First Validation of CIVA RT Module with a Linear Accelerator in a Nuclear Context

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Abstract. X-ray/gamma ray radiography is a commonly used non-destructive evaluation method. For several years, a research program funded by the French Institute for Radioprotection and Nuclear Safety (IRSN), in partnership with French Alternative Energies and Atomic Energy Commission (CEA), studies gamma/X-ray simulation tools for evaluating NDE methods in the nuclear domain. In the context of this program, IRSN is particularly interested in the validation of the RT module of CIVA software, which deals with a large range of energy. The aim of this paper is to present results of CIVA RT tools validation. The study consists in a cross comparison between experimental and simulation results with a linear accelerator and a 150 mm thick mockup. These have been carried out on very small opening notches (20 microns to 150 microns).

Introduction

X-ray/gamma ray radiography is a commonly used non-destructive evaluation method. For several years, a research program funded by the French Institute for Radioprotection and Nuclear Safety (IRSN), in partnership with CEA, studies gamma/X-ray simulation tools for evaluating NDE methods in the nuclear domain. In this context, IRSN has started in 2010 a program over several years for the validation of CIVA RT module [1-5]. In the view of the inspection of high thickness component, we have started a validation program of CIVA RT with linear accelerator model. The aim of this paper is to present first results of CIVA RT. The study consists in a cross comparison between classical X-ray films and simulation results in the case of high thickness cast steel mock-up (150 mm thick) . These have been carried out on very small openings notches (20 microns to 150 microns).

1. Material and methods

We used a cylindrical cast steel mock-up representative of typical nuclear component with an internal diameter of 937 mm and 75 mm thickness. This mock-up is made of 304L alloy (see figure 1). Six notches with several sizes (a height of 6 mm and an opening from 20 µm to 150 µm), orientations (axial or circumferential) and positions have been superimposed to the weld thanks to a manufactured insert (see figure 2 and table 1).

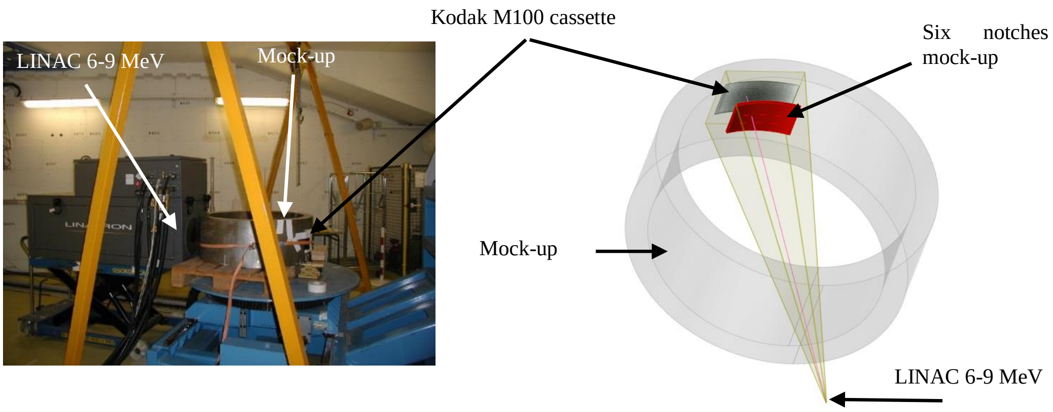

Fig. 1. On the left, real set-up. On the right, simulation set-up with CIVA RT.

