RT Modelling for NDT
Recent and Future Developments in the CIVA RT/CT Module

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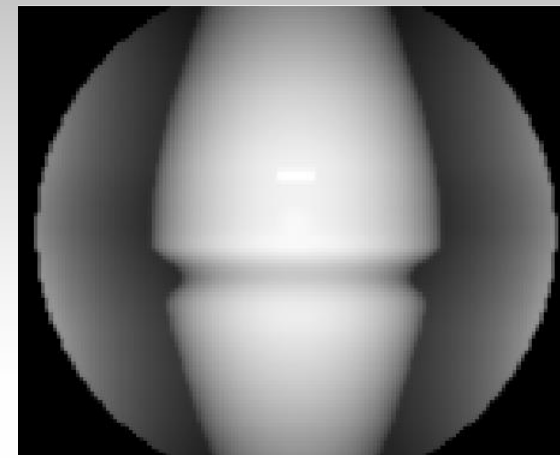
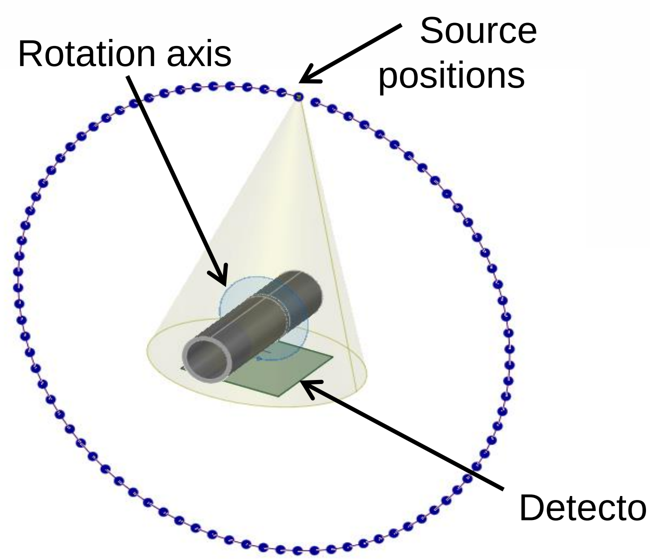
Summary

- CIVA RT platform
  - Models
  - Recent improvements
- CIVA CT platform
  - Models
  - Recent improvements
- Conclusion and on-going works





CIVA RT platform

- Collaboration of different entities:
  - CEA-LETI (fusion of Monte Carlo and analytical models, detectors model),
  - EDF (Ray tracing and Monte Carlo, detector model),
  - CEA-LIST (integration in the CIVA platform, GUI, detector models).
- Simulation of a global radiographic inspection taking into account the most influential parameters:
  - Sources,
  - Specimen geometries (2.5D, 3D, etc.), materials,
  - Detector (films, DR and CR),
  - Flaws,
  - IQI…
- Performance demonstration and qualification of methods, POD.
- Definition and validation of radiographic procedures.

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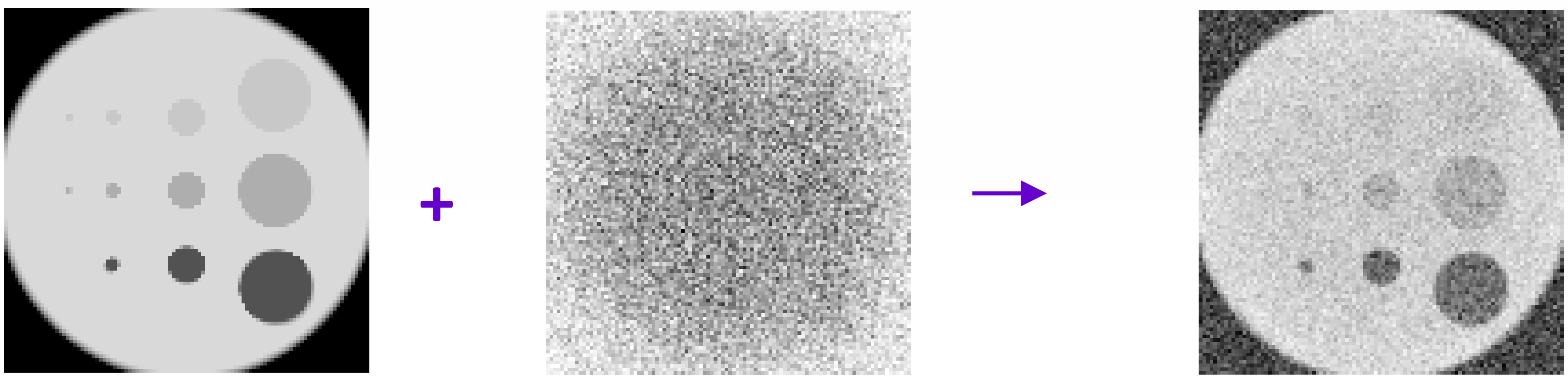
CIVA RT platform: Models

