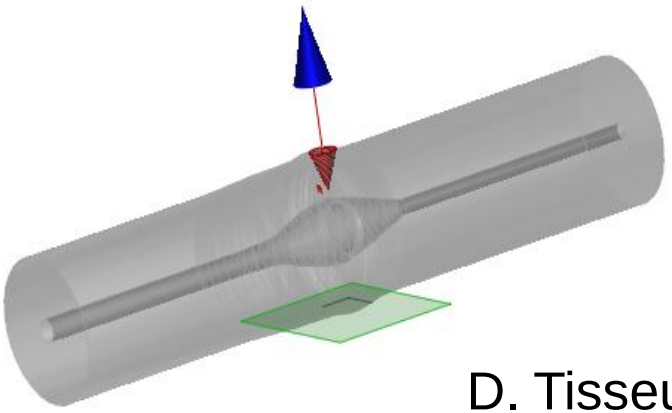
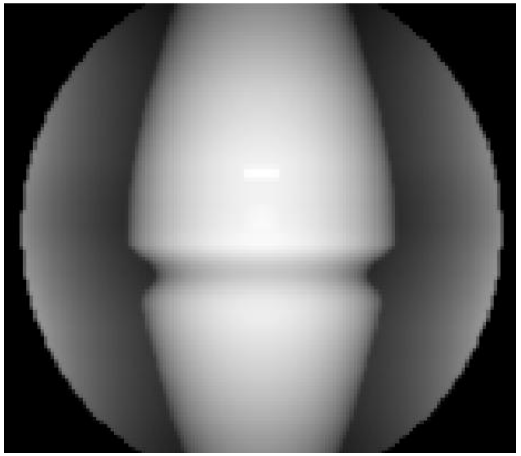
CIVA 10 RX module : Preliminary validation in a nuclear context



CIVA N·D·E | 10



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Outline

- **Context presentation**
- **CIVA RX platform presentation**

  Simulation of direct and scattered radiation.
  Available detectors
- **Validation process and results**
- **Conclusions and perspectives**

NDE in nuclear context

Inspection of nuclear component for maintenance operations: need to know the performances of NDE techniques (study of influential parameters)

- **Pipes, elbows, nozzle, heterogeneous components, welds …**
  - Mid and high thickness component (from several mm to 110 mm)
  - Flaws with complex shapes such as cracks, shrinkages, etc
- **Gamma Sources :** Iridium 192, Cobalt 60
- **Specific film detector**

CIVA simulation platform

- **Collaboration of different entities for the development of CIVA X-Ray**
  - CEA-LETI (Fusion Monte Carlo/direct beam, detectors model)
  - EDF (Ray tracing and Monte Carlo, detector model)
  - CEA-LIST (GUI, tomography)
  - IRSN (validation, case study on realistic nuclear component from various nuclear facilities)

- **Simulation of a global radiographic inspection taking into account the most influential parameters:**
  - X or gamma Source,
  - Complex specimen (2,5D, 3D…),
  - flaws,
  - detector.
- **Performance demonstration and qualification of methods.**
- **Validation of radiographic procedures.**

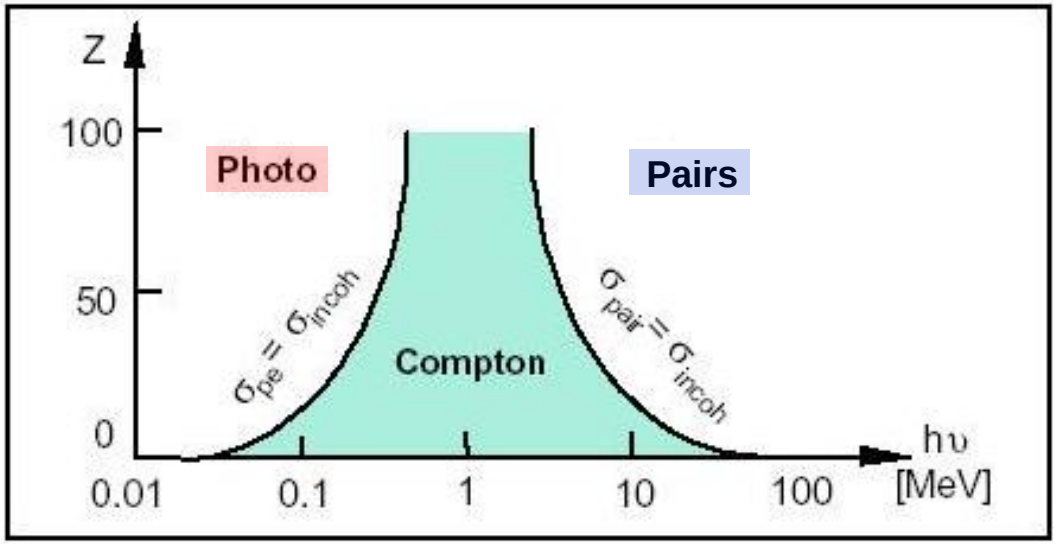
Principles of radiographic modeling

Interaction of photons with matter

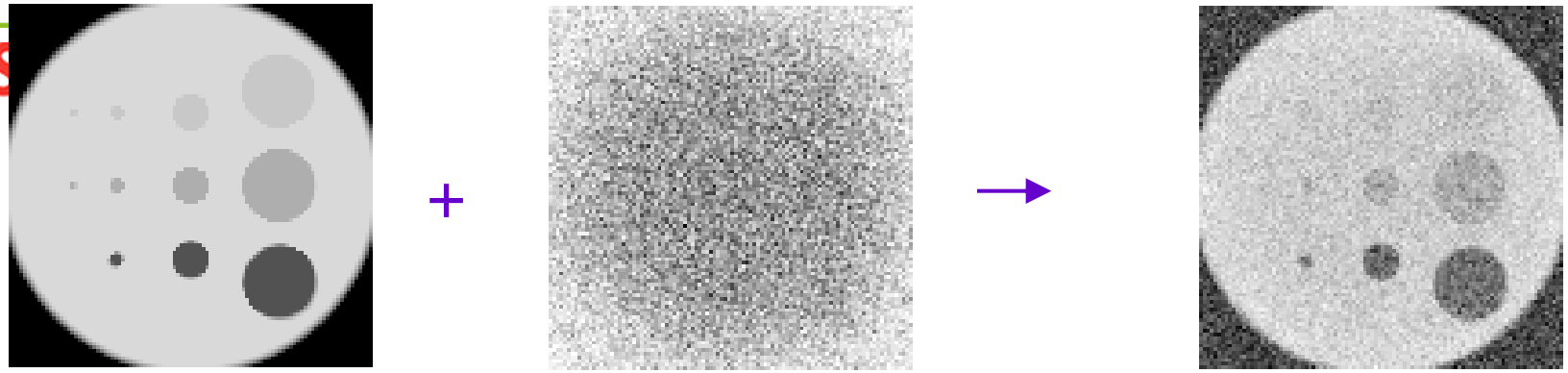
➡ 3 main modes :