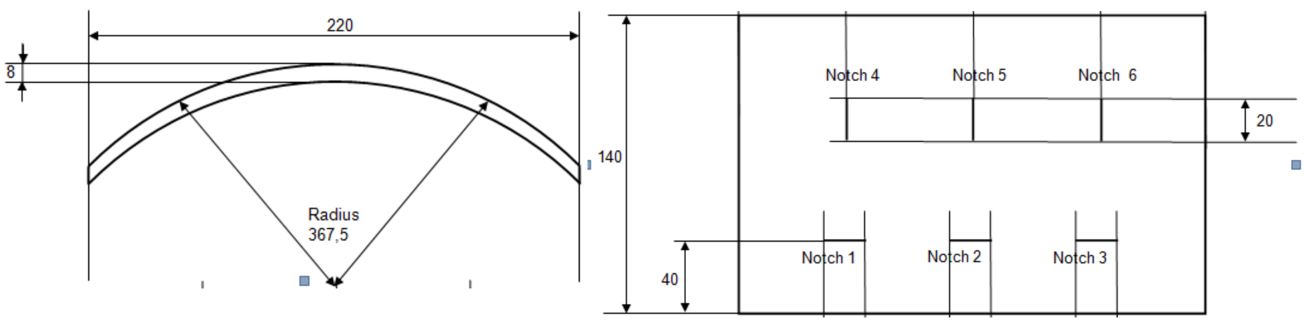

Fig. 2. Schema of the insert with the 6 notches.

Table 1. Description of the six notches.

Reference	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

For this validation, the notches are positioned in a circumferential and a longitudinal configuration (see figure 3) with three different source position (see figure 4).

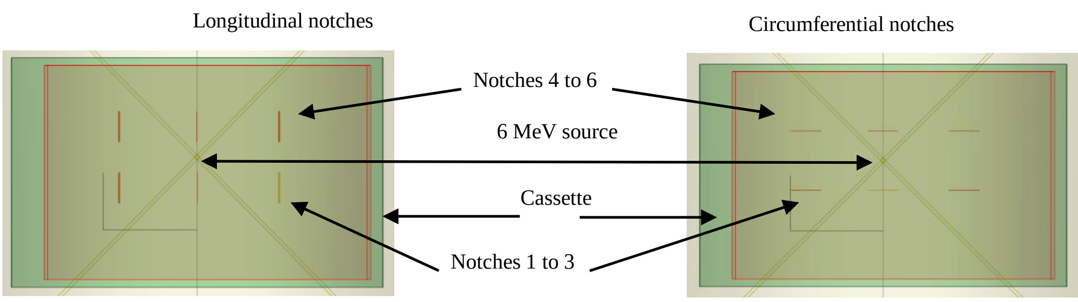

Fig. 3. Schema of the insert position (on the left, longitudinal position, on the right circumferential position).

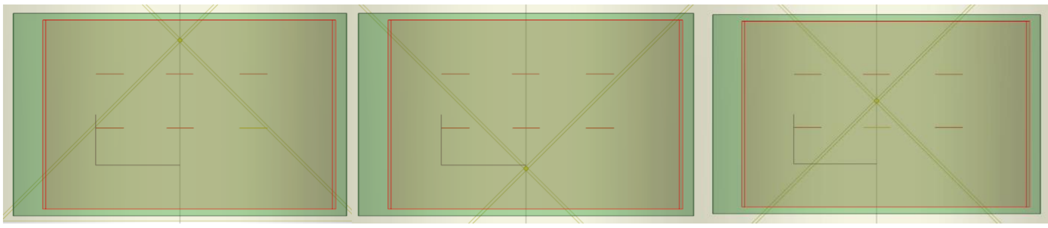

Fig. 4. Schema of the source position. On the left, source shifted to +45 mm. In the middle, source centred. On the right, source shifted to -50 mm.

Filters and reinforced used screens are in conformity with the French Regulatory requirements and design code (RCC-M) and European standard [9]. The films are digitized with a Ge FS50B scanner with a pixel size of 50 µm x 50 µm.

For this study, we used CIVA 2016 version. Given the context of thick components, we used the fusion approach of scattered and transmitted images respectively from Monte Carlo and analytical computations to simulate the final images [6]. The detector model (Gray model) developed by EDF [7] is based on the European standard EN 584-1 [8] and converts the incident dose into an optical density value. A decomposition of the source into several small source points allowed the simulation of the source blurring. For this study, the source has been decomposed into 20 sources point. We used a 6 and 9 MV linear accelerator spectrum simulated with Penelope [10] Monte Carlo code (see figure 5).

