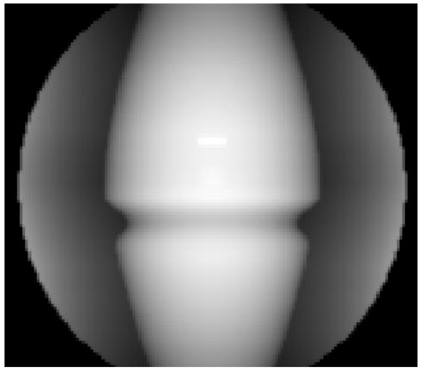
VALIDATION OF CIVA 10 RT MODULE IN A NUCLEAR CONTEXT



D. Tisseur, CEA-LIST, France
B. Rattoni, CEA-LIST, France
G. Cattiaux, IRSN, France
T. Sollier, IRSN, France

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SUMMARY

- Context presentation
- CIVA RX platform presentation
- Validation process and results
- Conclusions and perspectives

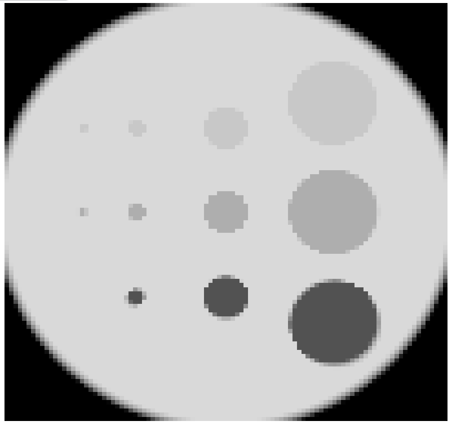
Inspection of nuclear components for maintenance operations: need to know the performances of NDE techniques (study of influentials parameters)

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

- 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 (case study on realistic nuclear component from various nuclear facilities, validation)

- 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.

CIVA simulation software



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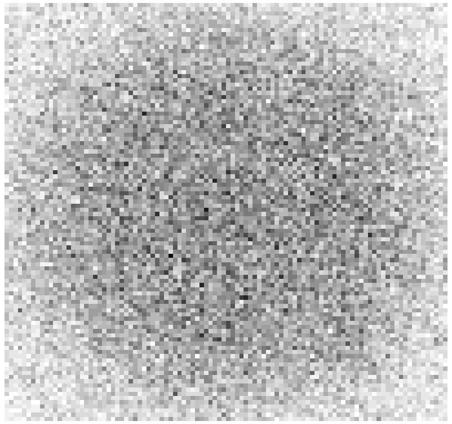

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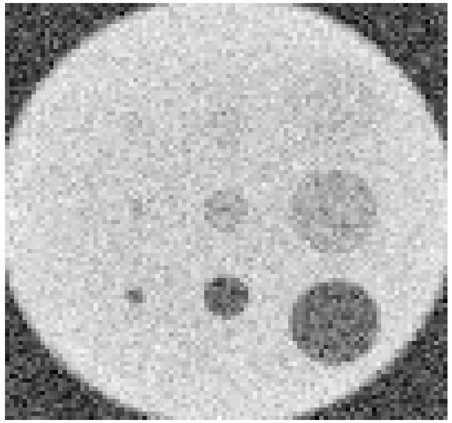


Attenuation model	Monte-Carlo approach	Final radiographic image

Monte-Carlo approach → Probabilistic computation of the path of the photons

Attenuation model ↓

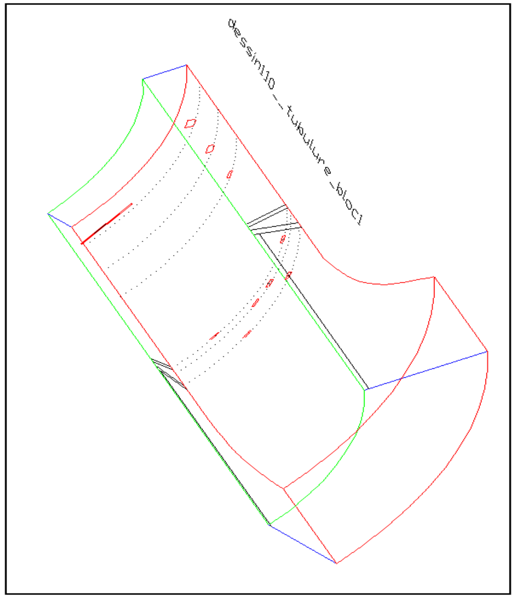
The straight-line attenuation is formulated by an exponential law applied along the straight-line between the source and the detector. It's defined by:

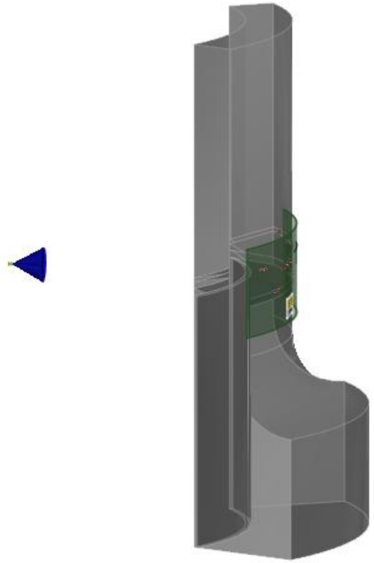
$$I = I0 \exp(-\mu x),$$

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

x : the photon course in the matter.