- Photoelectric absorption
- Compton (and Rayleigh) interaction
- Pair e+ e- creation

Relative importances of interaction modes vs photon energy :



Introduction to modeling



Attenuation model

Monte-Carlo approach

Final radiographic image

Probabilistic computation of the path of the photons

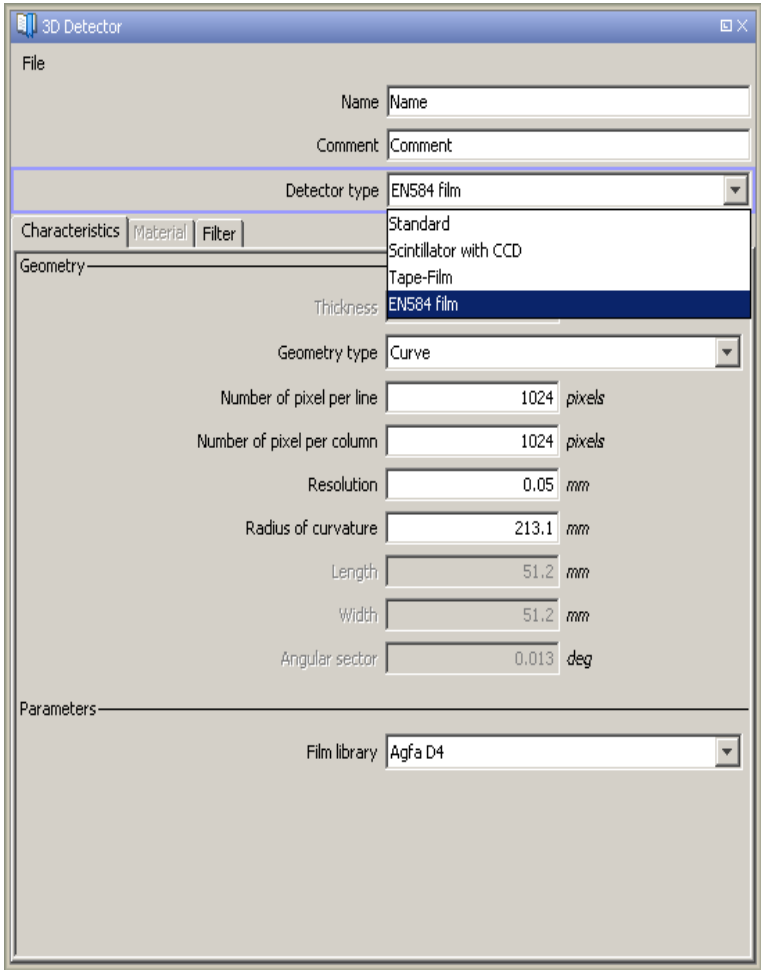
The straight-line attenuation is formulated by an exponential law applied along the straight-line between the source and the detector. It's defined by:

$$I = I0 \exp(-\mu x),$$

μ : the total attenuation coefficient for a given material and energy,

x : the photon course in the matter.

Computation steps-detector



4 models :

- Standard detector
- Scintillator + CCD
- Tape film (user can plug his specific detector response)
- Model of films based on the EN584-1 standard

+ common functionalities:

. Detector blur (MTF)

. Detector can be planar or curve

. A filter can be added

. A Region Of Interest can be added.

Main images displayed

Analytic computation only:

- - Image of deposited energy (with and without noise)
- - Image of attenuation
- - Image of dose in air
- - Image of« Detector Response» (with and without noise) or image of optical density

- **Monte-Carlo computation only:**
  - - MC direct
  - - MC scattered

- **Combination:**
  - - All mentioned above+
  - - Images of energy combination (with and without noise)
  - - Build-Up
  - - Final image of the detector response (or OD) of methods.

Experimental validations

- **Study of scattered / direct simulation**

→ Comparison between Penelope Monte Carlo code and CIVA RX

- **Optical density validation with a stainless steel step wedge**

→ Comparison between CIVA 10 simulations and experimental data with M100 and AA400 film type

- **Response with realistic flaws**

→ Preliminary results : Comparison between simulated and experimental on a dissimilar weld mockup

Experimental validations

CIVA 10

- **Study of scattered / direct simulation**

→ Comparison between Penelope Monte Carlo code and CIVA RX

- Optical density validation with an iron step wedge

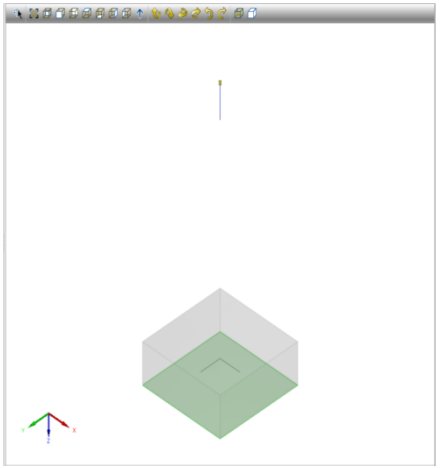
→ Comparison between CIVA 10 simulations with experimental data with M100 and AA400 film type

- Response with realistic flaws

→ Comparison between simulated and experimental data on a plate with notches and a dissimilar weld mockup

Study of scattered / direct simulation

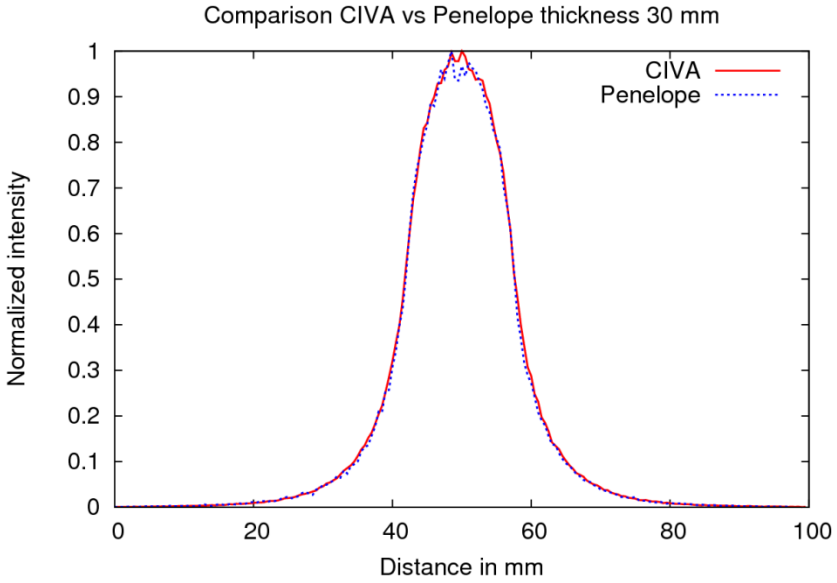
- **Comparison between Penelope and CIVA**
  - Penelope: a Monte Carlo code simulation of photon and electron transport
- **Configurations :**
  - Source ^{60}Co
  - Stainless steel thickness from 30 to 100 mm
  - Monte Carlo : 10^8 photons

