http://dx.doi.org/10.21611/qirt.2010.161



# Personal thoughts on the occasion of the Xth QIRT Conference

Daniel L. Balageas

Composite Materials and Systems Department

ONERA

THE FRENCH AEROSPACE LAB

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# Advertisement

I have been asked to present this keynote lecture relatively late. In these conditions I was unable to prepare a text to be included in the book of proceedings.

In counterpart, the PowerPoint transparencies of this presentation will be included with the rest of the proceedings in the QIRT Open Archives of the QIRT Website.

http://dx.doi.org/10.21611/qirt.2010.161

# Content of the presentation

- How all this started – QIRT'92
- A short history of the conference

Souvenirs and history

- QIRT is not only a conference
- A look at the QIRT Community

Information on QIRT activities

- Present situation of NDE techniques
- Comparison of techniques
- Flashbacks on pulse thermography
- Proposal for the organization of round-robins

Personal remarks concerning the NDE field

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# How all this started

The first **conference, QIRT'92**, started from several ideas based on my own thermographic experience:

- Thermography is a really powerful tool if sustained by a heat transfer knowledge and a theroretical background linked to the physics of the studied phenomena whatever be the application domain;

  ⇨ Importance of the adjective "qualitative"

- Thermography is not a simple technique. The investment required for achieving a good practice is not only a question of apparatus but also of well-trained experimenters. Furthermore, the experience adquired in one field can be applied in another field, often with novelty.

  ⇨ Interest of mixing practitionners from very varied fields of application in the same conference, with sessions on common basic topics and specialized applicative sessions

I had two models in mind:

- QNDE which was, and is still, the leading conference in the NDE field, the conference where new ideas are presented. This conference insists on the term "quantitative",
- Thermosense conference which was the annual thermographic key event.

In parallel to these technical motivations, and in the context of the beginning nineties (strengthening and possible enlargment of the European Community and end of the "cold war"), there was also "political" aims:

- to give to Europe (Eastern and Western Europe) a great conference comparable to what existed in USA,
- to help the establisment of friendly and scientific links between the different national thermographic communities of Europe

  ⇨ Make the conference travelling from one country to the other and not staying at the same place.

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# A short history of the conference

## First QIRT Conference

This idea of a QIRT Conference was submitted to colleagues from other European countries and we constituted a Scientific Committee composed of 8 members from 8 countries.

The first announcement of the conference was sent in Septembre 1991.

The first meeting of the committee, which took place in Paris on **March 16, 1992,** must be considered as the foundation of QIRT.

Ecole Centrale de Paris, Châtenay-Malabry (Paris), July 7-9,1992



Opening of QIRT'92

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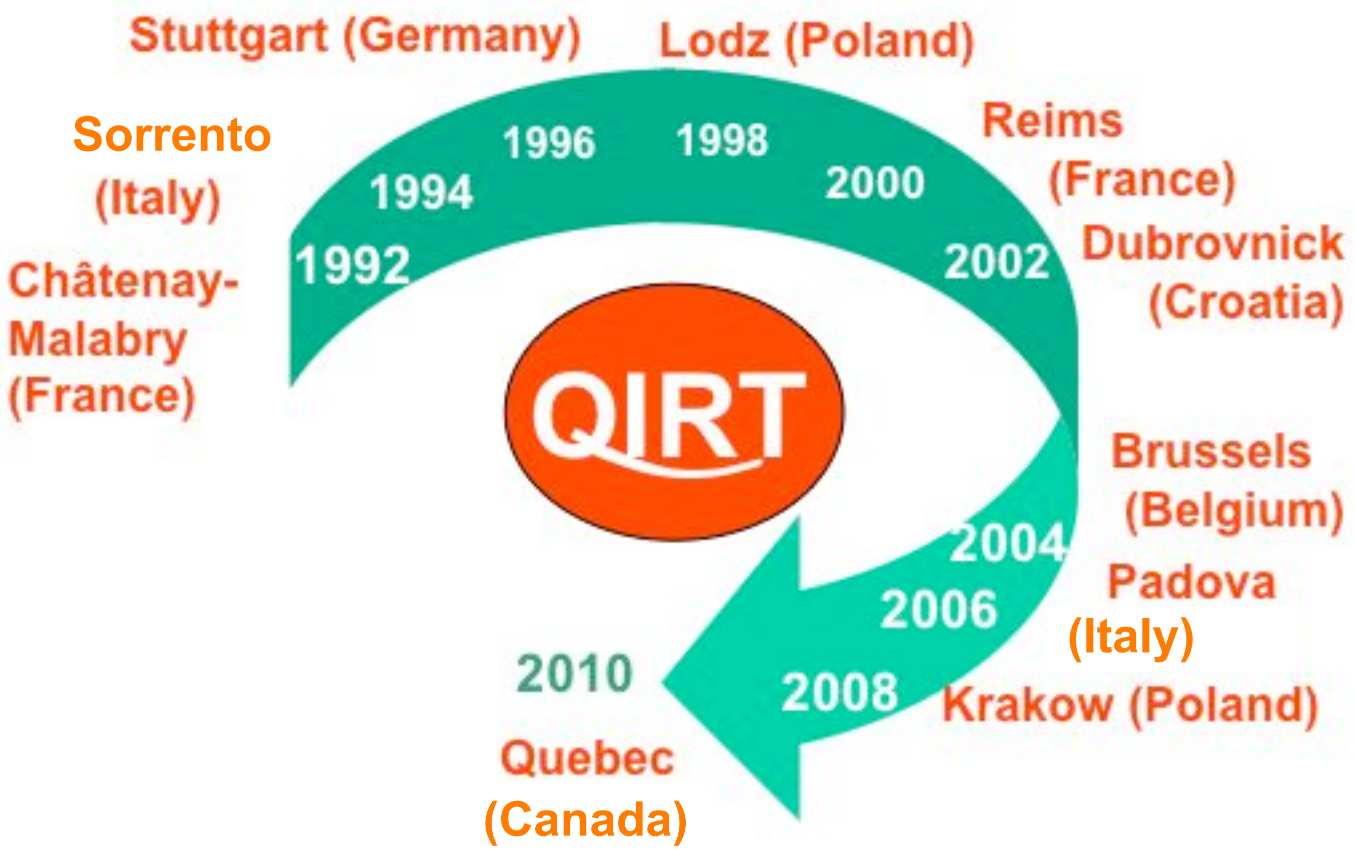
# A short history of the conference

## The QIRT Conference series



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# QIRT is not only a conference

## QIRT Web site – QIRT Open Archives

### QIRT Web site

http://qirt.gel.ulaval.ca

In French and English

Created in 2004

Upgrade of the site: 2006

### QIRT Open archives

http://qirt.gel.ulaval.ca/dynamique/index.php?idM=39&Lang=1

Started in 2007

**With the QIRT 2010 papers, there will be soon near 600 papers freely laodable (pdf)**

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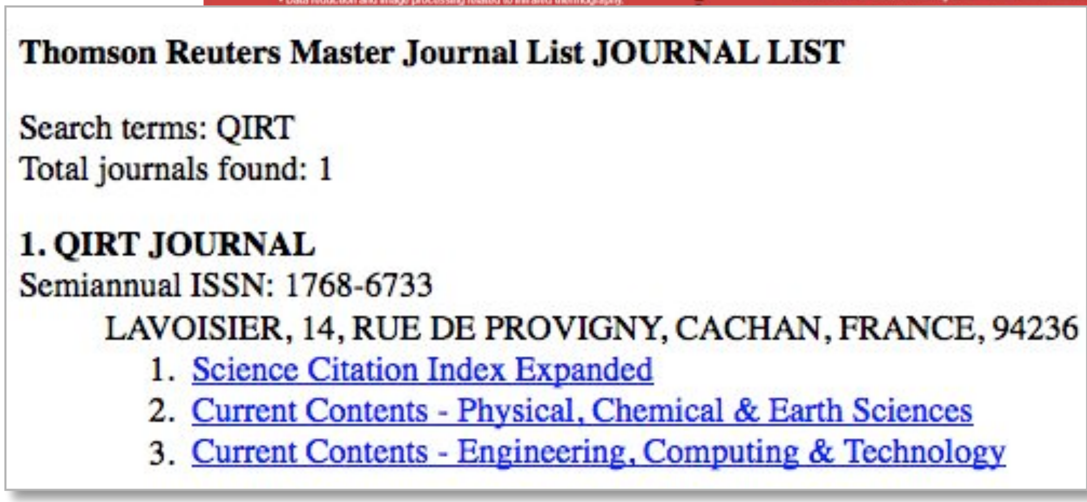
# QIRT is not only a conference

## Qirt Journal

### QIRT Journal

First issue: June 2004

Acceptance of the Journal in the ISI Web of Science: 2010

**Thomson Reuters Master Journal List JOURNAL LIST**

Search terms: QIRT
Total journals found: 1

**1. QIRT JOURNAL**
Semiannual ISSN: 1768-6733
LAVOISIER, 14, RUE DE PROVIGNY, CACHAN, FRANCE, 94236

1. Science Citation Index Expanded
2. Current Contents - Physical, Chemical & Earth Sciences
3. Current Contents - Engineering, Computing & Technology

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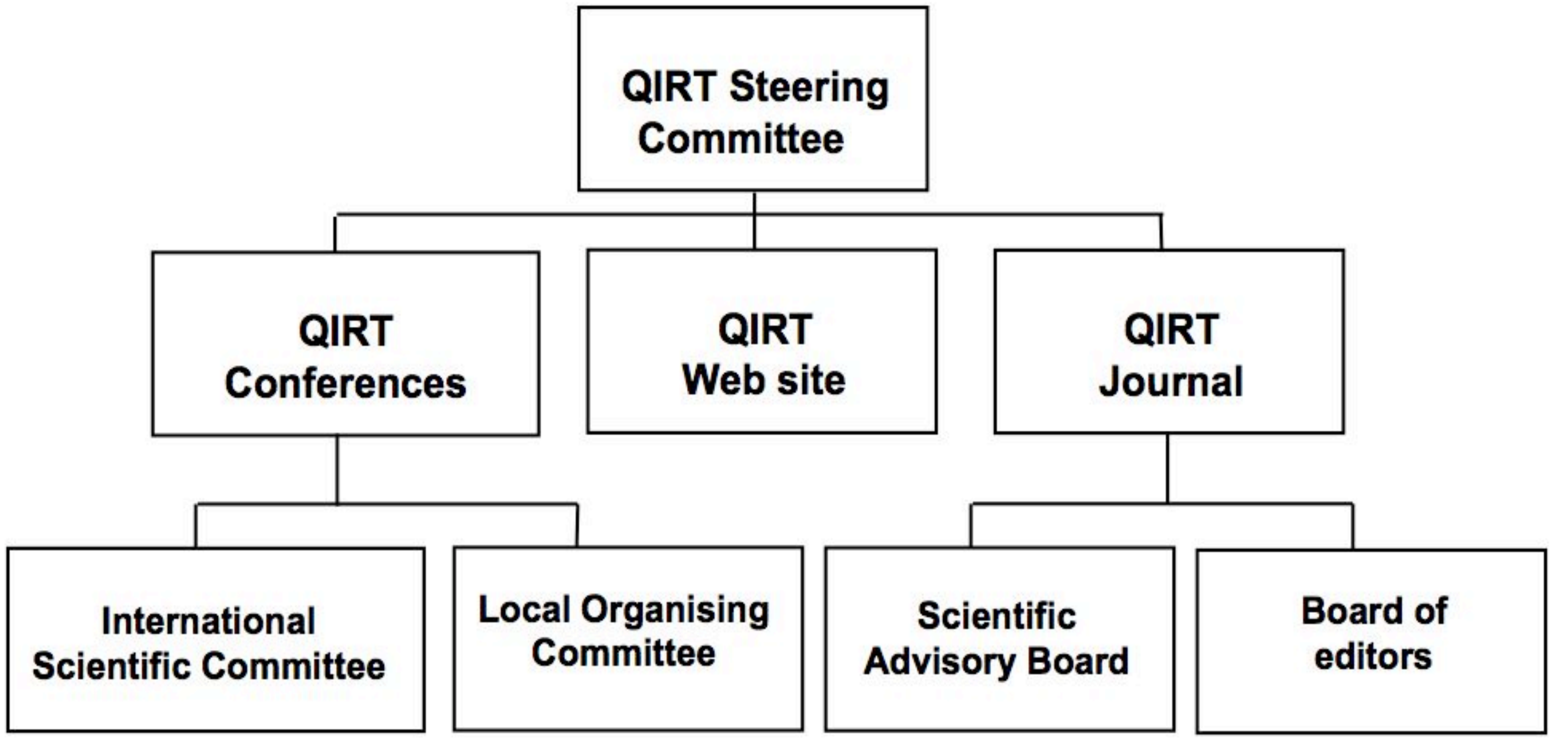
# QIRT is not only a conference