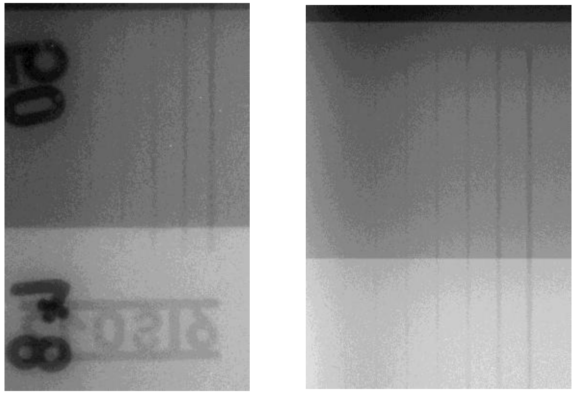
- **Experimental and simulation parameters**
  - Co60 and Ir192 gamma source
  - Source size : diameter 3.7 mm height 4.7 mm (Co60), 3mm x 3mm (Ir192)
  - Source –mockup distance 0.367 m
  - Dissimilar metal weld, civa modeled the true geometry and materials (316 L, nickel based alloy 82, low alloy carbon steel 16MND5, 309L and 308L)
  - 3 EDM notches : 20mm (length) x 5 mm (height) x 0.2mm(width)
  - 3 EDM notches : 20mm (length) x 3 mm (height) x 0.2mm(width)
  - KodaK M100
  - MC with 5×10^9 photons

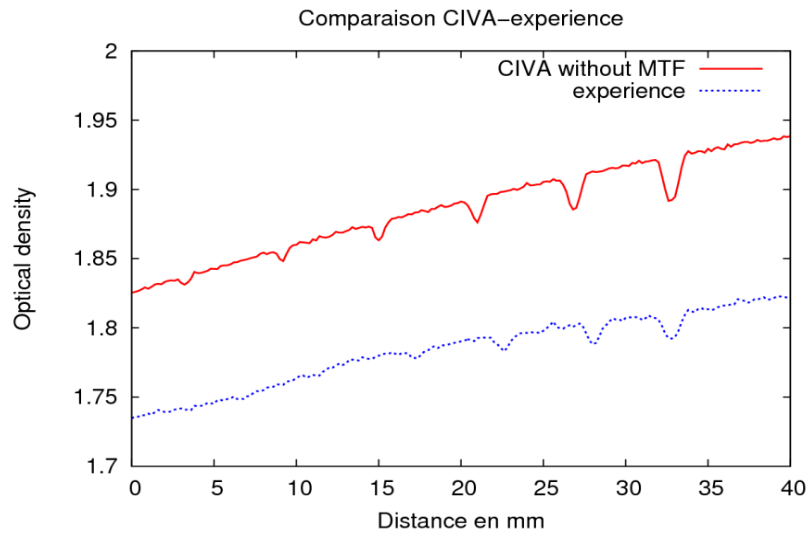




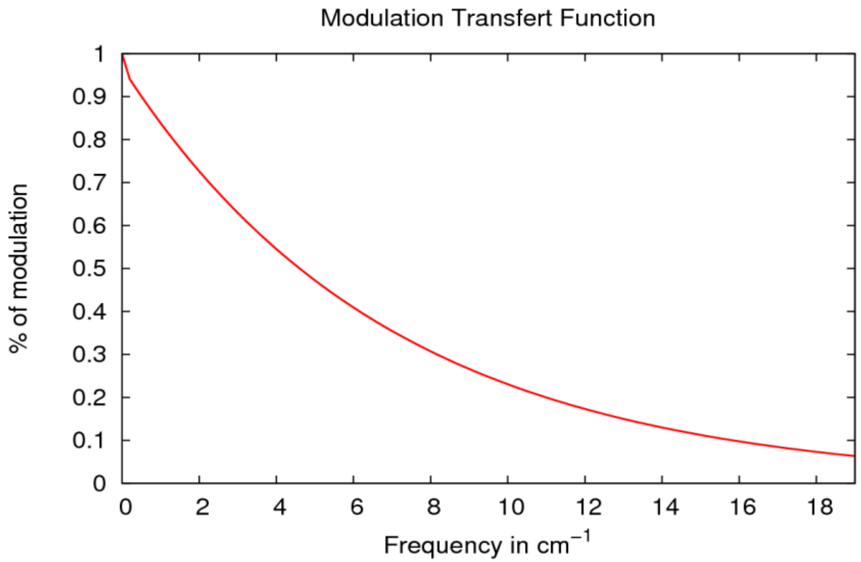
- **Preliminary results presented at the QNDE 2011 conference show a good accuracy between experiment and simulation for the 6 large notches inside the mock-up.**