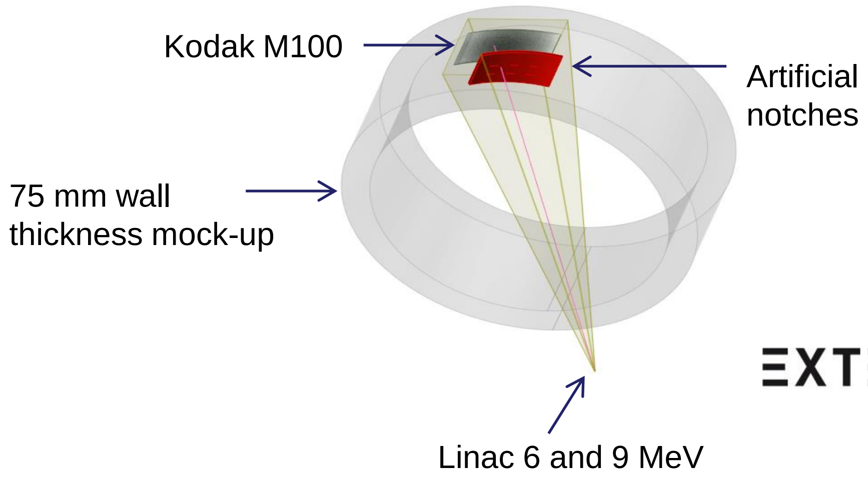
- Models account for
  - Analytical method: (Beer-Lambert law) to model direct radiation
  - Probabilistic method (Monte-Carlo approach) to model scattering phenomena
    - Compton interaction
    - Rayleigh interaction
    - Photoelectric absorption
    - Pair creation

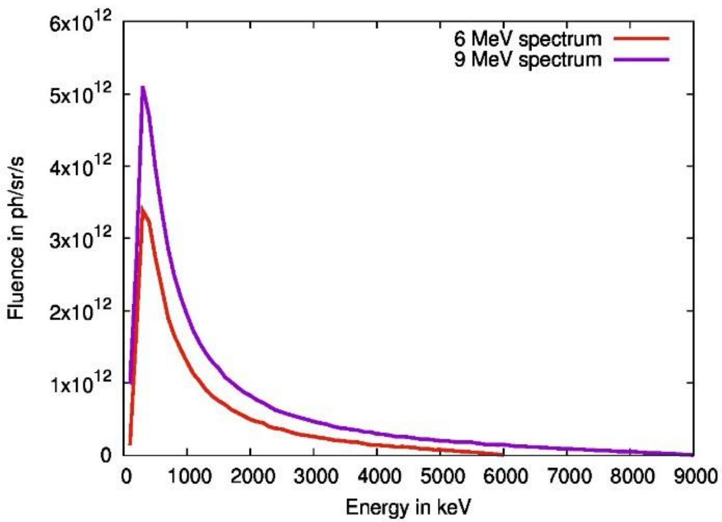


Direct radiation | Scattered radiation | Final image

CIVA RT platform: Recent developments

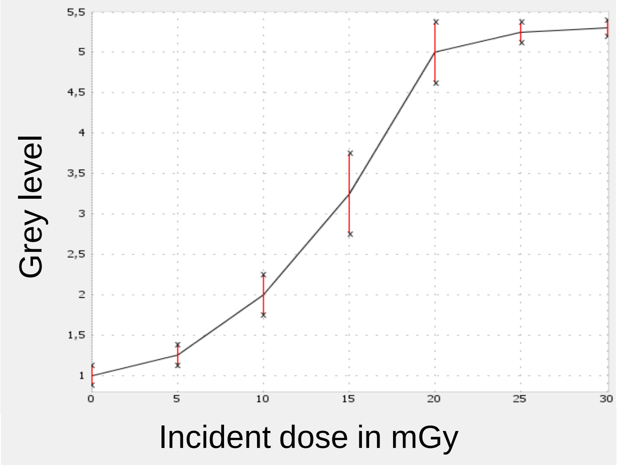
- High Energy sources
  - CIVA RT lets you easily model X-Ray spectra (from low keV to 450 keV) and Gamma sources such as Co60, Ir192, Se75
  - In addition to the sources already available the CIVA 2016 version has additional options allowing to model high energy sources:
    - Linear accelerator of 4, 6 and 9 MeV
    - “Betatron” of 2, 6, 7.5 and 9 MeV
  - Validations were achieved in a collaboration work between the CEA and the IRSN: “First validation of CIVA RT Module with a LINAC in a nuclear context”, WCNDT 2016)