## How all this works?



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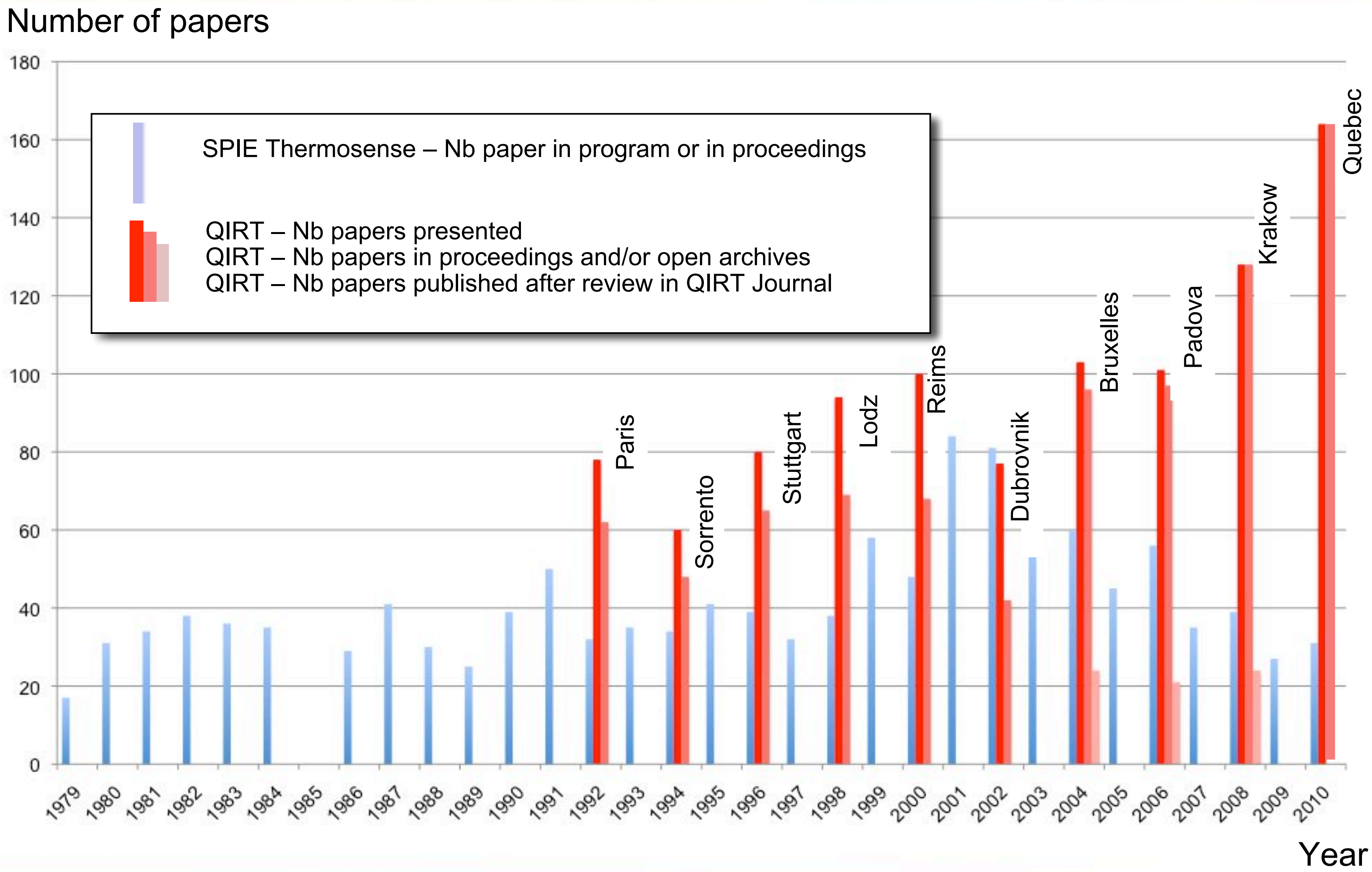
# A look at the QIRT Community

## Evolution of the number of communications at QIRT conferences



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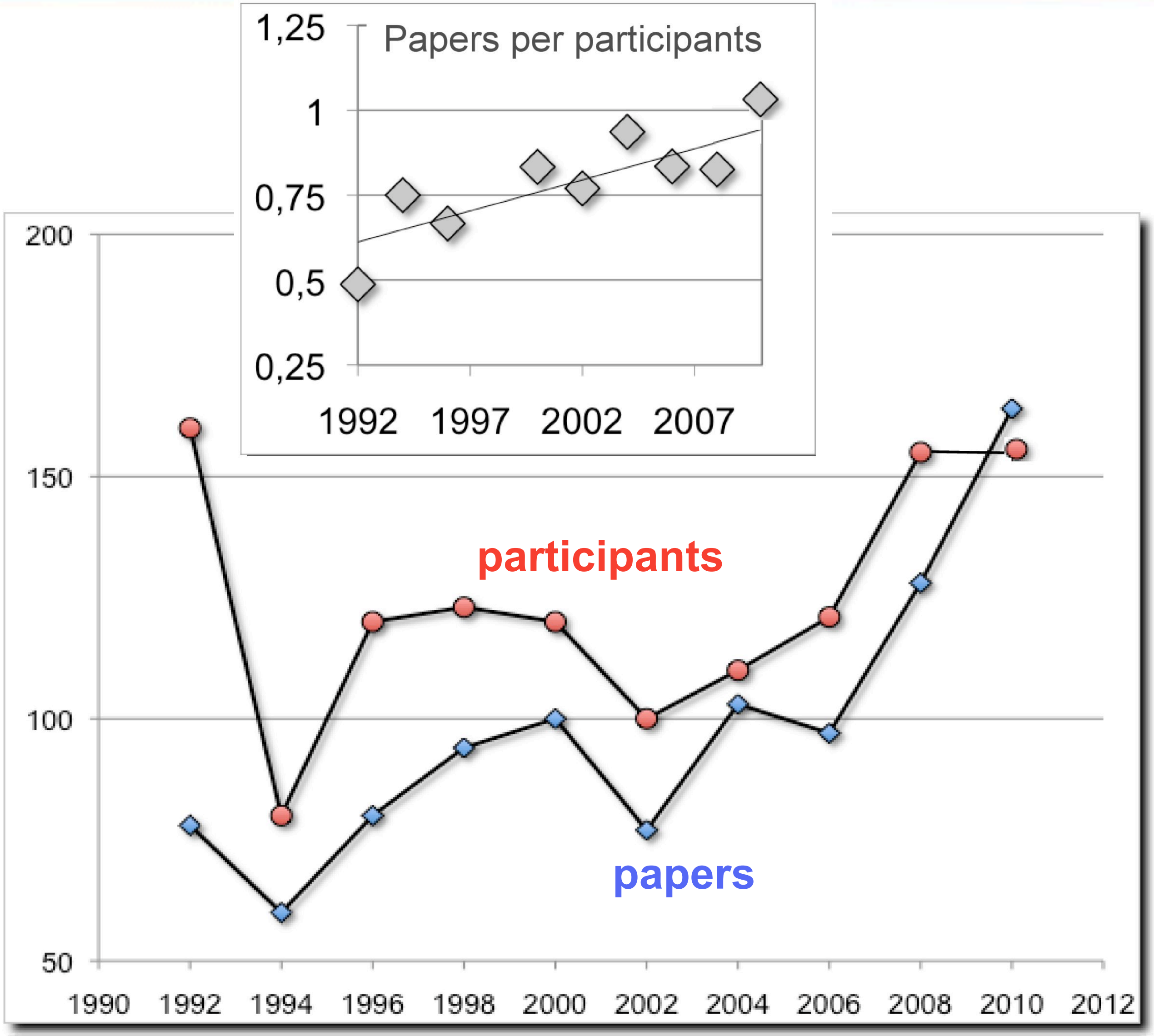
# A look at the QIRT Community

## Papers and participants at QIRT Conferences



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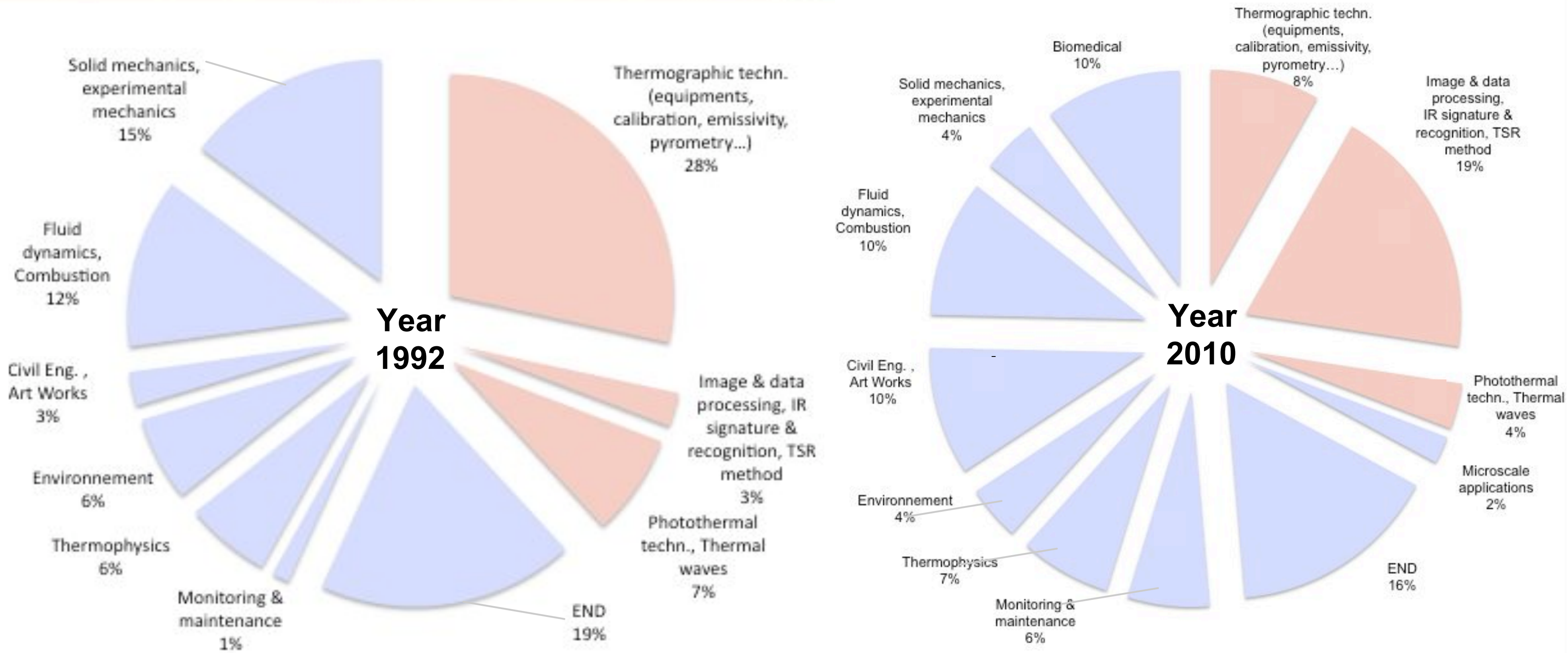
# Domains of interest of the QIRT community
## Comparison between the first and the present conferences




