GO-VIKING

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Final AUG recommendations report

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Intermediate Advisory and User Group recommendations report

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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
STH	System Thermal-Hydraulics Code
TSO	Technical Safety Organisation
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

1. Description of the Advisory and User Group

1.1 Mission of the AUG

The Advisory and User Group (AUG) 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 (FIV) in nuclear power plants was established. The experts were selected by the Project Management Office (GRS, NRG, LGI), 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 AUG, 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 17 members. In addition to the 13 members already on the AUG at the time of publication of deliverable D7.4: Intermediate AUG recommendations report, Texas A&M University and Rolls-Royce SMR (three persons) joined the AUG, following the signing of the NDA. Further competencies or expertise may be added during the course of the project, if considered necessary.

The list of the AUG members is provided below:

Table 1 - Qualification of the GO-VIKING AUG members

AUG member	Organisation
Salim El Bouzidi	**Canadian Nuclear Lab**
Bernd Dressel	**Framatome GmbH**
Christophe Riga	**Tractebel**
Graham Macpherson	**Frazer-Nash Consult.**
Philippe Bardet	**G. Washington University**
Pierre Moussou	**EDF**
Eric Lillberg	**Vattenfall**
Benjamin Chazot	**Framatome**
Kristian Angele	**Vattenfall**
Jan Klouzal	**ÚJV Řež**
Greg Wilkinson	**Rolls-Royce SMR**
Marwan Hassan	**University of Guelph**
Dong-Yuan Sheng	**Westinghouse**
Yassin A Hassan	**Texas A&M University**
Dean Patrick	**Rolls-Royce SMR**
Meyrick Hockly	**Rolls-Royce SMR**
Christopher Bennett	**Rolls-Royce SMR**

1.4 AUG involvement

The AUG members were invited to join every Progress Meeting organized and held from the beginning of the project. Additionally, they are encouraged to take part in each of the Work Package Leaders' technical presentations, as well as in sessions organized to gather the AUG members' feedback and recommendations on the consortium's work. Regarding the half-yearly Progress Meeting ,some of the AUG members participated either in-person or remotely in the progress meetings in Chatou/Saclay (December 2022) and Cadarache, France (June 2023); Ringhals, Sweden (November 2023); Erlangen, Germany (June 2024); Brussels, Belgium (December 2024); Petten, The Netherlands (May 2025). Their participation was a great added value for these meetings, with active participation from the members. All AUG members will be invited to join the next progress meeting in Ghent, Belgium in November, 2025.

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2. Intermediary recommendations of the Advisory and User Group

The second GO-VIKING AUG meeting took place virtually on April 25th 2025, and seven AUG members joined the meeting. In the two hours session, A. Papukchiev and K. Zwijsen first presented the current status of each project task. Emphasis was put on the achieved results on the experimental and the numerical side. Following the presentation, valuable discussions and recommendations for the project were given by the AUG members. In addition, some of the AUG members provided written feedback on the project status via email. This feedback, along with the recommendations given during the second GO-VIKING AUG meeting, is summarized below.

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 Sixth GO-VIKING Progress Meeting that took place in May 2025 at NRG in Petten, seven AUG members were present in the meeting room/virtual session 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 in the last virtual AUG meeting on April 25th 2025 that apply to the GO-VIKING project in general.

1) The GO-VIKING project has been coordinated in a calm, kind, and effective way towards a shared goal.

GO-VIKING response:

- Thanks, coordinating a large consortium can indeed be a challenge, especially when we try to stick to a pretty tight schedule. This applies not only to the project as a whole, but also to the progress meetings themselves. In the end, we believe we have a great group of experts and are very pleased with the progress achieved thus far. Hopefully we can keep this up for the final year.

2) It is both, stimulating and valuable, to see multiple teams engaging with a common set of reference test cases. The scientific exchanges were not only constructive and collegial, but also intellectually rigorous, driven by a shared commitment to achieving the highest possible quality in simulation results. While such an outcome might have been expected given the expertise of each partner, the process of thorough cross-verification clearly demonstrated that maintaining high standards was not just beneficial—it was essential.

