45th annual meeting
"Hot laboratories and remote handling"
Working Group

Quantification of the surface porosity in high burn-up fuel using image analysis tools

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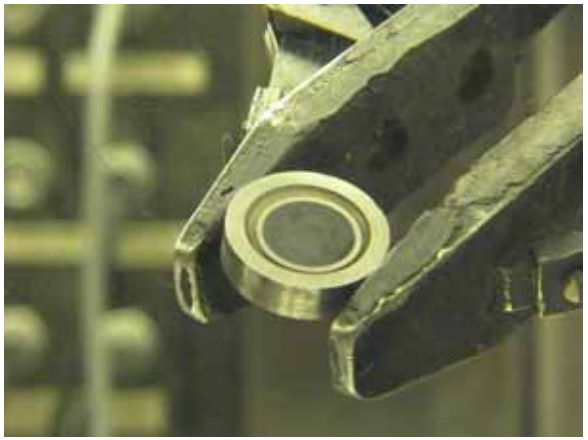
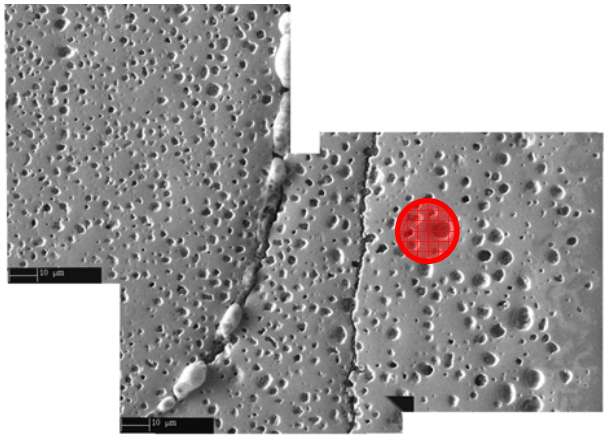
- Fuel analysed
- Analysis method
- Sensitivity evaluation / Validation procedure
- Control with high resolution SE images
- Conclusions

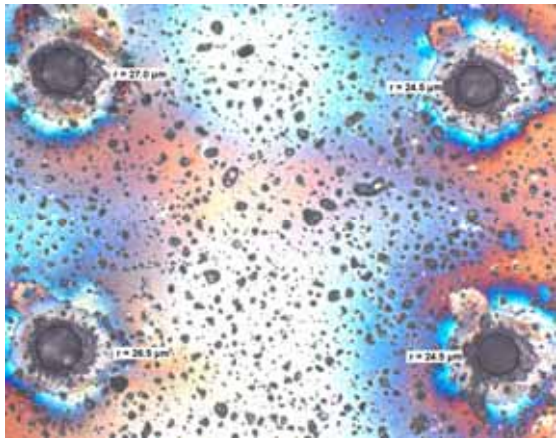
Incentives for the analysis

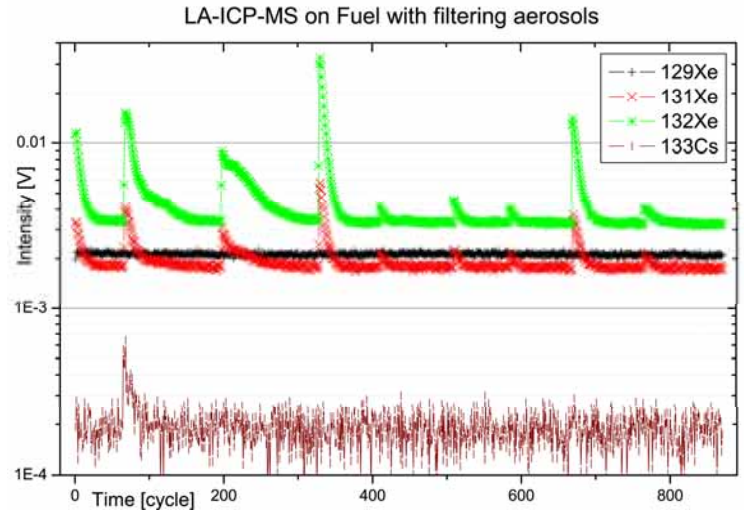
- **Study of the fuel behaviour at high burn-up**
  - Fission gas behaviour, release → modelisation
- **The development of model → Calibration / Validation**
- **Experimental Measurements**
  - EPMA for FP in the matrix and in small pores (<< 1 mm)
  - SIMS or Laser Ablation ICP-MS for larger pores
- **Quantification of the data**
  - With standards

Measurement of the FG in large pores (LA)









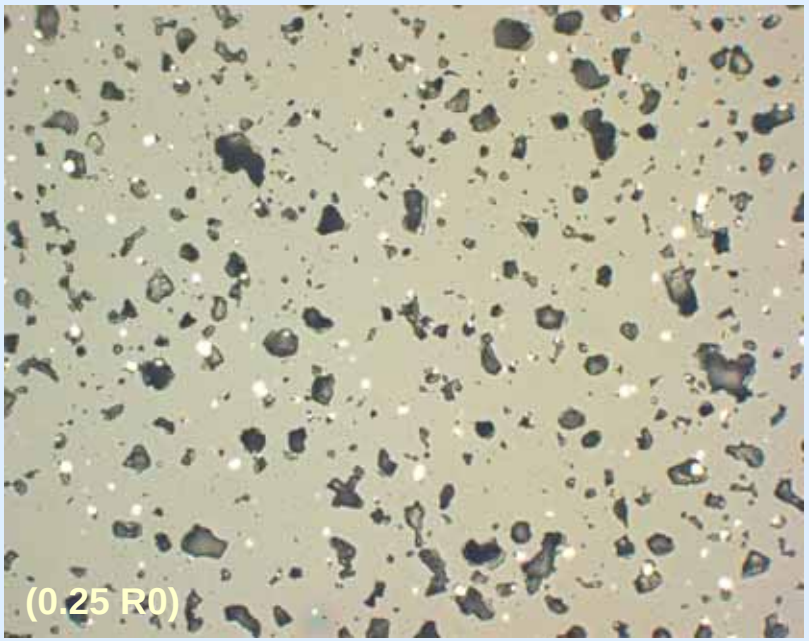
- **Measurement of peaks corresponding to the opening of one or more pore**
- **Calibration with controlled release of known gas quantity**

- **A precise quantification is only possible with a very good knowledge of the porosity size distribution and density (statistical treatment)**

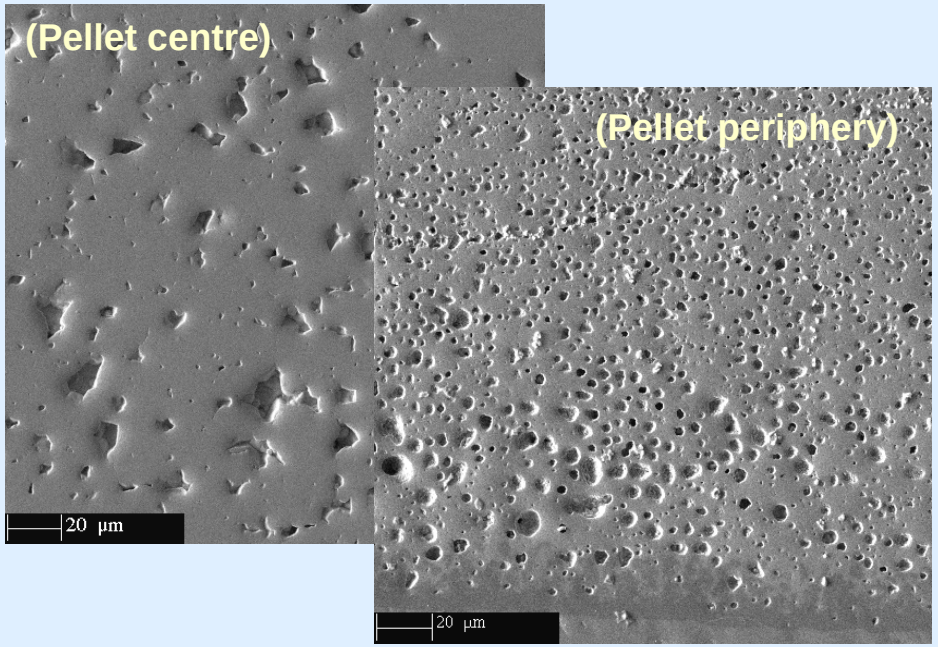
Method used for the analysis

➢ Image analysis

Optical Microscopy (OM)

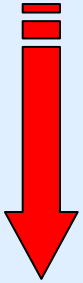


Secondary Electron (SE)