38% Common basic topics 31%

62% Particular application domains 69%

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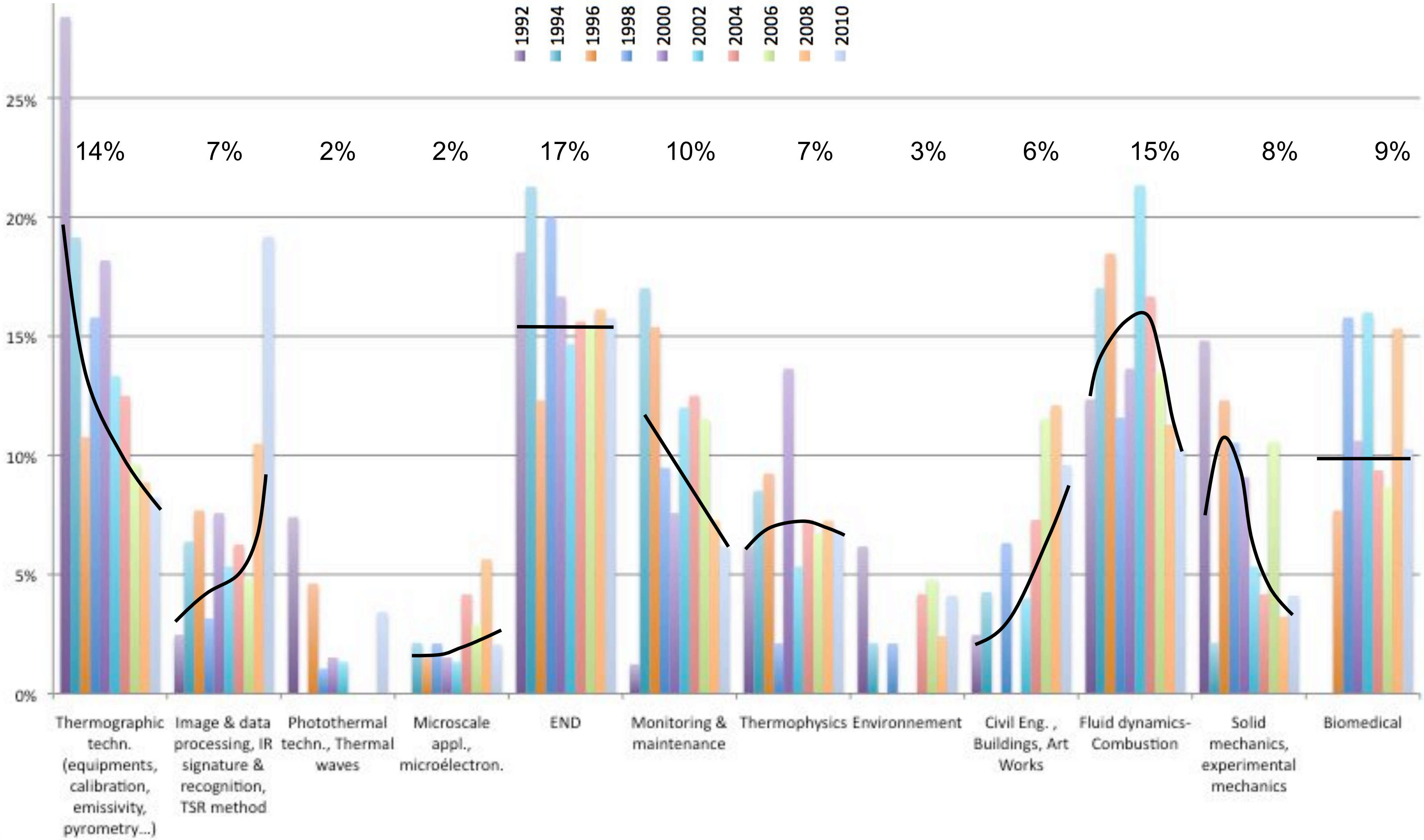
# Domains of interest of the QIRT community
## Time-evolution of the respective importance of the topics



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# Reflections on NDE applications

**Present situation of the main thermographic NDE techniques**

**Comparison between the main thermographic techniques**

**Flashbacks on pulsed thermography**

**Need of round-robins**

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# Present situation of the thermographic NDE techniques

In the field of non-destructive evaluation, every year, new refinements in image and data processing of thermographic experiments are proposed.

Nevertheless, often these works,
- do not take into consideration some basic thermal phenomena involved in real experiments,
- forget the abundant literature existing on the subject in the 80's and 90's,
- establish **non-objective comparisons** of techniques,
- and **finally lead to very view quantitative results** concerning the defect parameters: depth, extent, severity.

Most of the papers can be sorted into three categories: Pulse Thermography (PT), Pulse Phase Thermography (PPT), and Lock-in Thermography (LT). There is like a competition between these techniques. For his keynote lecture given in Cracow, this situation has inspired Steve Shepard to present the following transparency:

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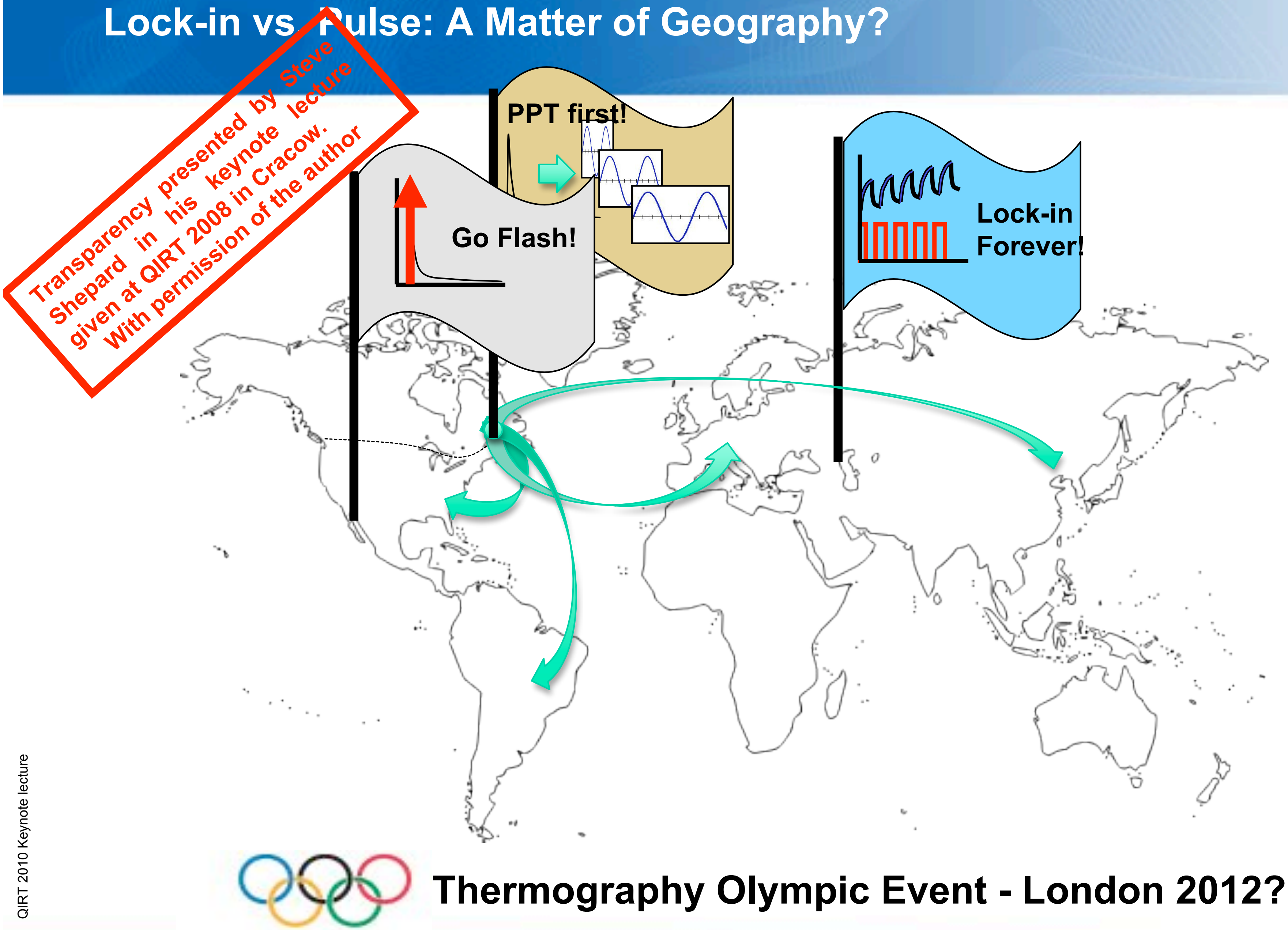
# Lock-in vs. Pulse: A Matter of Geography?




Thermography Olympic Event - London 2012?

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# Comparison of the respective merits of the three thermographic techniques

personal views open to contradictory discussions

| | Pulsed thermography | | Lock-in thermography |
|---|---|---|---|
| | Amplitude based (PT) | Phase based (PPT) | Phase based (LT) |
| Heat source | Heat pulse | | Periodic heating |
| Regime | Transient | | Permanent |
| Advantages | • Fast<br>• Multifrequency<br>• Signal-to-noise decreases with time but this is compensated by the increased number of acquired points per time scales | | • Low power injected in the sample<br>• Good signal-to-noise ratio possible |
| | • Possibility of rectification by log-log plot<br>• Non uniform heating easily corrected by normalisation<br>• Depth inversion technique simple | • Little impact of non uniform heating | |
| Disadvantages | | • For the inversion, adequate sampling and truncation parameters (functions of material thermal properties and defect depth) must be chosen interactively during the signal discretization. | • Method is slow because:<br>- as many tests required as defect depths<br>- permanent regime has to be reached<br>• Due to the need of a permanent regime: non uniform heating and 3-D conduction effects may take importance |

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# Flashbacks on pulse thermography

| | Pulsed thermography | | Lock-in thermography |
|---|---|---|---|
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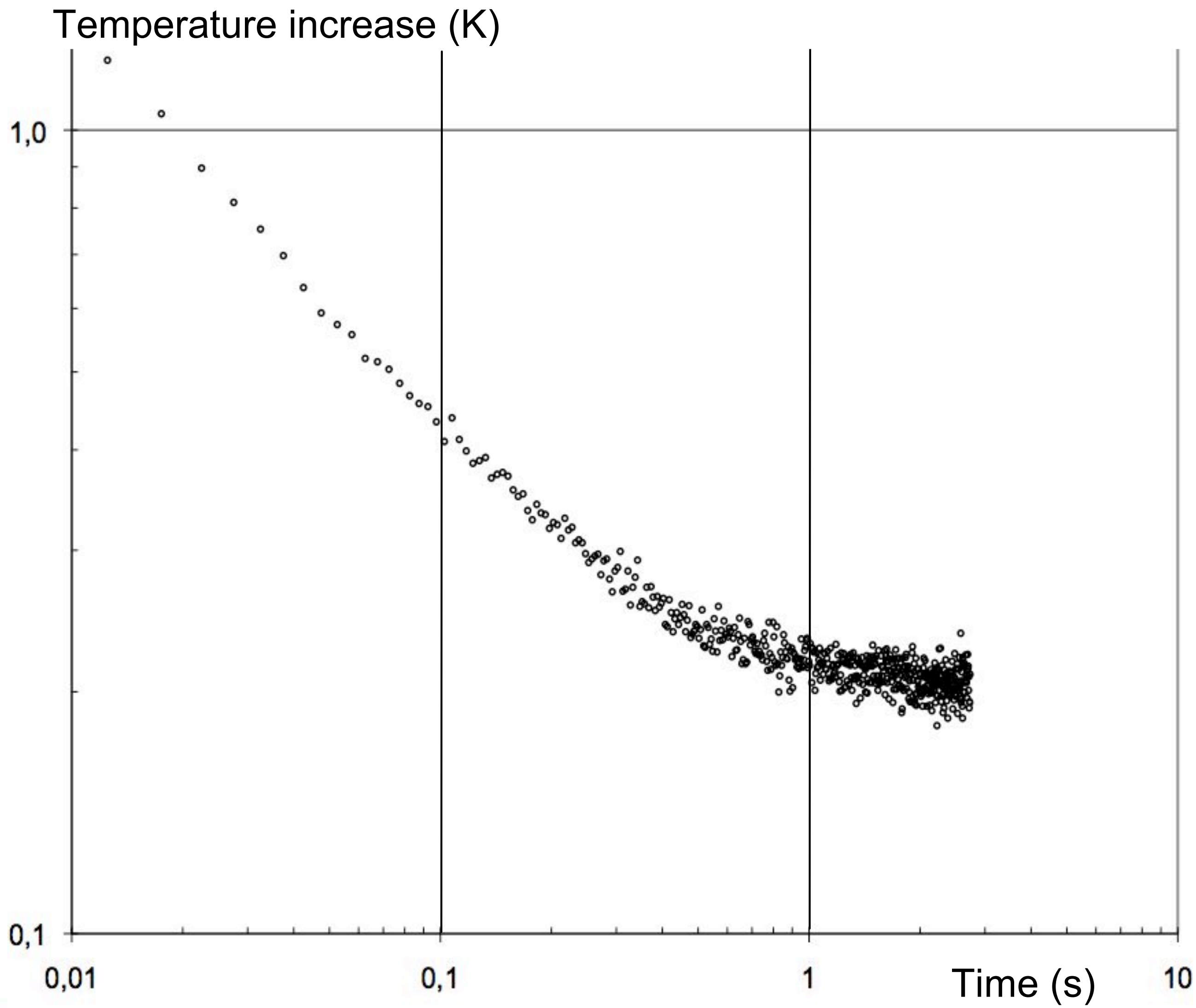
# Signal to noise ratio is compensated by the increase of the number of points per time scale

Typical pulse thermogram (here 10 mm-thick plate of duraluminum without black coating, frame rate 200 Hz)