CIVA RT platform: Recent developments

- Generic detector
  - With CIVA RT you can model grey level images for digital detectors and films (model developed by EDF where the deposited energy is converted to a gray value and then into optical density given the film modelled)
  - A new model called “generic detector” was recently implemented in CIVA and defined from experimental data. The goal are to:
    - Model a realistic detector with a minimum experimental calibration process
    - Upload a simple calibration file with the transfer function between measured incident dose and grey level
    - Measurements can be easily done with a step wedge where the Grey level will be extracted at the different material thicknesses



Incident dose	Grey level	Standard deviation
0	1	0.25
5	1.25	0.25
10	2	0.5
15	3.25	1
20	5	0.75
25	5.25	0.25
30	5.3	0.2

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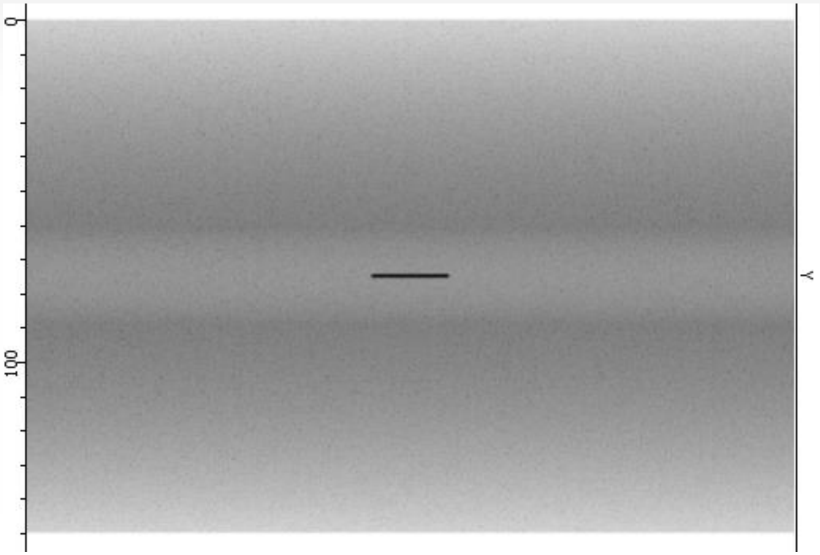
CIVA RT platform: Recent developments

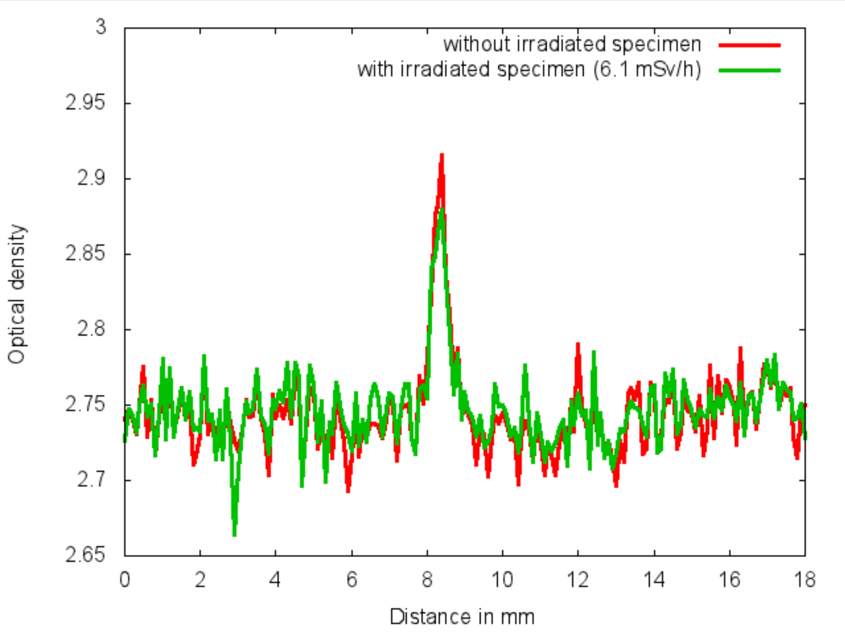
- Irradiated specimen
  - For nuclear applications, and in order to consider the potential presence of radioactive substances within solids that will have an impact on the darkening of the film a new functionality has been developed and integrated in CIVA 2016
  - This new model considers the influence of radioactive contamination on a cassette-film being in contact with an radioactive part
  - This additional dose is accounted for in the computation and in the final conversion of the dose to optical density on the radiogram. The final result corresponds to an offset on the dose value (dose * build-up + contact dose rate)
  - Application on a welded pipe with a 40 inches OD and a single wall thickness of 50 mm
    - Ir192 source of 4400 GBq centered in the middle of the pipe
    - “M100” film, source to film distance = 500 mm