Method limitation

- **Analysis of only one cross section**



- **Hypothesis:**
  - Spherical pores or randomly distributed non-spherical pores
  - Homogeneous pore distribution in the picture

Analysis procedure

- **The same procedure has been used for the analysis of the OM and the SE images**
- **The software AnalySIS® was used for the analysis**
  - AnalySIS® allows the determination of the main characteristics of the distribution of pores or particles exhibiting a well defined colour contrast variation with their surroundings.
- **The original images weren't optimised for the study but for the PIE analyses.**

Specimen / Analysis conditions

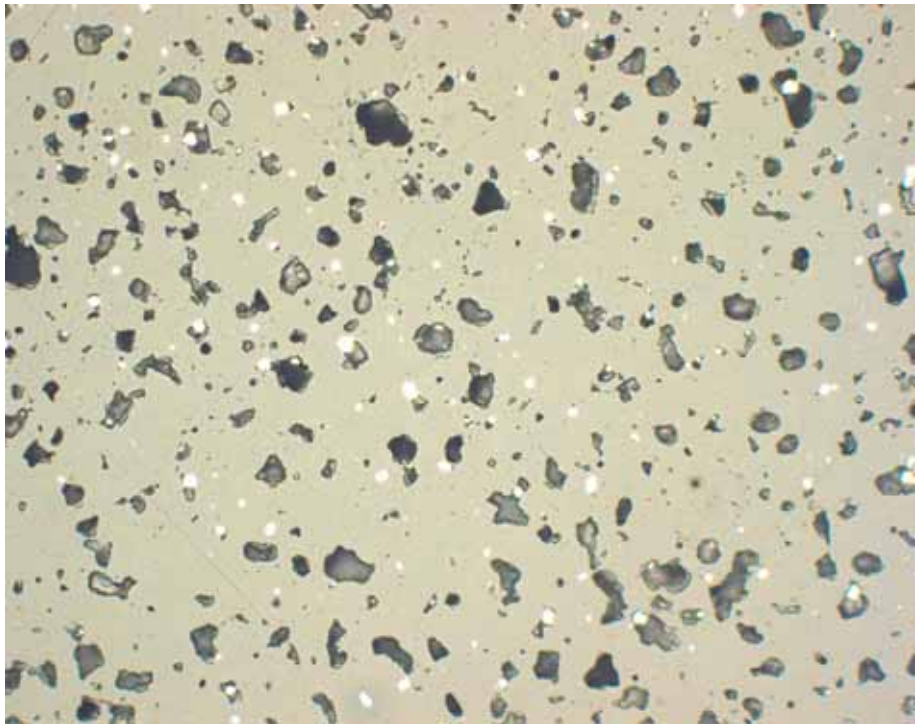
- **Fuel:**
  - PWR Fuel - UO_2 with an original Enrichment of 3.5 wt% ^{235}U
  - Rod average burn-up : 105 GWd/tHM / 10 cycles
  - Specimen burn-up : 120 GWd/tHM
- **Observation condition:**
  - Ceramography (optical magnification 500x)
  - EPMA / SE imaging (magnification of about 600x and 2500x)

Analysis procedure

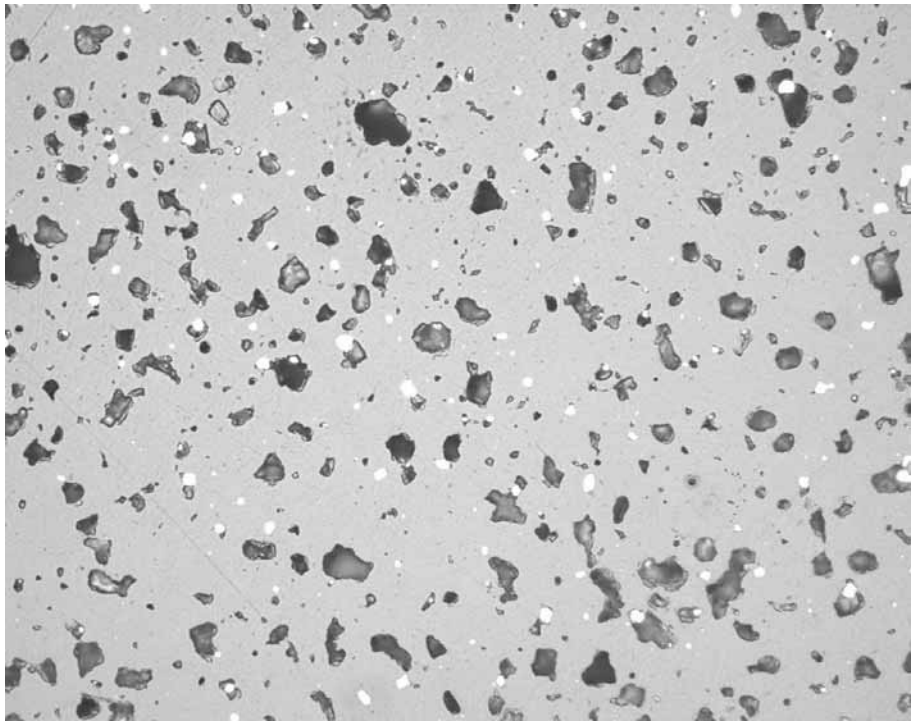
- **Contrast enhancement**
- **Binarisation of the image using operator adjusted thresholds**
- **Cleaning of the binary image with morphological filters (to remove the background noise and fill up the pores**
- **The software delivers tables containing the total fractional pore surface in % and the surface of every detected pore.**