GO-VIKING response:

- Thanks, the GO-VIKING project gathers partners from industry, research, Technical Safety Organisations (TSOs) and academia with a strong background in the Computational Fluid Dynamics (CFD), Computational Structural Mechanics (CSM), FSI-related research as well as in experimental work. The success of the project relies on bringing all these people together with their expertise to achieve a common goal while keeping high standards. For example, looking at a FIV problem from numerical and experimental perspective and the discussion between both teams improves the knowledge on the occurring phenomena and pushes further the development of numerical and experimental techniques for a better assessment.

3) From an industrial standpoint, there does not yet appear to be a definitive procedure that ensures CFD calculations yield exact results without the support of cross-verification or comparison with experimental data. This can understandably be a source of frustration—particularly given the pressing need for improved design guidelines in the development of new facilities.

GO-VIKING response:

- We agree that there is still room for improvement of the predictive capabilities of CFD and FSI tools. The simulations programs should not be used for analysis only, but also for predictions. Being able to correctly predict the behavior of the component you are designing is essential for the vendors and eventually for the reactor safety. In general, many scientists (also outside the nuclear field) are too much focused on proving they can match experimental results with their programs, and thus, demonstrate competence and skills, while forgetting that the final objective is to develop and validate a predictive tool that can significantly reduce the uncertainties already in the design process or later during licensing, operation, etc. Therefore, to overcome this bottleneck, more blind exercises are necessary. These will show us where we really are with our knowledge and analytical skills. We'll still need the experimental data to calibrate our models before diving into the blind predictions. Within GO-VIKING, a large focus was placed on sensitivity testing, for which obviously experimental data has to be made available already, for comparison purpose. Additionally, to mitigate risks, it was decided to include experimental data already available, or ready to be generated. This altogether limits the possibilities unfortunately of blind benchmarks. That said, we underscore the essence of such benchmarks, and will advocate that in the future, including blind or even double-blind (when the experimental facility to analyze is not yet built) exercises shall be an essential part of the scientific work. Such activities will shed more light on the weaknesses in our codes and modelling approaches.

4) At this stage, I do not have any specific recommendations or suggestions for the final months of the project. However, I would like to propose a few directions that could be valuable for future research. One motivation is to broaden the scope of CFD applications by exploring new domains where its predictive capabilities can offer an added value. Another is to pursue potential "quick wins"—achievable advancements that are more tractable than the formidable challenge of accurately predicting fluid-elastic instability thresholds.

GO-VIKING response:

- Indeed, sometimes "quick wins" are even more important than the most accurate prediction. A step in this direction is the development of reduced-order models (ROM) in our WP5. We have focused on both domains – the fluid (CFD) and solid (CSM). The analyses so far proved that the utilization of a reduced-order model for the solid domain can speed up the simulation by factor of 5 or 6. We expect even larger improvements when substituting the complex, high-resolution CFD domain with a reduced-order one. Three different fast-running methods, based on the fluid domain, have been developed within the project. Currently, these are being validated and investigated in terms of CPU time savings.

5) Another useful area of research involves what is often referred to as reduced-order modeling—that is, the development of intermediate-scale component models that can be integrated into larger system networks. A particularly compelling application of this approach is the simulation of noise generation and acoustic propagation within piping systems, where such models can offer both efficiency and valuable insights, especially in cases where full 3D simulations are often practically unfeasible. Valves and orifices would be natural starting points for such modeling efforts, given their relative simplicity and prevalence in industrial systems. Turbomachines could follow as a second step, offering a more complex but highly relevant challenge for reduced-order modeling approaches. A key factor in advancing this line of research would be to account for the interaction between each specific device and its surrounding environment. Capturing these interactions is essential for ensuring that the reduced-order models remain both realistic and predictive when integrated into larger system simulations.

GO-VIKING response:

- We also believe that intermediate-scale models and their integration in larger system networks is important. The utilities cannot afford to wait weeks or months for the result of a single calculations, we need efficient methods and models to provide results, even if we have to sacrifice some accuracy. These shall be in-between the existing correlations and the fine-resolution analyses. We are trying to do this within WP5 that is dedicated to fast-running methods and ROMs. Further, the turbomachinery was indeed a driving source for many developments. There's a lot what we could learn from the other industries. Integrating intermediate-scale models in system-networks would require the coupling of the FSI-tools with system simulation programs like System Thermal-Hydralics Codes (STH). CFD-STH couplings already exist, one shall also add the CSM program. Before doing this, we shall clearly identify the cases (for example, pressure wave propagations through the primary system?) of interest that require this sophisticated approach.

