Response time of thermometers for civil nuclear applications

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MEASUREMENT & STANDARDS
Keys to COMPETITIVENESS and A SAFER WORLD

Laboratoire national de métrologie et d'essais

Introduction

- Background/scene setting
- Response time and experimental methods
- A facility co-developed by EDF & LNE
- Measurement and uncertainty
- Summary

Setting the scene - I

- EDF evaluates conformity to specifications of instrumentation to be installed in nuclear power plants
- EDF and LNE started a collaboration 10 years ago on the qualification of temperature sensors
- Metrological parameters :

temperature & response time

Existing calibration facilities, traceability ensured

R&D required for improved confidence in the quality of measurements, notably

- development of adapted facilities
- assessment of important influencing factors
- thorough evaluation of uncertainties
- technical assistance & exchanges

Setting the scene - II

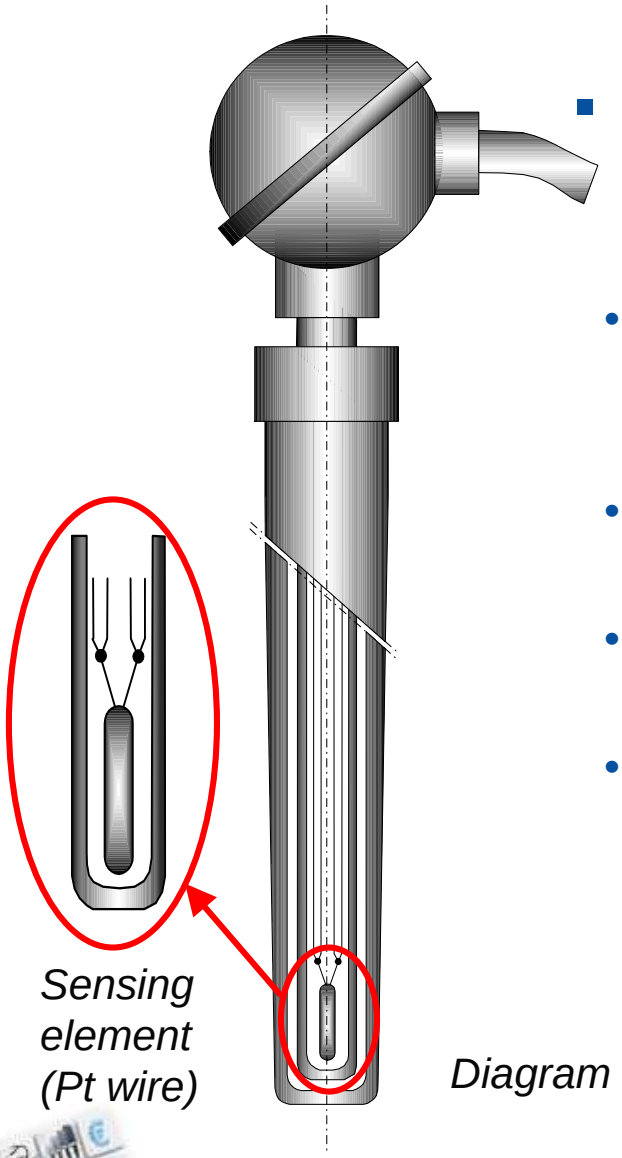
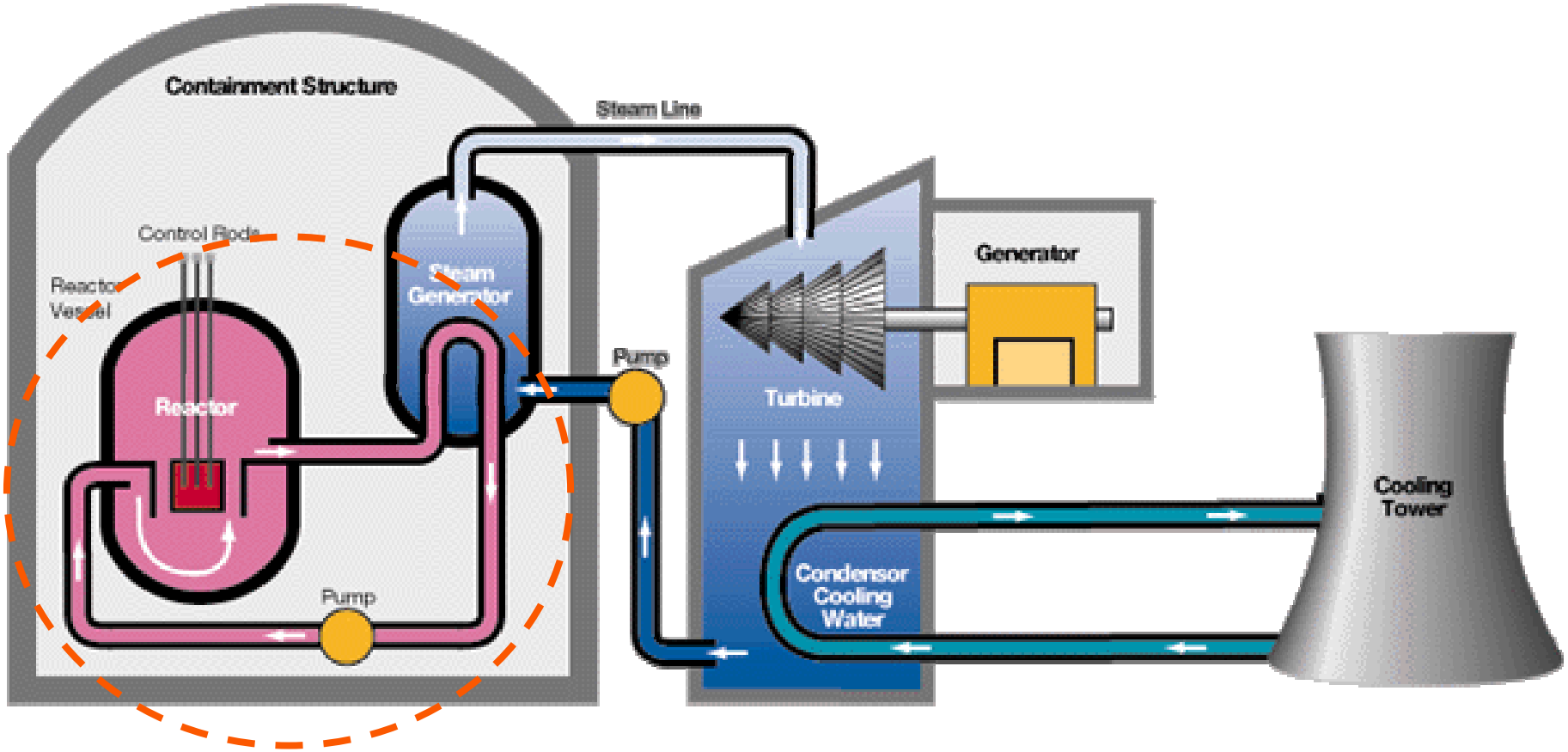


Diagram of an industrial PRT

- Sensors concerned : platinum resistance thermometers
  - temperature is proportional to ohmic value delivered by a platinum wire (100 Ω or 200 Ω @ 0 ℃)
  - Standardized ⇨ confer CEI 751:2008
  - 4 wires-connections
  - Sensing element encapsulated in a protection tube, possibly inserted in a thermowell