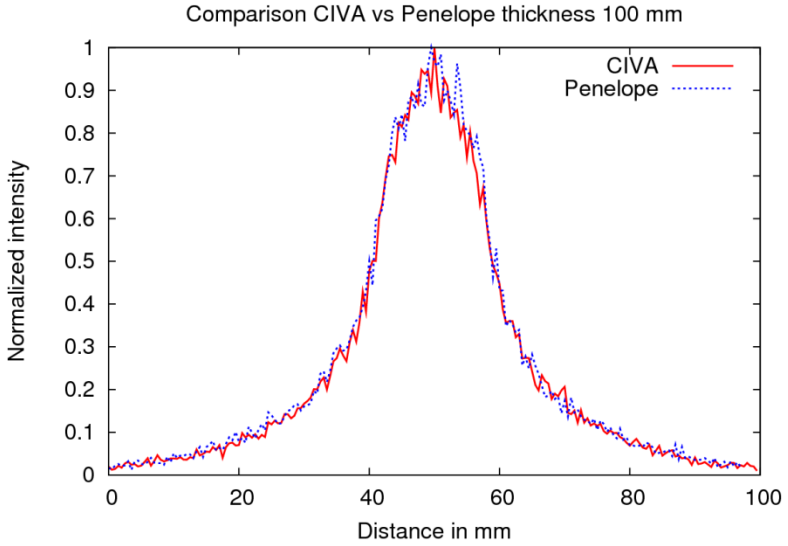


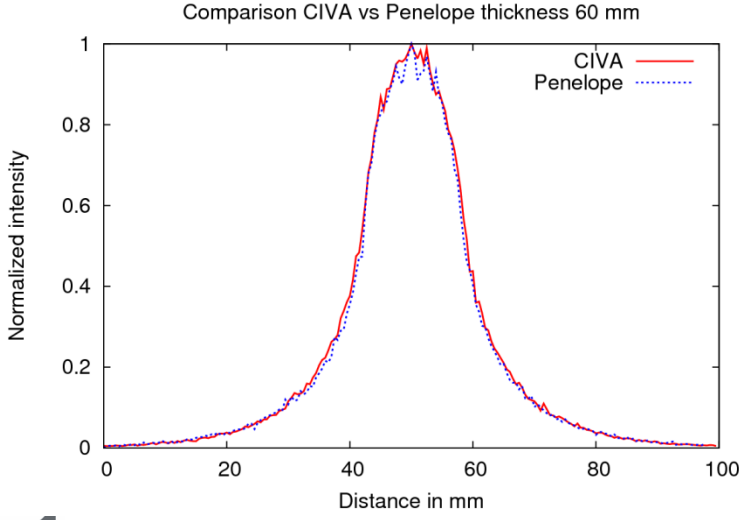
Vue 3D (Civa10.0)

Study of scattered / direct simulation

- **Comparison between CIVA and Penelope**







- **Conclusion: good agreement between CIVA and Penelope**

Experimental validations

CIVA 10

- Study of scattered / direct simulation

→ Comparison between Penelope Monte Carlo code and CIVA RX

- **Optical density validation with a stainless steel step wedge**

→ Comparison between CIVA 10 simulations with experimental data with M100 and AA400 film type

- Response with realistic flaws

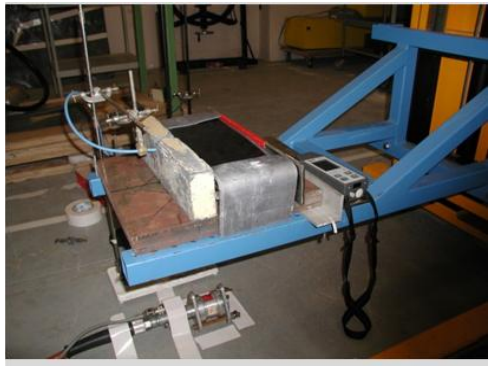
→ Comparison between simulated and experimental data on a plate with notches and a dissimilar weld mockup

Optical density validation with a stainless steel step wedge

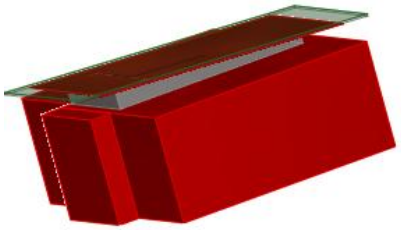
Expérimental and simulation parameters

- ^{60}Co gamma source
- Source size : diameter 3.7 mm high 3.7 mm,
- Opening 60°
- Source –film distance 0.367 m
- Inox wedge thickness from 104 to 118 mm
- KodaK M100
- MC with 1x10^{9} photons

Experimental setup



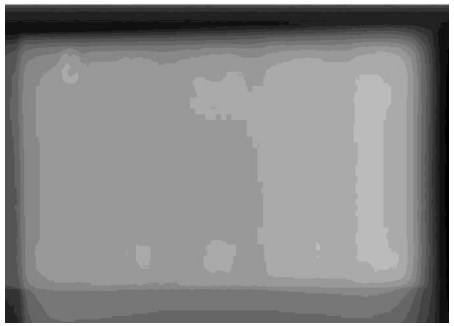
Simulation setup



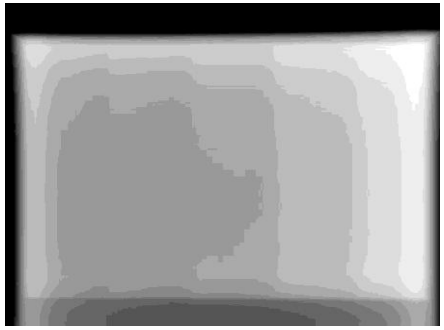
Optical density validation with a stainless steel step wedge