6) As a personal recommendation, I would suggest considering first the various unsteady fluid flow phenomena that can occur in a tee-junction—particularly in configurations where the lateral branch has no incoming flow. This test case is reasonably well documented in the literature, yet it still offers ample opportunity for exploring and benchmarking a wide range of

turbulence models. Two specific sub-topics could be particularly worth investigating. The first concerns the turbulent structures that enter the lateral branch—raising questions such as: What is the resulting pressure distribution along the walls? What is the effective penetration distance of these structures? The second sub-topic involves the self-sustained oscillations of the Strouhal–Rossiter type, which may arise under suitable boundary conditions.

GO-VIKING response:

- There seems to be a lot of interest from the industry in the T-junction problem that has been investigated within OECD/NEA benchmarks or international project like FATHER, FATHERINO, MOTHER. There is currently an OECD/NEA benchmark ongoing to study the flow in the T-junction with a dead leg, supported by a Vattenfall experiment. Some of the GO-VIKING partners are part of this benchmark and will bring the lessons learned into the project. Self-sustained oscillations of the Strouhal–Rossiter type are related to cavities with vortex-shedding and acoustic feedback. These phenomena are definitely interesting and worth investigating in a future project that is not mainly focused on the phenomena in reactor cores and steam generators (like GO-VIKING).

7) Suggestion: try to investigate the influence of the turbulence model on the pressure drop. It seems that different turbulence models can lead to different pressure drops and the effect of the turbulence modelling shall be studied. For proper comparison, it should be compared with the measured pressure drop, hence advice is to perform such measurements when running the experiments. Additionally, for further comparison, one may also compare with values reported in the VDI Heat Atlas.

GO-VIKING response:

- We agree that the turbulence modelling affects the CFD results in general. Within different project tasks, analyses are being carried out with different turbulence models, while using the same numerical setups. Although the focus was mainly put on the vibration characteristics (displacements, frequencies), the impact of the selected turbulence model on the pressure drop could be studied. Further, pressure measurements are available in at least one of the GO-VIKING experiments.

8) Suggestion: for the Best Practice Guidelines (BPGs), following the Uncertainty Quantification (UQ) done, it would be interesting and quite useful to create some sort of ranking or list indicating the most critical/influential factors affecting the results and observed simulation behaviour.

GO-VIKING response:

- Thank you for this suggestion regarding the BPGs. We completely agree with this suggestion, being that valuable information coming from the UQ performed within Work Package 5 would be a clear indication of which factors/parameters have the largest influence on the results, and hence need to be included accurately in the modeling. Identifying these factors/parameters is a large focus of the UQ done, and hopefully a clear ranking will ensue. Following this suggestion we will re-emphasize the importance of this ranking to the WP5 partners performing the UQ analyses.

9) In conclusion, I would like to express my appreciation for the quality of the work carried out so far and for the collaborative spirit that has guided this project. The progress made in applying advanced CFD tools to reference case tests is both impressive and promising. While some difficulties remain—particularly in achieving predictive accuracy without experimental support—the collective efforts have laid a strong foundation for future developments. I hope the ideas shared here may contribute to ongoing discussions and inspire further research directions. I remain confident that the collaboration between academic and industrial partners will lead to meaningful advances in the field.

GO-VIKING response:

- Thank you for the kind words. Code predictive capability is a very important topic, as already discussed above, and we'll try to address it as much as possible in the remaining year of the GO-VIKING project. If we don't manage to organize a blind exercise (for example within the analyses of the GOKSTAD experiment), we will at least bring the topic for a discussion among the GO-VIKING scientists.

10) The GO-VIKING focus has been on flow past columns/tubes akin to fuel assembly (FA) and steam generator structures, but can we apply lessons learned to other areas of a reactor where FIV assessments have to be made, such as the RPV downcomer, lower plenum, outlet plenum and head plenum? For example, how would the BPG apply for an FIV analysis for turbulent flow in the downcomer resulting in vibration of the core barrel.