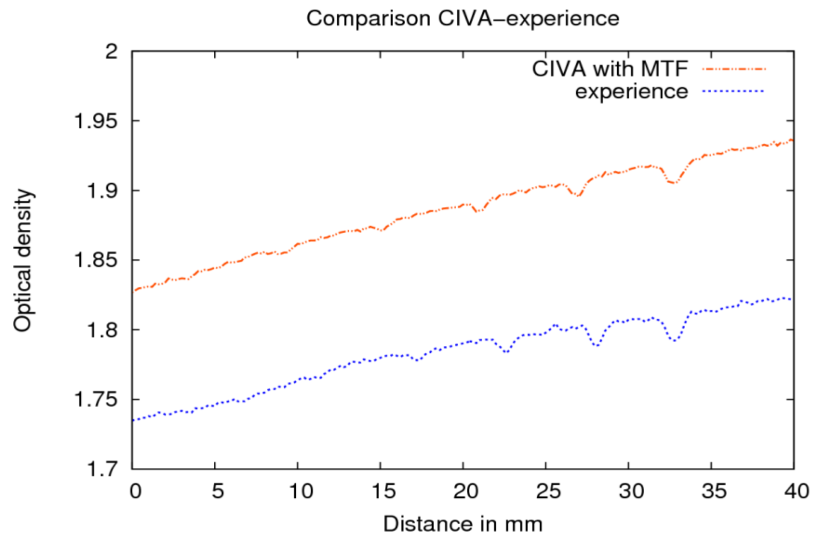
- **Importance of the modulation transfert function on the simulation accuracy**
  - » **Results on IQI profile**