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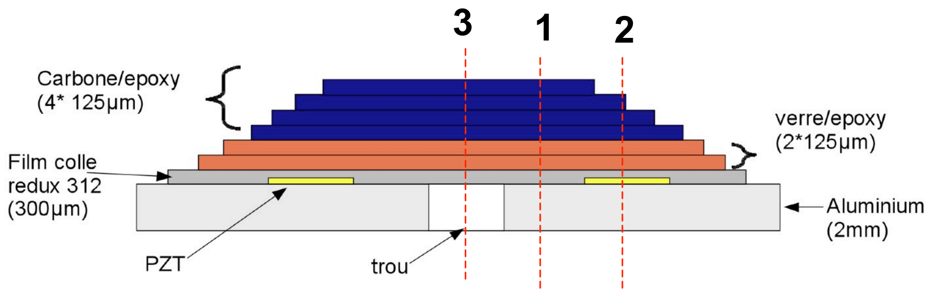
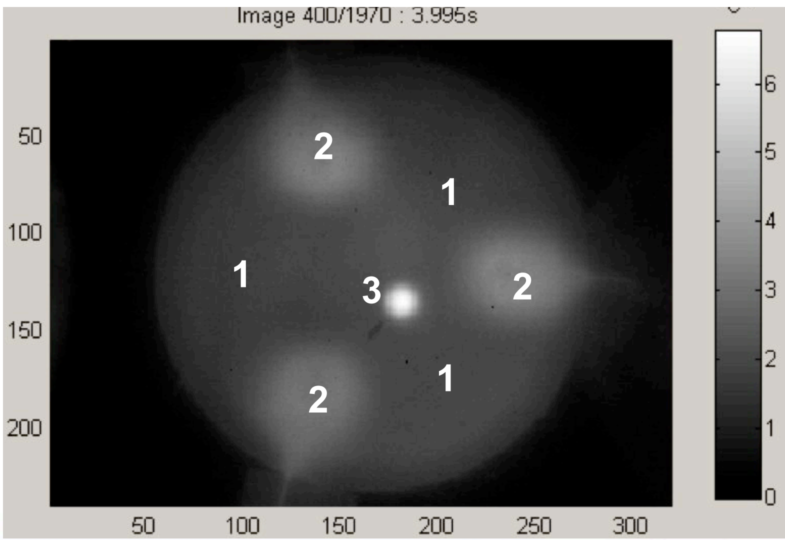
# Thermogram rectification

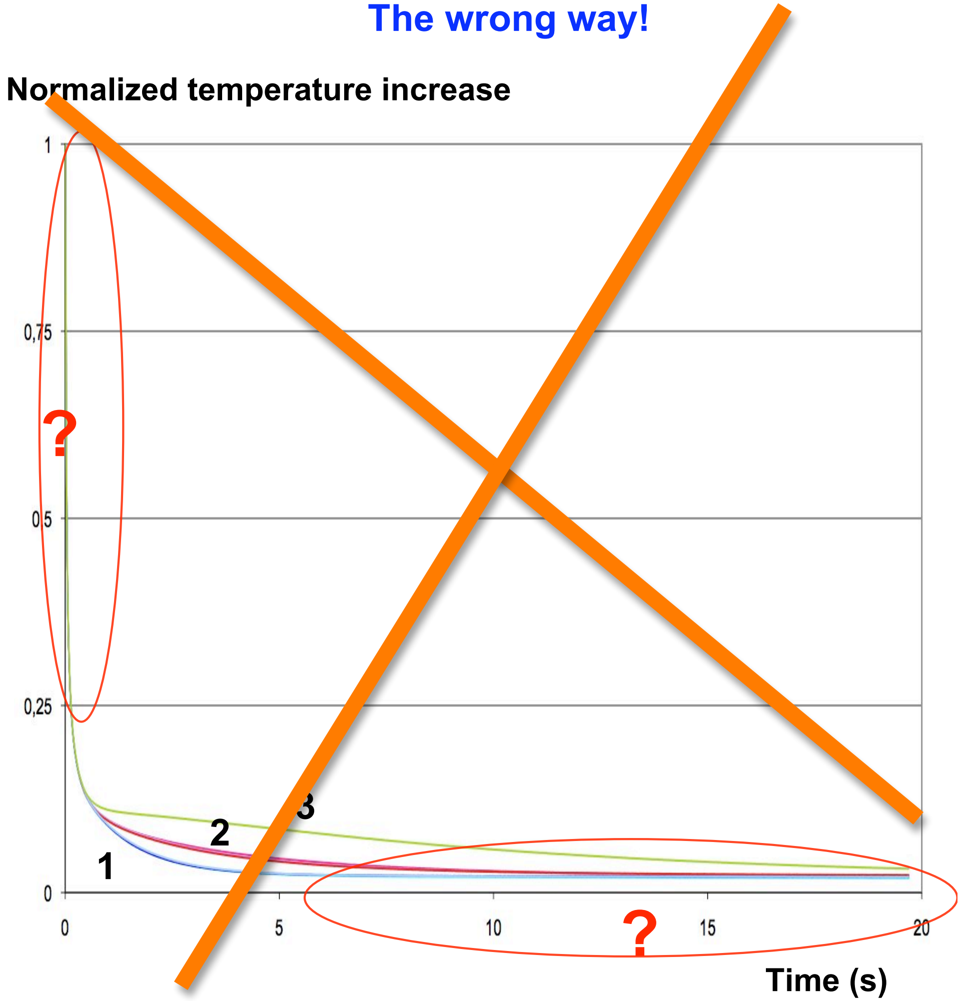
**The smart patch with an artificial defect**




**Thermographic image of the patch during cooling**




**The usual cartesian coordinates**
**The wrong way!**



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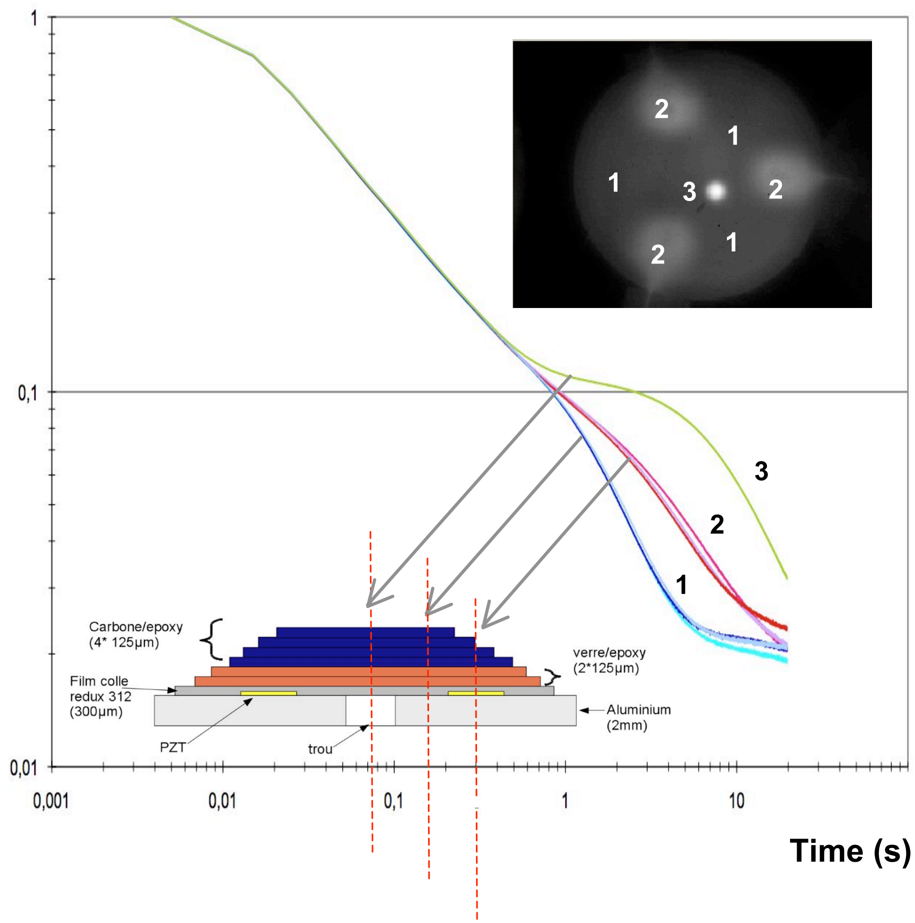
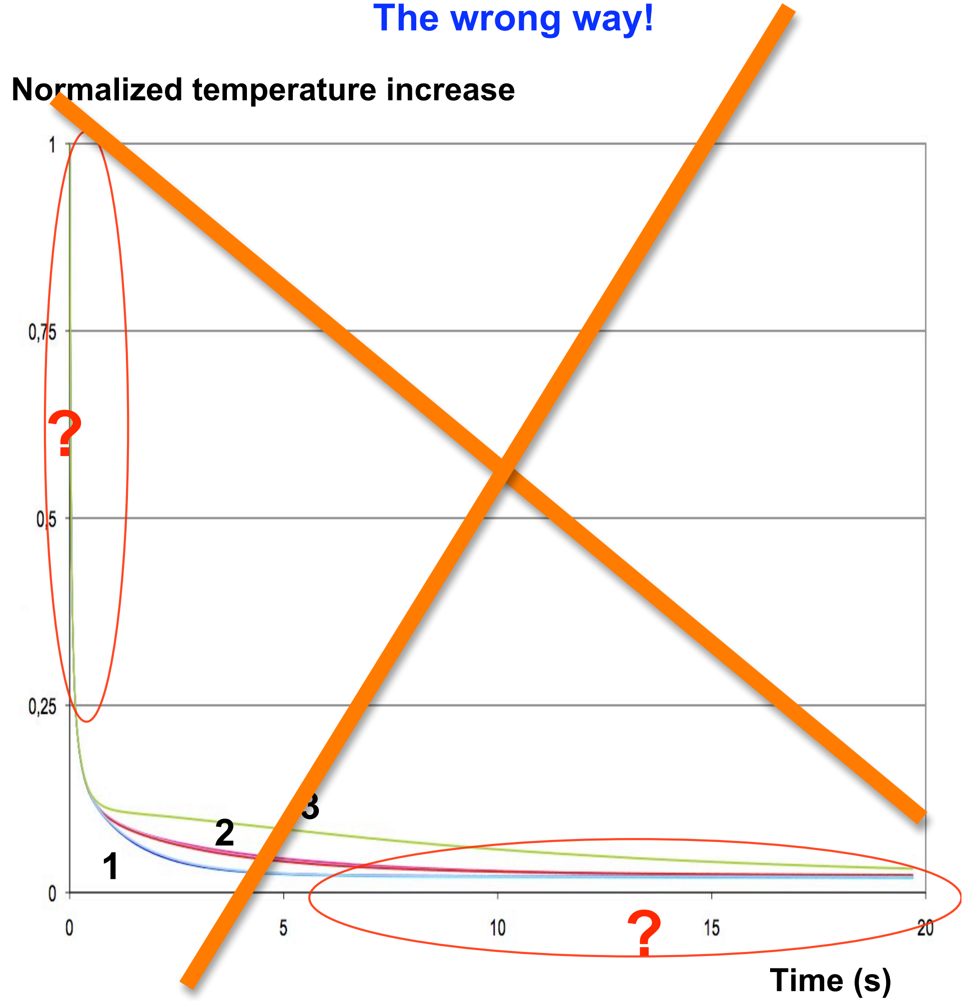
# Thermogram rectification by log-log plot

## The log-log plot

**Normalized temperature increase**




## The usual cartesian coordinates
## The wrong way!





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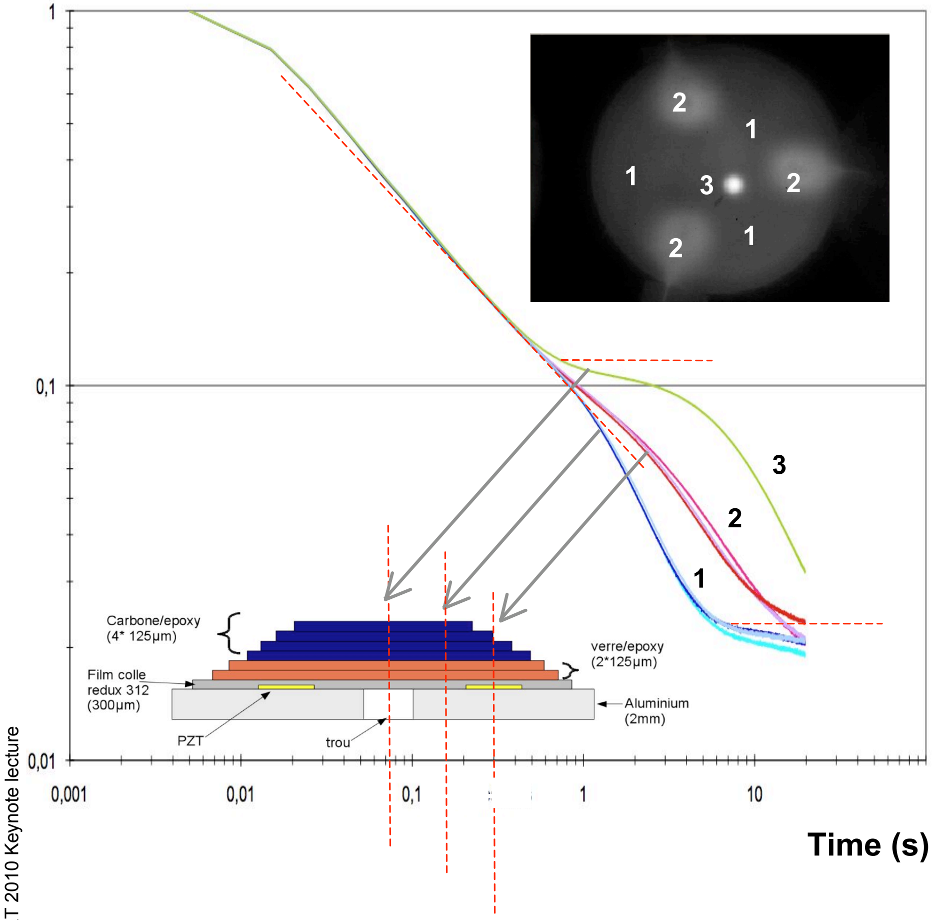
# Thermogram rectification by log-log plot

## The log-log plot

Normalized temperature increase




The **log-log plot is a means of rectification**…. "Rectification is important, since a curve having even a portion of its range plotting in a linear manner is far more revealing than one that curves over its entirety…. It divides that data into zones or regions anticipated by theoretical expectations, and provides confirmation by **slope measurements** that theory and experiments are in fair agreement".