Setting the scene - III

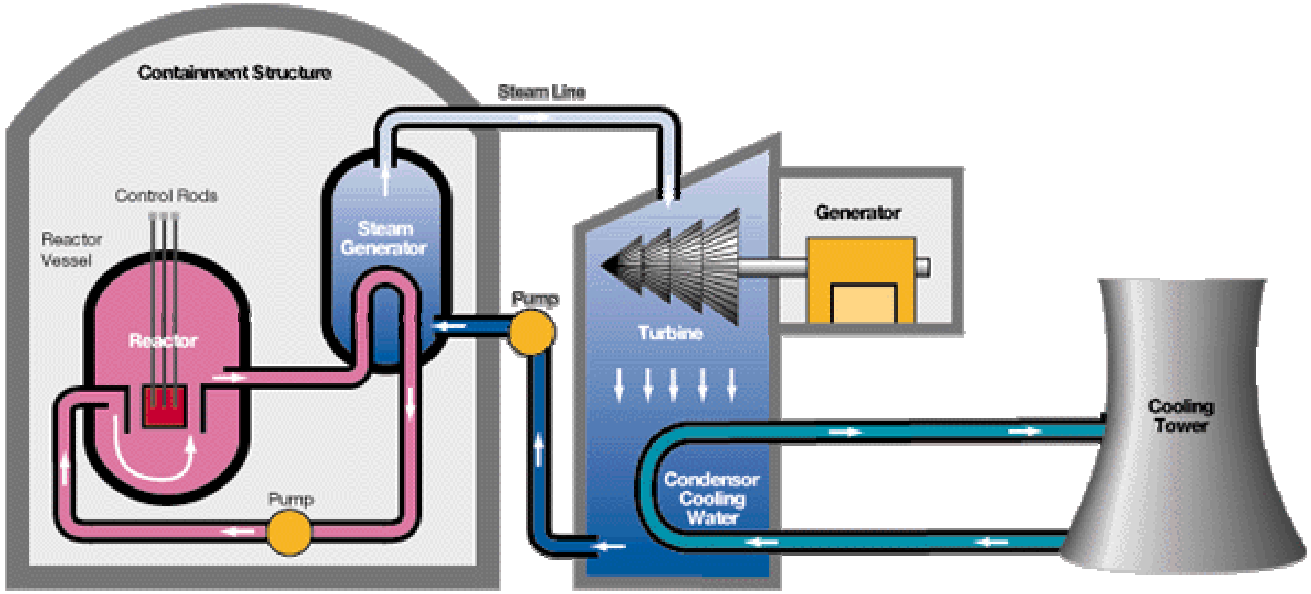
- In the primary circuit, thermometers are used to monitor control and for protection systems



Setting the scene - IV

- Response time of temperature sensors, as well as tolerances on temperature accuracy, contribute directly to the assumptions for the optimal operation of the reactor in compliance with the applicable safety rules.

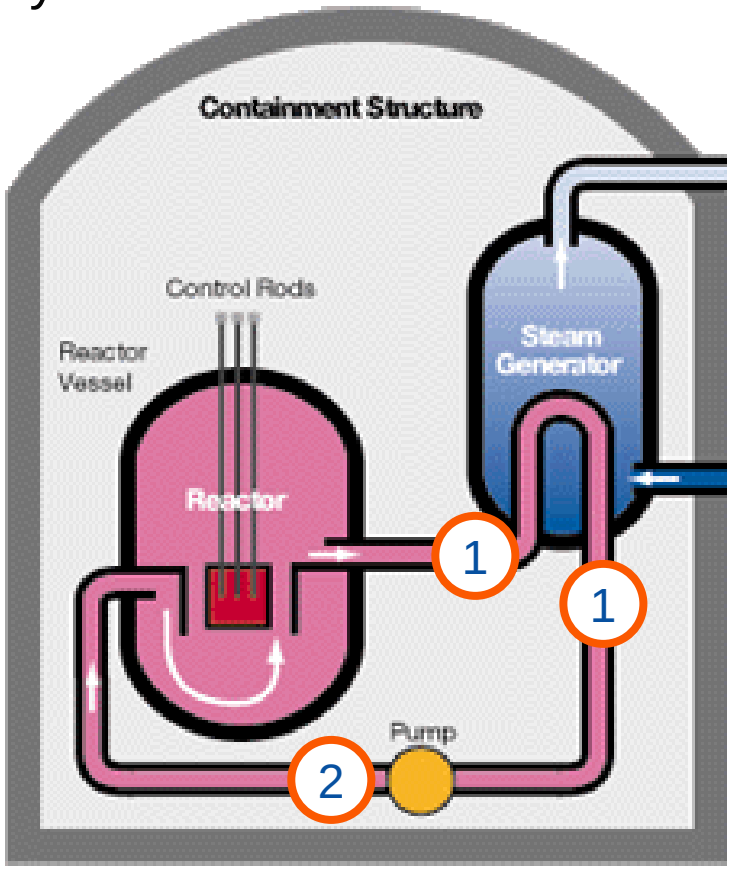
- In particular, the speed of signals sent to the Instrumentation and Control (I&C) systems ensures the smooth operation of the reactor and protection systems taking into account all different situations considered.



Setting the scene - V

- Instrumentation must be qualified to demonstrate ability to fulfill their mission, this throughout their operating life
- Response time of thermometers is a critical characteristic – must be validated in laboratory before their installation on site
- Various types of thermometers are used in the primary circuit

1. "Fast-time response" sensors (below 2 sec*)
2. "Semi-fast time response" sensors (below 10 sec*)
   "Classical" sensors (typ. a few min*)