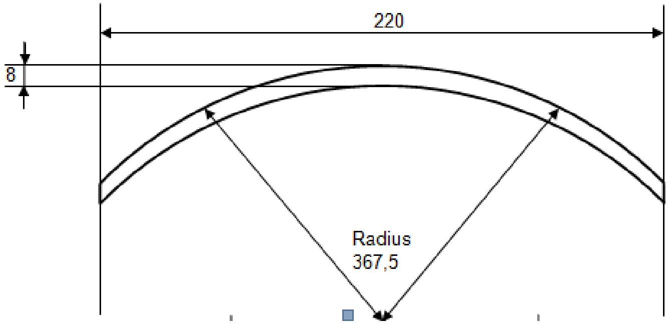


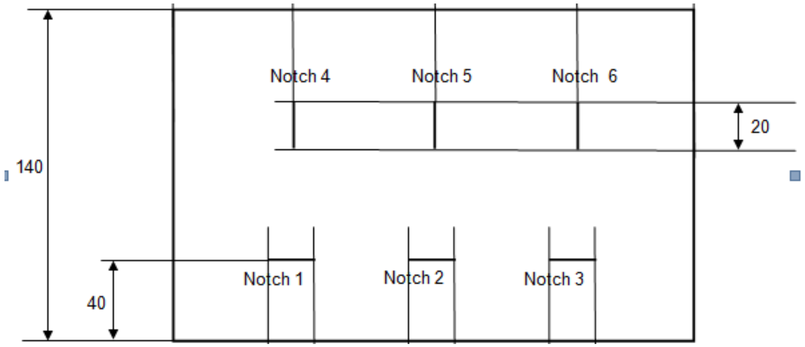
  - » **MTF estimation with an edge**





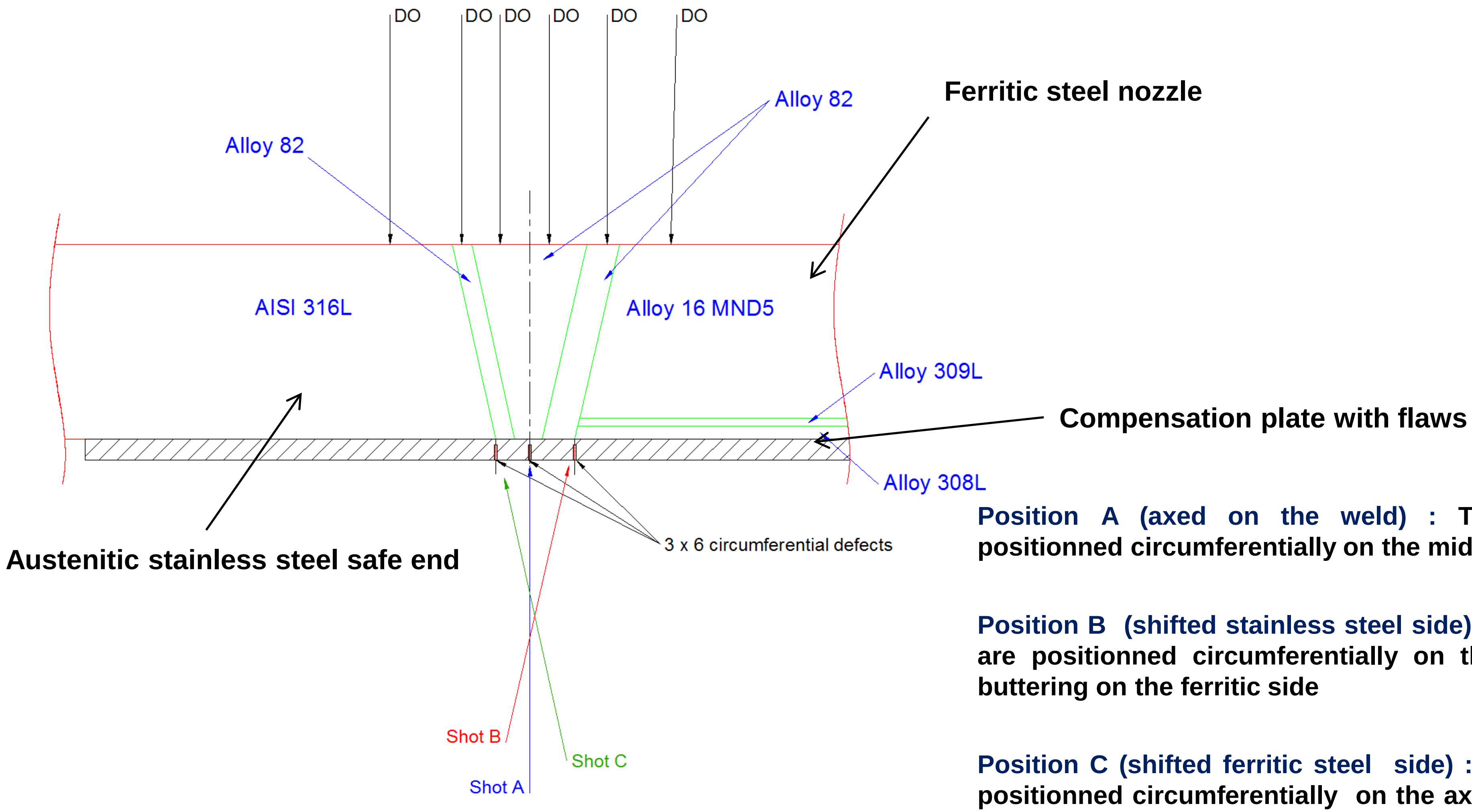
- **The aim of the following study is to validate CIVA with notches with a very small opening from 20 µm to 150 µm, a heigh of 6mm an a length of 20 mm . A compensation plate has been manufactured in order to obtain a mock-up with different flaws and different orientation (circumferential and axial).**





Référence	Name	Length (mm)	Height (mm)	Opening (mm)
Notch 1	C1E1-6-20	20	6	0,020
Notch 2	C1E2-6-40	20	6	0,040
Notch 3	C1E3-6-60	20	6	0,060
Notch 4	C1E4-6-80	20	6	0,080
Notch 5	C1E5-6-100	20	6	0,100
Notch 6	C1E6-6-150	20	6	0,150