Analysis procedure

Original image

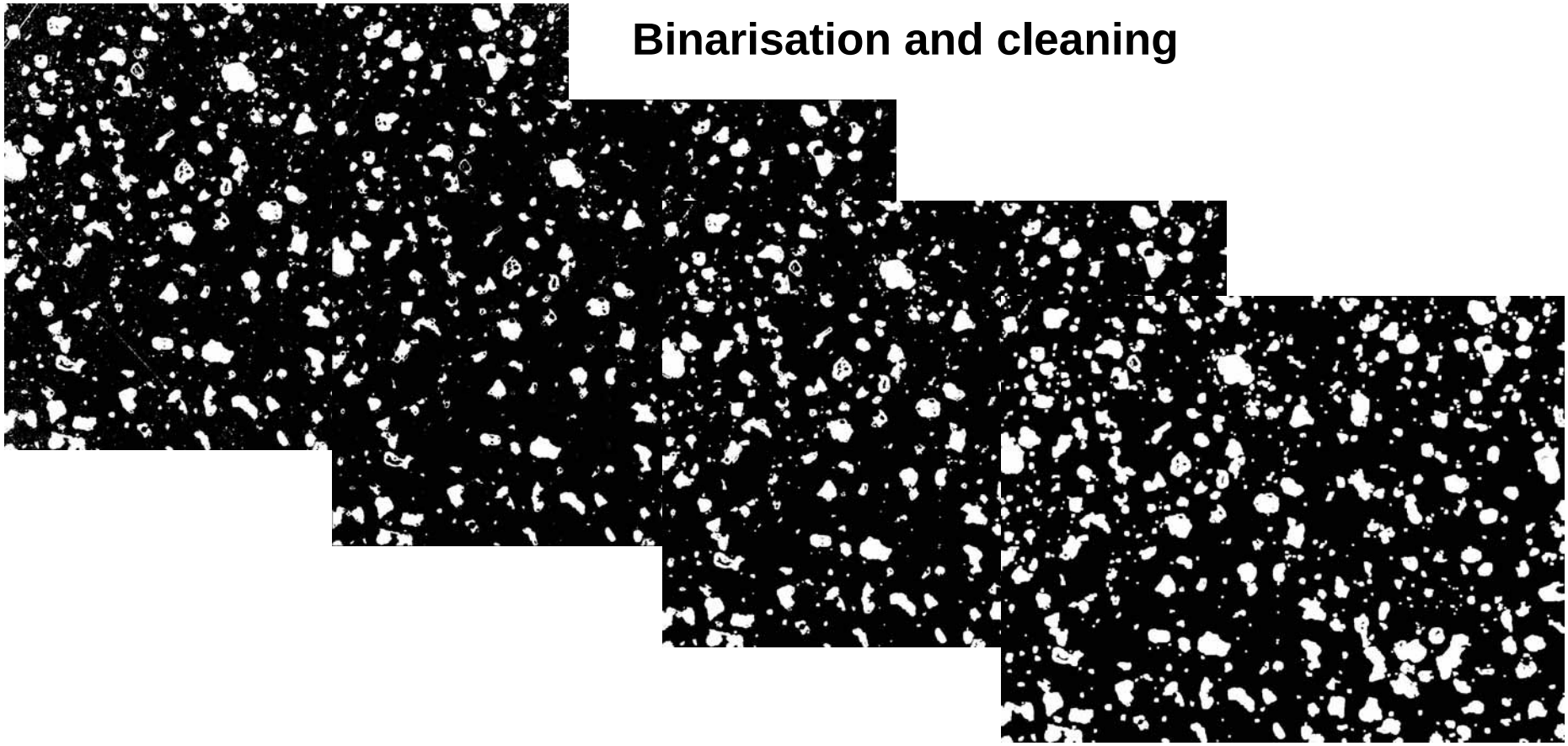


B & W image / threshold setting



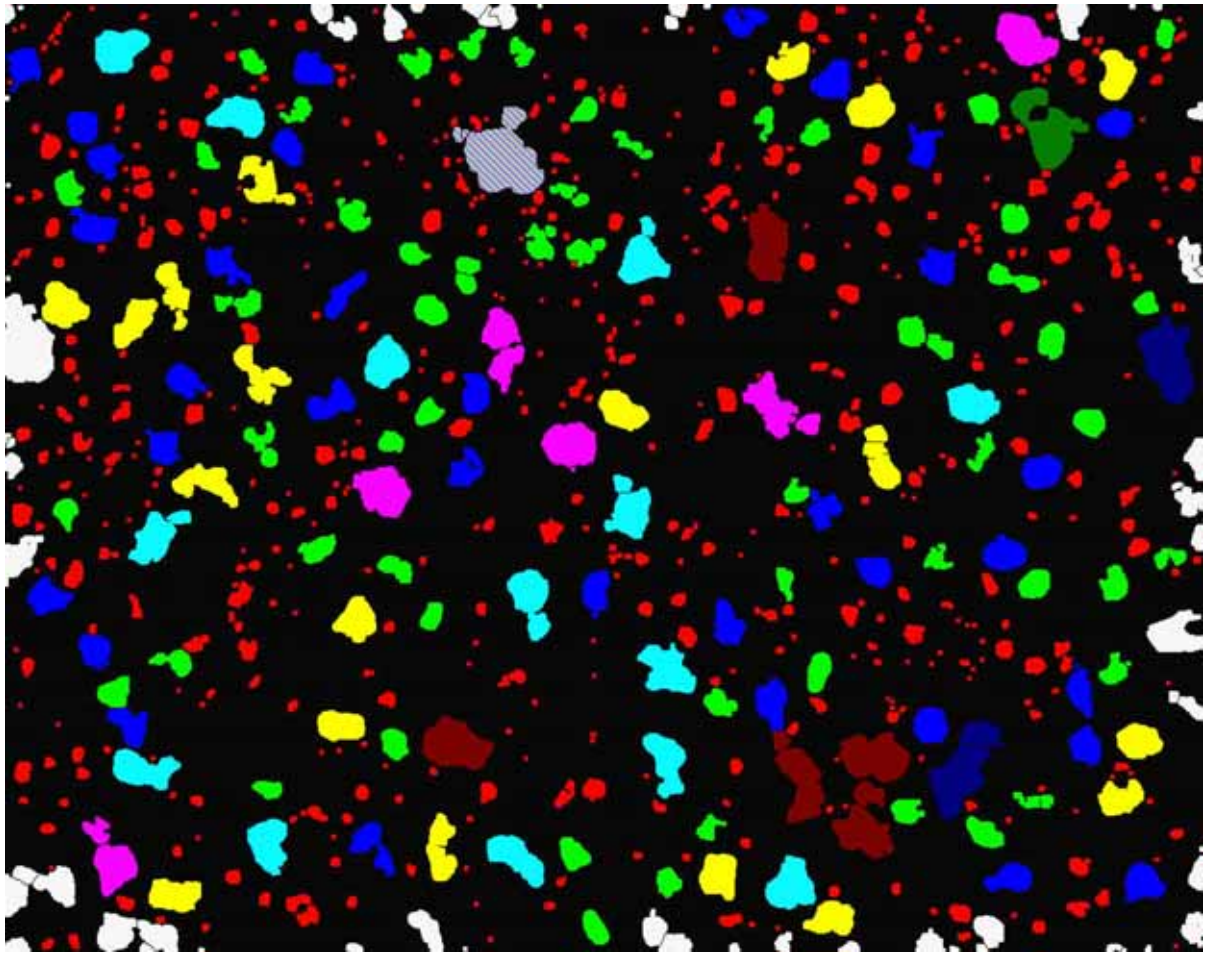
Analysis procedure

Binarisation and cleaning



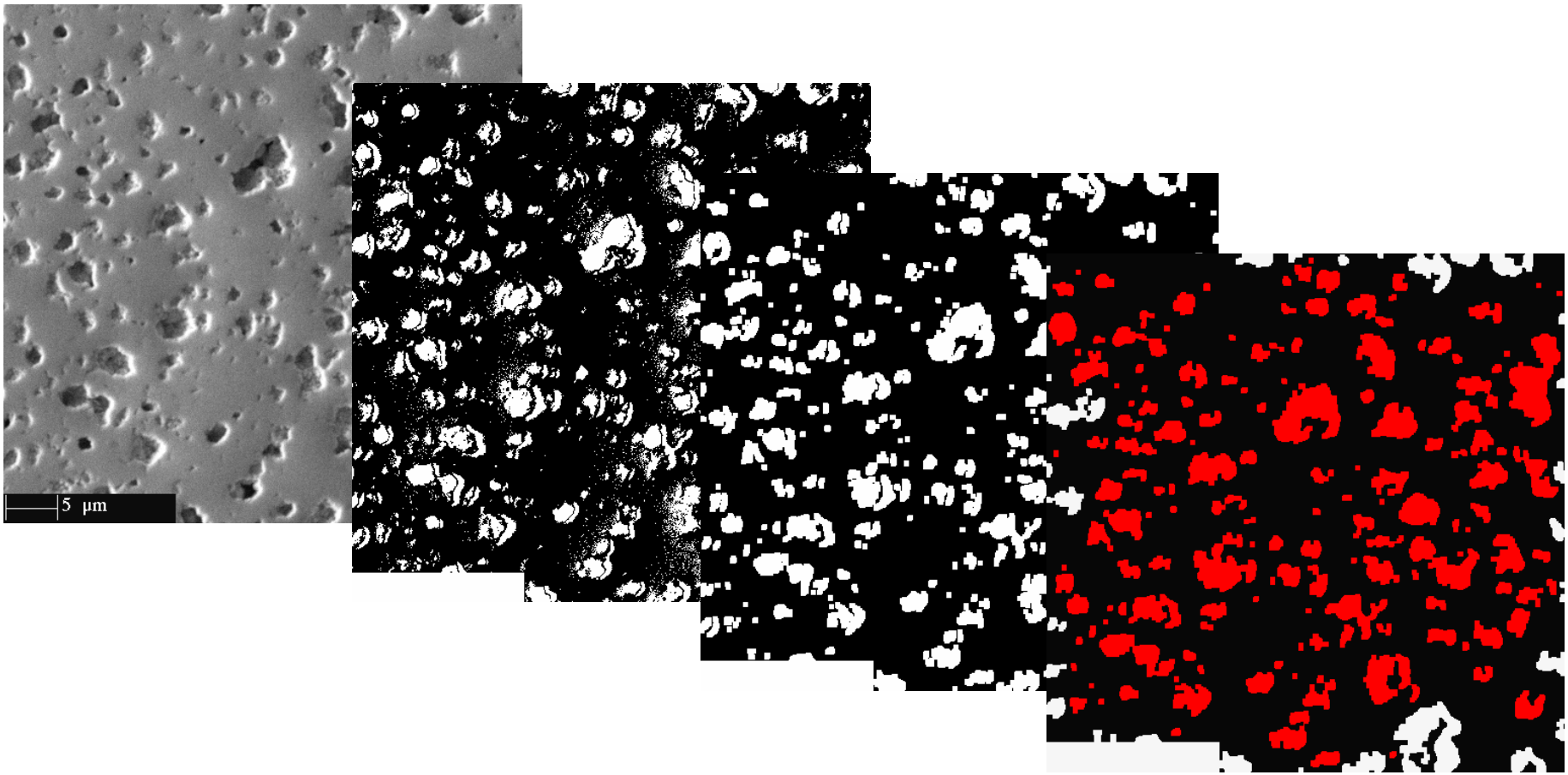
Analysis procedure

Detection and parameter calculation



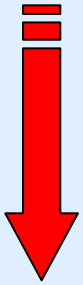
colour coded image

Analysis procedure EM images



Test / Validation of the procedure

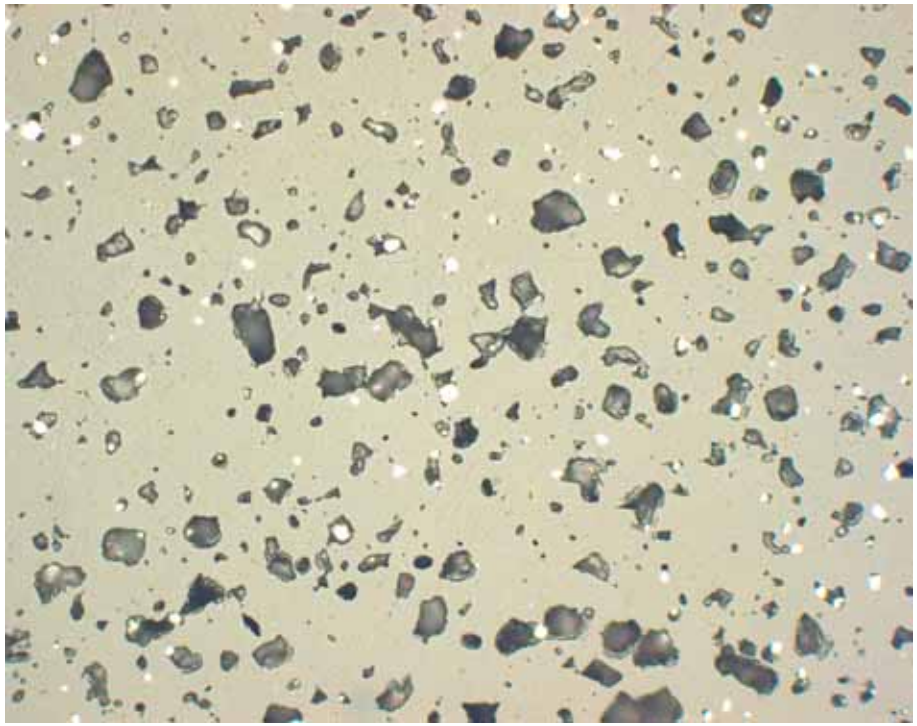
- **Threshold determination and cleaning process are operator dependant**
