Ref. Ares(2023)8590744 - 14/12/2023

GO-VIKING

Research and Innovation Action (RIA)

This project has received funding from the Euratom research and innovation programme 2021-2025 under Grant Agreement No 101059603

Start date : 2022-06-01 Duration : 48 Months

Intermediate AUG recommendations report

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GO-VIKING - Contract Number: 101059603

Project officer: Angelgiorgio IORIZZO

Document title	Intermediate AUG recommendations report
Author(s)	Dr. Papukchiev ANGEL
Number of pages	17
Document type	Deliverable
Work Package	WP7
Document number	D7.4
Issued by	GRS
Date of completion	2023-12-07 18:42:17
Dissemination level	Public

Summary

Intermediate summary report of the recommendations provided by the AUG

Approval

Date	By
2023-12-08 12:59:19	Mrs. Marianne GROS (LGI)
2023-12-14 14:04:40	Dr. Papukchiev ANGEL (GRS)

Deliverable 7.4

Intermediate Advisory and User Group recommendations report

Version N°1
07/12/2023

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Document information

Grant Agreement / Proposal ID	101060826
Project Title	Gathering expertise On Vibration ImpaKt In Nuclear power Generation
Project Acronym	GO-VIKING
Scientific Coordinator	Angel Papukchiev, angel.papukchiev@grs.de, GRS Kevin Zwijsen, zwijsen@nrg.eu, NRG
Project starting date (duration)	1st June 2022 – 31st May 2026 (48 Months)
Related Work Package	WP7
Related Task(s)	T7.3
Lead Organisation	GRS
Contributing Partner(s)	GRS, NRG
Due Date	30/11/2023
Submission Date	07/12/2023
Dissemination level	PU

History

Date	**Version**	**Submitted by**	**Reviewed by**	**Comments**
07/12/2023	V1.0	GRS, NRG	LGI	First submission

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Abbreviations and Acronyms

Acronym	Description
AUG	Advisory and User Group
CFD	Computational Fluid Dynamics
CSM	Computational Structural Mechanics
DEL	Deliverable
FA	Fuel Assembly
FIV	Flow-Induced Vibrations
FSI	Fluid-Structure Interaction
GO-VIKING	Gathering expertise On Vibration ImpaKt In Nuclear power Generation
NDA	Non-Disclosure Agreement
NPP	Nuclear Power Plant
PIRT	Phenomena Identification and Ranking Table
PIV	Particle-Image Velocimetry
UQ	Uncertainty Quantification
WP	Work package

Summary

The Advisory and User Group has an important role within the GO-VIKING project and its external, independent analysis and recommendations will ensure the quality and excellence of the project and will support the strategic decisions. The AUG involves representatives of organisations with strong background in FSI, fluid dynamics and/or structural mechanics.

The main recommendations provided by the Advisory and User Group concern the development of the GO-VIKING project progress; the identification of possible shortcomings and suggestion of steps for improvements; the exchange of knowledge and practical experience.

Keywords

Vibrations, flow, structure, frequency, amplitude, displacement

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1. Description of the Advisory and User Group

1.1 Mission of the AUG

The Advisory and User Group has an important role within the GO-VIKING project and its external, independent analysis and recommendations will ensure the quality and excellence of the project and will support the strategic decisions. The AUG involves representatives of organisations with strong background in fluid-structure interaction (FSI), fluid dynamics and/or structural mechanics.

The synergy between the Consortium and the AUG generates valuable feedback to the project in order to align its objectives and deliverables with end-user needs. Further, AUG members provide independent feedback on the project progress and advice on possible issues. AUG members have access to selected key deliverables and data, and are invited to share their insights regularly over the life of the project through attending meetings and participation to the lecture series and workshops.

The main recommendations provided by the Advisory and User Group concern the development of the GO-VIKING project progress; the identification of possible shortcomings and suggestion of steps for improvements; the exchange of knowledge and practical experience.

1.2 Selection process of the AUG

An initial list of experts coming from major stakeholders in the field of flow-induced vibrations in nuclear power plants was established. The experts were selected by the Project Management Office (GRS, NRG), with input from the work package leaders, on the basis of proven expertise in the field including methodological expertise and good knowledge of the EU research and innovation policy and EURATOM programme and availability to fulfil their responsibilities for the duration of the project.