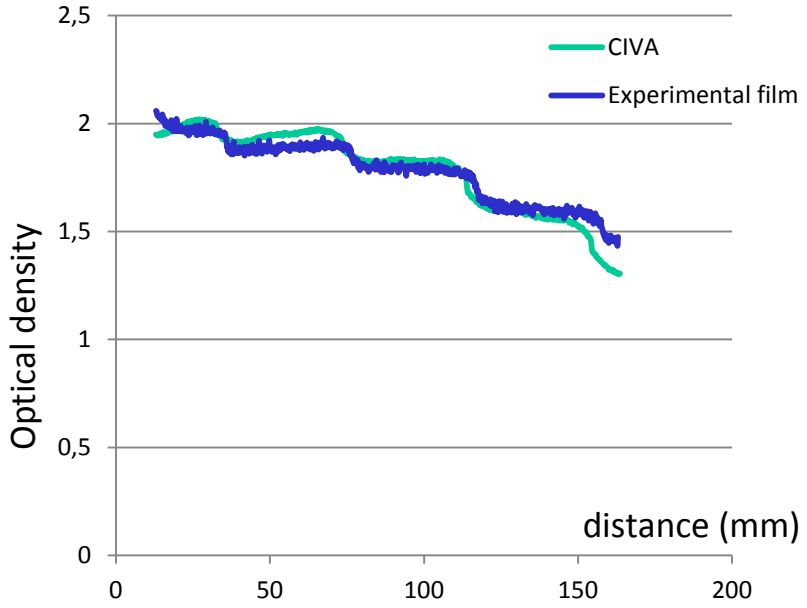
Results

Experimental film



Simulated film





→ **Relative error between 6% and -10%**

Optical density validation with a stainless steel step wedge

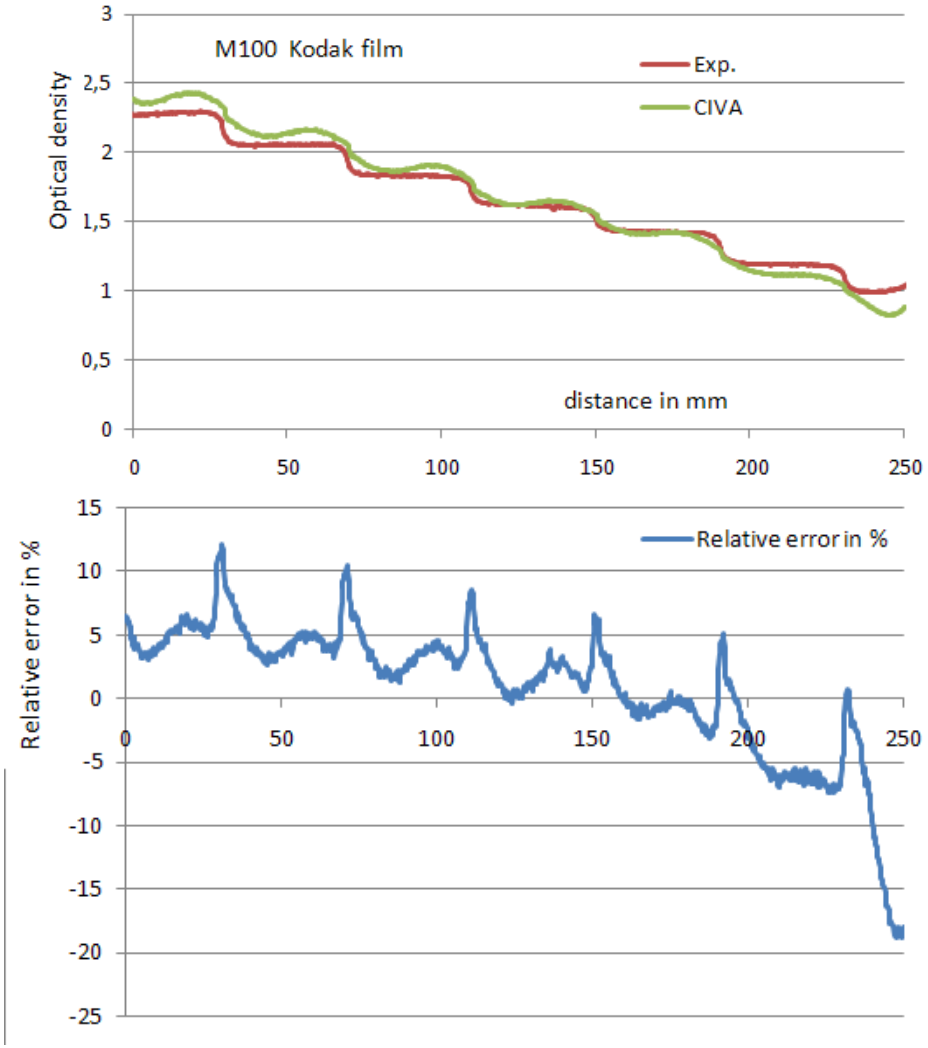
Experimental and simulation parameters

- Xray tube: 450 kV
- Source size : diameter 1 mm,
- Opening 30°
- Source –film distance 0.367 m
- Inox wedge thickness from 44 to 56 mm
- KodaK M100 and AA400 Xray film
- MC with 5 x10^9 photons