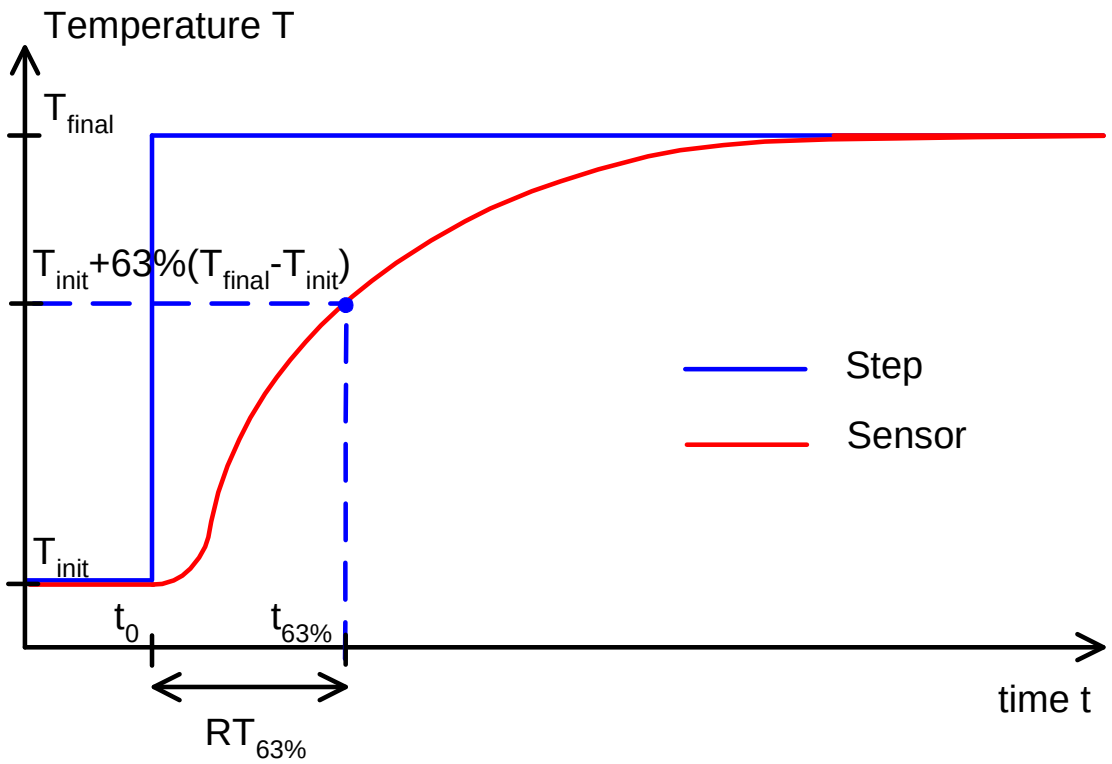


* *Exact value is confidential*

Response time & experimental methods - I

- Response time is, by convention, taken as the time $RT_{63\%}=t_{63\%}-t_0$ associated to *63%* of the step $(T_{final}-T_{init})$ to which the thermometer is exposed

- In general *[CEI 751:2008]*, response time can also be given at 10%, 50%, 90% of the temperature step

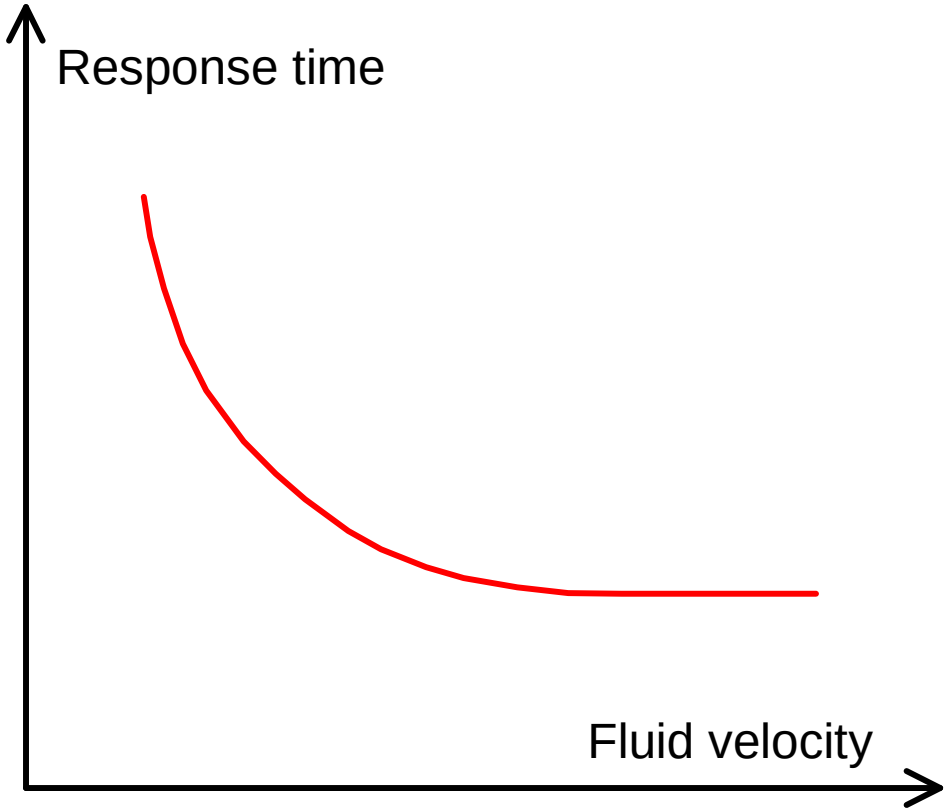


- *The response time depends upon the heat capacity of the sensor and the heat transfer with the environment*

Response time & experimental methods - II

- Convective heat transfer depends on the velocity of fluid, thermophysical properties of the fluid and sensor material, nature of the surface of the sensor

➢Response time vs velocity of the medium perpendicular to the thermometer stem *[El Hefni BH, Ensam, phD thesis, 8 july 1987]*



Response time & experimental methods - III

- Two ways to determine response time *[Techniques for Approximating the International Temperature Scale of 1990, BIPM, 1st Ed, 1990]*

  -In situ determination

  Analyse the response by using the thermometer resistance as a heating element, then deduce response time through an algorithm *[Kerlin et al., 1982]*

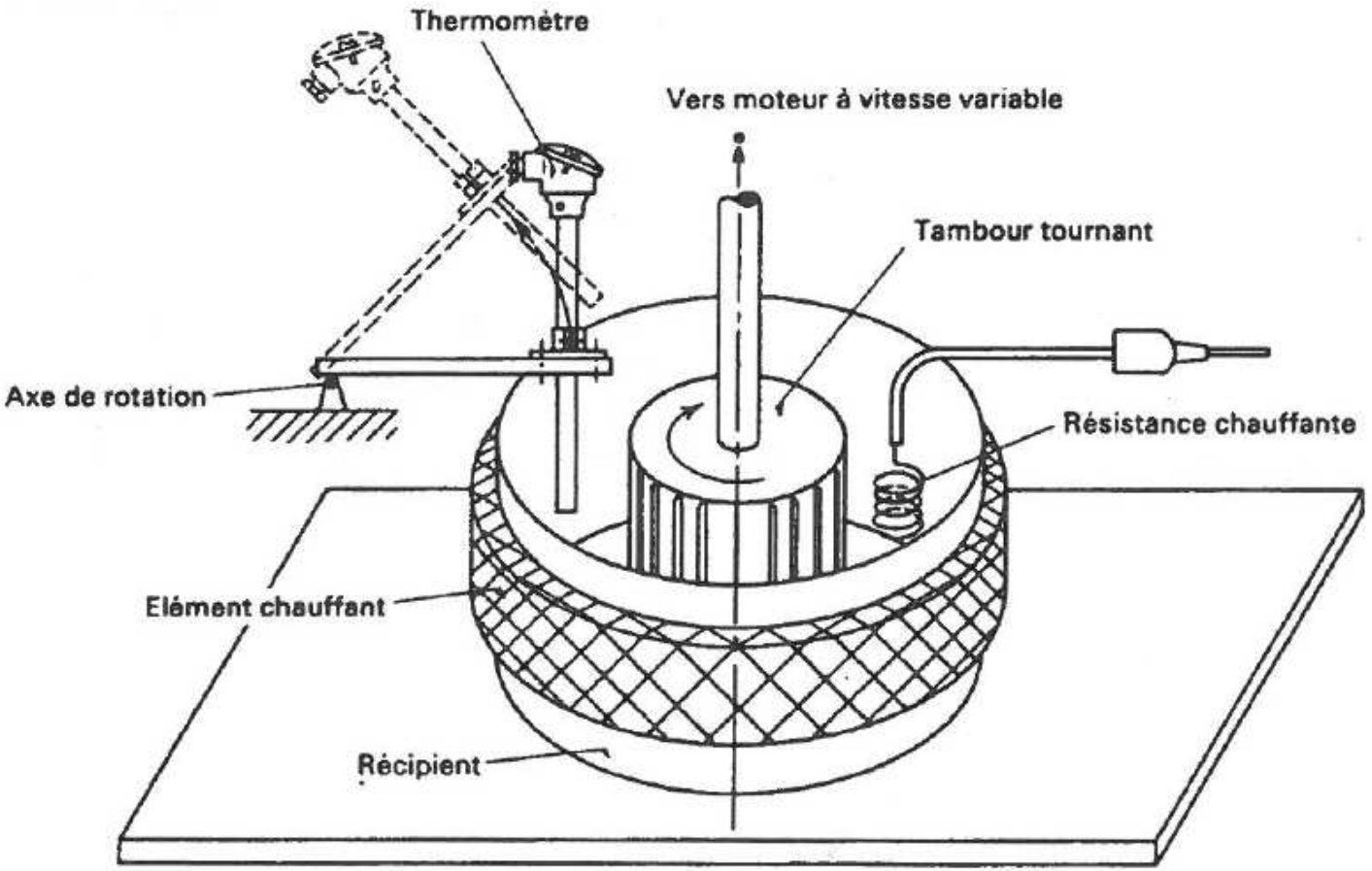
  -By immersion of the thermometer in a fluid