CIVA RT platform: Recent developments

- Irradiated specimen : example
  - Simulation on a “clean” component and a contaminated one where additional parasitic dose of 6.1 mSv/h is considered:



Simulation on the non irradiated part



Optical density profiles for a clean configuration and a second one with parasitic dose

CIVA RT platform: Recent developments

- Detectability criteria
  - In RT, observation and statement of an indication is directly linked to the human eye.
  - There is no criterion of "universal" visibility / detectability of flaws and IQIs for simulated radiography. However, at least one detectability criterion is required for an automatic analysis study of a given set-up.
  - In this framework criteria were integrated in CIVA in order to provide an automatic detectability threshold
    - The detectability criteria help the user to determine whether the simulated flawis seen or not for a given configuration.
    - They are based on comparisons of contrast to noise ratio on the images with and without flaw.
  - Since CIVA 2015 version, the so-called Rose criterion has been integrated and adapted to match with radiogram

$$Rose\ criterion = \frac{Mean\ grey\ value\ in\ the\ flaw\ - Mean\ grey\ value\ in\ the\ flaw\ vicinity}{Max(variance\ in\ the\ flaw,\ \ variance\ in\ the\ flaw\ vicinity)} \times \sqrt{surface}$$

CIVA RT platform: Recent developments

- Detectability criteria
  - The Rose criterion shows its limits for elongated flaws (Rose is strictly validated for circular shapes)
  - Therefore, a new criterion is now available: the **Fuchsia** one:
    - Based on the Rose model, the Fuchsia criterion depends on the signal value, the noise level, the surface of the indication.
    - Calculation of the contrast value $C = \left\| OD_{flaw} - OD_{bg} \right\|$
    - Calculation of the noise level $\sigma_D^{eye} = \sigma_D^{simu} \times \frac{pixel\_size}{eye\_resolution}$

With σ_D^{eye} the noise level corrected from the size of the pixel

σ_D^{simu} the noise level calculated in CIVA (dependent of the pixel size)

eye_resolution = 120 µm (for an eye to film distance equal to 40 cm)

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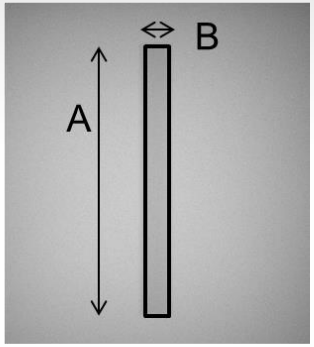
CIVA RT platform: Recent developments

- Detectability criteria
  - Calculation of the surface of the flaw with a generalization from circular to elongated cracks:
    - Surface S_{eq} of a circular shape of equivalent visibility $S_{eq} = \frac{\emptyset^2}{4} \times \pi$

      With $\emptyset = 2.5 \times B$*: diameter equivalent to hole to match with Rose*

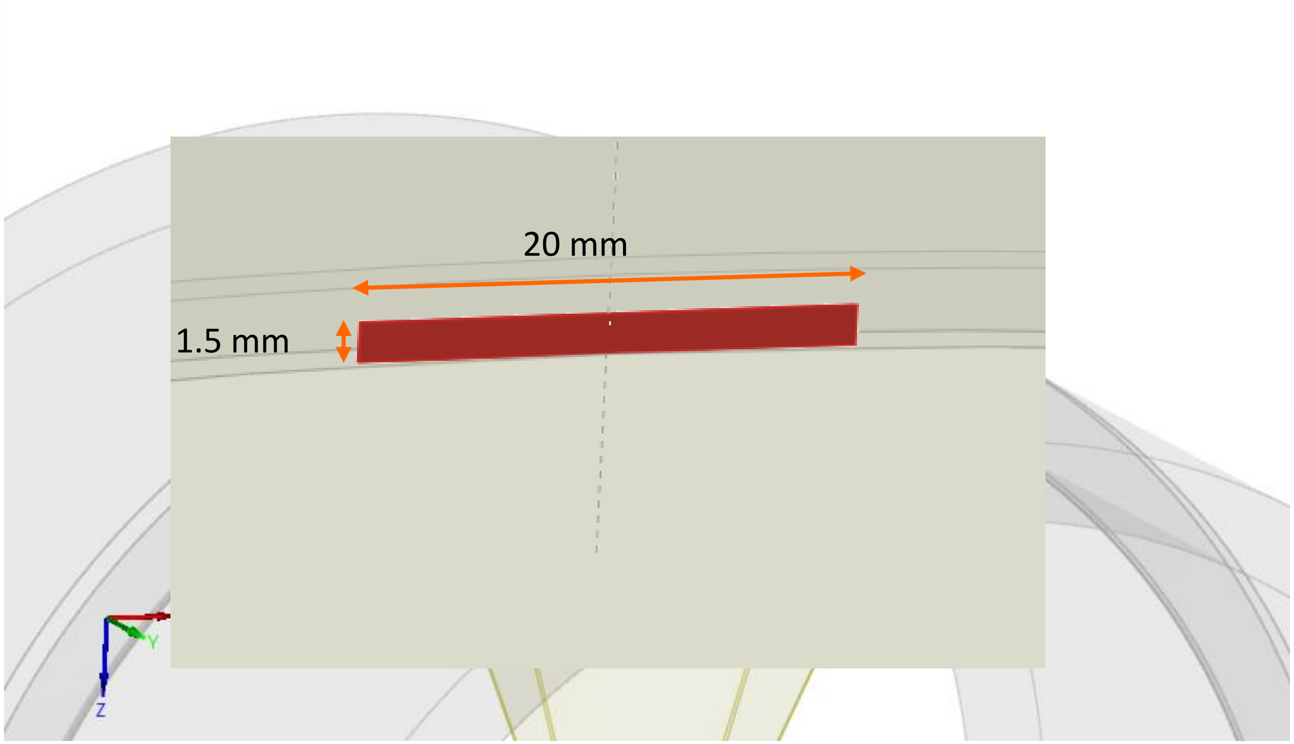
    - Above 1.6mm², a larger surface of the flaw does not imply a better detectability:
      - →Surface $S = \min(S_{eq}, 1.6)$