Setup

Optical density validation with a stainless steel step wedge

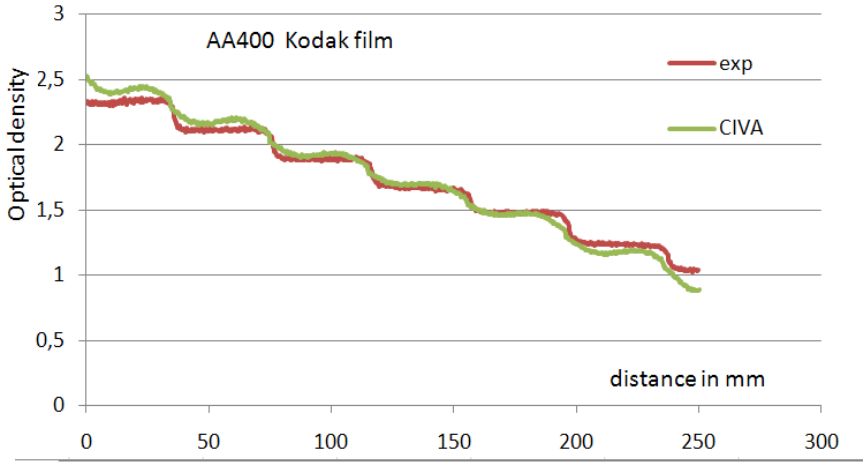
Results with Kodak M100

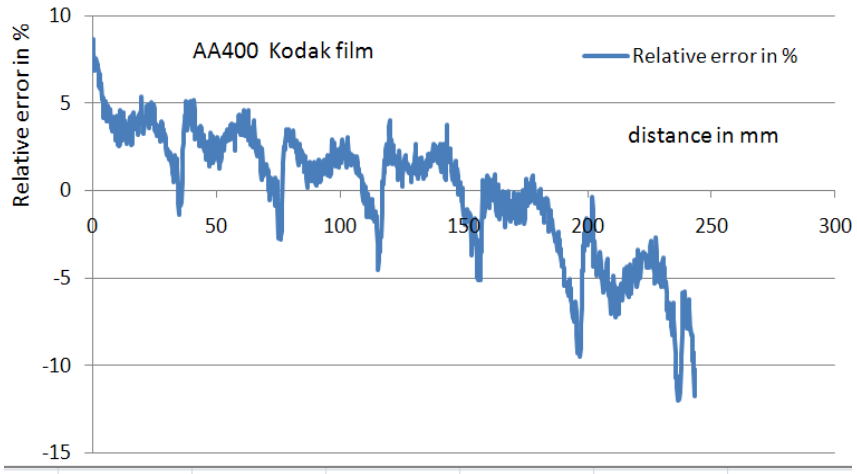


→ Relative error between 12% and -20%

Optical density validation with a stainless steel step wedge

Results with Kodak AA400

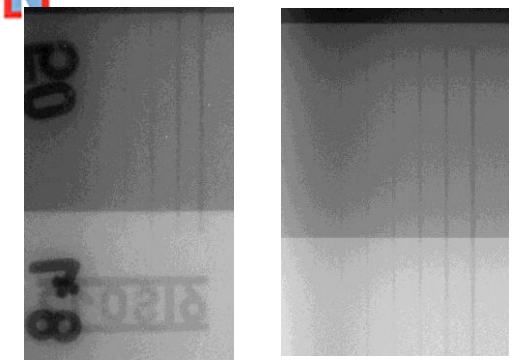




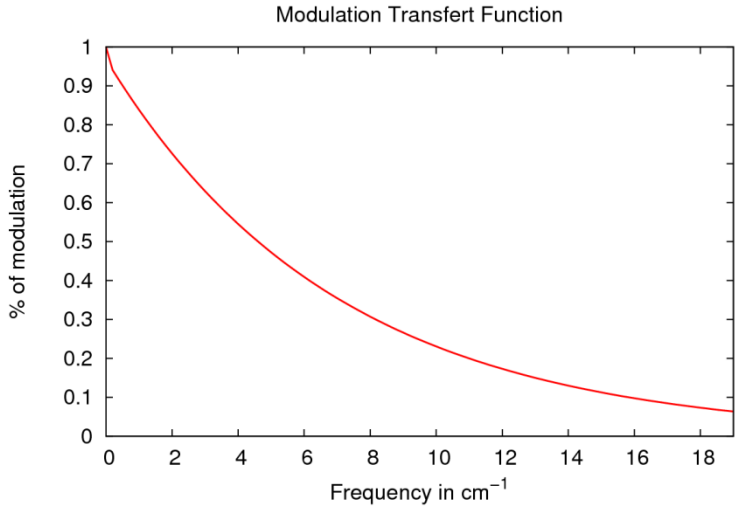
→ Relative error between -12% and 8%

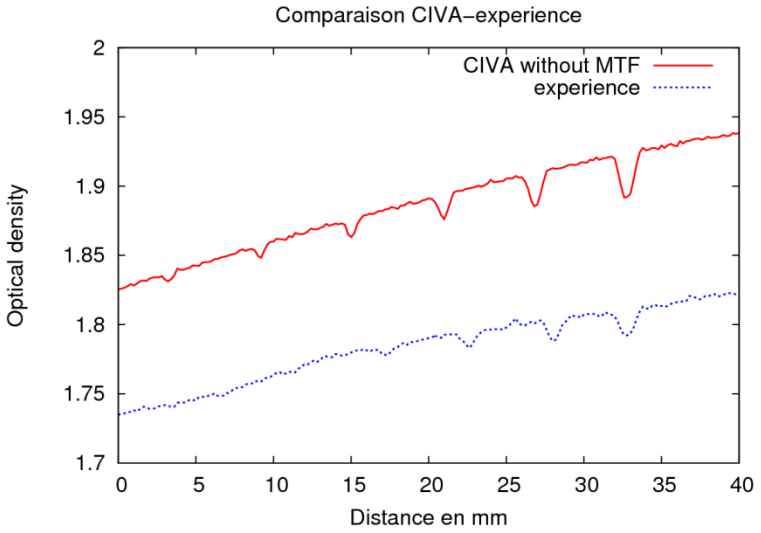
Optical density validation with a stainless steel step wedge

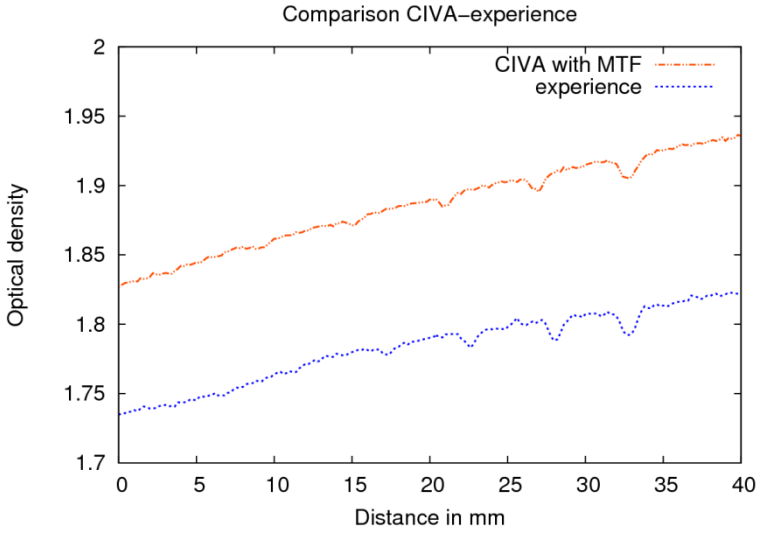
- **Results on IQI profile**



- **MTF estimation with an edge**







- **Need to include the MTF for an accurate simulation**

Experimental validations

CIVA 10

- Study of scattered / direct simulation

→ Comparison between Penelope Monte Carlo code and CIVA RX

- Optical density validation with an iron step wedge

→ Comparison between CIVA 10 simulations with experimental data with M100 and AA400 film type

- **Response with realistic flaws**

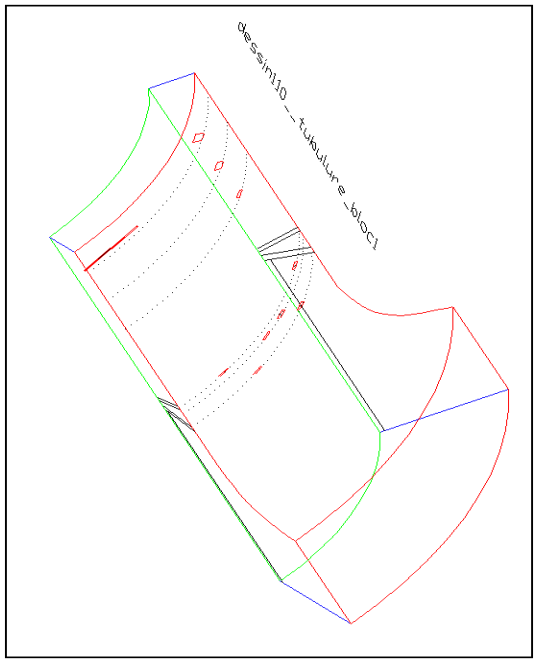
→ Comparison between simulated and experimental data with notches on a dissimilar weld mockup