  Response time measured under these conditions, then deduced by similarity in the medium to be used

  Examples of devices provided in the annexes of CEI 751:1995 standard – disappeared in the text of CEI 751:2008 standard

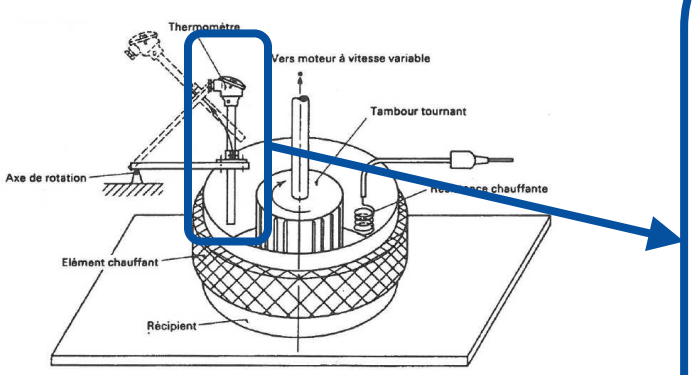
Device for measurement in water or other liquids :

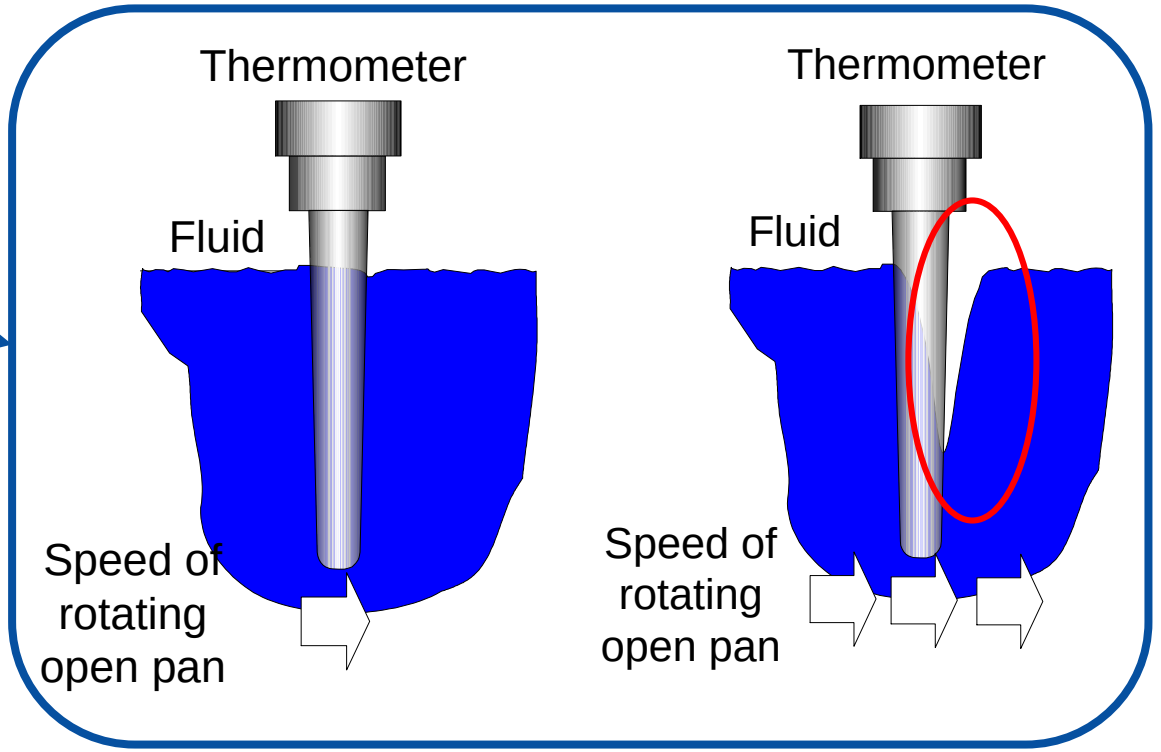
“rotating open pan method”



Response time & experimental methods - V

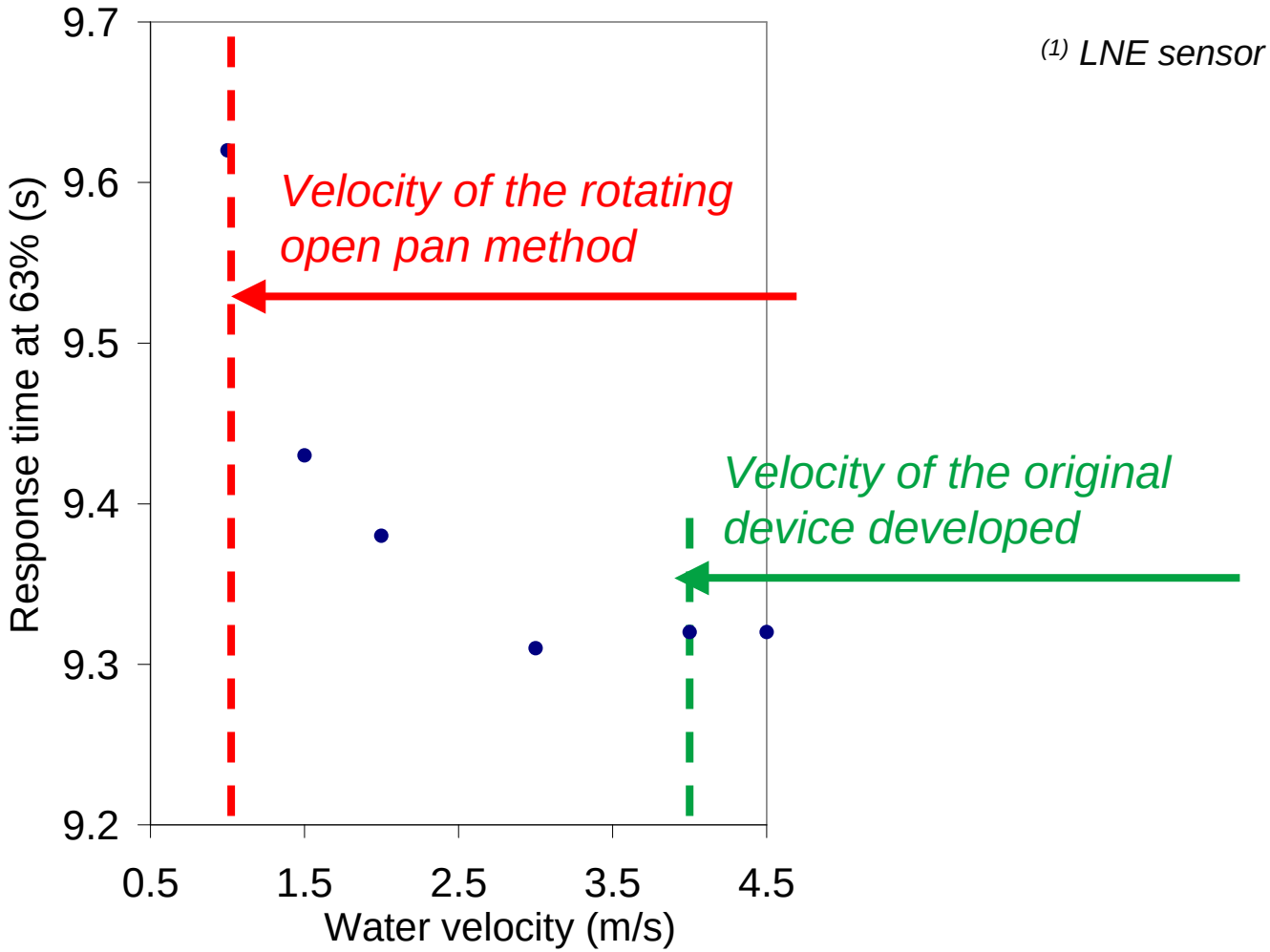
- Method generally used by sensors manufacturers
  … but limitations e.g. velocity of water limited (< 1 m/s), large uncertainties
- Deviates significantly from in situ conditions / thermometers in pipes, high flow rates (V ≥ 4.5 m/s)