After a written confirmation of participation of each AUG member, a Non-Disclosure Agreement (NDA) was created by LGI, GRS and NRG, and sent to the members for signature. The NDA protects confidential information disclosed by any of the Parties to any member of the Advisory and User Group, either directly or through the Coordinator in the case where the concerned partner gave to the Coordinator its prior written approval for such disclosure.

1.3 Members of the AUG

The GO-VIKING AUG is now composed of 13 members. The Canadian University of Guelph and Westinghouse expressed interest in GO-VIKING and recently joined the AUG. Another industrial company would like to join the AUG and already received the NDA for signature. Further competencies or expertise may be added during the course of the project, if considered necessary.

A short description of the qualifications of the members is provided here below:

Table 1 - Qualification of the GO-VIKING AUG members

AUG member	Organisation	Expertise
Salim Elbouzidi	**Canadian Nuclear Lab**	NPP related CFD, FIV and FSI
Bernd Dressel	**Framatome GmbH**	NPP related FIV, FSI
Christophe Riga	**Tractebel**	NPP related CFD, FIV and FSI
Graham Macpherson	**Frazer-Nash Consult.**	NPP related CFD, FIV and FSI
Philippe Bardet	**G. Washington University**	Experimental FSI and fluid mechanics
Pierre Moussou	**EDF**	NPP related FIV, FSI, operational experience
Eric Lillberg	**Vattenfall**	NPP related FSI&FIV experiments, CFD, numerical modeling
Benjamin Chazot	**Framatome**	FSI, NPP CFD
Kristian Angele	**Vattenfall**	NPP related FSI&FIV experiments
Jan Klouzal	**ÚJV Řež**	FSI, FIV and code coupling
Marwan Hassan	**University of Guelph**	CFD, FSI, FIV
Alireza Mofidi	**Westinghouse**	FSI, FIV

1.4 AUG involvement

The AUG members were invited to join every Progress Meeting organized and held from the beginning of the project. They are encouraged to take part in each of the Work Package Leaders' technical presentations, as well as in sessions dedicated to presenting their feedback and recommendations on the consortium's work: therefore, some of them participated in-person and remotely in the progress meetings in Chatou/Saclay (December 2022) and Cadarache, France (June 2023), and in Ringhals, Sweden (November 2023). Their participation was a great added value for these meetings. All AUG members will be invited to join the next progress meeting in Erlangen, Germany in June 19-20, 2024.

2. Intermediary recommendations of the Advisory and User Group

The first GO-VIKING AUG meeting took place virtually on October 2nd 2023, and three AUG members joined the meeting. In the two hours session, K. Zwijsen and A. Papukchiev first presented an overview of the GO-VIKING project and reported on the current status of each project task. Emphasis was put on the achieved results on the experimental and the numerical side. Following the presentation, for the project valuable discussions and recommendations were given by the AUG members. The recommendations given by the AUG members were written down in minutes created following the meeting. These minutes were subsequently distributed to all project partners, to ensure integration of the recommendations in the GO-VIKING project.

Additionally, some of the AUG members provided written feedback on the project status via email. This feedback, along with the recommendations given during the first GO-VIKING AUG meeting, is summarized in the sub-chapters below. Each suggestion/comment has been transcripted and stored in the meeting minutes in a dedicated folder on the project shared platform, in order to address them all along project duration when needed.

It should be noted here that further interaction with AUG members has taken place during the GO-VIKING Progress Meetings and the Work Package specific progress meetings. For example, during the Third GO-VIKING Progress Meeting that took place on 22-23.11.2023 at Ringhals NPP in Sweden, five AUG members were present in the meeting room and actively participated in the discussions after the technical presentations, providing the project partners and the coordinators with precious advices on the work performed. As feedback provided during these meetings was communicated directly to the project partner, and hence taken into consideration immediately, this feedback is not included in the current deliverable. Furthermore, these recommendations are generally also available for consultation by the project partner in the respective meeting minutes.