- **Validation set-up, circumferential flaws**

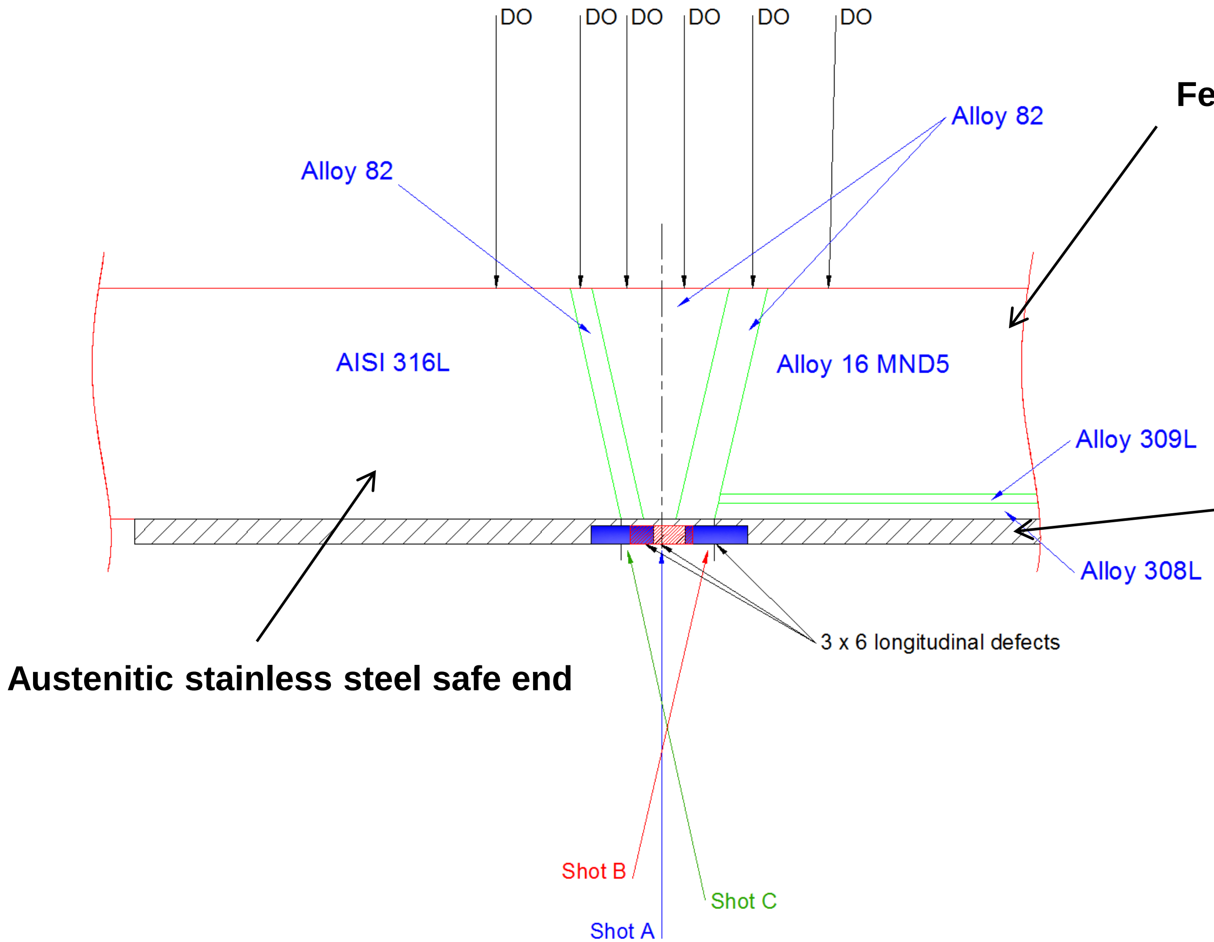


Position A (axed on the weld) : The notches are positionned circumferentially on the middle of the weld

Position B (shifted stainless steel side) : The notches are positionned circumferentially on the axe of the buttering on the ferritic side

Position C (shifted ferritic steel side) : The notches are positionned circumferentially on the axe of the buttering on the stainless steel side

- **Validation set-up, axial flaws**



Position A (axed on the weld) : The notches are positionned axially on the middle of the weld

Position B (shifted stainless steel side) : The notches are positionned axially on the axe of the buttering on the ferritic side

Position C (shifted ferritic steel side) : The notches are positionned axially on the axe of the buttering on the stainless steel side

- **Experimental and simulation parameters**
  - Co60 and Iridium 192 gamma source
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  - KodaK M100
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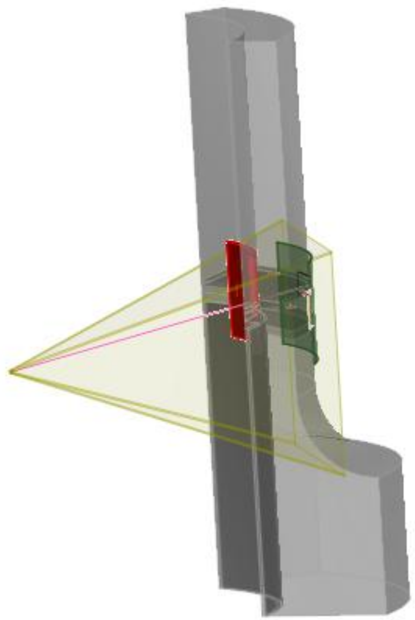
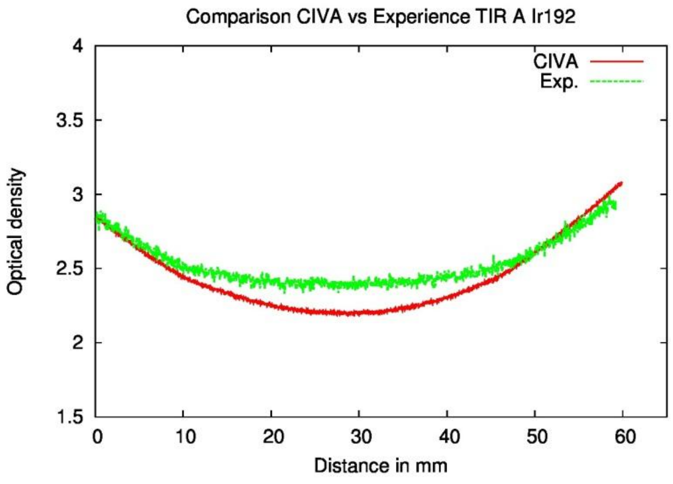
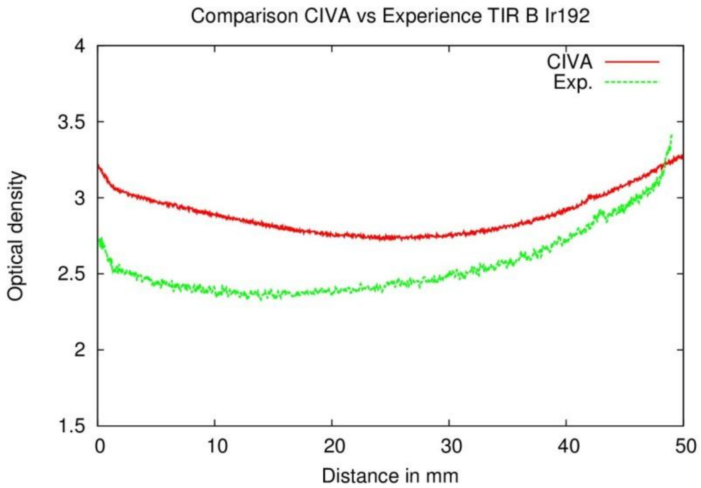
Experimental