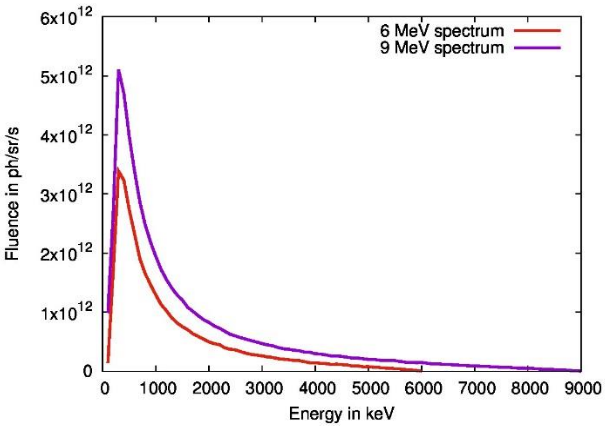

Fig. 5. 6 – 9 MV spectrum of the linear accelerator.

Optical density profiles have been extracted from the several images on the different notches (see figure 6).

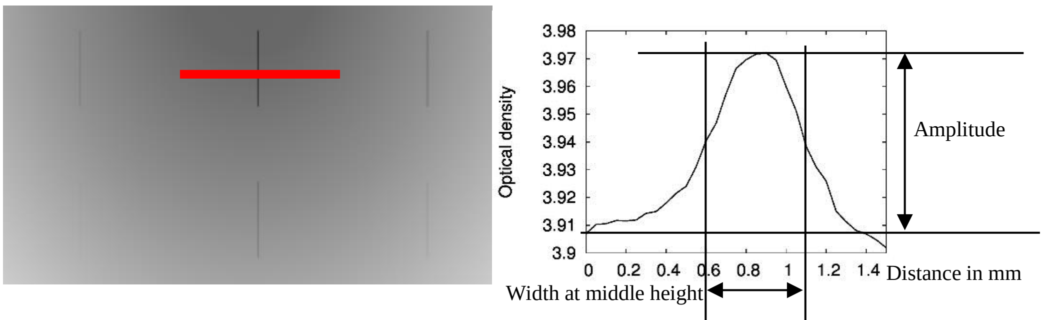

Fig. 6. Example of optical density profile extraction along the red line.

2. Results and discussion

2.1 Validation with a 6 MV linear accelerator

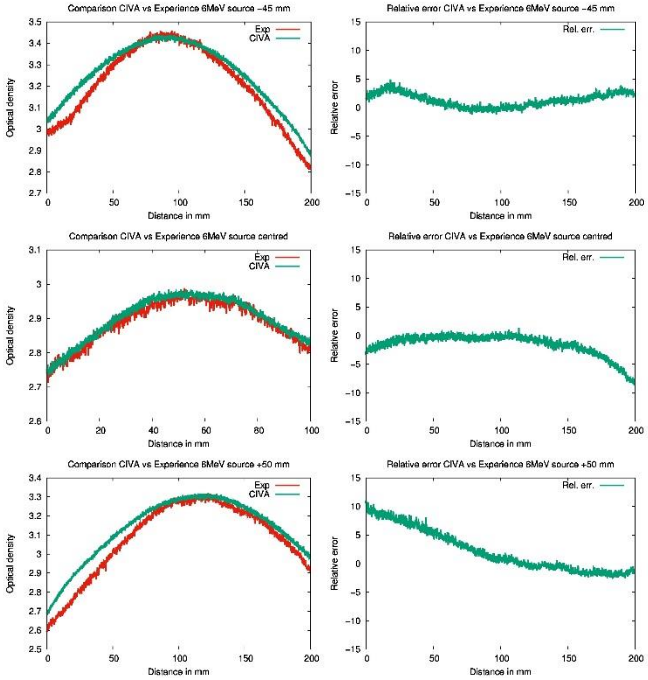

Fig. 5. Horizontal optical density profile along the notches mock-up: comparison between CIVA simulation and experimental data for 6 MV linear accelerator.

Table 2. Results synthesis of 6 MV configurations

	source centred			source shifted to +45 mm			source shifted to -50 mm		
6 MeV circumferential flaw	Measured amplitude	Simulated amplitude	Relative error expérience / simulation	Measured amplitude	Simulated amplitude	Relative error expérience / simulation	Measured amplitude	Simulated amplitude	Relative error expérience / simulation
EN20									
EN40									
EN60									
EN80	0.04	0.04	5	0.04	0.03	-3			
EN100	0.04	0.04	13	0.05	0.04	-9	0.03	0.02	-30
EN150	0.04	0.03	-8	0.05	0.05	1	0.04	0.04	7

	source centred			source shifted to +45 mm			source shifted to -50 mm		
6 MV longitudinal flaw	Measured amplitude	Simulated amplitude	Relative error expérience / simulation	Measured amplitude	Simulated amplitude	Relative error expérience / simulation	Measured amplitude	Simulated amplitude	Relative error expérience / simulation
EN20									
EN40									
EN60									
EN80	0.03	0.02	-28	0.02	0.03	33	0.02	0.02	-2
EN100	0.04	0.03	-27	0.03	0.04	16	0.02	0.02	-6
EN150	0.03	0.04	30	0.04	0.04	24	0.03	0.04	6