  - Finally, $Criterion = \frac{C}{\sigma_D^{eye}} \times \sqrt{S}$
  - Validations were achieved and a detectability threshold of 1.5 is the most suited for determining the detectability of the defects: "*A New Detectability Criterion for Conventional Radiography*, WCNDT 2016.

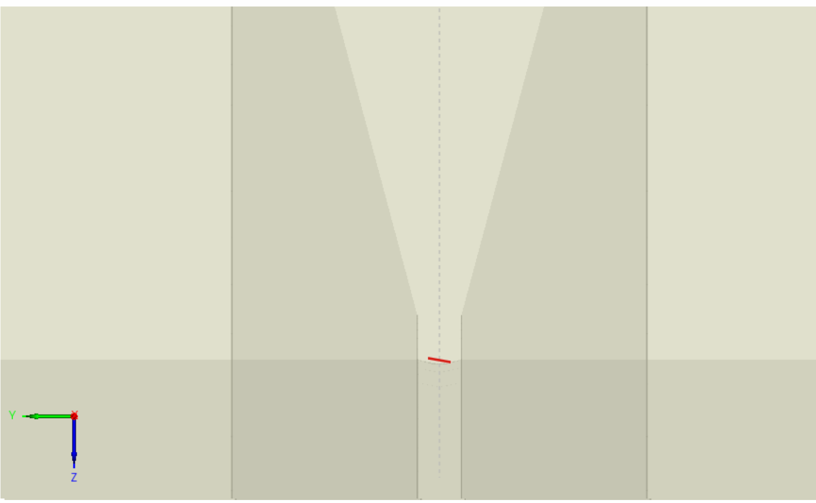
CIVA RT platform: Recent developments

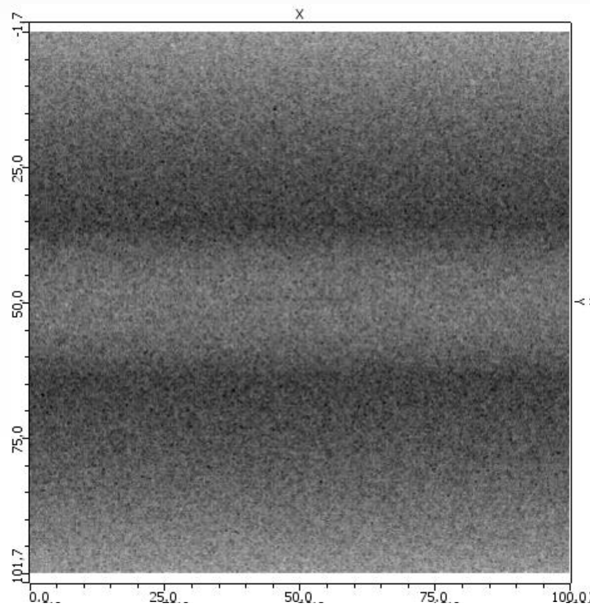
- Detectability criteria: Fuchsia
  - Impact of the variation of the tilt angle from 0 to 80° of a rectangular notch on the detectability criteria:
    - Same configuration as for the “irradiated” application
    - Flaw aperture of 100 µm