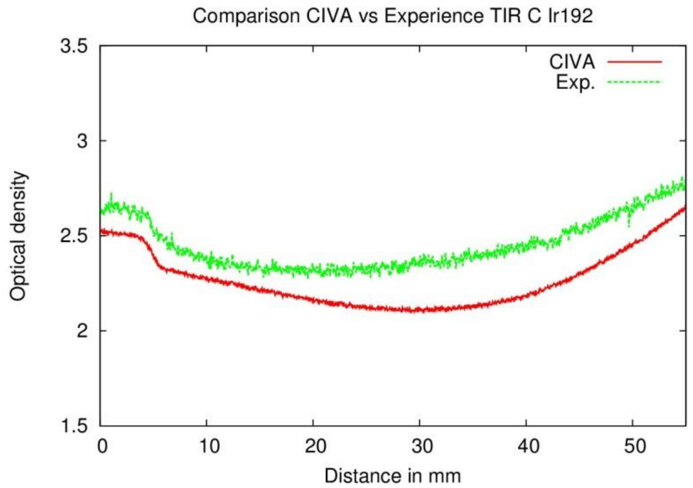
Simulation



- **Optical density comparison**







- **The maximum relative error between CIVA and experimental result is about 15 %. This is probably due to the scattered beam which is quite important with the ^{192}Ir source. The simulations show a build-up (ratio between scattered and direct beam) of 5.**

- **Optical density amplitude and width comparison**

	flaw	Measured Amplitude	Simulated amplitude	Measured width at middle height in mm	Simulated width at middle height in mm
Position A circumferential flaw	C1E1-6-20	0,011	0,008	0,53	0,55
	C1E2-6-40	0,011	0,010	0,51	0,52
	C1E3-6-60	0,013	0,013	0,69	0,71
	C1E4-6-80	0,025	0,015	0,61	0,64
	C1E5-6-100	0,031	0,018	0,67	0,61
	C1E6-6-150	0,041	0,020	0,61	0,63

Position A Axial flaw	C1E1-6-20	NC	NC	NC	NC
	C1E2-6-40	0,011	0,010	0,61	0,55
	C1E3-6-60	0,014	0,011	0,62	0,58
	C1E4-6-80	0,025	0,016	0,58	0,57
	C1E5-6-100	0,030	0,019	0,65	0,61
	C1E6-6-150	0,042	0,028	0,69	0,62

- **Optical density amplitude and width comparison**

	flaw	Measured Amplitude	Simulated amplitude	Measured width at middle height in mm	Simulated width at middle height in mm
Position B circumferential flaw	C1E1-6-20	NC	NC	NC	NC
	C1E2-6-40	NC	NC	NC	NC
	C1E3-6-60	NC	NC	NC	NC
	C1E4-6-80	0,002	0,005	1,31	1,44
	C1E5-6-100	0,009	0,007	1,44	1,38
	C1E6-6-150	0,026	0,021	1,65	1,67

Position B axial flaw	C1E1-6-20	0,008	0,005	0,56	0,59
	C1E2-6-40	0,016	0,010	0,61	0,58
	C1E3-6-60	0,020	0,015	0,64	0,61
	C1E4-6-80	0,024	0,021	0,61	0,68
	C1E5-6-100	0,035	0,026	0,59	0,69
	C1E6-6-150	0,050	0,032	0,62	0,64