2.2 Validation with a 9 MeV linear accelerator

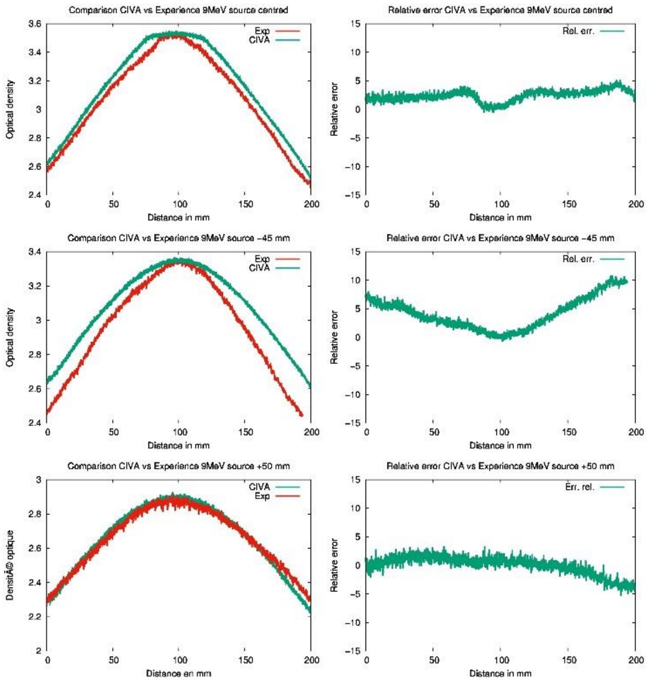

Fig. 6. Horizontal optical density profile along the notches mock-up: comparison between CIVA simulation and experimental data for 9 MV linear accelerator.

Table 3. Synthesis of 9 MV configurations

	source centred			source shifted to +45 mm			source shifted to -50 mm		
9 MV circumferential flaw	Measured amplitude	Simulated amplitude	Relative error expérience / simulation	Measured amplitude	Simulated amplitude	Relative error expérience / simulation	Measured amplitude	Simulated amplitude	Relative error expérience / simulation
EN20									
EN40									
EN60									
EN80	0.02	0.025	25						
EN100	0.03	0.05	67	0.044	0.033	-25	0.035	0.032	-7
EN150	0.028	0.032	16	0.038	0.042	10	0.023	0.033	45

	source centred			source shifted to +45 mm			source shifted to -50 mm		
9 MV longitudinal flaw	Measured amplitude	Simulated amplitude	Relative error expérience / simulation	Measured amplitude	Simulated amplitude	Relative error expérience / simulation	Measured amplitude	Simulated amplitude	Relative error expérience / simulation
EN20									
EN40									
EN60									
EN80	0.023	0.028	23						
EN100	0.035	0.043	25	0.043	0.032	-26	0.031	0.028	-11
EN150	0.033	0.04	19	0.036	0.023	-35	0.031	0.036	18

3. Conclusion and perspectives

Comparison of simulated performed with CIVA 2016 and experimental profiles is satisfactory for configurations to 6 and 9 MV. Indeed, on a qualitative level, flaws that are detected are also experimentally by simulation, and vice versa. The opening notches below 80 microns are never detected. When the source is centered, the opening flaw greater than 80 microns are still detectable. When the source is off, opening notches 80 microns are however not always detectable.
The relative difference between the amplitudes measured on the simulated and experimental profiles is difficult to calculate due to the values near the noise level. Overall, it is nevertheless clear that the trend of the relative standard deviation values are more important with the photon beam to 9 MV with the beam at 6 MV.
Work is under progress in order to improve the high-energy model (including electron interaction in the Monte Carlo simulation).

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