*Theory of engineering experimentation*, by Hilbert Schenck, 3rd edition, Hemisphere Publishing Co., 1979

In pulse heat transfer **log-log plot is a tool for multi-scale analysis** of the phenomena occuring. This is based on the notion of heat diffusion length $d \sim \sqrt{\alpha}\,\sqrt{t}$, relating the time and the space

**Polynomial regression in log-log leads to a better fit than in cartesian coordinates.** Practically with polynomials of degree <10, fitting is satisfactory on the full domain of the thermogram, leading to $R^2$ coefficients very near 1 (i.e. 0.9999).

➡ The TSR technique is based on that.

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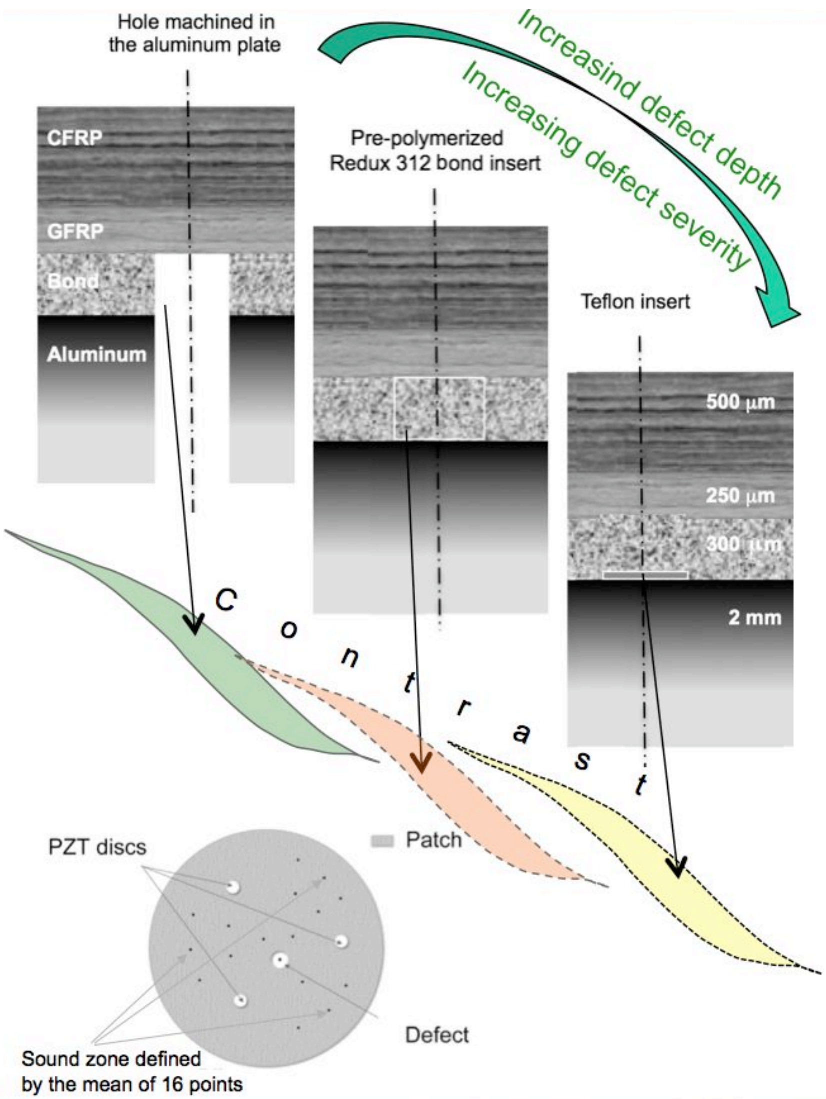
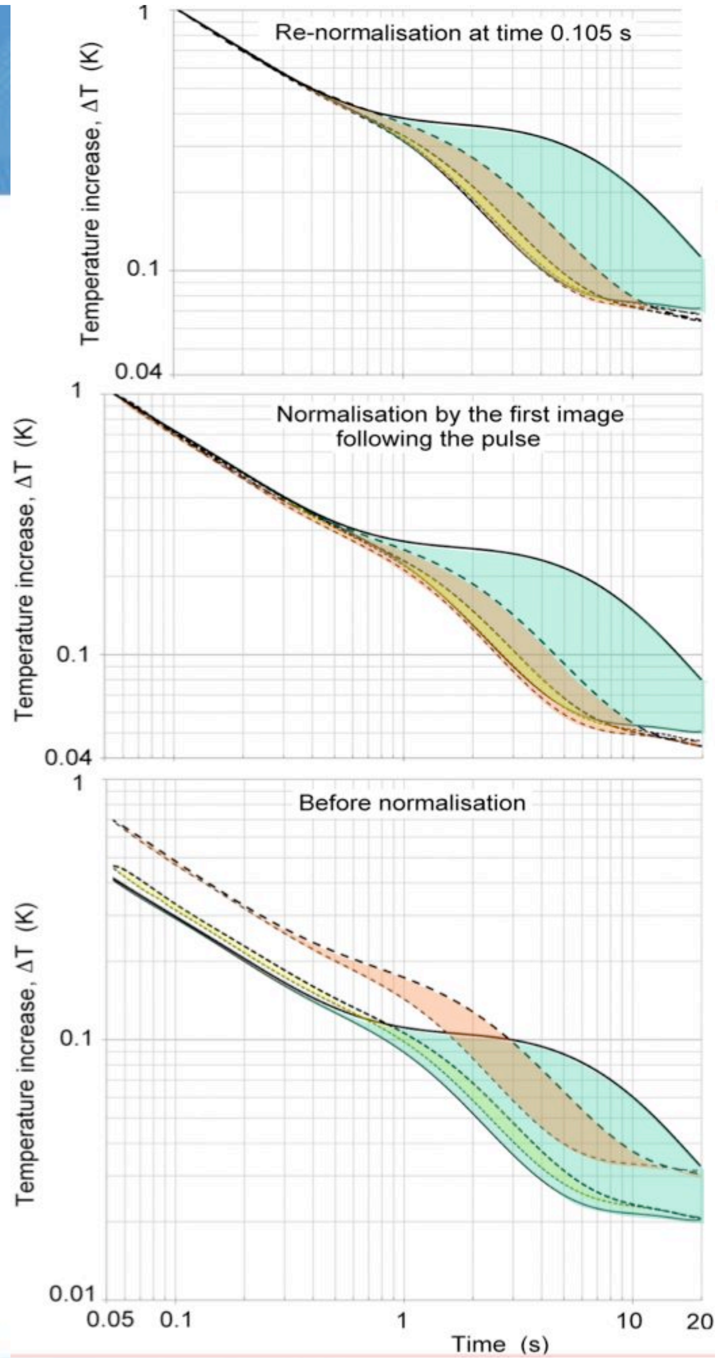
# Non-uniform heating suppression by normalization



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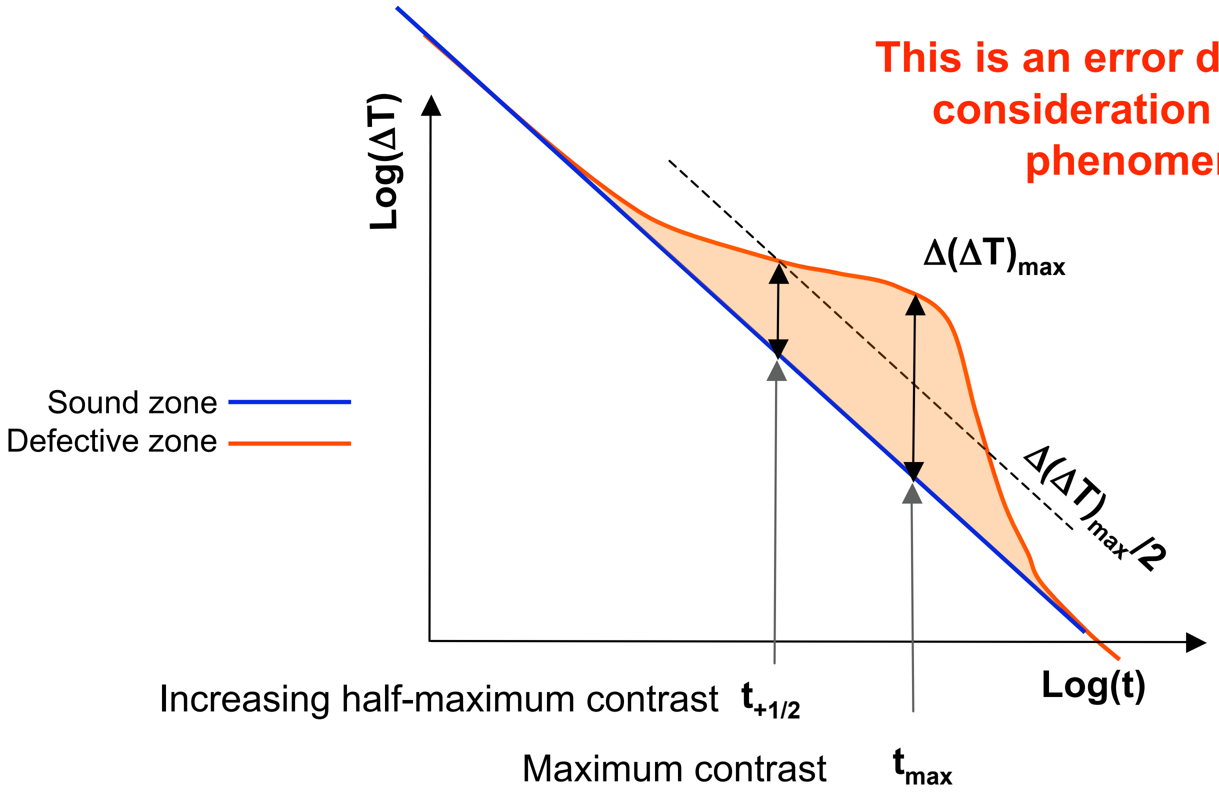
# Depth determination of a defect from the time analysis of the thermal contrast

Based on the intuitive reasoning consisting in optimizing the signal-to-noise ratio of the contrast, since the 1980', to identifiy the depth of defects, most of the experimenters use the occurence time of the maximum contrast, or sometimes on the occurrence time of half this maximum.