Optical density validation with a dissimilar weld

Experimental and simulation parameters

- Co60 gamma source
- Source size : diameter 3.7 mm high 4.7 mm,
- Source –mockup distance 0.367 m
- Dissimilar weld, civa modeled the true geometry and materials (316 L, inconel 82, 16MND5, 309L and 308L)
- 3 EDM notches : 20mm (length) x 5 mm (high) x 0.2mm(width)
- 3 EDM notches : 20mm (length) x 3 mm (high) x 0.2mm(width)
- KodaK M100
- MC with 5 x10^9 photons

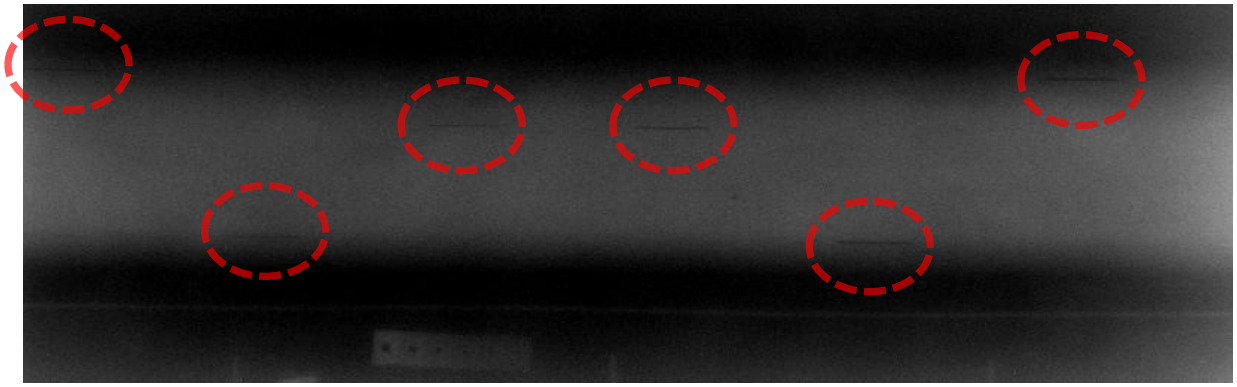
Experimental setup



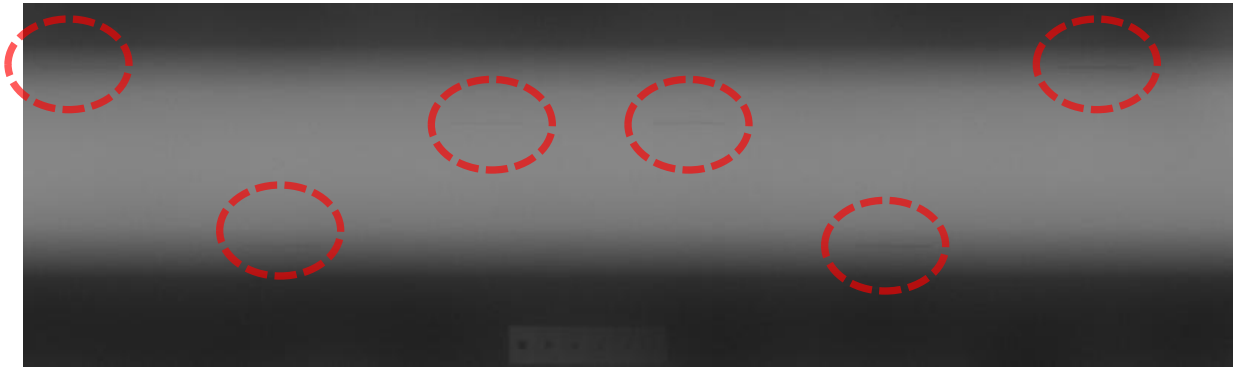
Simulation setup

Optical density validation with dissimilar weld

- Experimental radiography

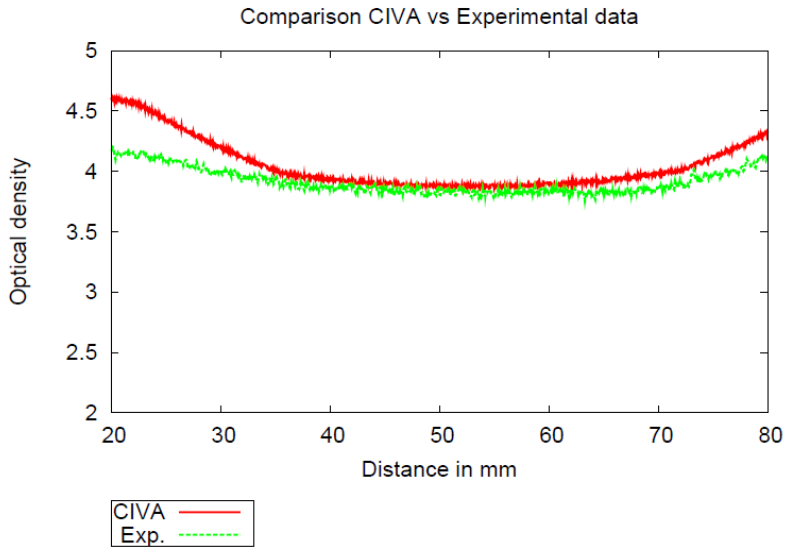


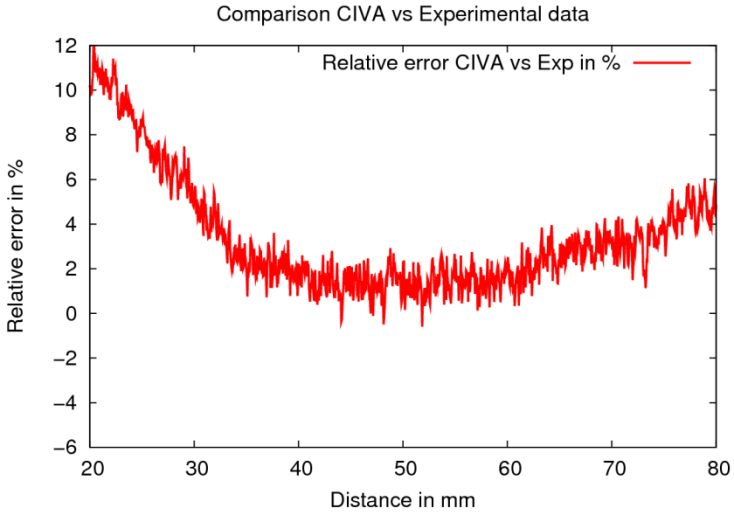
- CIVA simulated radiography



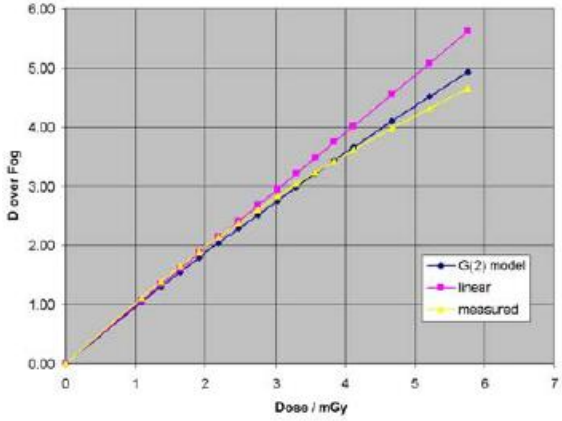
Optical density validation with dissimilar weld