- **Quality of the images / Size of the pores have an impact on the procedure**



- **Sensitivity test including Reference Images**

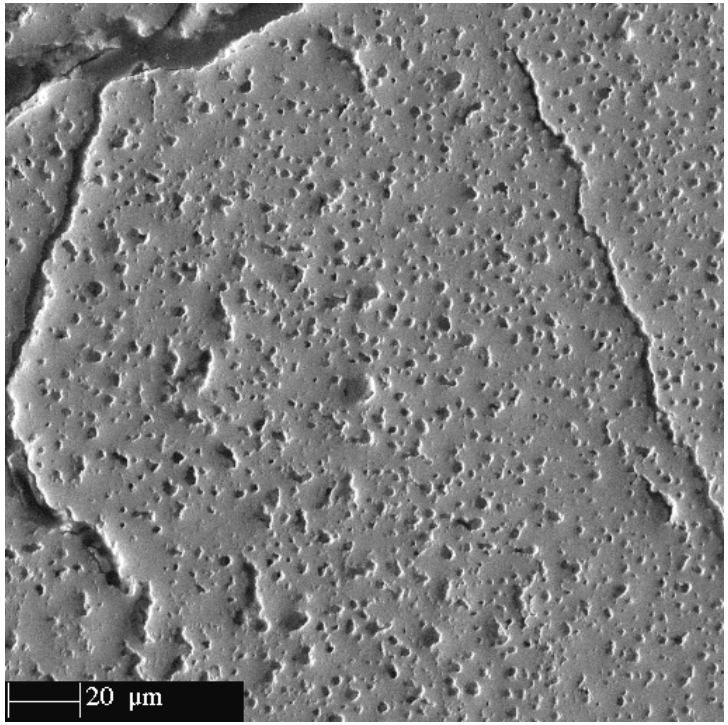
Reference images (OM)

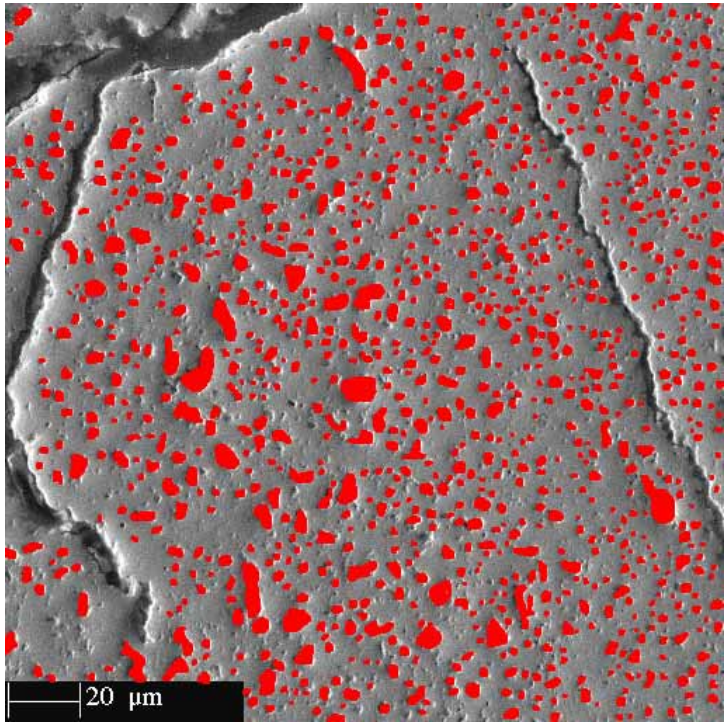
Manually binarised images



Reference images (SE)

Manually binarised images



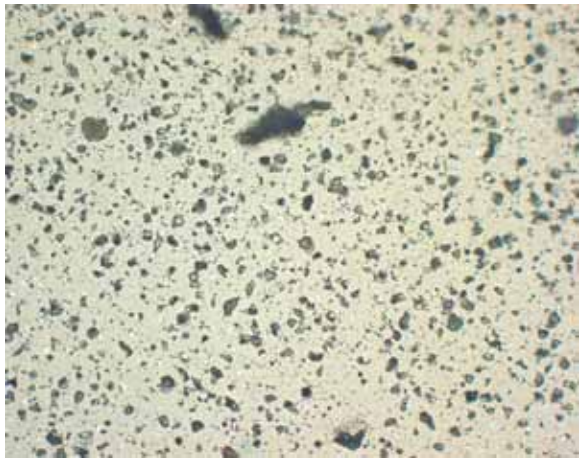


Validation of the procedure

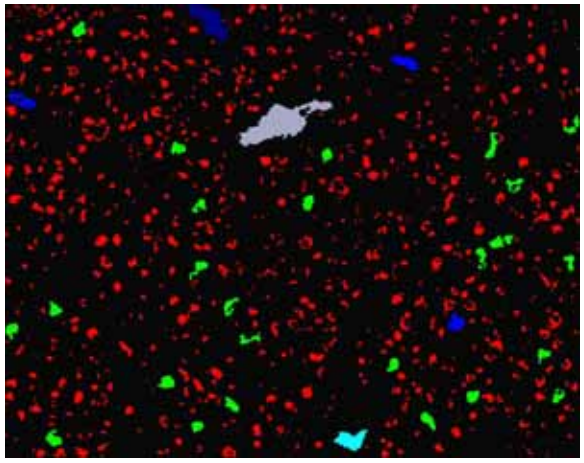
- **Sensibility test on the threshold settings and cleaning / filtering procedure**
- **Comparison with reference image analysis**