Response time & experimental methods - VI

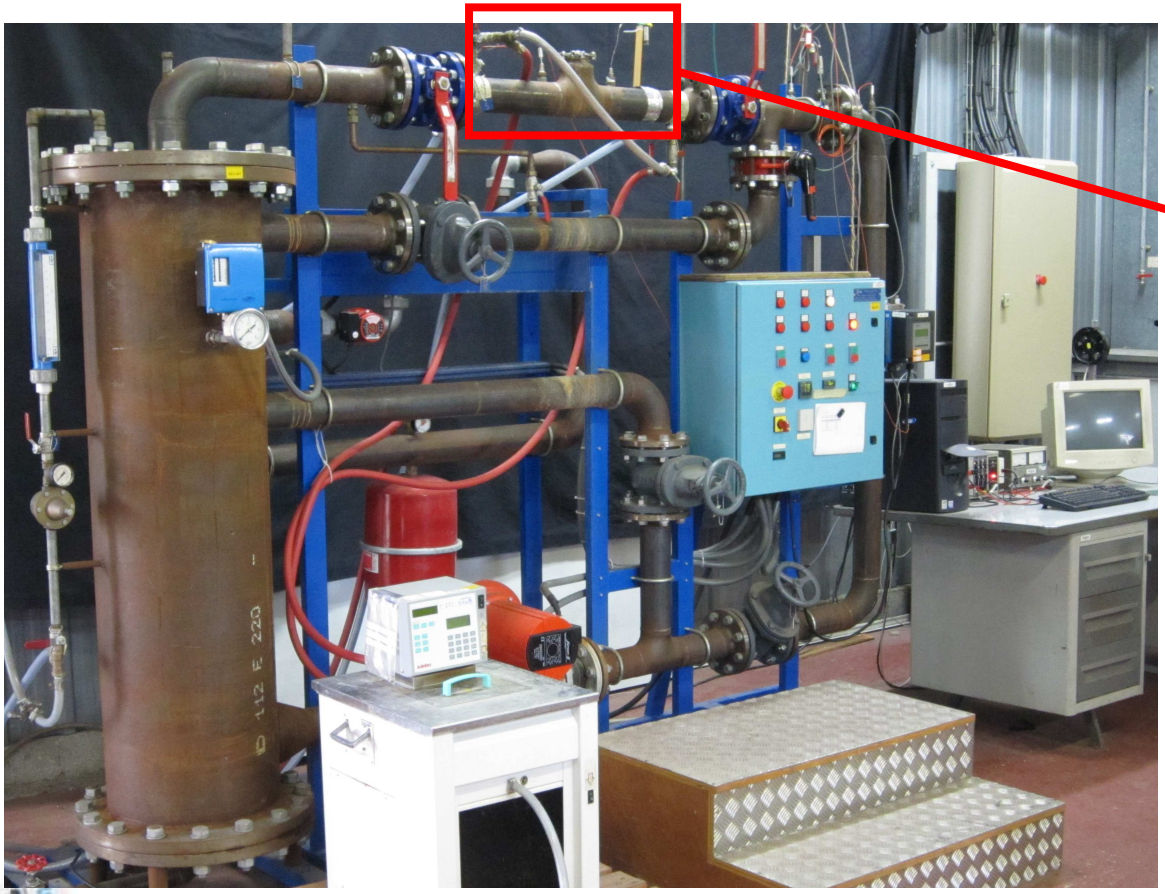
Example : experimental assessment at LNE of the influence of water velocity on the response time of a platinum resistance thermometer(1)



(1) *LNE sensor*

A facility co-developed by EDF & LNE - I

- Rotating open pan replaced by water tank system + water circulation in pipes ⇨ V increased to approach in-situ conditions
- Thermometer under test perpendicular to pipe axis