2.1 GO-VIKING general comments and recommendations

This paragraph summarizes the comments and recommendations given by the AUG members that apply to the GO-VIKING project in general.

1) The project is moving at a good pace, making progress on establishing the experimental data needs to support the development of simulation codes. Experimental activities have been conducted and have already generated data for some of the experimental facilities.
2) The technical approaches pursued are sound and are expected to yield valuable results to the research community on issues that are very relevant to the nuclear industry.
3) Suggestion: the project should consider cross-flow excitation mechanisms in fuel assemblies, such as due to jet flow from LOCA holes.

GO-VIKING response:

- We agree cross-flow excitation mechanisms in fuel assemblies is an important FIV mechanism. Initially, we considered including it through a dedicated experimental and numerical campaign. In the end, we decided, partly due to budget constraints, to limit the scope of the project to axial FIV in fuel assemblies, and cross-flow induced vibrations for steam generators. The latter will also provide a first-order insight into cross-flow excitation in fuel assemblies. The developed and applied numerical methods should be also applicable for cross-flow vibration mechanisms relevant for fuel assemblies. Moreover, the baffle jetting problem, associated with cross-flow jets in the reactor core, is extensively reviewed is D1.2.

4) In general, the work program is well balanced and challenging. The scheduled experiments and the benchmarking simulation will allow to gain important insights into FIV and improve its methodology
5) You are doing a great job and the topic of flow-induced vibration is of paramount importance in the perspective of an European nuclear renaissance.
6) CFD is a wonderful tool that can provide hindsight on details of the unsteady flow in conditions that can hardly be met in test rigs. It may be tempting to consider it as the reference approach, especially when designing a new facility. Of course, experimental validation is crucial.
7) PWR have been originally designed by Westinghouse in the 60s and 70s, a period where obviously CFD was not available to design engineers. This achievement is still somehow a mystery to some people (think about the incredible complexity of the flow inside fuel

assemblies). Many aspects were covered by a smart physical approach (consider the Tanaka paper for instance in the field of fluidelastic instability). A huge amount of practical knowledge was elaborated within four decades, and this knowledge is at risk of vanishing, because the founding fathers have retired or passed away and because the 2000s have not been favourable to the emergence of a new generation (the shale gas among other factors has made the nuclear industry miserable at that time).

8) It is suggested that GO-VIKING should pay attention to the contributions of people like Blevins, Païdoussis, Rockwell or Weaver, who have produced a huge amount of valuable results, which are still of interest today. One possible way to gather this knowledge would be to share a list of must-read references within WP6 and to have all people contribute to it. It would be nice to show how CFD makes a difference (for instance by providing correlation lengths dedicated to turbulent loading), and also how to compare results (plotting the pressure profile around a cylinder in the form p(theta)/rho U^2 is customary since Zdravkovich).

GO-VIKING response:

- Having a list of must-read references within WP6 is an excellent suggestion. GO-VIKING partners shall work on generating such a list. D1.2 already gives a good overview on what has been done in this field and has more than 200 references.

9) Great, comprehensive work done so far in GO-VIKING.
10) GO-VIKING has a well-written program and a large set of experiments.

2.2 Work Package overarching comments and recommendations

This paragraph summarizes the comments and recommendations given by the AUG members that apply to multiple work packages, such as general recommendations for experiments or numerical approaches.

WP2-4:

- Try to specify/measure the inflow conditions as far as possible. These might have a great influence on the investigated vibration phenomena. These are particularly important for the partners performing numerical simulations. Therefore, precise flow measurements of the inlet flow conditions should be carried out in the GO-VIKING experiments.
- It would make sense to perform also measurements with and without test section in the flow channel. This could in particular be of interest for GOKSTAD (VKI) as that facility is still under construction. Suggestion is to perform PIV measurements of the flow before the rods are installed. Additionally, if possible, perform experiment, with flow measurements, with a single rod, as canonical test.
- Attention should be paid to the refractive index matching of the fluids used for PIV measurements in the GO-VIKING experiments.
- The old measurements provide displacement and frequency information. No detailed information on the flow is available. Such information is important for code validation. Validation of the flow field should be done before proceeding to FSI simulations
- Explain clearly what you want to measure and why. This will make the comparison with numerical simulations better and clearer.