**This is an error due to a lack of consideration of the thermal phenomena occuring in a real sample.**

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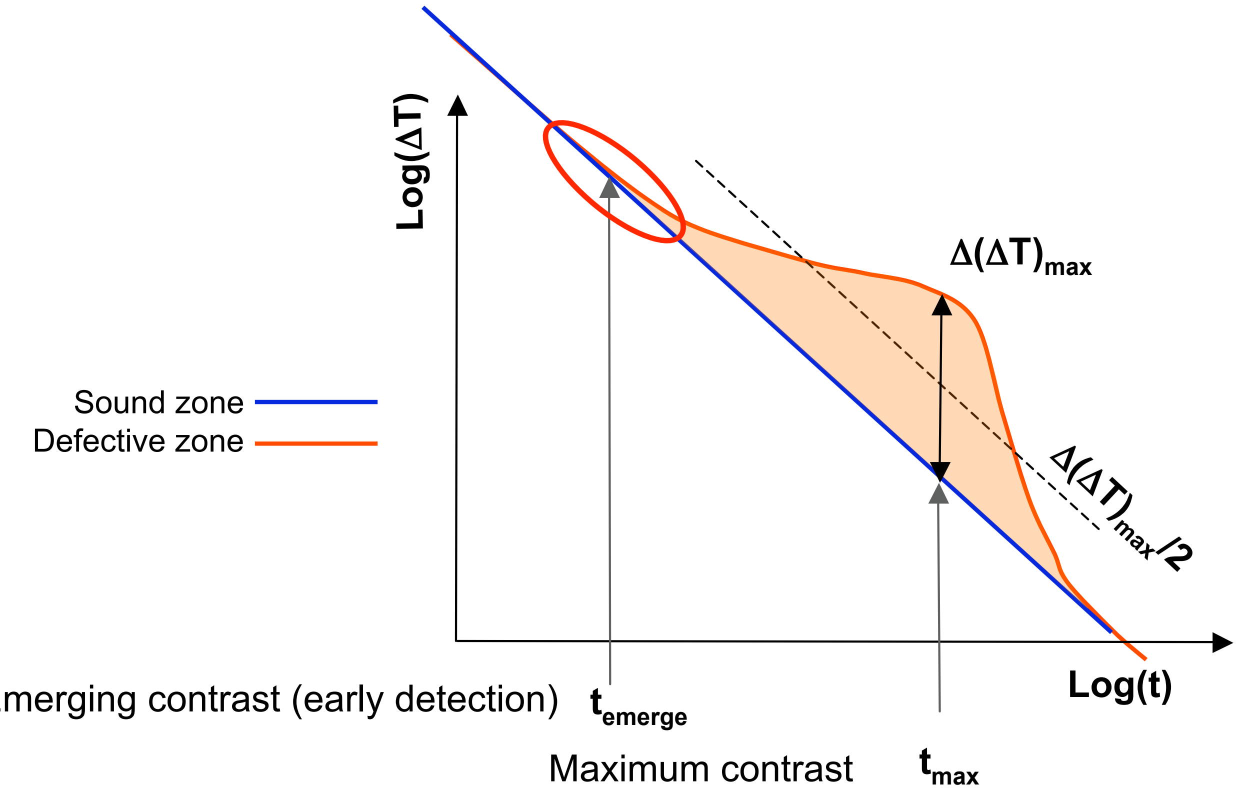
# Depth determination of a defect from the time analysis of the emerging thermal contrast

In 1994, Krapez and colleagues * proposed the use of an early detection and characterization of the defect to avoid 3-D internal conduction effect producing blurring of the images, and sensitivity of the identification to multiple parameters.




* J.C. Krapez, D. Balageas, A. Déom, F. Lepoutre, *Early detection by stimulated infrared thermography. Comparison with ultrasonics and holo/shearography,* in *Advances in signal processing fo non destructive evaluation of materials*, Kluwer Academic Publisher, The Netherlands, 1994, pp 303-321.

J.C. Krapez et D. Balageas, *Early detection of thermal contrast in pulsed stimulated infrared thermography,* QIRT'94, ed. D. Balageas, G. Busse, G. Carlomagno, Ed. Europ. Thermique et Industrie, Paris, 1995, pp. 260-266.

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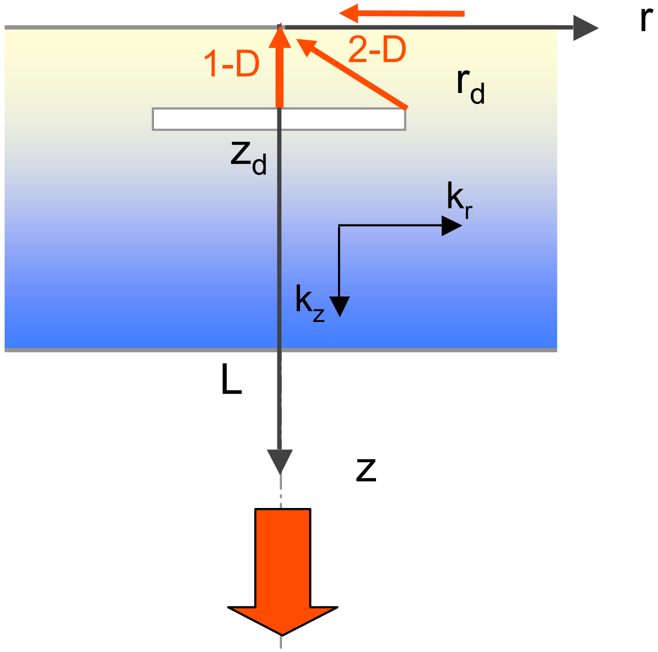
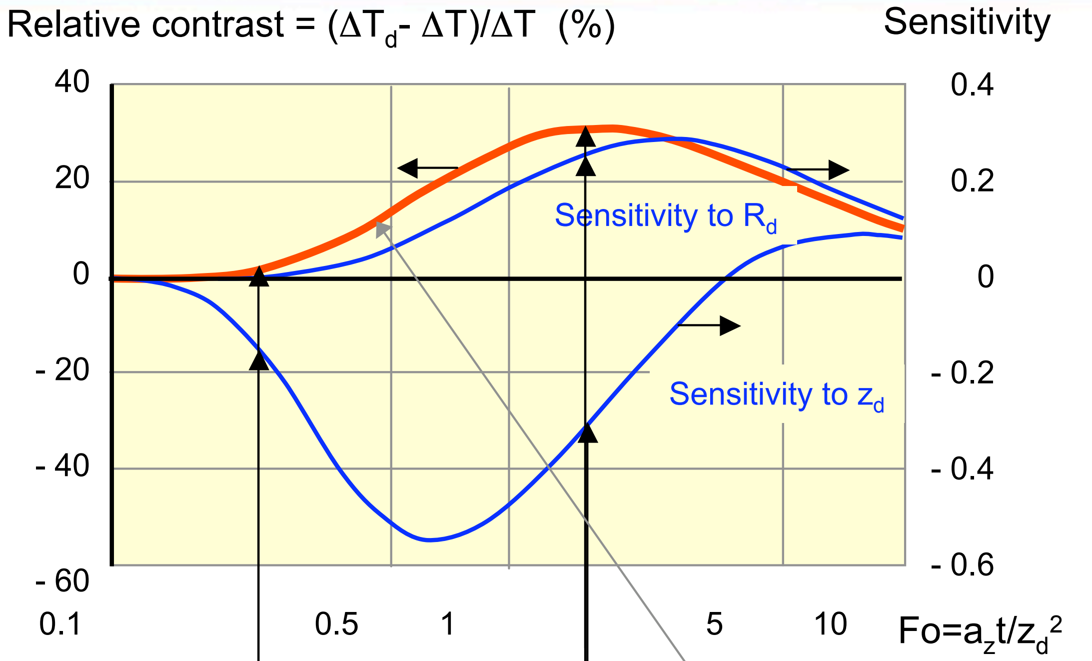
# The double advantage of the early detection




The earlier the identification, the less sensitive to 3-D effects the result

Identification from the emerging contrast: higly sensitive to $z_d$, insensitive to $R_d$

*Relative contrast for*
*$R_d = z_d / k_z$ ($R^* = 1$)*
*$z_d / L = 0.91$ (1-D model)*

Identification from the maximum contrast: higly sensitive to both $z_d$ and $R_d$

The earlier the identification of $z_d$, the less the result is sensitive to the thermal resistance of the defect

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# Principle of the identification of defect depth and thermal resistance using the emerging thermal contrast

A time $t_{emerge}$ is chosen at which the absolute contrast emerges from noise ($\pm \delta T$), as earlier as possible.

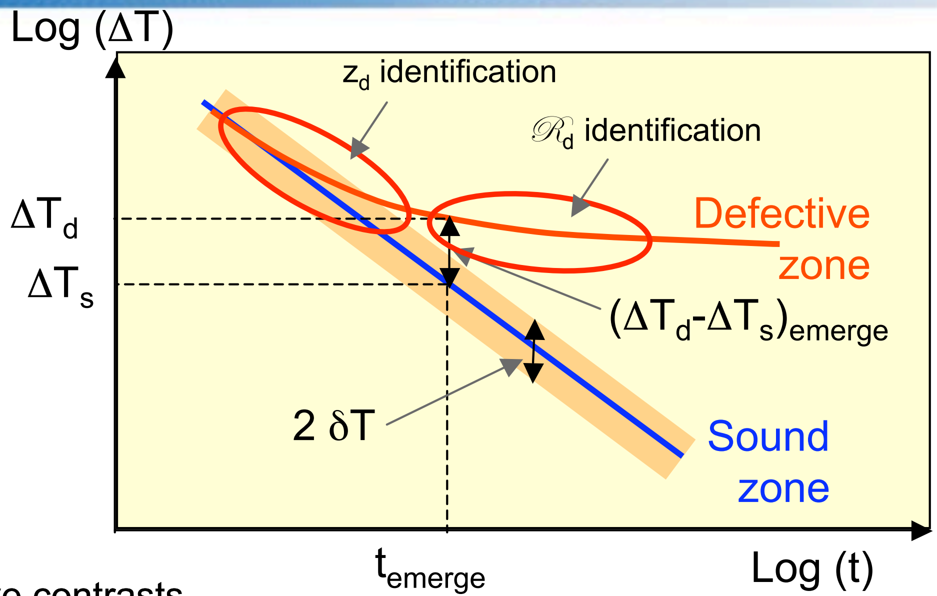
The emergence criterium is : $(\Delta T_d - \Delta T_s)_{emerge} > \delta T$

The defect depth is given by the simple formula*:

$$z_d = \sqrt{\kappa_{z_d} . t_{emerge} . \mathrm{Ln}(2/Cr_{emerge})}$$

$Cr_{emerge}$ being the relative contrast at time $t_{emerge}$:

$Cr_{emerge} = (\Delta T_d - \Delta T_s)_{emerge} / \Delta T_{emerge}$




The depth can be calculated for several different relative contrasts, depending on the experimental noise and possiby extrapolated to a quasi null contrast.

Then, $z_d$ being identified, the thermal resistance of the defect, $\mathcal{R}_d$, can be evaluated through an implicite inversion process using the equation (*) simplified by replacing the erfc function by its development:

$Cr_{emerge} = 2 \exp(-1/Fo_d) [1-2 Fo_d/(R_d+2Fo_d)]$ ⇨ $\mathcal{R}_d$

* This expression is the asymptotic behaviour for an infinite thermal resistance of the approximate expression of the relative contrast in the emergence zone:

$Cr_{emerge} = [(\Delta T_d - \Delta T_s)/\Delta T_s)]_{emerge} = 2 \exp(-1/Fo_d) - 4\sqrt{\pi}(\sqrt{Fo_d}/R_d) . \exp[4(1+Fo_d/R_d)/R_d] . \mathrm{erfc}(1/\sqrt{Fo_d} + 2\sqrt{Fo_d}/R_d)$ (*)

with: $\mathbf{Fo_d = \kappa_{z_d} t / z_d^2}$ and $\mathbf{R_d = \mathcal{R}_d k_{z_d} / z_d}$

J.C. Krapez et D. Balageas, *Early detection of thermal contrast in pulsed stimulated infrared thermography,* Proc. QIRT'94, Paris, 1995, pp. 260-266.