Optical density profiles comparison between experimental and simulation



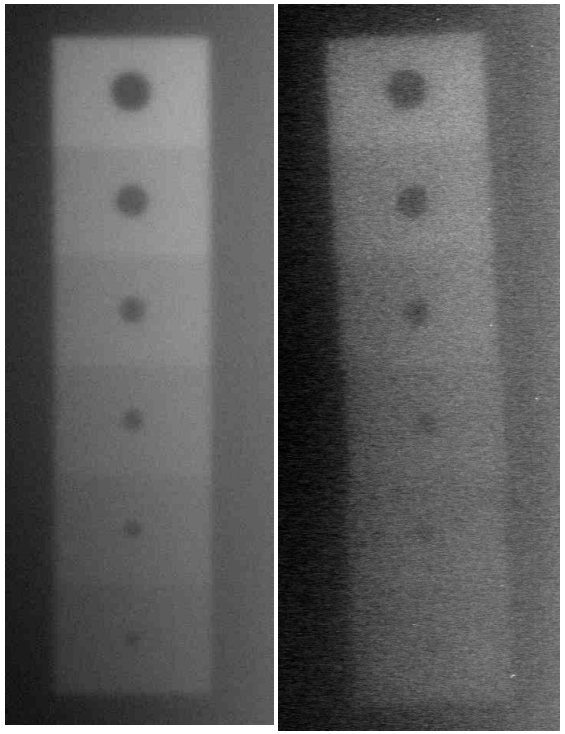


- The maximum relative error on the film side is due to the limitation of our film model which does not take into account the saturation effect.