GO-VIKING response:

- ➢ Very valuable recommendations regarding flow field measurements. We agree that flow field measurements are crucial for CFD validation, and that this validation should be done before performing FSI simulations. This is already the case for some experiments. For example, the first CFD simulations of AMOVI are performed with rigid tubes and the corresponding forces are compared with measured data. We have tried to ensure that, in particular for the single-phase experiments, PIV measurements are performed for all experiments. In addition, for AMOVI, LDV measurements are done. For the experiments still to be performed, in particular GOKSTAD, we shall take these recommendations in account when drafting the experimental test matrix. Tests of pure flow without cylinders, and of a single rod cylinder, shall be included, if possible. Attention will be paid to provide accurate boundary conditions for all planned benchmarks.

WP2-5:

- o It is important to investigate which physics is missing in the analyses and to put this information in the deliverables.
- o Establish a clear validation matrix, allowing for a more structured comparison between the numerical and experimental results and also between the various numerical simulations.
- o The difference between vibrations in single- and two-phase flows is important and has to be addressed by the project. PIRTs and physical analyses are required by the regulators. One should know what the target is and what the result.
- o Apply the same post-processing methods for the experimental and numerical data.

GO-VIKING response:

- ➢ Good points regarding being clear about the physics captured and possibly missing in the analyses. This shall be communicated to the consortium. Similarly, about the validation matrix, and ensuring proper comparison by using same post-processing techniques. This in particular will be communicated with the work package leaders. The numerical benchmark planned within WP6 will help identifying missing physical models as well as the strengths and weaknesses of the different simulation approaches. The outcome of this and the other benchmarks (within the technical WPs) will be synthesized in Best Practice Guidelines on the Use of FSI Methods for the Evaluation of FIV in Nuclear Applications.

2.3 Work Package specific comments and recommendations

This paragraph summarizes the comments and recommendations given by the AUG members that apply to specific work packages, specific experiments or numerical approaches used to simulate the experiments.

WP2, simulations of Cantilever Rod Experiment (NRG):

- o Values for density, frequency reported to high number of decimals. Suggest avoiding reporting values to that level of precision, as it is clearly not possible to bring uncertainty down to that level for several of the physical parameters considered (e.g. 3.696 Hz, 3.242 Hz, density of hollow cylinder reported to 8+ digits).

- Structural mesh seems over-defined for the needs of the dynamic simulation: you're only interested in the first cantilever mode, and the plug behaves as an added mass. Unclear why this is set up as a 3D mesh. Consider:
  - Shell elements.
  - Beam elements with added mass. Use smarter meshing to allow for fluid force distribution to be applied adequately to the structure.

GO-VIKING response:

- Valid point regarding number of decimals. Comparisons, and reporting, should be restricted to accuracy of measurement techniques. Regarding structural mesh used in numerical simulations, initial idea was that WP3 should mainly use FEM with 3D solid elements, and WP5 should focus on lower order models and elements. This in order to have a comparison between the methods and establish what approach is needed for a certain level of accuracy. Having said that, since NRG did not commit to lower order models on the structural side in WP5, only on the fluid side, they perhaps could consider using the proposed element types.

WP2, ALAIN experiment:

- Indicate in the project outcome that the experiments related to vibrations in fuel assemblies (FA) are focused on axial flow in a single fuel assembly (FA) only. In reality there are cross-flows in reactor cores that might be important as well, as well as interactions due to the motion of multiple FAs. ALAIN experiment is one reduced FA and cannot address these global cross-flows and interactions. The experimental facility is already dismantled

GO-VIKING response:

- We shall ensure this is more clearly emphasized. Additionally, the baffle jetting topic (vibrations due to cross-flows in the reactor cores) is discussed in D1.2.

WP3:

- There are simple experiments for axial flow to understand the structural vibration, it would be nice if there are similar simple experiments also for cross-flow.

GO-VIKING response:

- We agree with that. In the AMOVI experiment (WP3) there are particular runs, in which in the test channel there is only one tube exposed to cross-flow. First simulations have already been performed by GRS for such configurations, and these show promising results. In particular for the experiments still running we shall try to incorporate these simple experiments, such as a single rigid cylinder in cross-flow and a single moving cylinder in cross flow. This could perhaps be included in the GOKSTAD experimental campaign.

