Fluid Structure Interaction: A Multi-Physics Application for Design and LTO Support

The VIKING collaboration

Petten, 3 February 2021

Ferry Roelofs (NRG)

Juan Uribe (EDF Energy), Benjamin Chazot, Nicolas Goreaud (Framatome), Hidajet Hadzic, Celine Lascar (Framatome GmbH), Angel Papukchiev (GRS), Enrico Deri, Sofiane Benhamadouche (IMSIA), Daniele Vivaldi (IRSN), Kevin Zwijsen (NRG) Hector Iacovides, Andrea Cioncolini (University Manchester), Nicholas Edh, Eric Lillberg, Kristian Angele (Vattenfall)

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Contents

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Introduction

VIKING
(Vibration ImpaKt In Nuclear power Generation)

- Collaboration start: 1 January 2020
- Duration 2+1 years (2020-2022)

Vibrations induced by the coolant flow in nuclear power plants

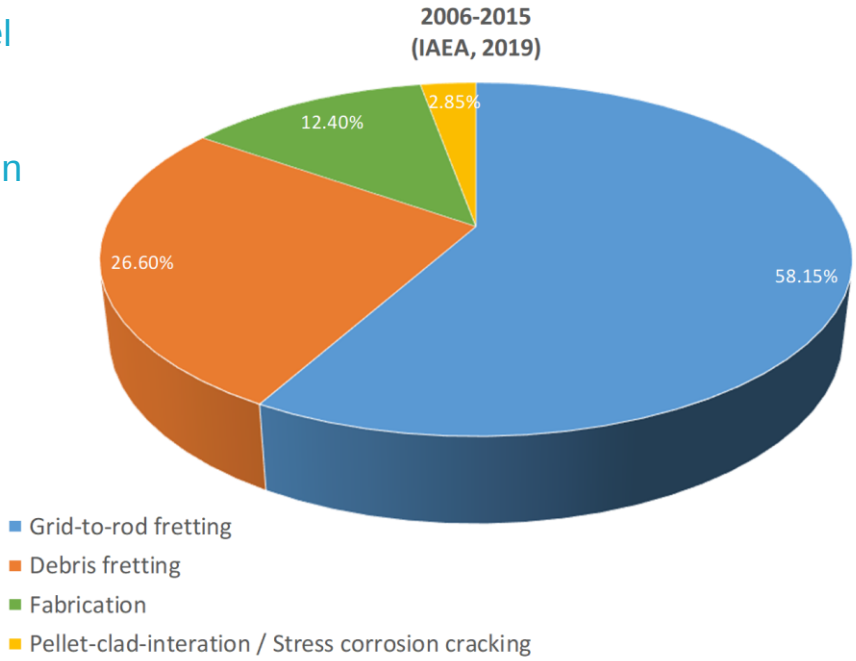
Kick-off meeting, February 2020 Amsterdam

Introduction
FIV in Fuel Assemblies

Grid-to-rod fretting is the largest source of fuel failure in PWRs (IAEA, 2019)

- In period 2006-2015: 58% of fuel failures in PWRs due to grid-to-rod fretting

Grid-to-rod fretting in an EDF PWR 1300 (IAEA, 2010)



Introduction
FIV in Heat Exchangers

Mihama (Japan), 1991
- SGTR upper U-bend
- Activation of the ECCS
- Caused by incorrect insertion of anti-vibration bars 20 years before

Replace SG

San Onofre (US), 2012
(NRC website)
- SG tube leak in unit 3 > shutdown
- SGs replaced in 2011
- Unexpected wear in ~10% of tubes (units 2 & 3)

Close the units

Wylfa (UK), 1972
- Boiler tube leaks after 1-2 yr
- Plugging of leaking tubes costs ~£100 000 per tube
- In 1974 every few days a tube had to be plugged

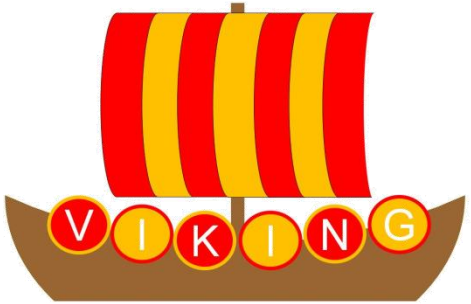
7 months repair with 40 people per shift

Introduction

VIKING collaboration

- Focus on two types of vibration issues:
  - Fuel assembly rod bundles
  - Rod bundles in cross flow, e.g. in heat exchangers (steam generators)

- Objective:
  - to utilize experimental data available from the partners together with reference numerical data (LES) to further develop and validate numerical engineering methods (unsteady RANS simulations, Hybrid LES-URANS simulations), or new methods like the pressure fluctuation method (PFM).