GO-VIKING response:

- This is for sure an interesting question. While GO-VIKING was primarily focused on FIV in reactor cores and steam generators, there are other components in the NPP that also experience vibrations induced by a flowing fluid. The core barrel is one of these reactor pressure vessel (RPV) components. Its size, mass, shape, mass distribution differ significantly from the ones of the investigated rod and tube bundles within GO-VIKING. Still, the underlying flow and structural phenomena shall be similar to some extent: the structure is being set into motion by forces, induced by the flowing water. Therefore, the methods developed, validated and applied within the project shall be applicable to a great extent also for such components. It is clear that imposing the correct boundary conditions at the proper location (in both, fluid and solid domains) is essential for the quality of the results. The numerical methods used in GO-VIKING shall be applicable for such components. Even beyond that – the FSI methods being developed and validated within GO-VIKING shall be of general purpose, i.e. applicable to problems in other industries.

11) It would be useful to include some detail on the different methods available for applying loads resulting from CFD analyses to CSM models for uncoupled assessments, including simple/bounding approaches, and the relative pros and cons.

GO-VIKING response:

- This is an important topic. Although most of the partners strive to use coupled codes or CFD codes with embedded structural solvers in their analyses, the decoupled approach still might be useful, especially in cases, where the feedback from the structural motion to the flow pattern is negligible. This might be the case in turbulence-induced vibrations with low displacement amplitudes. There are analyses within the project (for example on the ALAIN experiment) that are being performed in uncoupled manner. It will be communicated to the involved partners to present and document their data transfer (CFD→CSM) procedures in the respective deliverables and milestones, since this might be of general interest.

12) In general, it would be useful to understand how the detailed analysis methods that are investigated in GO-VIKING compare to any simple bounding approaches that may be available, to allow certain FIV excitation mechanisms to be 'screened out' for certain components/areas to negate the need for detailed assessments.

GO-VIKING response:

- Good point, analytical methods for FIV evaluation have been extensively used in the past and even today for orientation before starting the expensive FSI analyses. Although most of the partners strive to use coupled codes or CFD codes with embedded structural solvers in their analyses, it is interesting to compare their results with the analytical predictions. The partners/benchmark leaders will be encouraged to allow such comparison.

13) The BPG content is proposed to focus on FIV analysis – could the scope also include Uncertainty Quantification (UQ) in such assessments?

GO-VIKING response:

- The most important outcome of the analyses with the developed within WP5 UQ methods will be definitely included in the BPGs. UQ methods are important, since here we are dealing with best-estimate simulations, and according to IAEA, best-estimate analyses have to be complemented by uncertainty quantification. The latter is very challenging because of the large number of anyway expensive simulation FSI runs. Therefore, very efficient UQ methods (like the Polynomial Chaos Expansion) are developed with GO-VIKING WP5.

14) It is great to see the progress on commissioning activities and initial results with the GOKSTAD facility. Based on shown results, it is suggested to investigate whether the additional peak observed in the spectra (13Hz?) corresponds to a rocking mode of the tube-springs assembly.

GO-VIKING response:

- Thank you for this comment. We are quite pleased with the successful timely construction of the GOKSTAD facility and the results it has already produced, even though a significant part of the experimental campaign still has to be performed. The comment regarding the additional peak is duly noted and shall be communicated to the experimentalists responsible for operating the facility. We agree this needs to be further investigated and clarified.

15) The community is looking forward to seeing a guidance document summarizing lessons learned from the GO-VIKING effort. It is suggested to contextualize the document compared to previous FIV guidance such as: Pettigrew, Rogers, and Axisa (2011); Pettigrew & Taylor (2003), US NRC RG-1.20 which provide industry accepted analysis approaches and tools for FIV problems. The guidance document should indicate how it fits in the existing context, to enable practitioners to make use of it.

GO-VIKING response:

- Thank you for providing valuable feedback regarding the Best Practice Guidelines (BPGs) to be issued towards the end of the project. It is important these guidelines are proven valuable to the industry and end-users, hence this comment is taken to heart and will be kept in mind when formulating the BPGs. To that end, we will consult the referred existing guidelines and ensure proper positioning of the BPGs in relation to the existing guidelines.

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