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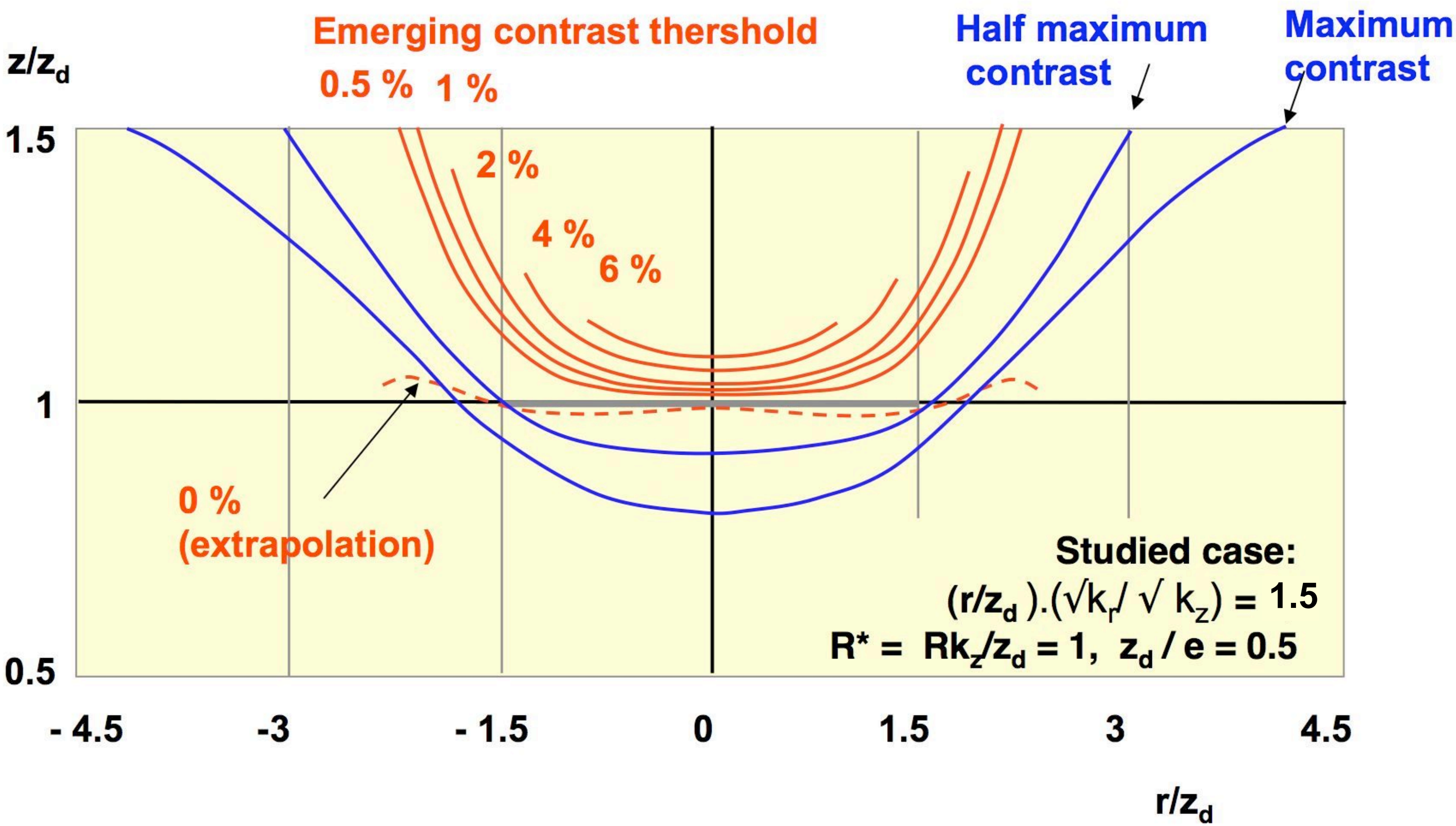
# Validation of the early detection method by numerical simulation ($z_d/r_d$ = 0.66)



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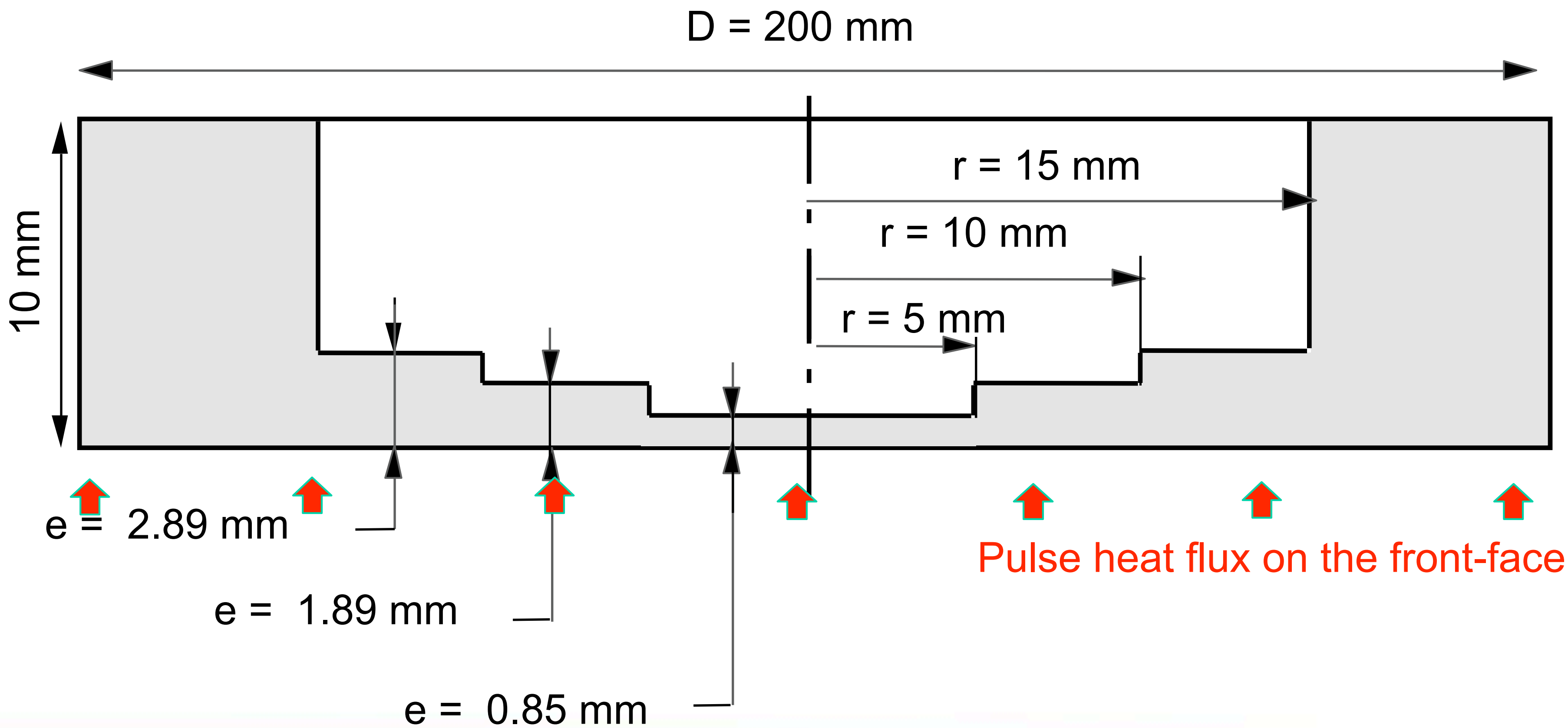
# Experimental validation of the early detection method

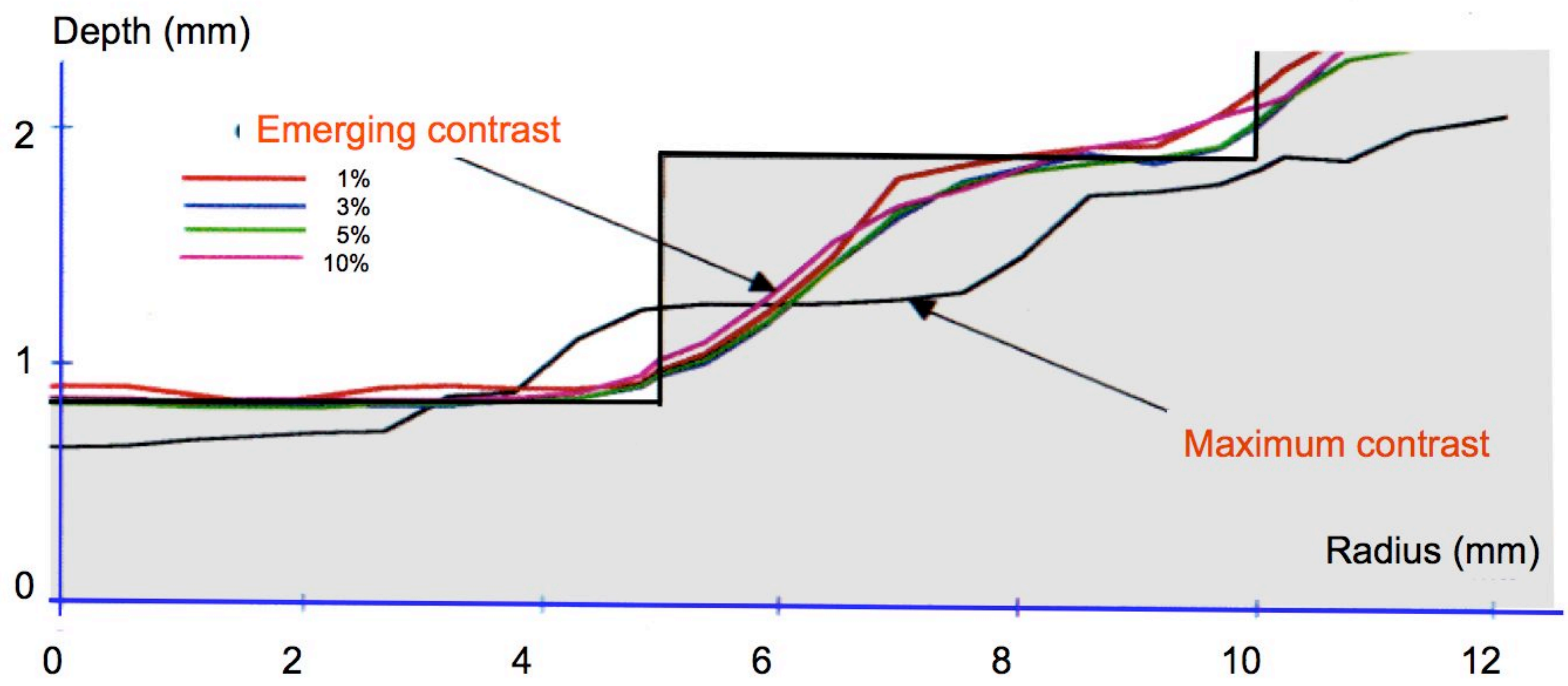
**Black Plexiglas® sample containing an axisymmetric rear-face open cavity**



http://dx.doi.org/10.21611/qirt.2010.161

# Experimental validation of the early detection method

Black Plexiglas® sample containing a 3-D axisymmetric void
Depth profile deduced from a pulse heating




The early detection is clearly better than the one using the maximum contrast
The optimum contrast threshold seems to be between 3 and 5 %

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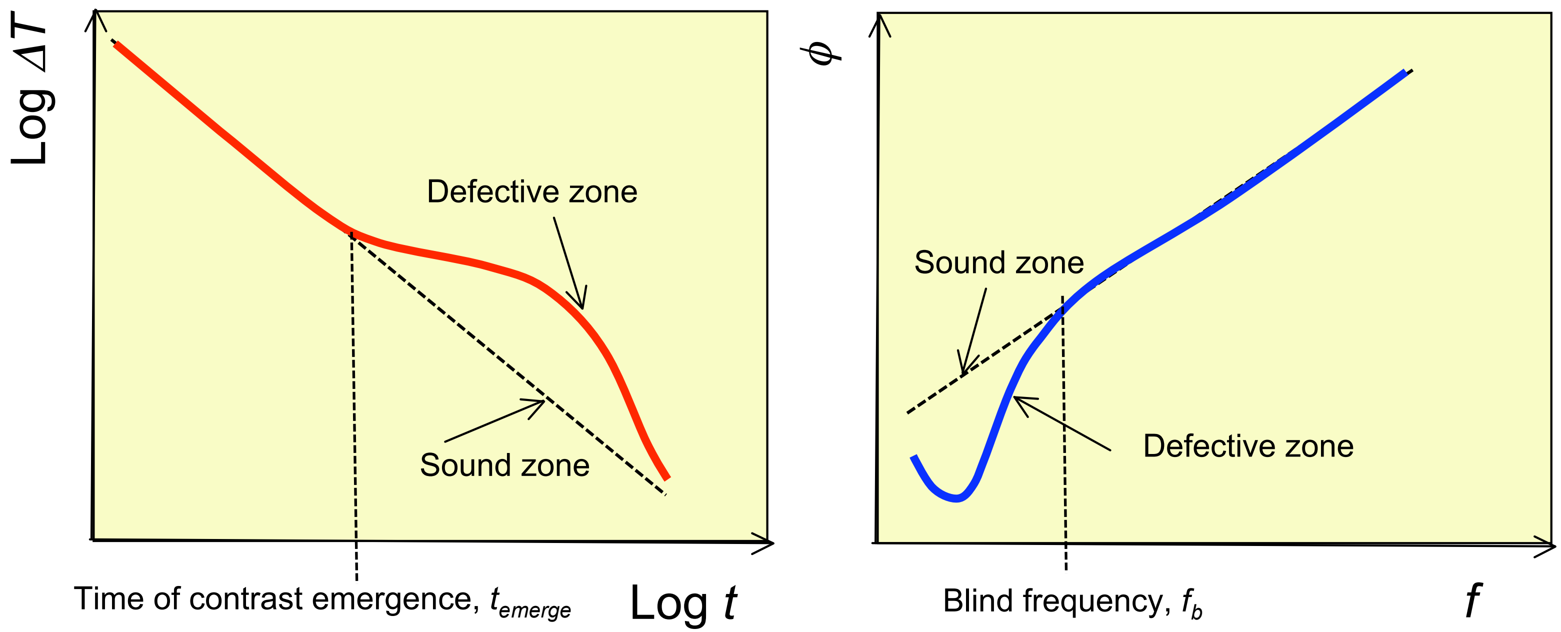
# Emerging contrast and blind frequency

The detection of the emerging contrast in Pulsed Thermography and of the blind frequency in Pulsed Phase Thermography are equivalent approaches.