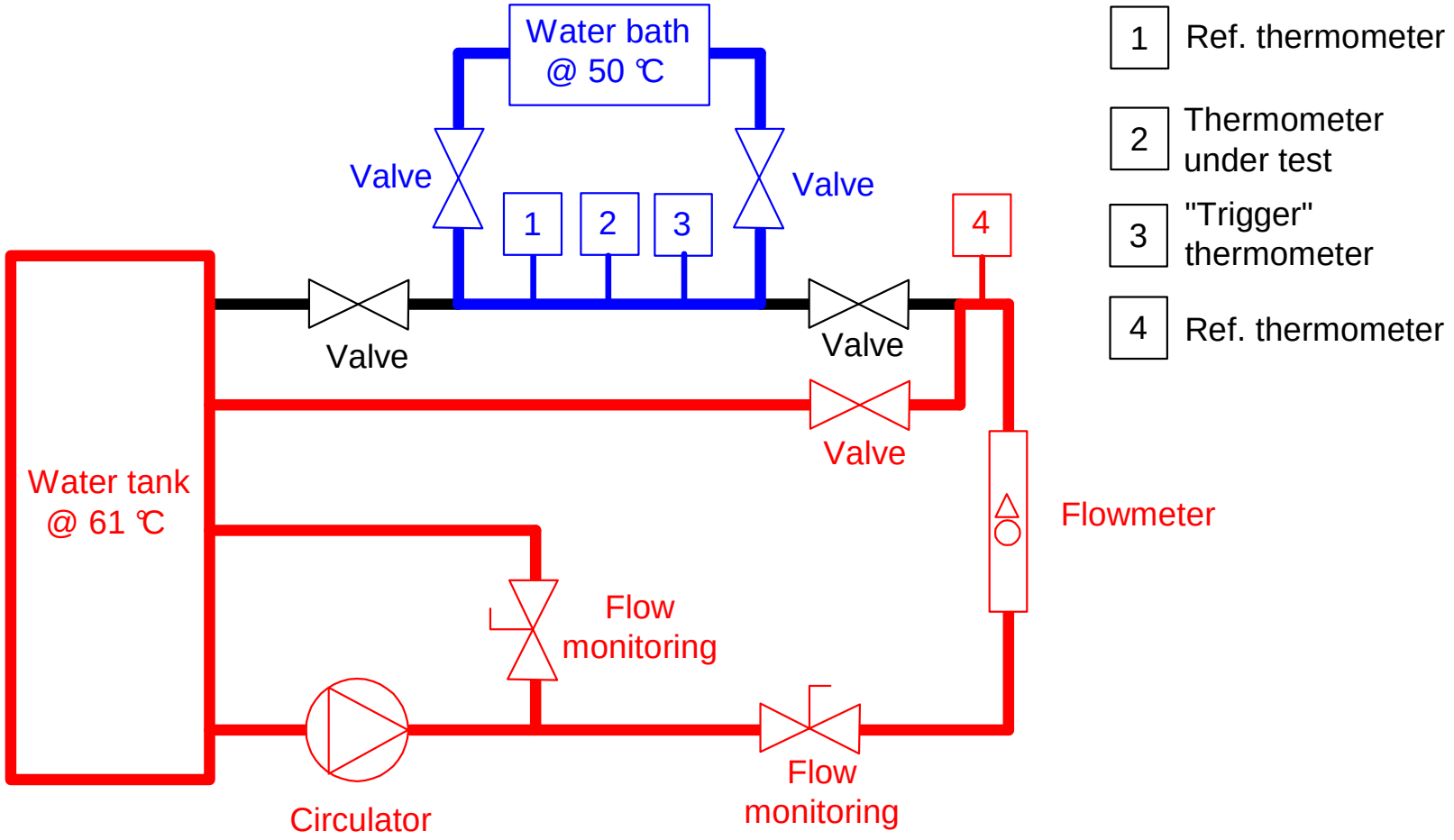


Test section

Response time facility

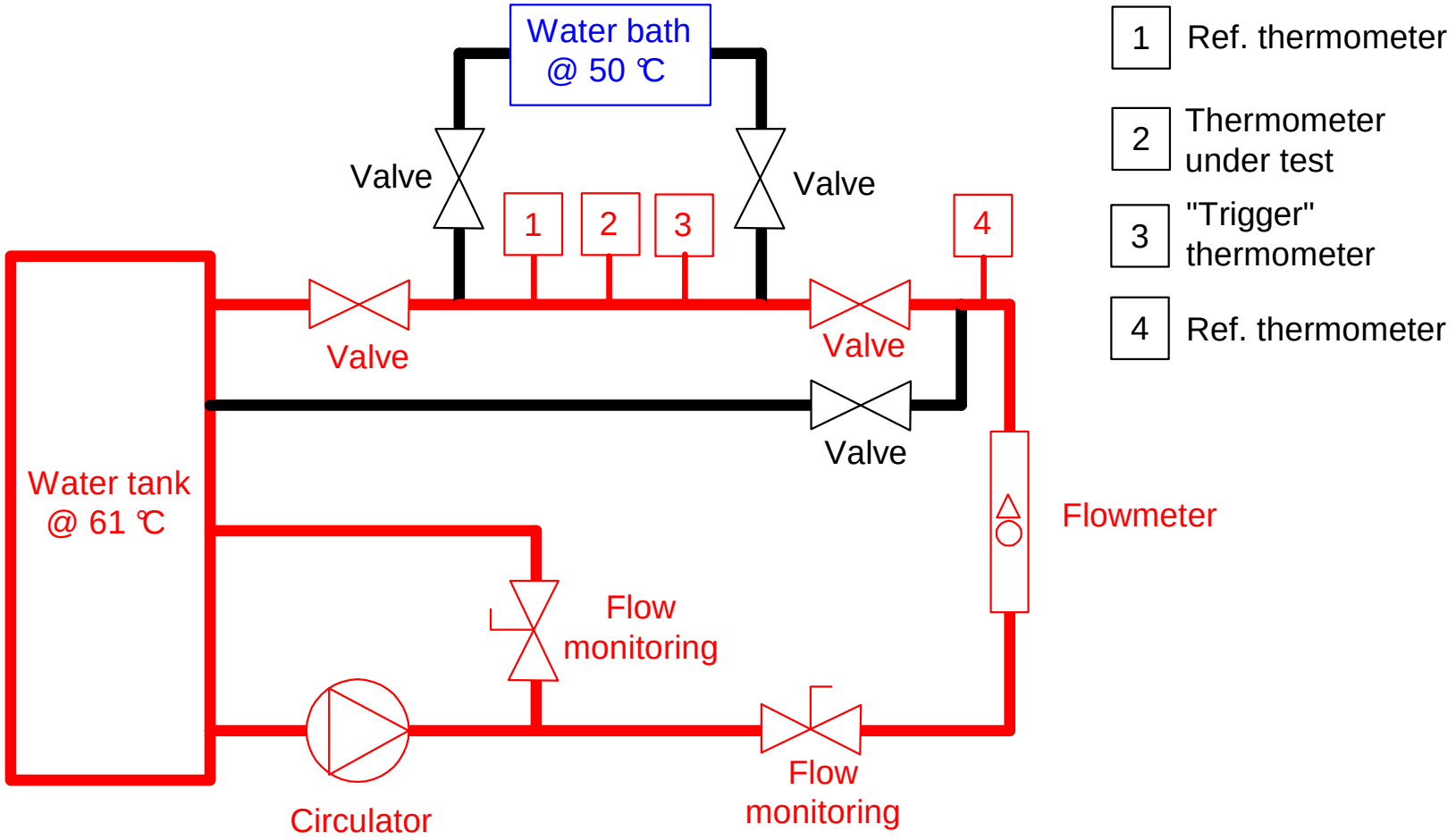
A facility co-developed by EDF & LNE - II

- STEP 1 : sensor “2” under test perpendicular to pipe axis, temperature stabilized at 50 ℃; “hot” water at 61 ℃ is by-pass ed