R&D

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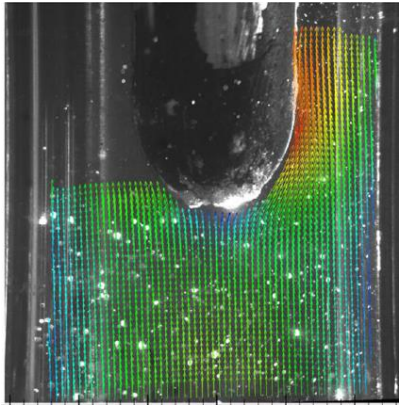
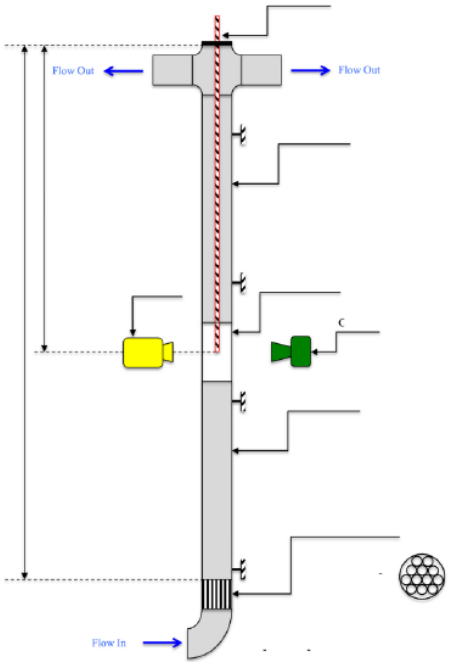
Cantilever Beam

Experiment (UoM)
- Axial-flow-induced vibrations
- Clamped-free cantilever rod confined in a tube
- Axial water flow
- *Cioncolini et al. (2018)*

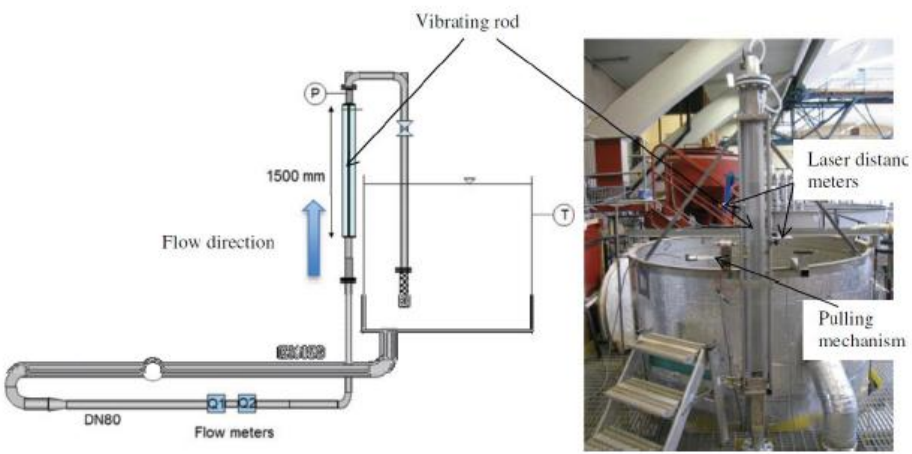
Numerical reference data
- Wall resolved LES (IMSIA)

Engineering simulations
- URANS (EDF-Energy & NRG)





Single Vibrating Rod



Experiment (Vattenfall)

- Damping of free rod vibrations
- Slender rectangular fixed – pinned rod
- Forced vibration by pulling the rod
- *Lillberg (2015)*

Engineering simulations

- URANS (Vattenfall & NRG)