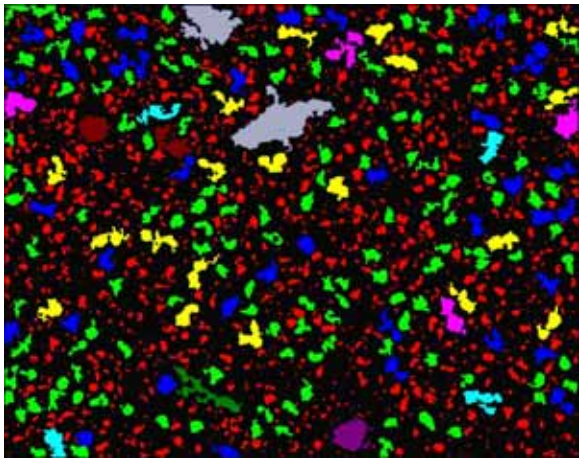
Sensitivity analysis of OM images

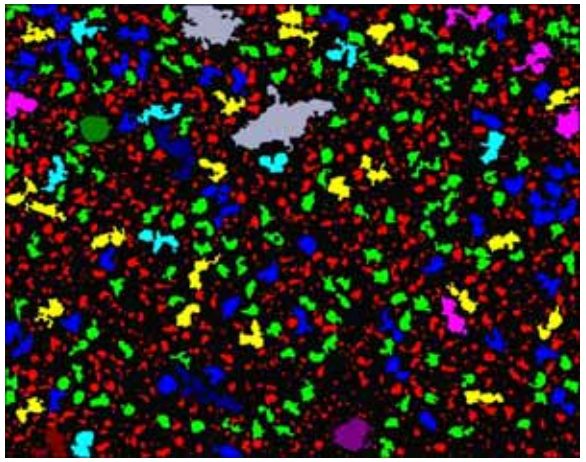
Original image



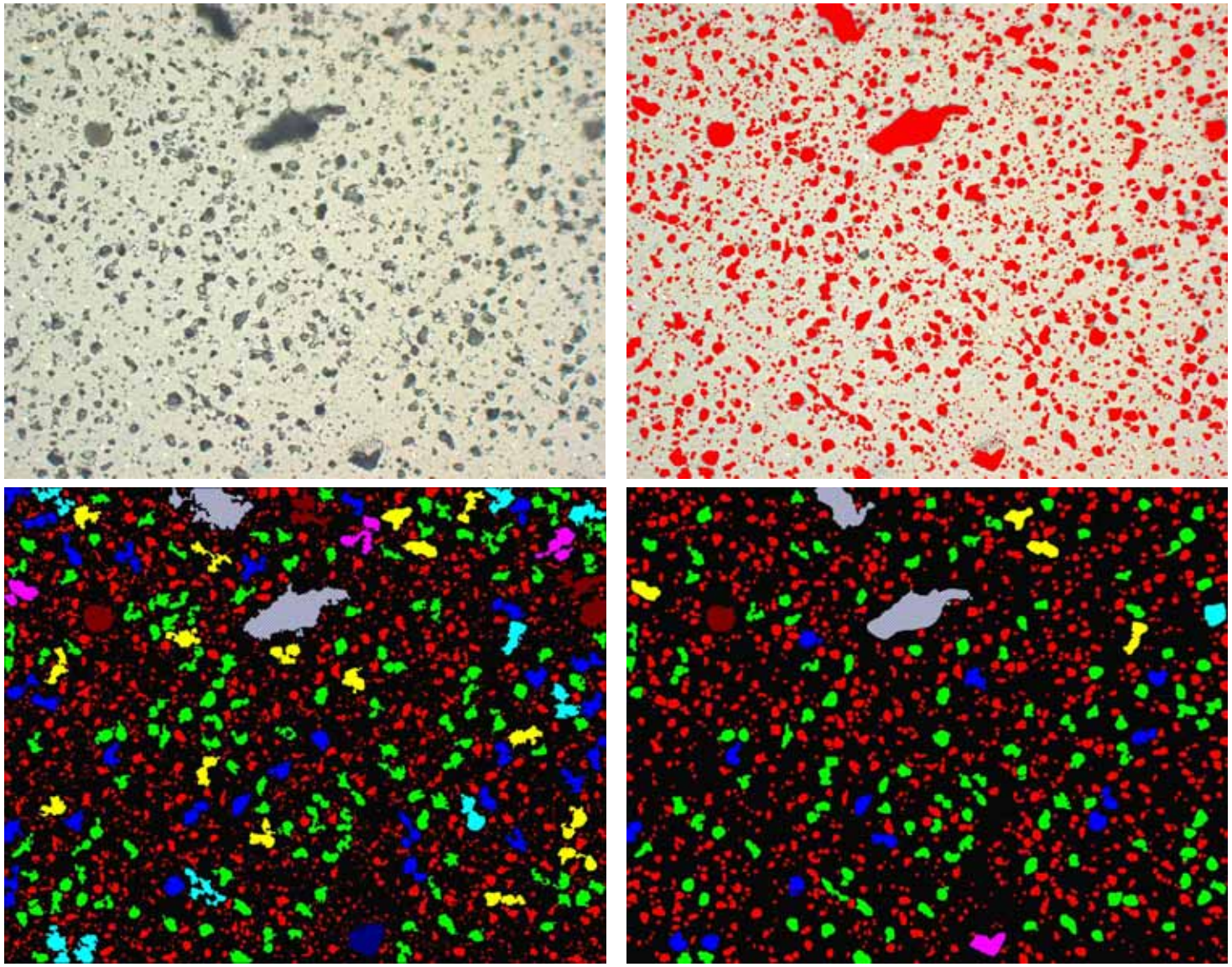
Different semi-automatic analyses





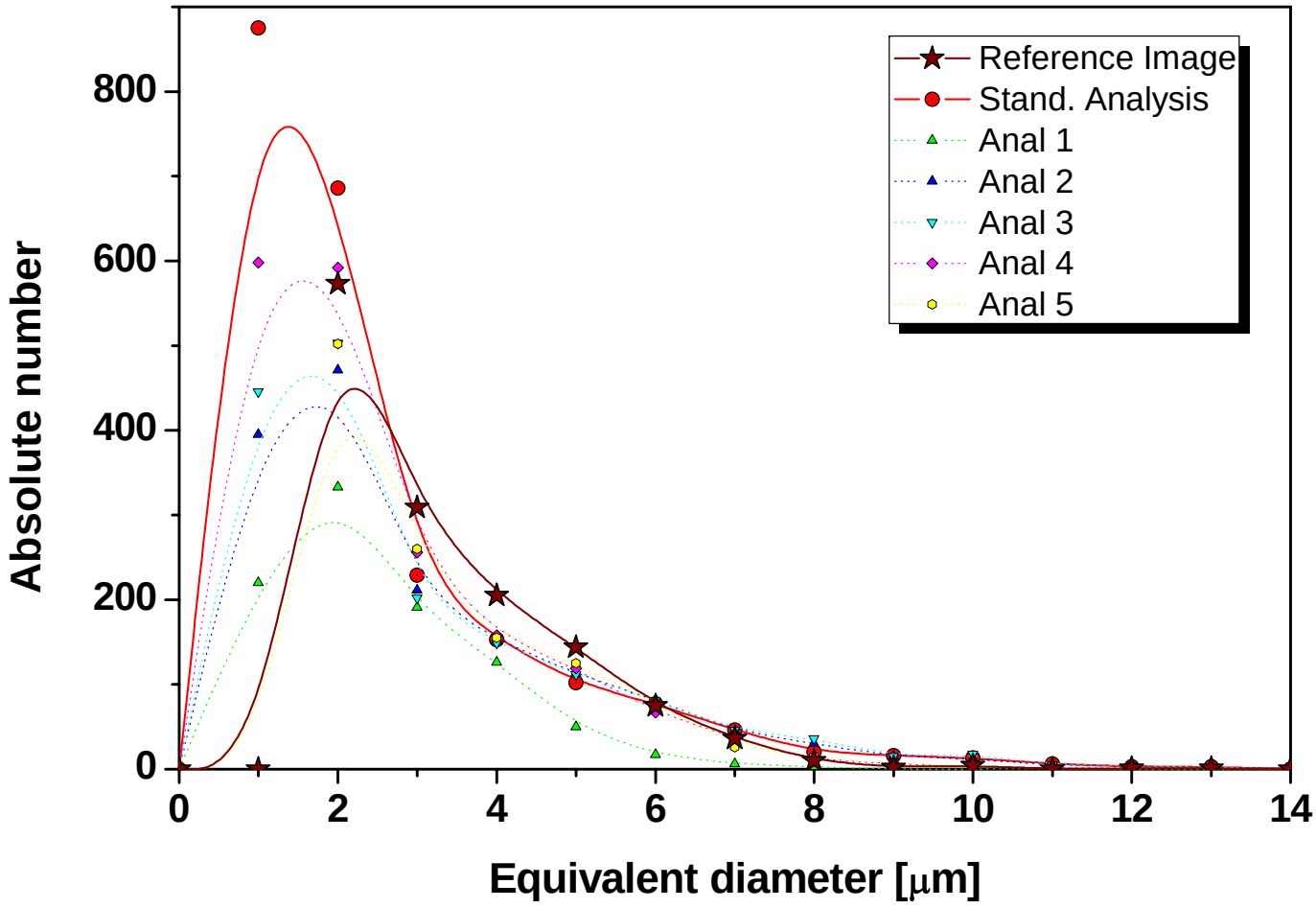


Standard semi-automatic analysis

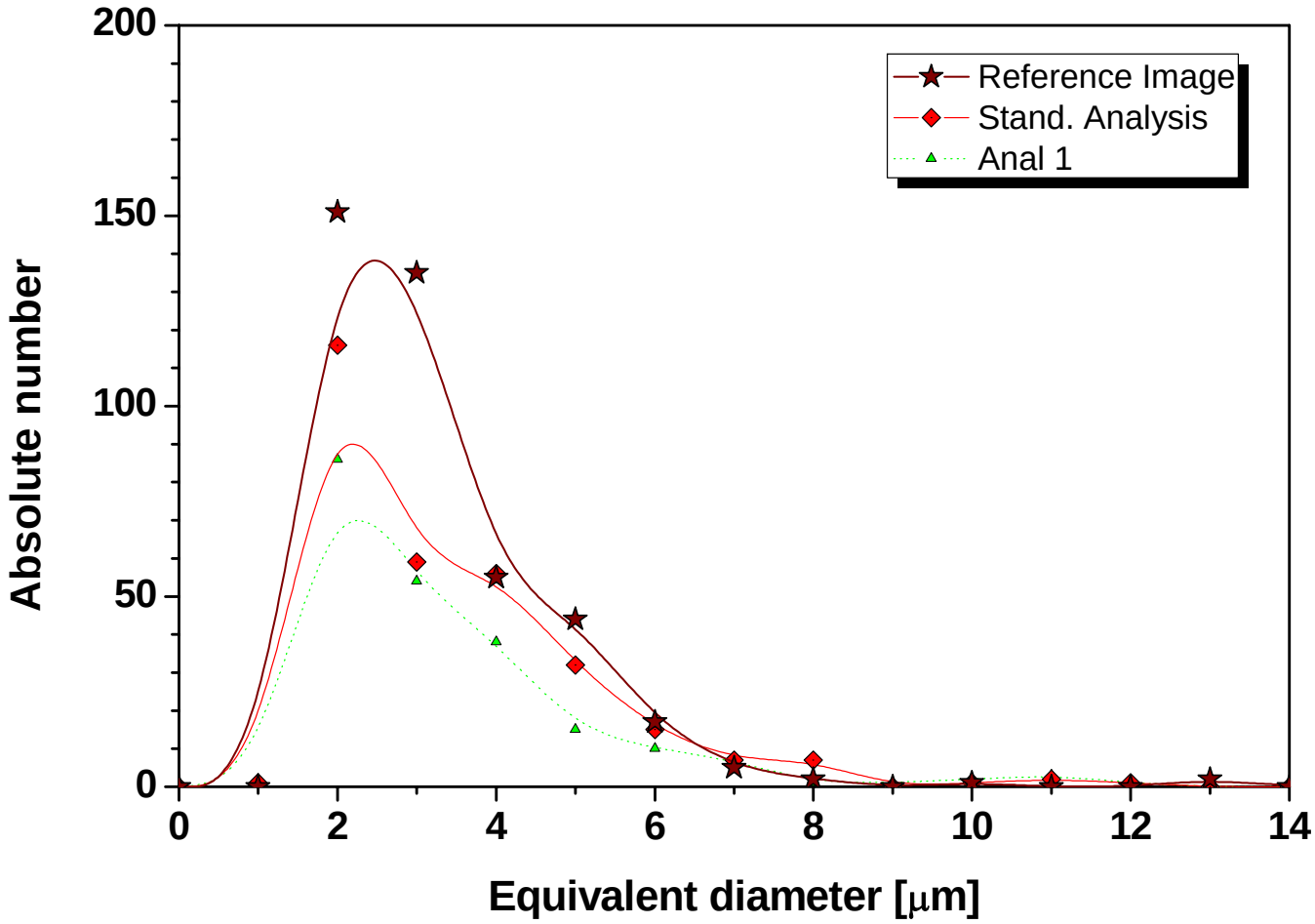


Analysis of the reference image

Sensitivity analysis OM images



Sensitivity analysis on SE images

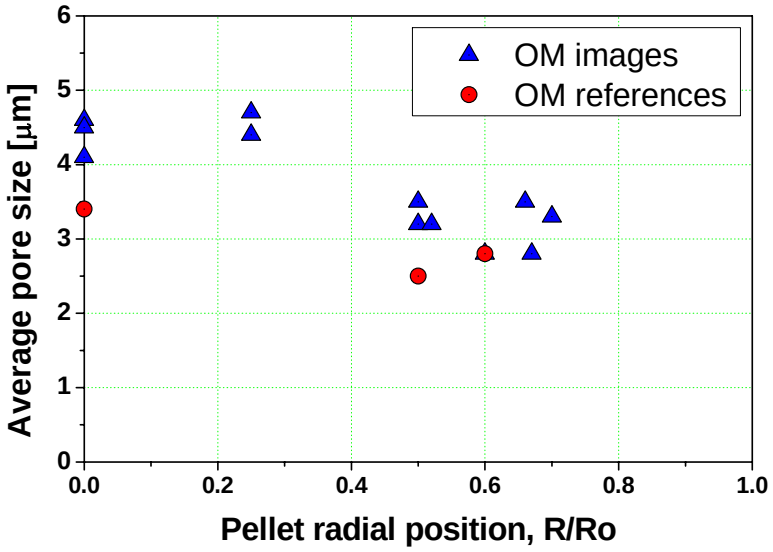


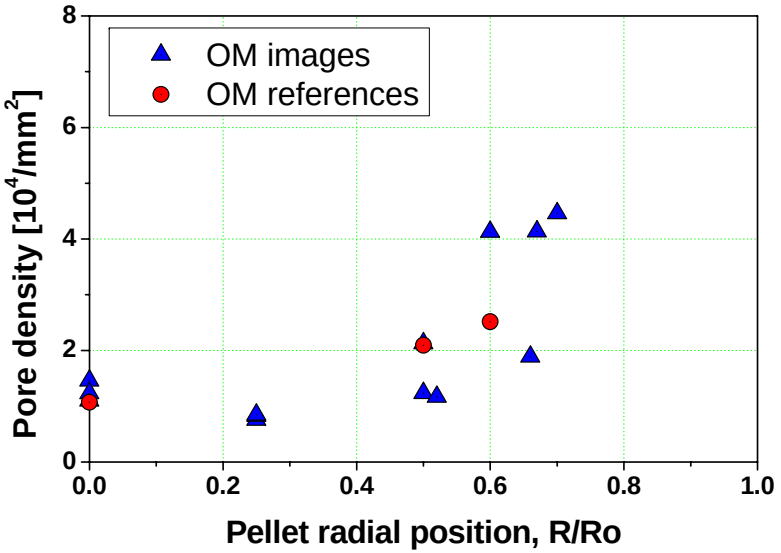