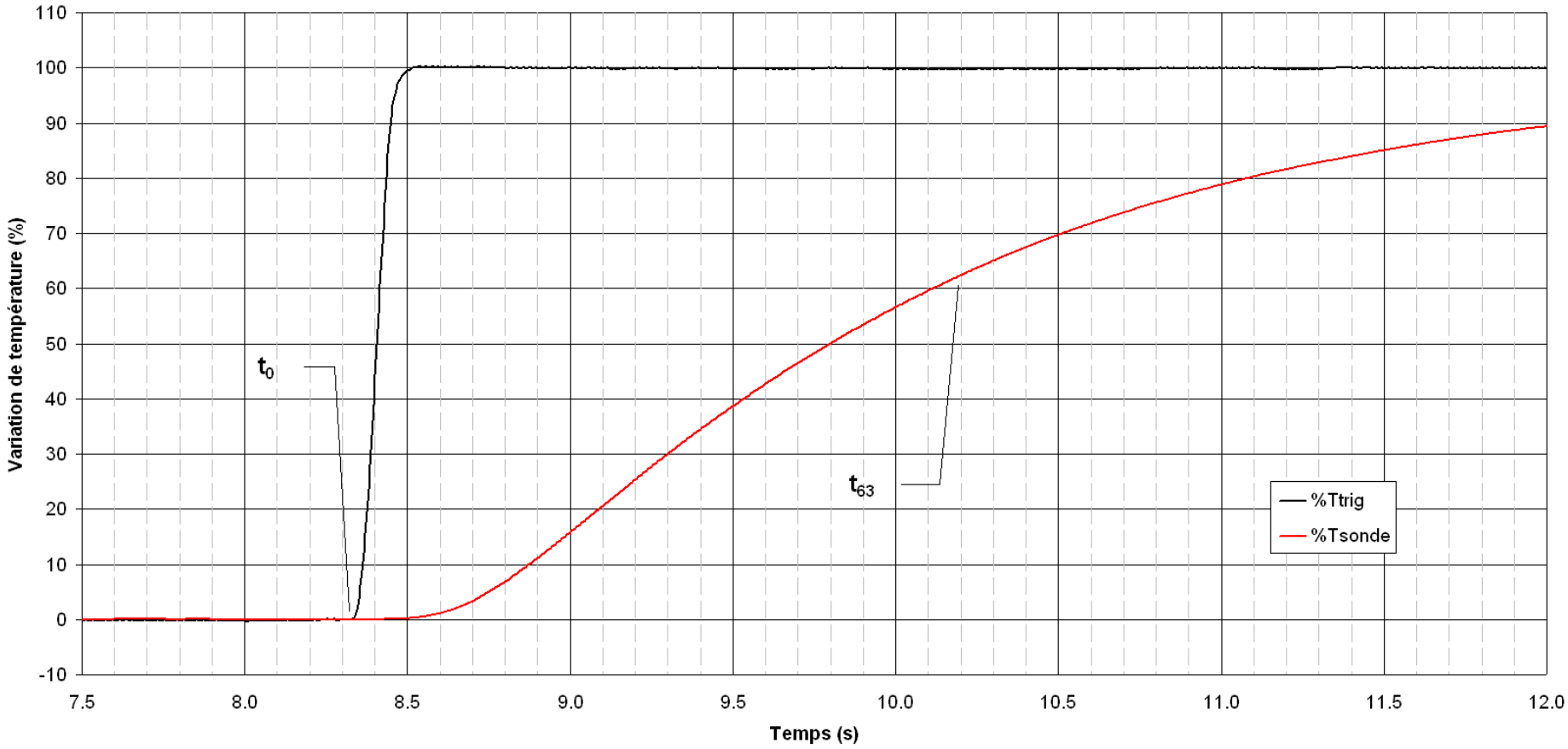
A facility co-developed by EDF & LNE - III

- STEP 2 : “cold” water circuit is by-passed in the bath; “hot” water circulates in the test section (thermometers 1, 2, 3), water at fixed speed (0.5 m/s – 4.5 m/s)



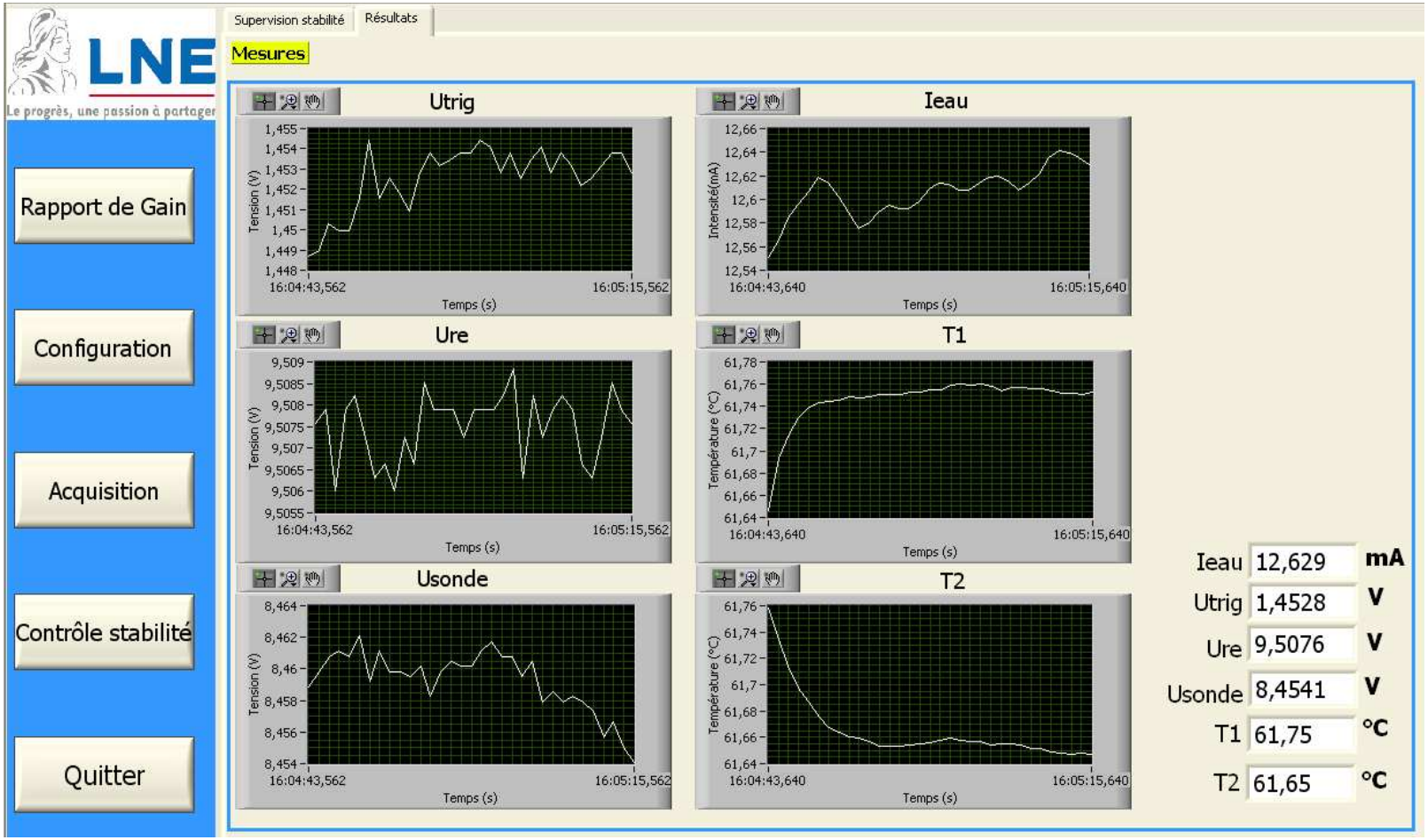
A facility co-developed by EDF & LNE - IV

- A “trigger” sensor (“ultra-fast” response time, pre-determined value) detects the hot waterfront, providing time “t0” used for the determination of the response time at 63% of the sensor under test



A facility co-developed by EDF & LNE - V

- For each experiment : acquisition of signals from the trigger sensor, sensor under test, water flow, temperatures of “cold” and “hot” circuits
- Adjustable frequency (up to 400 Hz)



Measurement & uncertainty - I

- Amplified, low noise signals (Trigger, Sensor under test, electrical reference)

Instrument	σ (%) of signal output at 200 Hz
Trigger	0.21
Electrical reference	0.005
Thermometer	0.005