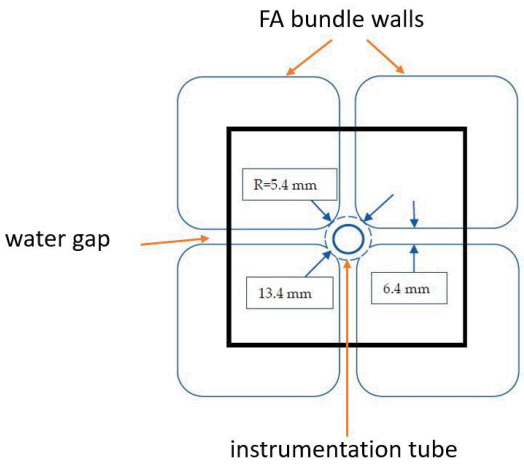
Instrumentation Guide Tube

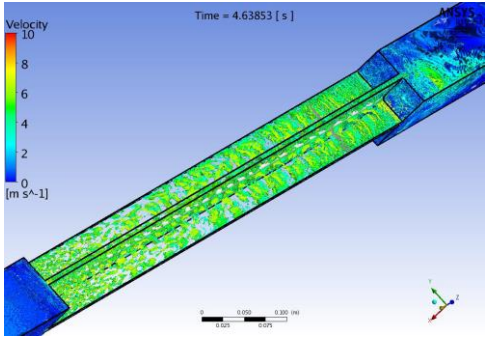
Experiment (Vattenfall)
- Instrumentation guide tube
- In-between fuel boxes section
- Axial flow
- *Lillberg (2015)*

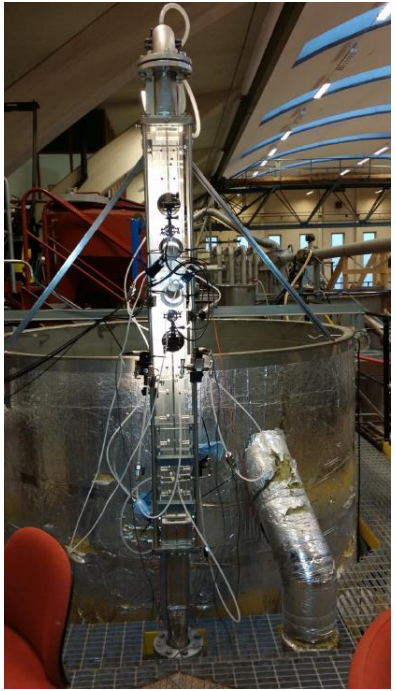
Numerical reference data
- LES (Vattenfall* & GRS*)

Engineering simulations
- Hybrid (GRS)
- URANS (NRG, FRA-F*, Vattenfall* & EDF-E*)

*if time and budget allows







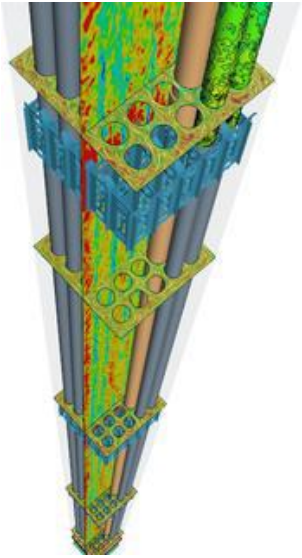
ALAIN 5x5 Rod Bundle

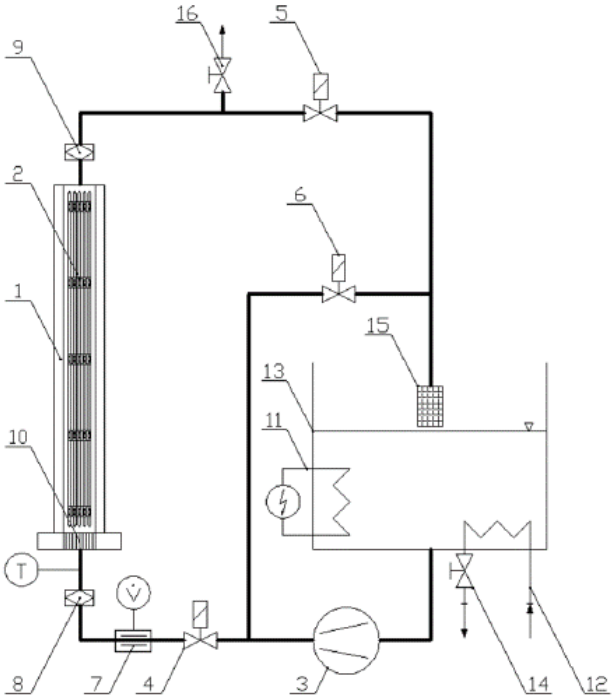
Experiment (Framatome)

- Axial self-induced exitation
- Reduced 5x5 rod bundle configuration
- Mini test loop of Framatome
- *Münch (2018)*

Numerical reference data

- LES (FRA)