WP3, AMOVI single rigid tube in channel simulation (GRS):

- Block averaging your FFTs is suggested, to reduce the noise in your FFTs

GO-VIKING response:

- Thank you for the recommendation. Will be communicated to the partner.

WP4, Wire-Mesh Sensor in TREFLE:

- Experimental work is descriptive, but not predictive (does not seek to explain the physics, just describe what is happening and provide statistical metrics). The risk there is that the results would not translate to two-phase steam due to mass ratio and surface tension distortions in the experimental modelling.
- It's understood that the purpose is to provide a validation of the approach, and in future work to extend to two-phase simulations. One should seek to compare the numerical modelling predictions to the experimental results, and not tune the numerical models to replicate the experimental results.

GO-VIKING response:

- That is a good point. We shall remember this when setting up the numerical models. Tuning should indeed be avoided, but models instead should be developed/setup/calibrated based on underlying physics and available results.

WP6:

- Fluid ROMs:
  - Unclear how this work can be positioned to serve a need that isn't already addressed by a long list of established design tools and analysis methods:
    - Flow cell model, Leaver & Weaver.
      - Lever, J. H., and D. S. Weaver. "A theoretical model for fluid-elastic instability in heat exchanger tube bundles." (1982): 147-158.
      - Hassan, M., & Weaver, D. S. (2016). Modeling of streamwise and transverse fluidelastic instability in tube arrays. Journal of Pressure Vessel Technology, 138(5), 051304.
      - El Bouzidi, S., & Hassan, M. (2015). An investigation of time lag causing fluidelastic instability in tube arrays. Journal of Fluids and Structures, 57, 264-276.
      - Rehman, S. A., El Bouzidi, S., Elbanhawy, O., Hassan, M., & Weaver, D. (2023). Numerical Prediction of the Streamwise Fluidelastic Instability. Journal of Pressure Vessel Technology, 145(5).
    - Quasi-steady model, Price & Paidoussis.
      - Price, S. J., & Paidoussis, M. P. (1986). A single-flexible-cylinder analysis for the fluidelastic instability of an array of flexible cylinders in cross-flow.
      - Later developed to model a whole bundle:
        - Sawadogo, T., Smith, B., & McLellan, A. (2022). Effects of tube-support clearance and preload on in-plane fluidelastic instability of tube arrays. Journal of Fluids and Structures, 115, 103783.
    - Unsteady model, Tanaka and Takahara.
      - Tanaka, H., & Takahara, S. (1981). Fluid elastic vibration of tube array in cross flow. Journal of sound and vibration, 77(1), 19-37.
      - Chen, S. S. , 1983, "Instability Mechanisms and Stability Criteria of a Group of Cylinders Subjected to Cross-Flow. Part

1: Theory," ASME J. Vib., Acoust., Stress, Reliab. Des. 0739-3717, 105, pp. 51–58.
        - Hassan, M., Gerber, A., & Omar, H. (2010). Numerical estimation of fluidelastic instability in tube arrays.
    - Papers which look at/implement several models:
        - Hassan, M., & Hossen, A. (2010). Time domain models for damping-controlled fluidelastic instability forces in tubes with loose supports.
        - Price, S. J. (1995). A review of theoretical models for fluidelastic instability of cylinder arrays in cross-flow. Journal of Fluids and Structures, 9(5), 463-518.
    - Joint acceptance method
        - Textbook by M.K. Au Yang, Chapter 8/9.
    - Simulating forces due to turbulence (some variation of inverse FFT from PSD method):
        - Axisa, F., Antunes, J., & Villard, B. (1990). Random excitation of heat exchanger tubes by cross-flows. Journal of Fluids and Structures, 4(3), 321-341.
        - Hassan, M. A., Weaver, D. S., & Dokainish, M. A. (2002). A simulation of the turbulence response of heat exchanger tubes in lattice-bar supports. Journal of Fluids and Structures, 16(8), 1145-1176.
        - Antunes, J., Piteau, P., Delaune, X., & Borsoi, L. (2015). A new method for the generation of representative time-domain turbulence excitations. Journal of Fluids and Structures, 58, 1-19.
    - Modelling of fully flexible fuel bundles:
        - Elbanhawy, O., Hassan, M., & Mohany, A. (2020). Simulation of motion-dependent fluid forces in fuel bundles. Nuclear Engineering and Design, 356, 110373.
        - Elbanhawy, O., Hassan, M., & Mohany, A. (2021). Modelling of fully-flexible fuel bundles. Nuclear Engineering and Design, 378, 111014.
  - It is suggested that the researchers consider either adapting existing methods, or clearly articulate what gap is being addressed by their proposed methods explicitly in terms of existing approaches.
- Uncertainty Quantification in FSI:
  - Method is being applied to fluidelastic instability threshold. However, it is sensitive to cliff-edge effects. Fluidelastic instability is known to have a lot of cliff edge behaviours depending on parameters such as velocity and void fraction.

