical mechanism. Moreover, it was highlighted that this was a preliminary study and that the qualification of the CFD tool was not performed for this application.

6. Conclusions

The stakeholders' workshop organized within WP1 of GO-VIKING succeeded in gathering several international nuclear stakeholders to present and discuss topics related to FIV in NPPs. Bringing together different institutions in a such sensitive engineering field was not easy, but has been shown to be feasible. The content of the presentations ranged from current numerical tools used for FIV, needs and expectations in terms of FIV numerical simulations and tools for NPPs, examples of FIV issues encountered, and of how numerical simulations were used to understand and solve such issues.

For FAs, LES represent the most advanced choice to estimate turbulence-induced forces on the fuel rods. The need for experimental measurements in relevant configurations was identified as necessary to validate LES results. Such experimental measurements will be generated in the frame of GO-VIKING and LES validation and assessment is, therefore, identified as a potentially relevant outcome to this topic from GO-VIKING. Today, strongly coupled FIV mechanisms (such as baffle jetting and self-induced resonance) cannot be simulated through CFD-CSM analysis, because of the too high CPU resources and time required. Such simulations are identified as a future challenge for FIV numerical prediction and investigation: in the frame of GO-VIKING, participants will perform strongly coupled CFD-CSM simulations of FA configurations, the results and the assessment of these simulations can be identified as a further potentially relevant outcome of the project.

For SGs, several modelling approaches for FIV were presented, ranging from component-scale porous media approaches, to multi mono-dimensional models of the flow channels between tubes coupled to structural beam models to predict fluid elastic instability (FEI), to CFD-scale simulations coupled to structural beam models to predict FEI. Regarding porous media approaches, the experimental local (i.e., in different region around the tube bundle) measurement of velocities and void fraction was identified as a beneficial aspect, since it would allow to assess the flow prediction by closure laws (for pressure loss and drift-flux) needed in porous media: this type of measurements will be performed in the frame of GO-VIKING and, therefore, can be considered as a potentially relevant outcome of the project. The same kind of experimental results were identified also as necessary for the future application of CFD to study FIV in SGs: two-phase CFD simulations of the different possible two-phase flow-regimes inside a SG require a dedicated CFD-grade experimental database, not available today. The new generated experimental data from GO-VIKING represent, therefore, a potentially relevant outcome of the European project for future CFD-scale simulations of FIV in SGs. Moreover, the numerical simulations that will be performed in the frame of GO-VIKING will represent a first numerical assessment of CFD used for two-phase flows in SGs in different flow-regimes.

Although not explicitly mentioned during the workshop, there might be also an interest for two-phase axial flows. GO-VIKING will provide experimental data for the cantilevered beam and coupled CFD-CSM computations will be performed. This will also show a first assessment of the ability of current CFD approaches to predict such flows.

The application and the practical use of CFD and coupled CFD-CSM analysis to configurations different from FAs and SGs was also presented. This shows the interest of disposing of numerical tools able to predict and analyze FIV phenomena in NPPs. The significant variety of methods, codes and fluid/structure approaches that will be used by GO-VIKING participants will allow obtaining a relevant numerical assessment that will contribute to identify strength, weaknesses and needs for coupled CFD-CSM analysis in different configurations. The Best Practice Guidelines to be synthesized at the end of the project will provide important information on the FSI methods that can be used for further NPP components and structures. Since CFD and structural mechanics codes are general purpose tools, many of the developed FSI approaches would be also applicable to vibration problems in other industries.,

Safety authorities and TSOs presented their requirements in terms of quality plan, verification and validation and uncertainty quantification process for numerical tools used to submit analysis and results to them. The acceptance of CFD-CSM results is therefore subjected to a rigorous preliminary "validation" phase, and this represents a primary aspect to be considered by stakeholders. The GO-VIKING project aims at providing valuable and high-quality data for this purpose.

Appendix 1

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GO-VIKING *STAKEHOLDERS' WORKSHOP*

Thursday 16 FEBRUARY 2023 – Amphi H

EDF Lab Chatou

06 Quai Watier,

78400 Chatou (Paris, France)

08:30	Welcome Breakfast
09:00	Welcome, Daniele Vivaldi (IRSN, France) and Sofiane Benhamadouche (EDF, France)
09:05	Flow Induced Vibrations issues in NPPs: old and new challenges for modelling. Pierre Moussou (EDF/IMSIA, France)
09:30	The European GO-VIKING Project on Flow-Induced Vibrations. Angel Papukchiev (GRS, Germany)
09:55	Experience of flow induced vibrations at Ringhals NPP. John Lorentzon, Pascal Veber, Jonas Gunnarsson, Stefan Melby (Vattenfall (Ringhals), Sweden)
10:15	How things can go really wrong, high vibration levels in steam lines. Hans Lindqvist (Vattenfall (Forsmark), Sweden)
10:35	Coffee Break
10:50	Some examples of Fluid Structure Interaction from the UK Nuclear Fleet. James Pethan (EDF Energy, UK)
11:10	OL1/OL2 power uprate prestudy – risk survey for flow-induced vibration (FIV) of RPV internals. Paulus Smeekes (TVO, Finland)
11:35	Flow-induced vibrations in steam isolation valves and feed-water check-valves. Thomas Probert (OKG Uniper Energy,Sweden)
12:00	Flow-induced vibrations of fuel assemblies – Advances and current stakes. Julien Pacull, David Tumbajoy-Spinel, Elodie Mery de Montigny, Benjamin Farges (Framatome, France)
12:20	Flow induced vibrations EDF operating experience on reactor vessel internals. Michel Guivarch (EDF, France)
13:00	Lunch break

14:00	NRC Regulatory Perspective for Future Computational Models of FIV FEI and FSI. Andrew Johnson (NRC, US)
14:20	Flow-induced vibrations analyses from GRS perspective: potential, challenges, and the need for improvements. Angel Papukchiev (GRS, Germany)
14:40	FSI in French safety studies: examples, requirements and illustration. Clément Viron (IRSN, France)
15:05	Grid-to-Rod Fretting Wear Simulation – VITRAN Code. Alireza Mofidi (Westinghouse, US)
15:30	Coffee Break
15:45	Modelling FIV in tube arrays. Marwan Hassan (Guelph University, Canada), Jovica Riznic (CNSC, Canada), Salim El Bouzidi (CNL, Canada)
16:10	Flow-Induced Vibration in EDF Steam Generator fleet. Jérôme Delplace (EDF, France), Sylvain Dupraz (EDF, France), William Benguigui (EDF/IMSIA, France)
16:35	Westinghouse Steam Generator Flow-Induced Vibration Overview. Creed Taylor (Westinghouse, US)
17:00	EPRI SGMP Report – Degradations by FIV and Research Interests. Sean Kil (EPRI, US)
17:25	Closing remarks. Adjourn.
17:30	Visit to MEDOC Facility. Christophe Pinto (EDF, France), Olivier Ries (EDF, France), William Benguigui (EDF/IMSIA, France).

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