Results of the Sensitivity analysis

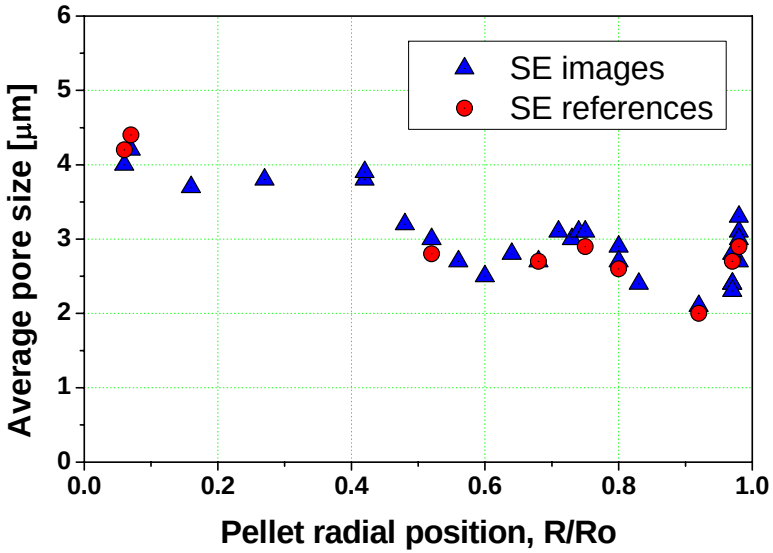
- **Low sensitivity on the pore size distribution and average size**
- **Large sensitivity on the fractional porosity and the number of pores detected per frame**
- **Clear effect of the image magnification: at small magnification the procedure is very sensitive to threshold settings**
- **Analysis of SE image are less sensitive but large variation of the fractional density is observed due to the complicated contrast structure**