- **Optical density amplitude and width comparison**

	flaw	Measured Amplitude	Simulated amplitude	Measured width at middle height in mm	Simulated width at middle height in mm
Position C circumferential flaw	C1E1-6-20	NC	NC	NC	NC
	C1E2-6-40	NC	NC	NC	NC
	C1E3-6-60	NC	NC	NC	NC
	C1E4-6-80	NC	NC	NC	NC
	C1E5-6-100	NC	NC	NC	NC
	C1E6-6-150	NC	NC	NC	NC

Position C axial flaw	C1E1-6-20	0,009	0,008	0,52	0,56
	C1E2-6-40	0,012	0,015	0,59	0,67
	C1E3-6-60	0,018	0,019	0,59	0,53
	C1E4-6-80	0,023	0,027	0,64	0,56
	C1E5-6-100	0,035	0,035	0,67	0,59
	C1E6-6-150	0,046	0,045	0,58	0,59

- Conclusions

→The comparisons between CIVA and experimental data show a good adequation. The maximal errors are observed in high optical density gradient (position B and C) do to the measuring difficulty. However, all the flaws detected on the radiographic film are detected on the simulated film. The non detected flaws on the simulation are not detected on the radiographic film.

→For the B position with circumferential flaw, the smallest notches are not detected because there are in a area with an important optical density gradient

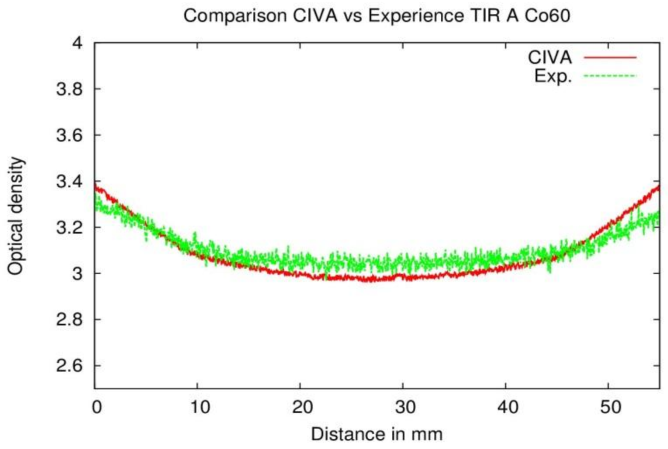
→For the B position with circumferential flaw, the smallest notches are not detected because there are in a area with an important optical density gradient.

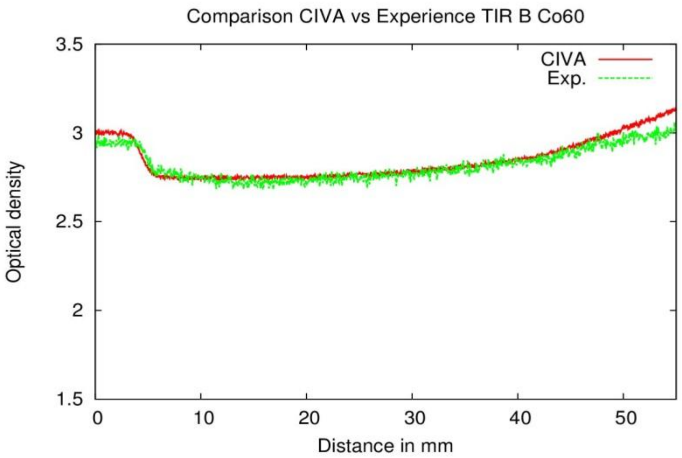
→ The absolute error in term of optical density are more important for the B and C position (influence of scattered beam, the build-up is more important)

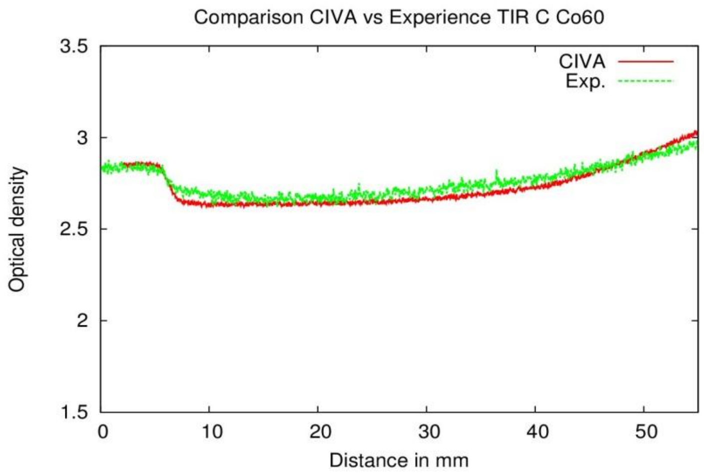
→ The maximal error are observed for the smallest flaws.