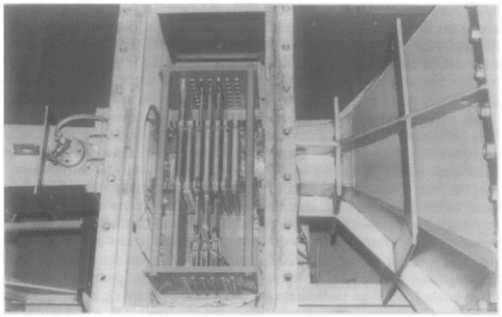
1 - plexiglas channel
2 - fuel assembly
3 - pump
4 - throttling valve
5 - throttling valve
6 - throttling valve
7 - flow meter
8 - rubber absorber
9 - rubber absorber
10 - flow straightener
11 - electrical heater
12 - cooler
13 - storage tank
14 - cooling control
15 - filter
16 - deaerator

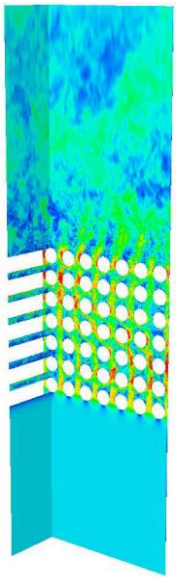
VISCACHE

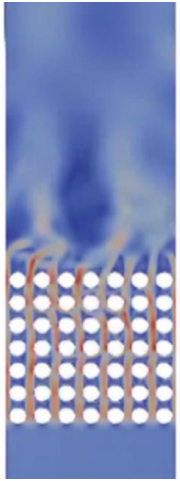
Experiment (IMSIA)
- Single moving central rod
- 7x7 rod bundle in cross flow
- *Granger et al. (1993)*

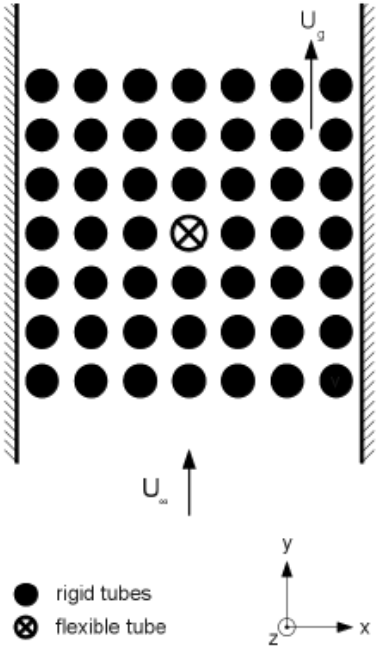
Numerical reference data
- Wall resolved LES (IMSIA)

Engineering simulations
- URANS (IRSN, Framatome, NRG)









Timeline & Summary

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VIKING			Y1				Y2				Y3			
WP1	Fretting		1	2	3	4	5	6	7	8	9	10	11	12
T1.1	Cantilever Beam													
		Experiment	X											
		URANS						X						
T1.2	ALAIN 5x5 Rod Bundle													
		Experiment			X									
		LES								X				
T1.3	Vattenfall 1 Single Beam													
		Experiment	X											
		URANS				X								
T1.4	Vattenfall 2													
		Experiment	X											
		LES				X				X				
		URANS & Hybrid							X					
WP2	Fluid Elastic Instability		1	2	3	4	5	6	7	8	9	10	11	12
T2.1	VISCACHE Single Moving Rod													
		Experiment	X											
		URANS & Hybrid								X				
WP3	Consolidation		1	2	3	4	5	6	7	8	9	10	11	12
	Consolidation of Results													
		Consolidation Report												X

Company	Cantilever beam	Single Vibrating Rod	Instrument-ation Guide Tube	ALAIN 5x5 Rod Bundle	VISCACHE single moving rod	Code
framatome			URANS*		URANS	SIEMENS STAR-CCM+
framatome GmbH			(Hybrid/LES)*	Experiment LES		SIEMENS STAR-CCM+
GRS			Hybrid LES*			ANSYS CFX
IMSIA	LES				Experiment LES	CODE SATURNE
IRSN					URANS Hybrid*	ANSYS FLUENT
NRG	URANS	URANS	URANS		URANS	SIEMENS STAR-CCM+ OpenFOAM
MANCHESTER 1824 The University of Manchester	Experiment					
EDF ENERGY	URANS		URANS*			*In-house* OpenFOAM
VATTENFALL		Experiment URANS*	Experiment URANS*			OpenFOAM

Questions?

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