Nevertheless, more works is needed for making the depth identification from the blind frequency rigourously quantitative. A comparative study starting from same thermograms would be highly interesting to judge of the respective merits of the two approaches.

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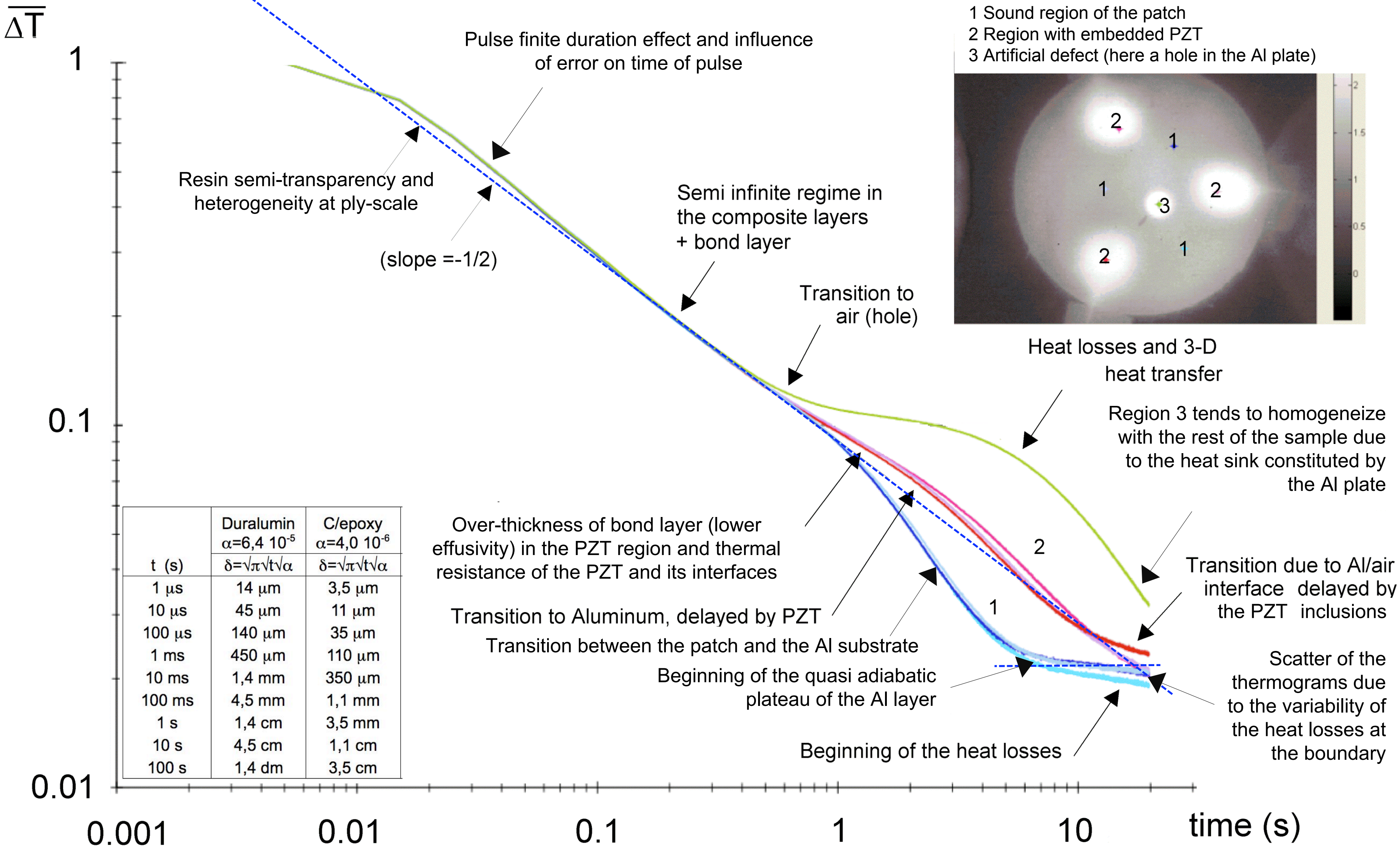
# PT is the best thermographic tool for multi scale analysis of material and structure




| t (s) | Duralumin $\alpha$=6,4 $10^{-5}$ $\delta=\sqrt{\pi}\sqrt{t}\sqrt{\alpha}$ | C/epoxy $\alpha$=4,0 $10^{-6}$ $\delta=\sqrt{\pi}\sqrt{t}\sqrt{\alpha}$ |
|---|---|---|
| 1 µs | 14 µm | 3,5 µm |
| 10 µs | 45 µm | 11 µm |
| 100 µs | 140 µm | 35 µm |
| 1 ms | 450 µm | 110 µm |
| 10 ms | 1,4 mm | 350 µm |
| 100 ms | 4,5 mm | 1,1 mm |
| 1 s | 1,4 cm | 3,5 mm |
| 10 s | 4,5 cm | 1,1 cm |
| 100 s | 1,4 dm | 3,5 cm |

http://dx.doi.org/10.21611/qirt.2010.161

# Conclusions

- Time-resolved pulsed thermography is the best tool for quantitative multi-scale thermal analysis of materials/structures, if using:
  - Normalisation,
  - Log-Log plot for rectification,
  - Early detection/characterisation based on the emerging contrast,
  - TSR (thermographic signal reconstruction) approach for denoising and the related log derivatives for earlier information.
- In these conditions, and in the case of composite materials, thermography can compete with ultrasonics.

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  - Early detection/characterisation based on the emerging contrast,
  - TSR (thermographic signal reconstruction) approach for denoising and the related log derivatives for earlier information.
- In these conditions, and in the case of composite materials, thermography can compete with ultrasonics.
- There is a severe lack of really objective and quantitative comparisons between the existing thermographic methods applied to realistic and representative samples.

➔ Need for a general round-robin comparing PT, PPT and LT.

Future QIRT conferences are the ideal place for organizing such a round-robin on this thematic and disseminating the information.

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# Practical organisation of a round-robin on PT, PPT and LT techniques

The QIRT community is perfectly able to organize such a round-robin, by constituting a group of experts in charge of:

- Defining the type of coupons to test, the thermo-graphic techniques to involve, the criteria to use for objective comparison of the various techniques,
- Finding the best laboratories to generate well-documented experimental data,
- Finding the laboratories able to apply the various techniques for defect and/or thermal properties identification from the experimental data,
- Compiling the results and elaborating a synthesis,
- Writing a report which could be presented at the next QIRT Conference under the form of a plenary lecture.

**By the past, this type of collective work has been achieved and presented at QIRT'98 and QIRT'2000**

QIRT'2000 Proceedings, p. 224-229

**Round Robin comparison II of the capabilities of various thermographic techniques in the detection of defects in carbon fibre composites.**

by D.P. Almond*, R.J. Ball*, A. Dillenz**, G. Busse**
J.-C. Krapez***, F. Galmiche**** and X. Maldague****

*Department of Engineering and Applied Science, University of Bath, Bath, BA2 7AY, UK.
**IKP, Universität Stuttgart, Pfaffenwaldring 32, D-70569 Stuttgart, Germany.
***Structure and Damage Mechanics Department, ONERA, BP 72, 92322 Châtillon cedex, France.
****Université Laval, Cité Universitaire, Quebec, Canada, GIK 7P4.

**Abstract:**

Four samples of carbon fibre reinforced composite which contained impact damage sites, verified by ultrasonic C-scans, have been studied independently by the groups participating in this second QIRT Round Robin exercise. The samples were selected from a much larger collection because long pulse heating transient thermography (Bath) had failed to detect the presence of the defects at the front (impact) faces. The other techniques employed were: optical lock-in thermography and ultrasound lock-in thermography (Stuttgart); pulsed thermography using the emerging contrast technique (ONERA) and pulsed phase thermography (Laval). Only ultrasound lock-in thermography was successful in detecting the defects at the front faces.

**1. Introduction**

This second QIRT Round Robin exercise, devoted to investigating the relative merits of different thermographic techniques in detecting and characterising impact damage in carbon fibre composites, arose from a presentation at QIRT 98 on the detection of impact damage in thick carbon fibre composites [1]. At this presentation it was reported that a total of 88 samples, with thicknesses ranging from 3.44mm to 16mm, had been examined using the long pulse heating transient thermography technique and that impact damage in 19 samples had not been detected at the impact face. As in practice it is only the front face (impact face) that is accessible to an inspector, of an aircraft structure for example, these failures cast doubt about the reliability of thermography in this important application. It was decided to circulate a number of these 19 samples amongst the participants of this round robin exercise as a challenging test of their particular thermographic techniques for defect detection.

impact damage are presented.

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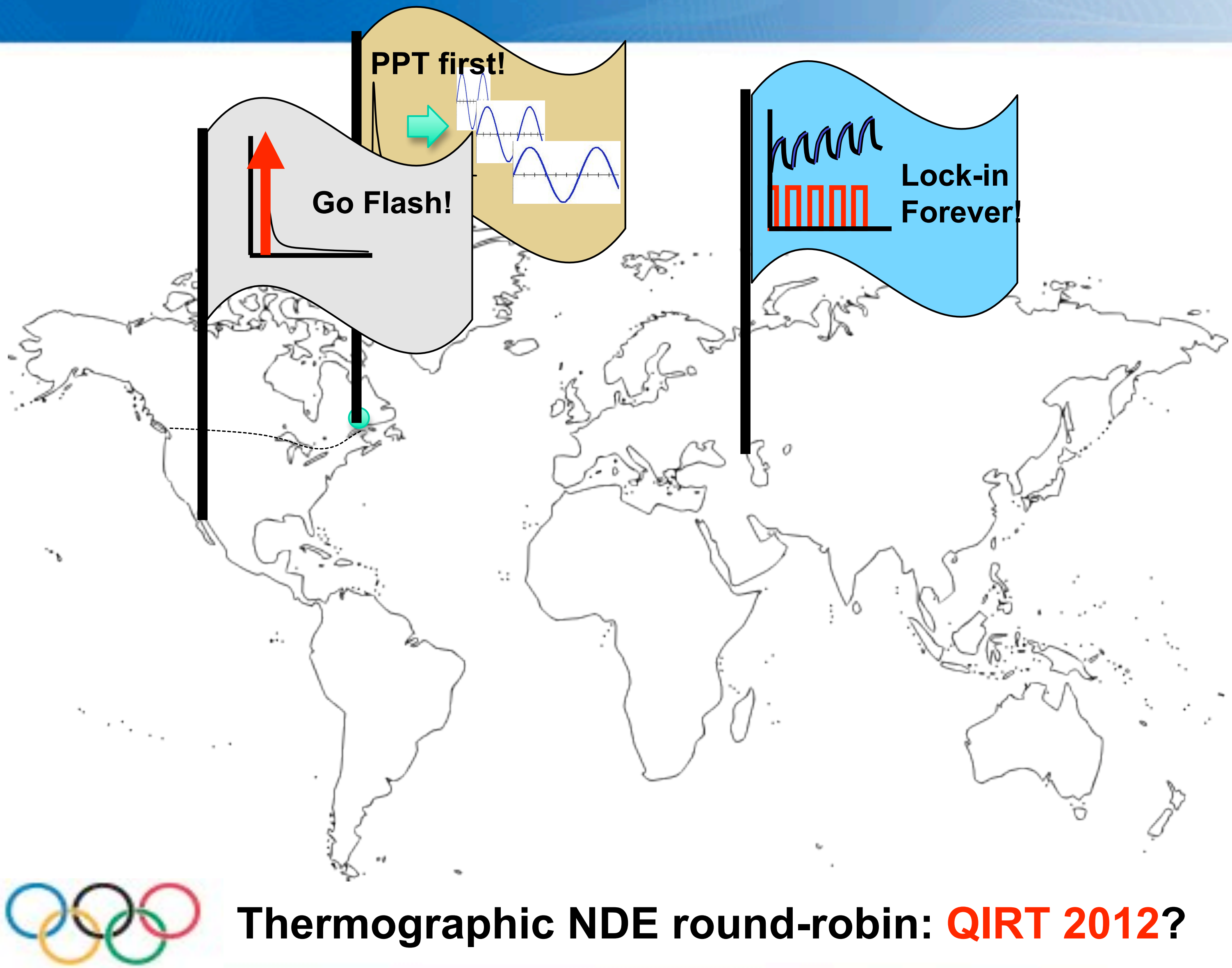
# Lock-in vs. Pulse (or Phase vs Amplitude): Need for round-robins




**Thermographic NDE round-robin: QIRT 2012?**

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Thank you for your attention