→ The comparisons show that the simulation tend to underestimate the flaw amplitude and over estimate the flaws width. The effects are probably due to the modulation transfert function estimation (response on the film)

- **Optical density comparison**







- **The difference between CIVA and experimental results are much smaller for the cobalt 60 results probably due to the build-up. The simulations show a build-up (ratio between scattered and direct beam) of 3 (in comparison of 5 with ^{192}Ir).**

- **Optical density amplitude and width comparison**

	flaw	Measured Amplitude	Simulated amplitude	Measured width at middle height in mm	Simulated width at middle height in mm
Position A circumferential flaw	C1E1-6-20	0,007	0,005	0,60	0,74
	C1E2-6-40	0,014	0,011	0,99	0,85
	C1E3-6-60	0,018	0,010	0,70	0,84
	C1E4-6-80	0,023	0,019	0,75	0,83
	C1E5-6-100	0,035	0,025	0,78	0,88
	C1E6-6-150	0,047	0,035	0,79	0,91

Position A axial flaw	C1E1-6-20	0,006	0,005	0,52	0,47
	C1E2-6-40	0,009	0,009	0,69	0,72
	C1E3-6-60	0,016	0,012	0,97	0,71
	C1E4-6-80	0,021	0,020	0,91	0,85
	C1E5-6-100	0,021	0,022	0,87	0,82
	C1E6-6-150	0,036	0,036	0,91	0,84

- **Optical density amplitude and width comparison**

	flaw	Measured Amplitude	Simulated amplitude	Measured width at middle height in mm	Simulated width at middle height in mm
Position B circumferential flaw	C1E1-6-20	NC	NC	NC	NC
	C1E2-6-40	NC	NC	NC	NC
	C1E3-6-60	NC	NC	NC	NC
	C1E4-6-80	0,013	0,010	1,54	1,36
	C1E5-6-100	0,015	0,012	1,65	1,43
	C1E6-6-150	0,022	0,018	1,69	1,57

Position B axial flaw	C1E1-6-20	0,008	0,008	0,89	0,99
	C1E2-6-40	0,011	0,012	0,98	0,92
	C1E3-6-60	0,020	0,015	0,92	0,81
	C1E4-6-80	0,022	0,024	0,99	0,90
	C1E5-6-100	0,033	0,030	1,00	0,89
	C1E6-6-150	0,042	0,042	0,99	0,88

- **Optical density amplitude and width comparison**

	flaw	Measured Amplitude	Simulated amplitude	Measured width at middle height in mm	Simulated width at middle height in mm
Position C circumferential flaw	C1E1-6-20	NC	NC	NC	NC
	C1E2-6-40	NC	NC	NC	NC
	C1E3-6-60	NC	NC	NC	NC
	C1E4-6-80	NC	NC	NC	NC
	C1E5-6-100	NC	NC	NC	NC
	C1E6-6-150	NC	NC	NC	NC

Position A axial flaw	C1E1-6-20	0,005	0,003	1,13	0,87
	C1E2-6-40	0,007	0,008	1,04	0,98
	C1E3-6-60	0,012	0,011	1,09	0,95
	C1E4-6-80	0,019	0,017	0,95	0,89
	C1E5-6-100	0,022	0,021	0,98	0,95
	C1E6-6-150	0,032	0,030	1,01	0,91

- Conclusions

→The comparisons between CIVA and experimental data show a good accuracy. The maximal errors are observed in high optical density gradient (position B and C) do to the measuring difficulty. However, all the flaws detected on the radiographic film are detected on the simulated film. The non detected flaws on the simulation are not detected on the radiographic film.

→For the B position with circumferential flaw, the smallest notches are not detected because there are in a area with an important optical density gradient

→For the C position with circumferential flaw, the flaws are detected with a lot of difficulties. There is a important uncertainty to say if the flaws are detected.

→ The absolute error in term of optical density are less important for the cobalt 60 source in comparison with ^{192}Ir source.

→ The maximal error are observed for the smallest flaws.

→ The comparisons show that the simulation tend to underestimate the amplitude and the width of the flaws. The effects are probably due to the Modulation Transfert function estimation (response on the film)

- **Validation of the simulation model for the EN584-1 film type in the scope of large thickness component**

  → **Experimental validation on dissimilar weld + flaw plate with ^{192}Ir and ^{60}Co source**

  → The comparisons between CIVA and experimental data show a good accuracy. The maximal errors are observed in high optical density gradient (position B and C) do to the measuring difficulty. However, all the flaws detected on the radiographic film are detected on the simulated film. The non detected flaws on the simulation are not detected on the radiographic film The absolute error is more important for the ^{192}Ir source (scattered beam).

  → The most important error are observed for the smallest flaws.

  → With ^{192}Ir source, the comparisons show that the simulation under-estimate the flaw amplitude and overestimate the flaw width.

  → With ^{60}Co source, the comparisons show that the simulation under-estimate the amplitude and the width of the flaws.

- **Perspectives for 2012**

  → **Experimental validation on a stainless steel cast mockup**

  → Single wall, panoramic exposure with ^{192}Ir source

  → Double wall, source on contact with ^{60}Co source

  → **Experimental validation on small diameter pipes (< 100 mm)**