CIVA RT platform: Recent developments

- Detectability criteria: Fuchsia
  - Impact of the variation of the tilt angle from 0 to 80° of a rectangular notch on the detectability criteria:
    - Same configuration as for the “irradiated” application





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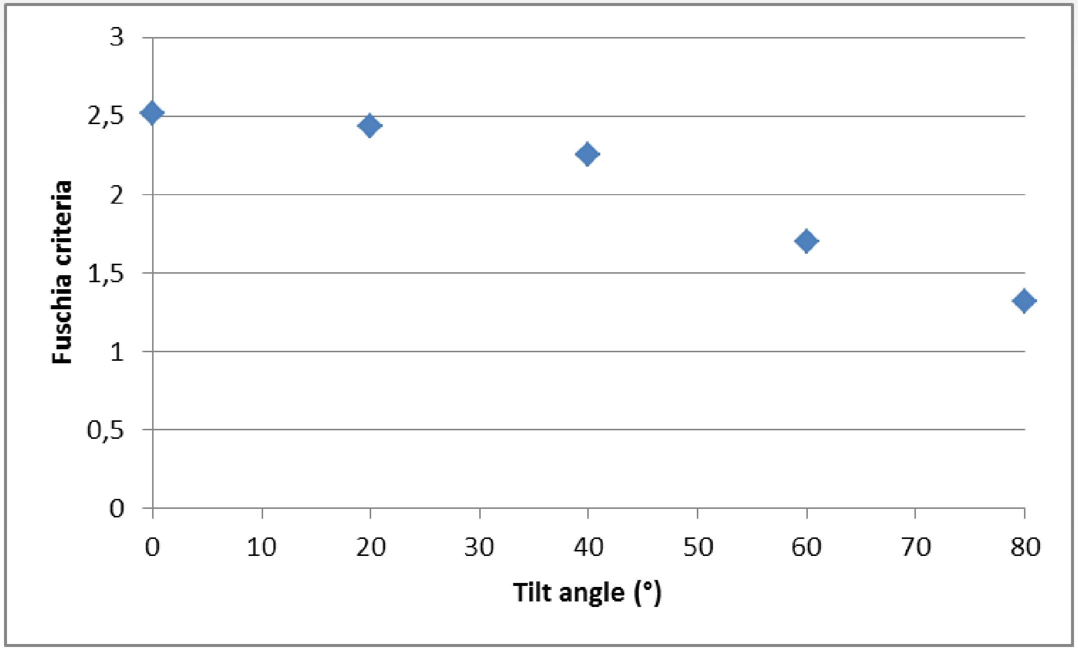
CIVA RT platform: Recent developments

- Detectability criteria: Fuchsia
  - Impact of the variation of the tilt angle from 0 to 80° of a rectangular notch on the detectability criteria:



  - → the limit of detection is for a tilt angle around 60°

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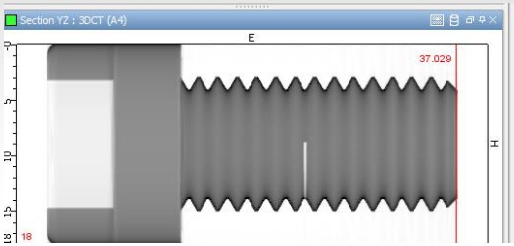
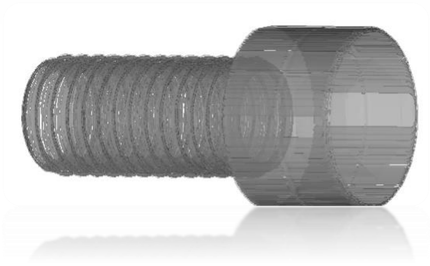
CIVA CT platform

- Based on the RT module for :
  - Geometries
  - Sources,
  - Digital detectors
  - Flaws
  - Computation options (direct and scattered radiation)



- Specific « CT » parameters
  - Projections angles / positions
  - Number of projections
  - Reconstruction algorithms
  - Post processing
  - Import of experimental projections