GO-VIKING response:

- Thank you for sharing this extensive list of references. This is very valuable for the partners working on fluid ROMs, and hence shall be distributed to them. We shall study the references and also possibly include them in the earlier proposed reference list to be established as part of WP6. The methods proposed in GO-VIKING shall differ either in the physics or in the implementation (particular code) from the ones mentioned. They should definitely show added value in comparison to the available tools and methods to the GO-VIKING partners before the project start. The comment on UQ will be communicated to the partner performing the work.

2.4 Deliverable specific comments and recommendations

This paragraph summarizes the comments and recommendations given by the AUG members that apply to specific deliverables.

Deliverable D1.1:

- In Section 3.1, the language seems to indicate that the only approach pursued in Canada is the flow cell approach, using a time-domain implementation of the Lever & Weaver model. This is a bit misleading as there are other approaches used, like the time-domain implementation of the quasi-steady model of Price & Paidoussis.
- In the Section 6 „Conclusions", it is stated that "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". It is agreed that one needs two-way FSI coupled simulations, presumably with LES approach, to address these phenomena. These are, however, scheduled within GO-VIKING as "strongly coupled CFD-CSM simulations of FA-configurations". It is assumed that the computational structural mechanics (CSM) model in these simulations considers the full FA structure and does not combine separate structural models for each fuel rod and the skeleton. Therefore, one will not be able to address baffle jetting or fluid stiffness instabilities with coupling between individual fuel rod motions. However, one should be able to address self-induced resonance phenomena which affect the complete fuel bundle. Maybe, one should be more precise and address that the difficulty for the baffle jetting simulation lies in implementing the structural model and the mesh motion inside the spacer grid structures. The CPU resources and time required would not be higher than for the scheduled FSI coupled CFD simulations of FA structures.

GO-VIKING response:

- ➢ The missing reference/approach is an unfortunate oversight. Perhaps we can add an addendum of some sorts. This will be discussed. As for the simulations of the ALAIN experiment, and what approaches are being used, this will be better explained in the final deliverable on this experiment, which includes the numerical results. There, the given comment will be addressed and D1.2 will be referred, which provides further information on baffle jetting.

Deliverable D1.2:

- FA Bow description does not appear to include neutron-induced creep as a possible contributor. Example source that mentions creep resistance improvements to mitigate the issue: https://www.euronuclear.org/archiv/topfuel2018/fullpapers/TopFuel2018-A0185-fullpaper.pdf
- Jet flow instability mechanism due to LOCA holes is missing in list of FA FIV issues, I suggest taking a look at the following paper:

- Gad-el-Hak, I., Mureithi, N., Karazis, K., & Williams, G. (2023). Principal component analysis of vibration response of a rod bundle subjected to jet cross-flow. *Journal of Sound and Vibration*, 550, 117592.
- Gad-el-Hak, I., Mureithi, N., Karazis, K., & Williams, G. (2023). Jet cross-flow induced vibrations in rod bundles. Part I: Experimental apparatus and stream-wise vibration results. *Nuclear Engineering and Design*, *401*, 112046.