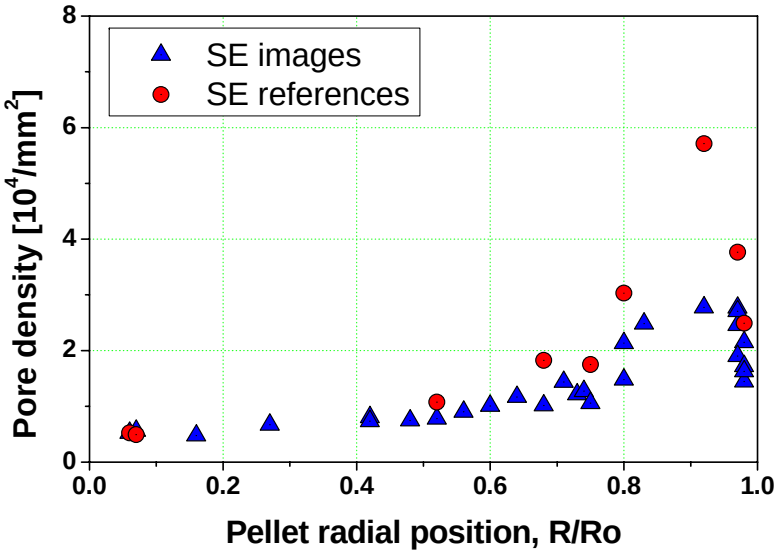
Results of the Sensitivity analysis

- An optimum must be found between good statistic (low magnification) and good analysis (high magnification)
- Acquisition of the images must be optimised in order to get good analysis
- A standard procedure must be defined and used on all pictures


OM images
OM references
Average pore size [μm]
Pellet radial position, R/Ro

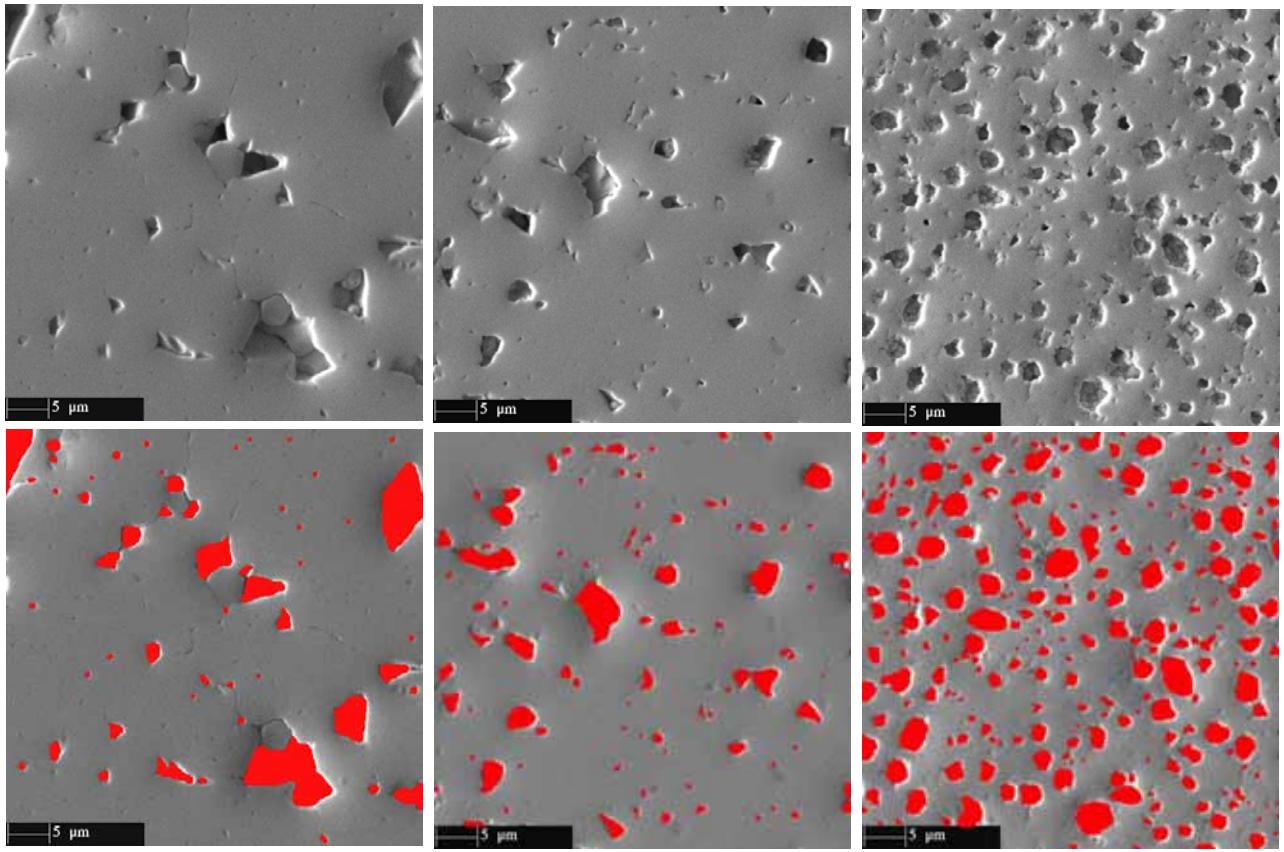

OM images
OM references
Pore density [10⁴/mm²]
Pellet radial position, R/Ro


SE images
SE references
Average pore size [μm]
Pellet radial position, R/Ro


SE images
SE references
Pore density [10⁴/mm²]
Pellet radial position, R/Ro

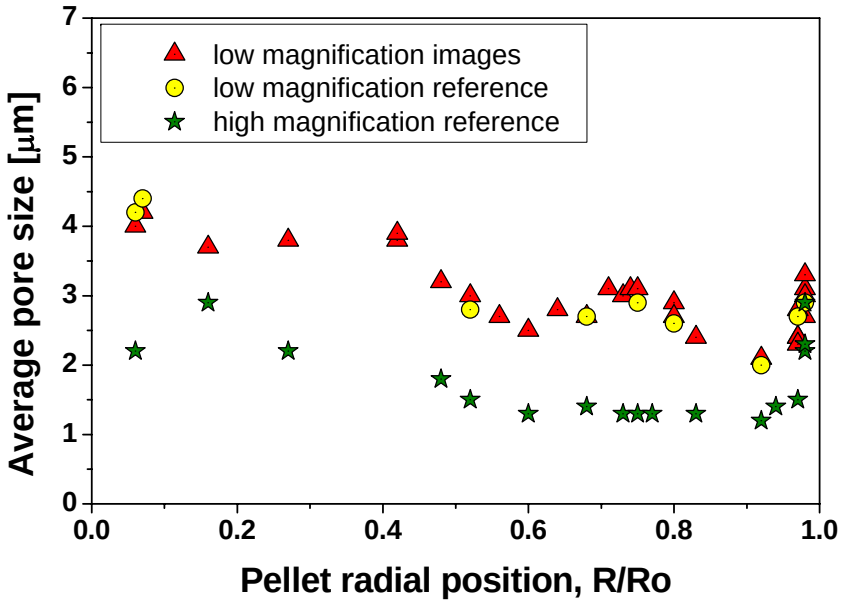
Control with high resolution SE images

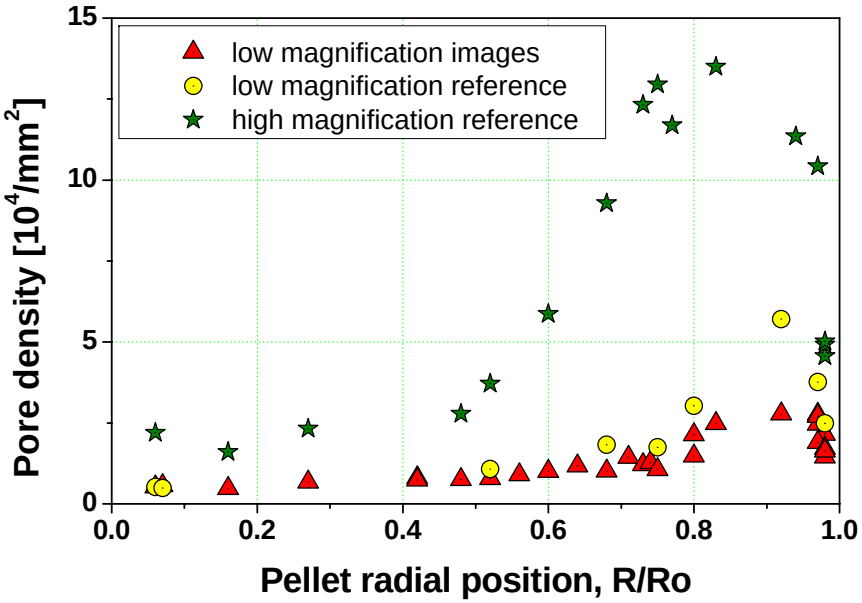
- **High magnification images have been manually digitised and analysed to get good data for small pores**