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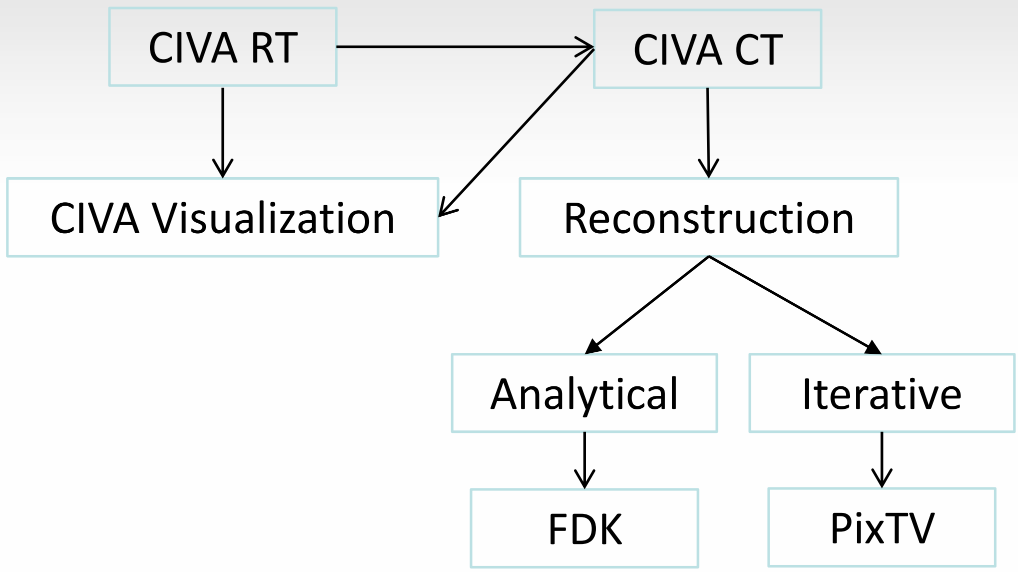
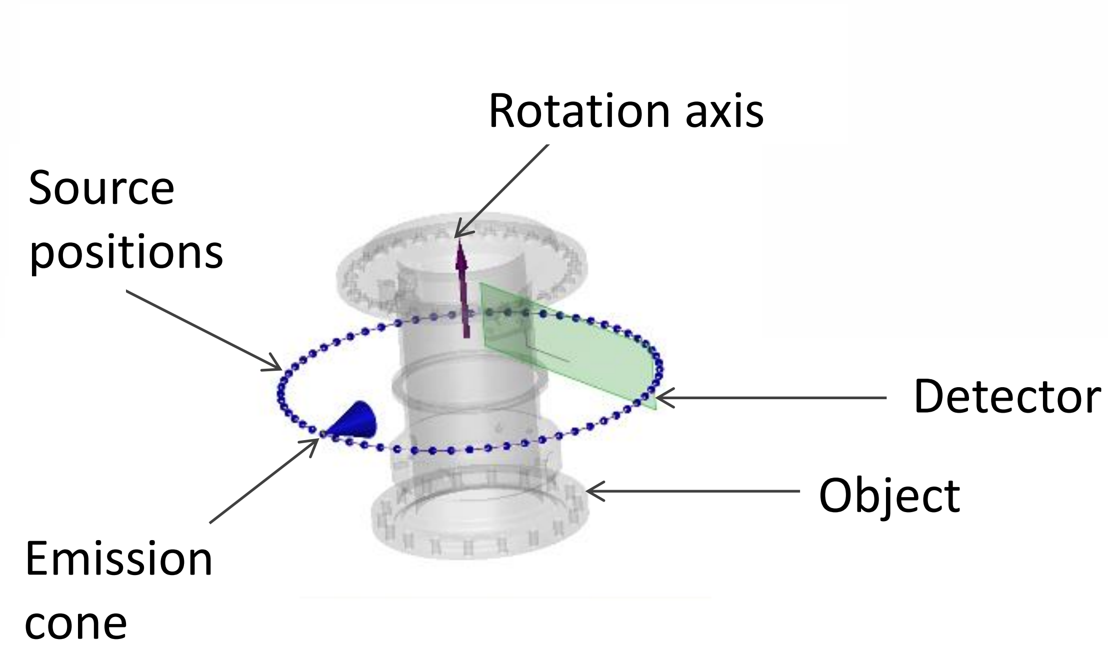
CIVA CT platform