- Experiments on SG Tube Arrays review doesn't include some key studies:
  - Feenstra, P., Sawadogo, T., Smith, B., Janzen, V., & Cothron, H. (2023). Investigations of In-Plane Fluidelastic Instability in a Multispan U-Bend Tube Array—Part I: Tests in Air Flow. *Journal of Pressure Vessel Technology*, *145*(2), 021402.
  - Feenstra, P., Sawadogo, T., Smith, B., Janzen, V., McLellan, A., Cothron, H., & Kil, S. (2023). Investigations of In-Plane Fluidelastic Instability in a Multispan U-Bend Tube Array—Part II: Tests in Two-Phase Flow. *Journal of Pressure Vessel Technology*, *145*(2), 021403.
- Numerical studies do not include some work that uses URANS to support reduced-order model development:
  - El Bouzidi, S., & Hassan, M. (2015). An investigation of time lag causing fluidelastic instability in tube arrays. *Journal of Fluids and Structures*, *57*, 264-276.
  - Rehman, S. A., El Bouzidi, S., Elbanhawy, O., Hassan, M., & Weaver, D. (2023). Numerical Prediction of the Streamwise Fluidelastic Instability. *Journal of Pressure Vessel Technology*, 145(5).

GO-VIKING response:

- ➢ Similar to D1.1, it's unfortunate to see quite some relevant and important references were not included. We tried to be as thorough as possible, but with there being so many out there, it's not easy to find and include them all properly. Perhaps also for D1.2 an addendum can be written. If the deliverable leads to a journal publication, these can be included.

Deliverable D2.1:

- The current work provides sufficient data to establish the inlet boundary conditions of the flow for numerical simulations. But as future work, the project members could consider performing phase-locked and time-resolved PIV measurements to complement the time-averaged measurements, to enable validation of the dynamic characteristics of the fluid-structure coupling.
- One should precise for which FA component one makes a validation. The boundary conditions resemble a control rod finger inside a guide tube. If one addresses the validation of the flow field around a fuel rod, one should mention that turbulence in a real FA is also generated by the spacer grid structures which are missing in the test setup.
- The test is, however, very interesting because it allows to quantify which FIV vibration amplitudes are generated by wall generated turbulences. If one makes benchmarking CFD simulations, one could compare the fluid force time histories between turbulence models which resolve the boundary layer against one with wall functions (e.g. both based on Large Eddy Simulation).
- Depending on the outcome one could make conclusions on the appropriate turbulence approach for FIV of FA structure.

GO-VIKING response:

- ➢ Time-resolved PIV would indeed provide valuable data for deeper validation. Unfortunately, the partner had no access to a time-resolved PIV system. Such a system will be used for the GOKSTAD experimental campaign though. As for the Cantilever Rod experiment, it focuses more on wall generated turbulence, and not so much on vibrations of a fuel rod, precisely due to the missing spacer grid. This will be clarified in the deliverable describing the numerical work. Hopefully, though the methods studied here, and found to most accurate, will perform well also for FIV of fuel rods with spacer grids. Still, the proper simulation of this FIV experiment represents a challenge and is therefore of great interest.

Deliverable D2.3:

- o It would be also interesting to include the URANS based STRUCT turbulence approach (see publication “Struct:A Second-Generation URANS Approach for Effective Design Of Advanced Systems” Proceedings of the ASME 2017 Fluids Engineering Division Summer Meeting FEDSM2017”). The model claims to capture FIV excitations generated by turbulence to a good extend.
- o For the FSI coupled CFD simulations, I would suggest to also calculate separately fluid force time histories for selected fuel rods. This fluid force time histories could be compared to the ones without FSI coupling to a structural model. It would be interesting to know if the FA motion effects the turbulent excitations on the fuel rod. The knowledge about possible coupling effects could help to improve the modeling approach for grid to rod fretting (see Framatome presentation in D1.1)

GO-VIKING response:

- ➢ Very valuable suggestions. We shall look into the STRUCT turbulence approach and perhaps test it, if it can be implemented in the used numerical software, taking into account the constraints of the GO-VIKING working program and available budget and time. Also, comparing fluid force time histories for rigid rods with those of moving rods is an interesting suggestion. This will be communicated to the work package leader such that it can be further communicated to the involved partners.

Funded by
the European Union