- Repeatable measurements of response time at 63%

Exemple of two sensors under test

Water speed	Ref #1 (1) (sec)	Ref #2 (1) (sec)
2 m/s	1.79	9.39
	1.78	9.36
	1.78	9.35
	1.77	9.35
	1.78	9.34
	1.79	9.36
	1.8	9.34
	1.79	9.33
	1.78	9.34
	1.78	9.33
Mean	**1.78**	**9.35**
σ	**0.01**	**0.02**

(1) *LNE sensors*

Measurement & uncertainty - II

- Impact of successive assembly removals on time response at 63%

Water speed	**Ref #1** (1)	**Ref #2** (1)
	(sec)	**(sec)**
2 m/s	1.78	9.33
	1.77	9.33
	1.8	9.35
	1.8	9.3
	1.79	9.34
Mean	**1.79**	**9.33**
σ	**0.02**	**0.02**

(1) LNE sensors

Measurement & uncertainty - III

- Thorough evaluation of uncertainties
- Mathematical model (simplified / emphasis on 2 components) :

$$RT_{63\%} = t_{63} - t_0 + \delta t_{valve} + \delta t_{mixing} + \sum_{i=1}^{n} \delta t_i$$

$$u(RT_{63\%}) = \sqrt{u^2(t_{63}) + u^2(t_0) + u^2(\delta t_{valve}) + u^2(\delta t_{mixing}) + \sum_{i=1}^{n} u^2(\delta t_i)}$$

$u(t_{63})$ & $u(t_0)$ are due to the determination of the signal of the sensor at 63% & 0% of the temperature step

δt_x are various time corrections, in particular :

$u(\delta t_{valve})$ is due to non-ideality of the hot waterfront generated by the operator

$u(\delta t_{mixing})$ is due to the re-circulation of mixed (“hot” and “cold”) in the test section

Measurement & uncertainty - IV

- For “Semi-fast time response” sensors (ca 10 sec),

  $u(\delta t_{mixing})$ is the largest contribution to the uncertainty budget

- For “Fast time response” sensors (ca 2 sec),

  $u(\delta t_{valve})$ is the largest contribution to the uncertainty budget

- Example of uncertainties (k=2) delivered for three thermometers

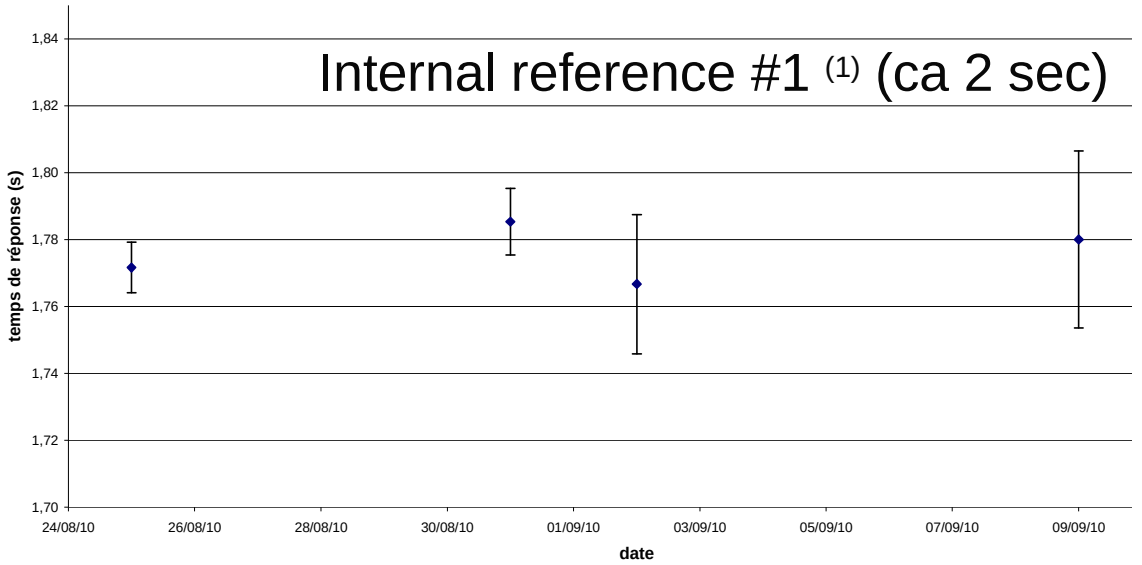
Water speed	$RT_{63\%}$	U (k=2)
(m/s)	(s)	(s)
1	ca 9.5 (1)	± 0,10
2		± 0,15
4		± 0,20
2	ca 6 (1)	± 0,10
1	ca 1.5 (1)	± 0,10
2		± 0,10
4		± 0,10

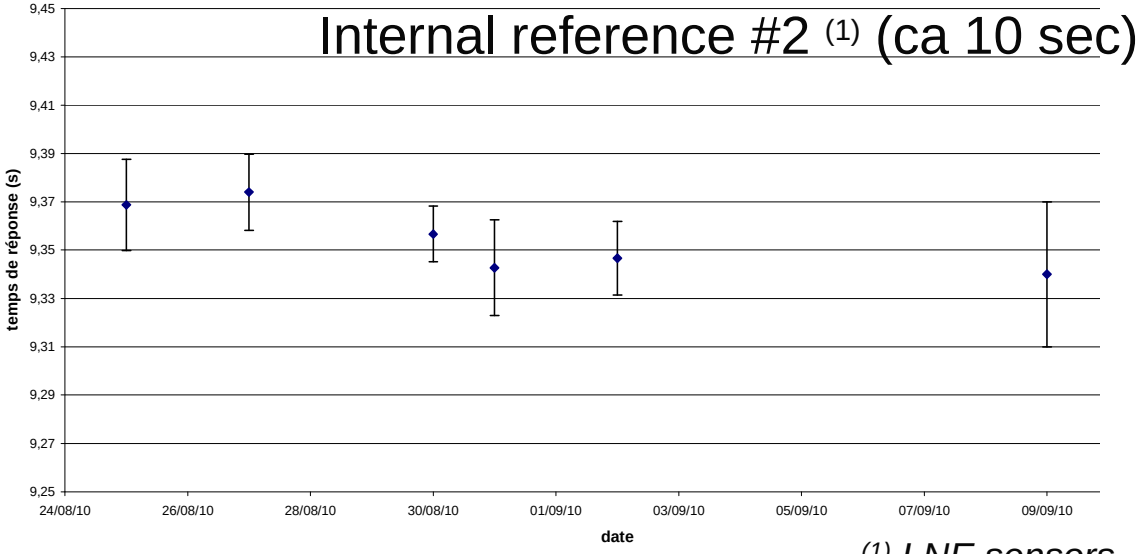
(1) *LNE sensors*

Measurement & uncertainty - V

Calibration of references
Periodical checks

- Electrical reference, measuring systems, sensors periodically re-calibrated
- In between, checks are made on internal sensors, used as secondary references, before and after each series of experiments
- Service under quality insurance





(1) LNE sensors

Summary

- Presentation of achievements in the field of response time measurements, from co-development of innovative facilities to services activities on a routine basis

- Necessary high level metrology on critical parameters (calibrations, R&D, scientific exchanges, technical assistance) ; demonstrate the required confidence in the quality of response time measurement

- Example of a + 10-years exchanges between a NMI and a major player of nuclear industry on instrumentation
  - to continuously support improvements of industrial best-practices
  - To provide LNE with new fields of research

Thank you for your attention