- Computed Tomography module in CIVA





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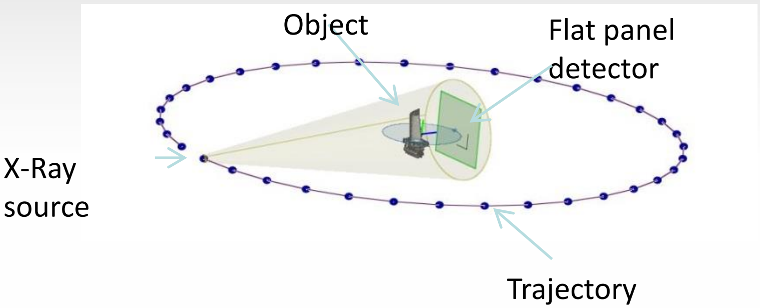
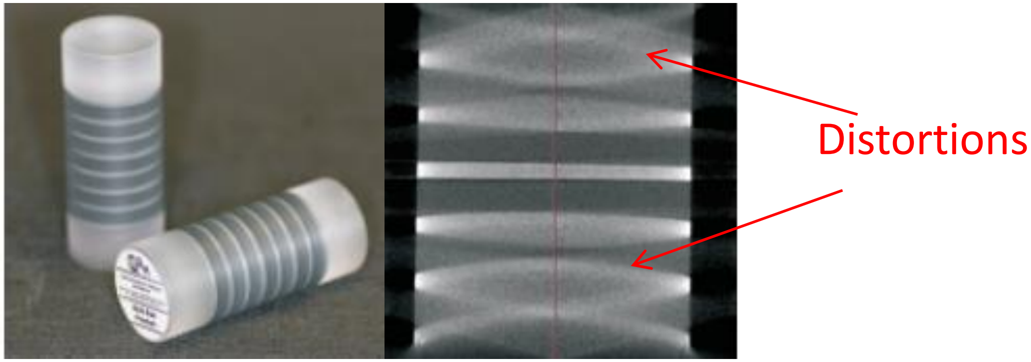
CIVA CT platform: Recent developments

- New Helical scan for Computed Tomography
  - Initially only the circular trajectory was modelled in CIVA for Computed Tomography simulations

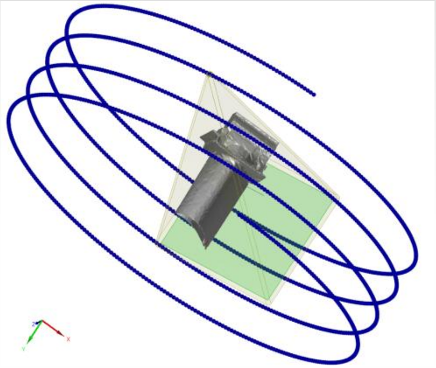


  - The circular trajectory provides theoretically exact reconstructions only in the central plane of the object
  - However, when inspecting a long object, this acquisition geometry leads to severe artifacts in the reconstructed image

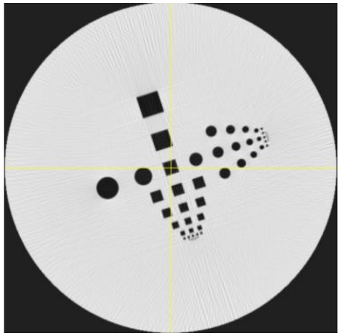


CIVA CT platform: Recent developments

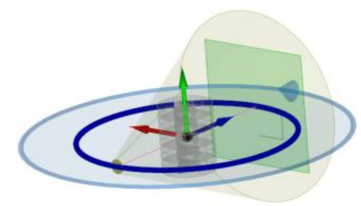
- New Helical scan for Computed Tomography
  - Helical or partially helical trajectories allow to handle this problem and theoretically exact algorithms are now integrated in CIVA 2016
  - Simulation of CT scan with circular/helical scan in CIVA RT/CT



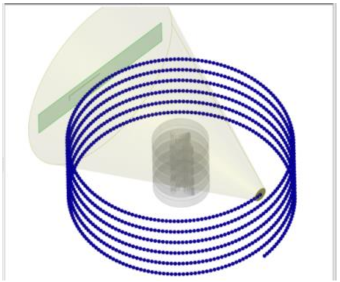
Stack of 5 disks with tomographic phantoms

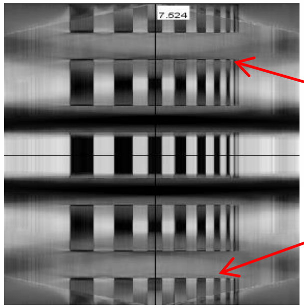


Circular scan

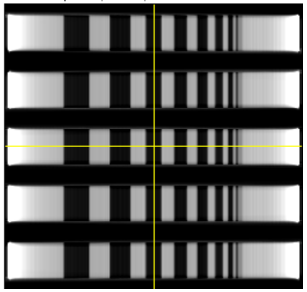


Helical scan





Distortions



Accurate reconstructions for all disks

Conclusion and future works

- CIVA RT - CT is in continuous improvements with an increase of the scope of applications
  - High Energy sources
  - Irradiated specimen
  - New detector based on experimental results
  - New detectability criterion
  - Helical trajectories and optimized reconstruction algorithm for such trajectory
  - …
- On-going developments:
  - Improvement of the Monte-Carlo algorithm to account for the electron paths
  - advanced trajectories for CT: Short scan or robotic trajectories
  - Iterative reconstruction algorithms based on standard iterative approach (SART and OSEM) are under development to address such complex trajectories with Nvidia CUDA implementation
  - Development of a method for correction of scattering due to object and detector together (Scatter Kernel Superposition deconvolution method with a continuous approach)