Results high resolution SE

- **The over all variation of the pore size, pore density and fractional density are similar but the pore density is much larger mostly at the pellet periphery and the average pore size is much smaller at all radii.**



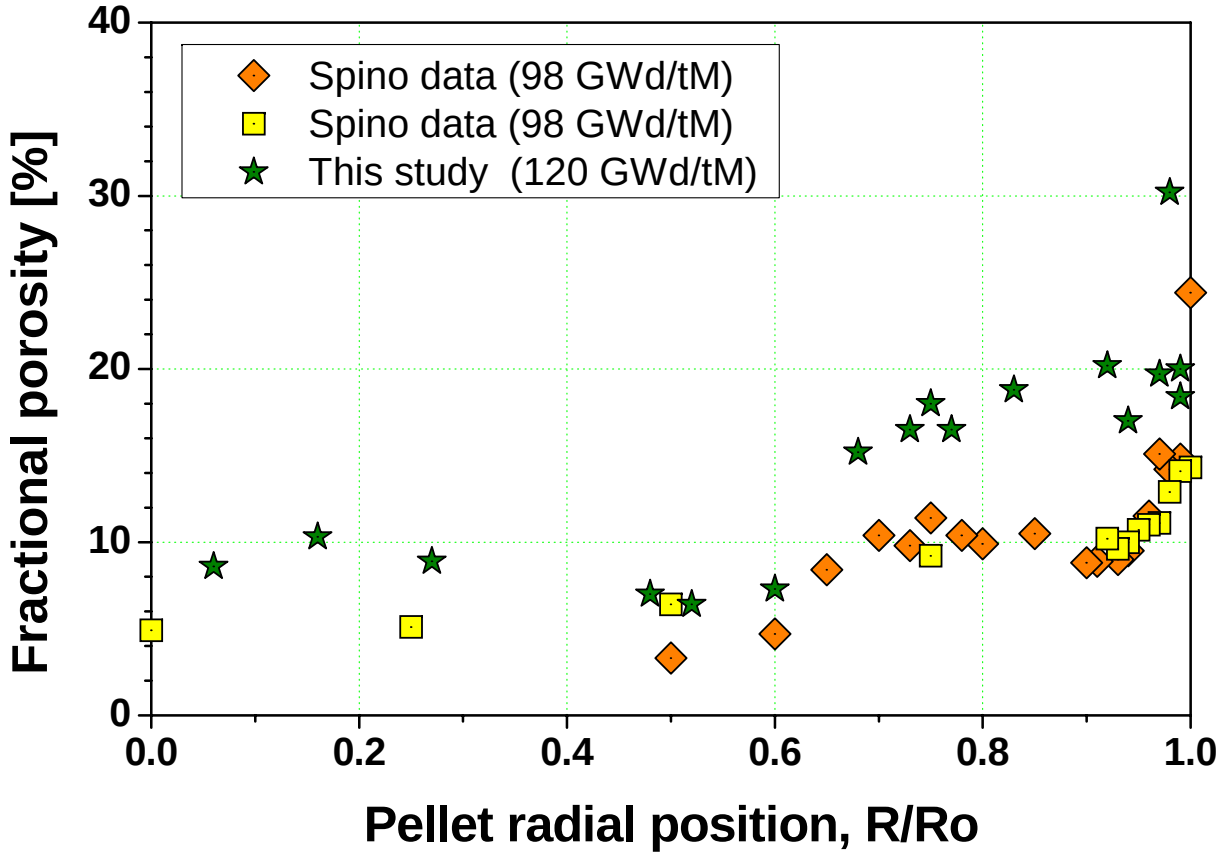


Results of the high resolution Image analysis

- The shape of the pore size distribution is basically identical to the one obtained on the previous analysis
- The fine porosity is not well recorded by the analysis of relatively low magnification images but the fractional porosity is relatively correctly evaluated as the small pores do not contribute significantly to this parameter
- The author considers that the porosity parameters generated from the high resolution SE images is the most precise in spite of the low statistics

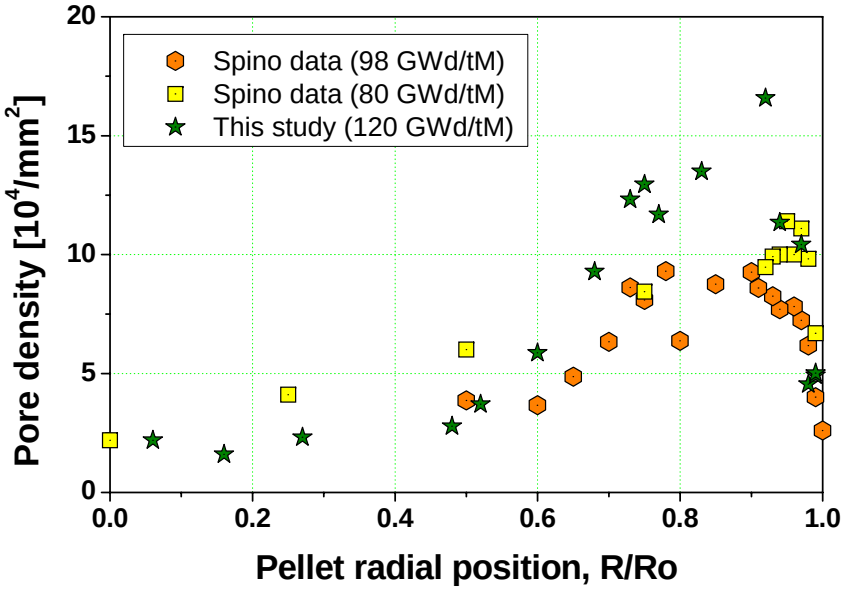
Comparison with published data

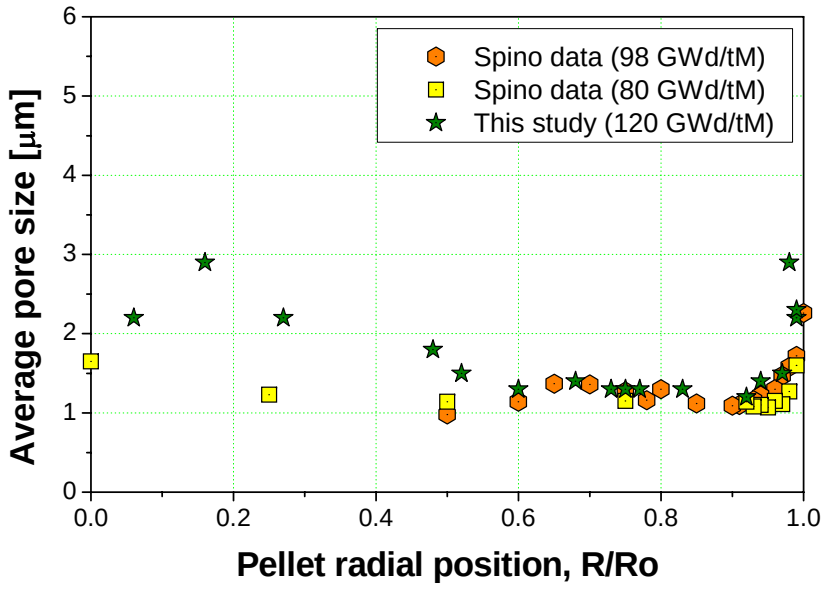
- **A slightly higher fractional porosity and the strong increase of the porosity at the edge of the pellet can be explain by the burn-up difference**



Comparison with published data

- **In the centre of the pellet a slightly higher average pore radius but a slightly lower pore density is observed. This, with the low increase of fractional porosity could indicate that some pore growth has occurred in this region**





Conclusions

- **The detailed study has demonstrated that the choice of magnification of the images used in such a study is critical in order to obtain a good determination of the porosity parameters**
- **It also shows that the acquisition of the images in future studies must be specifically optimised to get good contrasts of the pore edges**
- **For this study, on non-optimised images, good data have been obtained on high magnification SE images binarised manually at the cost of a relatively poor statistics**
- **The analysis add up important data for the knowledge of the fission gas location at very high burnup**

Acknowledgement

- The author would like to acknowledge the contribution of R. Restani and A. Urech who realised the EPMA and the ceramography analyses respectively and produced all pictures used in this study.
- The author wants also to thank R. Brütsch for the help in the definition of the image analysis procedure used in this study.