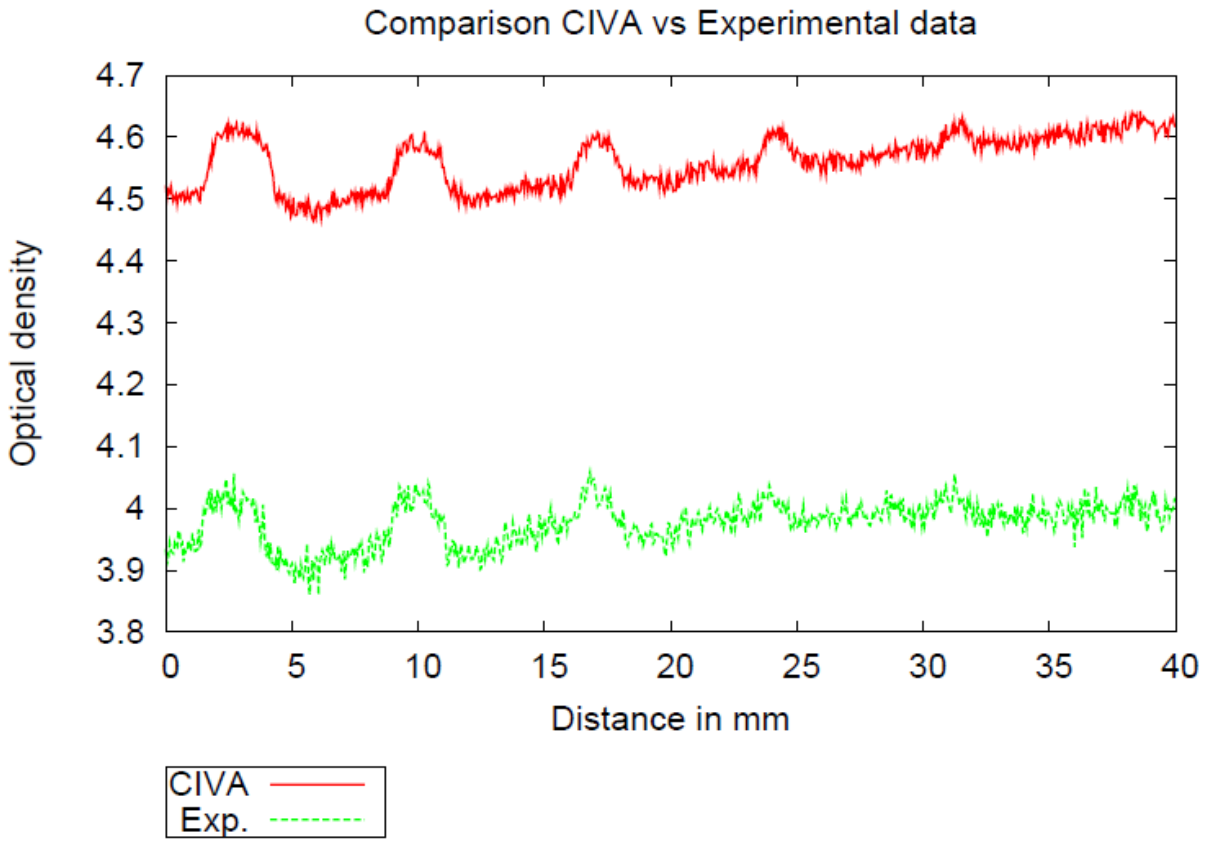


Optical density validation with dissimilar weld

Profiles comparison between experimental and simulation on hole IQI

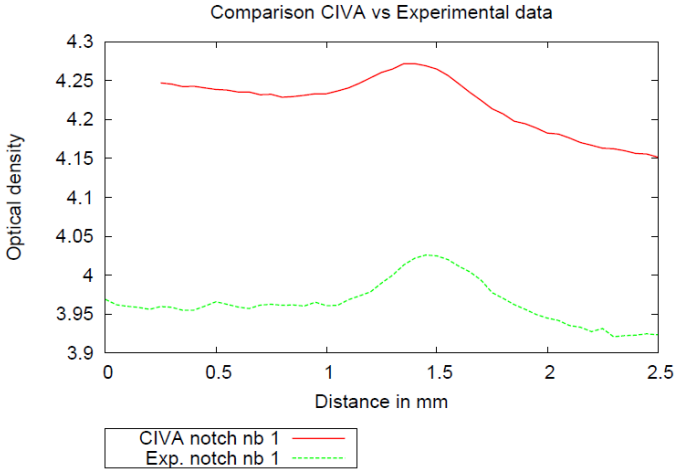


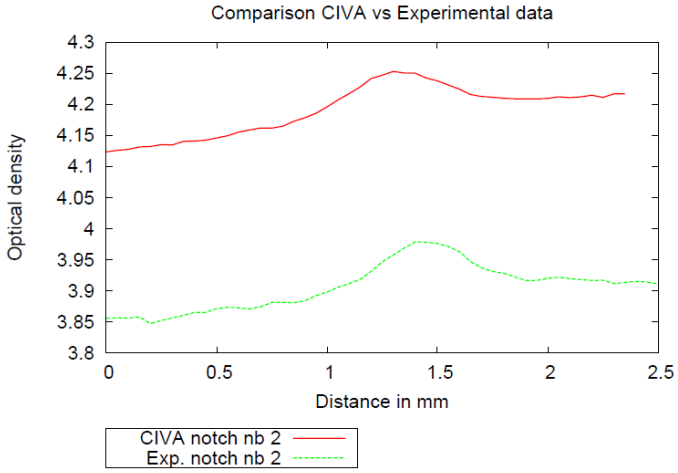
- CIVA EXP

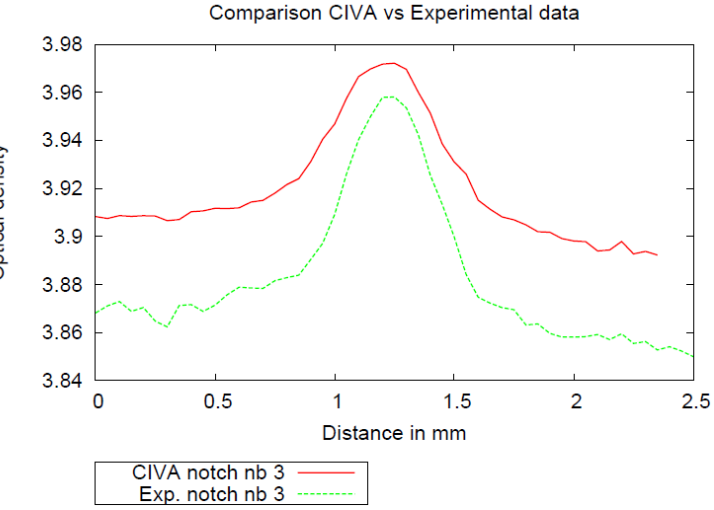


Optical density validation with dissimilar weld

Profiles comparison between experimental and simulation on 5 mm high notches





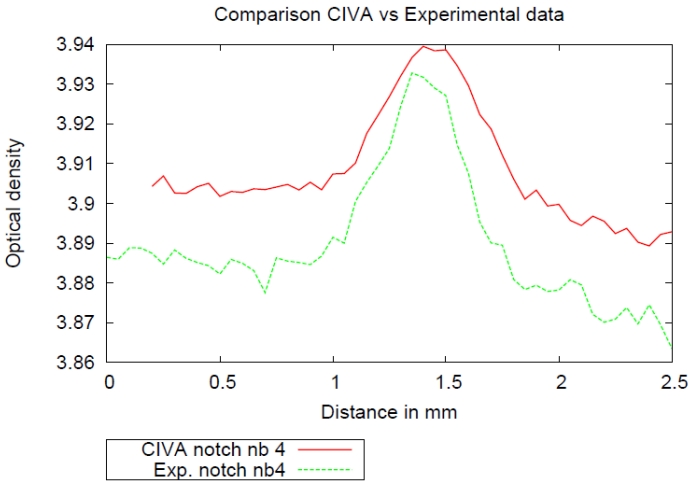


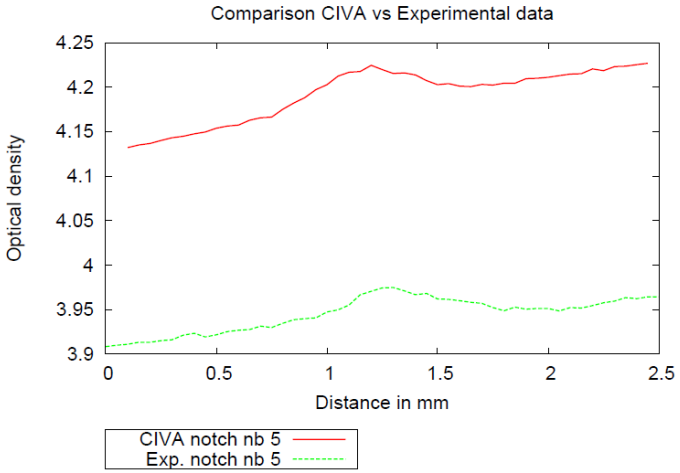
	Flaw amplitude Exp (OD)	Flaw amplitude Civa (OD)
notch 1	0,07	0,06
notch 2	0,08	0,07
notch 3	0,09	0,06

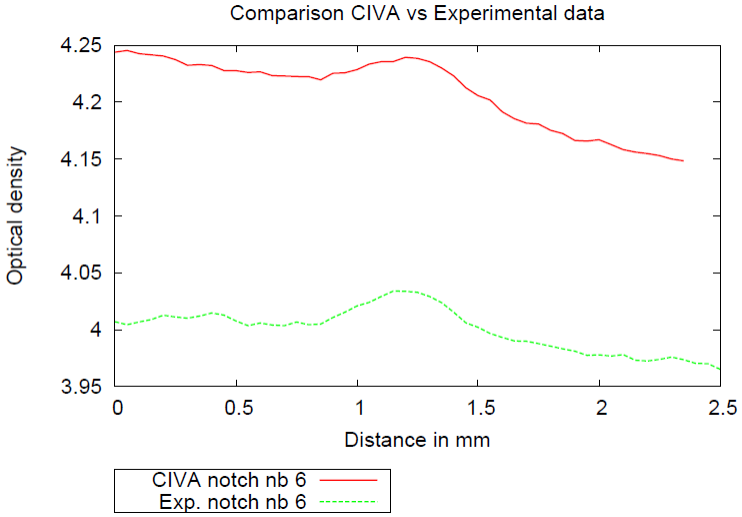
	Flaw width Exp (mm)	Flaw width Civa (mm)
notch 1	0,83	0,88
notch 2	0,78	0,71
notch 3	0,89	0,95

Optical density validation with dissimilar weld

Profiles comparison between experimental and simulation on 3 mm high notches







	Flaw amplitude Exp (OD)	Flaw amplitude Civa (OD)
notch 4	0,04	0,03
notch 5	0,03	0,03
notch 6	0,04	0,03

	Flaw width Exp (mm)	Flaw width Civa (mm)
notch 4	0,66	0,68
notch 5	0,79	0,75
notch 6	0,92	0,90

Conclusions and perspectives

Specific validations

- Comparisons between CIVA and Penelope validate the scattered simulation module
- The first results obtained for high energy gamma sources show a good accuracy between experiment and simulation with an EN584-1 film model.
- Validation shows the importance of the MTF.

Works in progress

- Large validation study on dissimilar weld and cast steel with notches with different sizes (high, opening), orientations and positions
- Analyse of differences between experimental and simulated data and adapted corrective actions

Future possibilities:

- Post processing options, POD
- Determination of a reliability coefficient of the simulation
- Simulation of the environment scattered beam
- Integration of an analytic model to simulate the scattering radiation (and dose)
- Generic detector model