Modelling the influence of the water level on radiographic inspection of pipes

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Abstract. One of the preoccupations for the operating conditions of a radiographic inspection concerns the water level of pipes: is it preferable to evacuate the pipe, or to fill it completely? Or is the water level without impact on the radiograph? Not surprisingly, the answer depends on the particular configuration, and several examples will be used to show in this conference that Radiographic Modelling can be used to evaluate the influence of the water level on the quality of the resulting radiograph. We illustrate the approach with EDF's radiographic modelling code MODERATO.

Introduction

Simulation of radiographic inspections for technique performance demonstration has become customary at EDF since 2004 [1], using the computer code MODERATO [2] as a complement to a reduced number of experiments. One of the recently investigated subjects is the influence of remaining water in the pipes during in-service inspections. This possible procedure non-conformity may decrease the inspection performance. As the modelling code MODERATO is perfectly suited to quantify the impact of procedure non-conformities, some specific calculations were performed on 2 inches in diameter butt-weld pipe configurations. For this paper, some additional calculations were performed on a 6 inches in diameter pipe to illustrate the valuable information made available by modelling. EDF's modelling code MODERATO (Figure 1) determines for instance the incoming photon statistics (energy spectrum and scatter histograms), the optical density mapping, the scattered / direct ratio mapping (equivalent to build-up factor mapping), a quantitative visibility interpretation of defect indications, etc. [1] This paper puts forward the advantages of using modelling codes to evaluate the impact of inspection parameters during RT procedure qualification or in service inspections. [3].

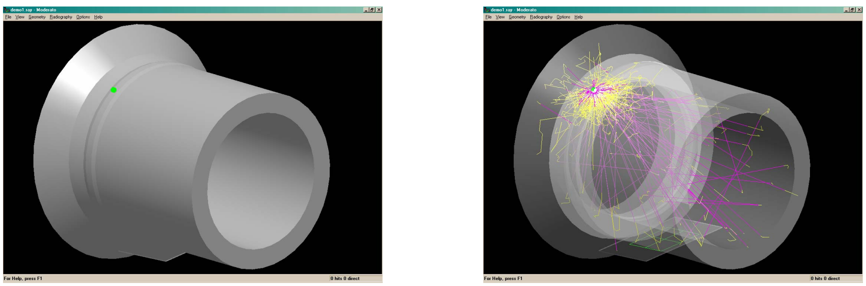
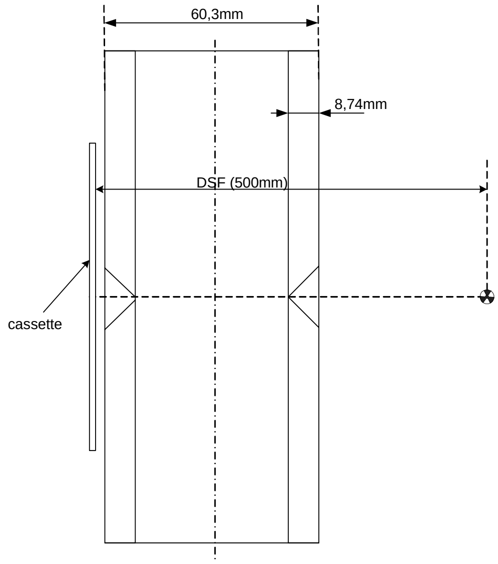


Figure 1: one MODERATO configuration used in a RT procedure qualification program (left) and illustration of some photon trajectories inside the pipe, as calculated by MODERATO's Monte-Carlo algorithm.

1. Results for the two inch butt-weld pipe

1.1 Simulated configurations

The inspection of two-inch butt-welded pipes (Figure 2) requires four expositions, each shifted by a 45° angle, as shown in Figure 3. In this figure, one can see that the defect can be on the water side or at the opposite. Eight simulation configurations will thus be tested with five different water levels (the pipe has a 42,82 mm internal diameter): empty pipe, 2 mm, 5 mm, 10 mm and full pipe.



Simulation parameters	**Values**
Diameter D	2" = 60,3 mm
Thickness (Ep)	8,74 mm
Pipe Material	Stainless steel
Source-Film Distance (DSF)	500 mm
Film Class	C2
Lead filter thickness	0,5 mm
Axial shift of the source	0 mm
Angular source positions	0°, 45°, 90°et 135°
Source	Iridium
Source dim. (height x diam.)	3 x 3 mm
Simulated crack positions	see Figure 3
Crack opening	50µm
Crack length	20 mm
Crack height	2 mm
Film fog	0,3
Aimed optical density at defect position	2,7
Water levels	0, 2, 5 , 10 mm and full

Figure 2: Simulation configuration of 2 inch butt welded pipes.

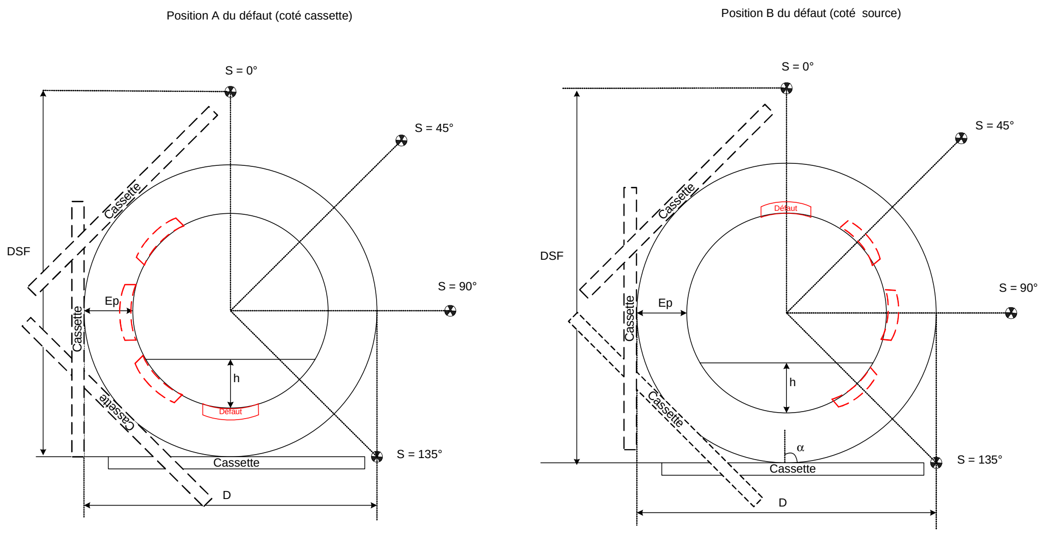


Figure 3: Source - Defect - Film orientations. A (left): defect on film side, B (right): defect on source side.

1.2 Simulation results for the two inch butt-weld pipe

The local build-up factor (BUF) on the film is one important image quality indicator. This factor is obtained by dividing the incoming energy by the unscattered (direct) photon energy. A higher build-up factor corresponds to a lower amount of unscattered photons for a same optical density level on the film, and thus, to decreased defect contrast and detection performance. We use more often the Scattered Direct Ratio (SDR) that is obtained by dividing the incoming scattered photon energy by the incoming unscattered (direct) photon energy. It is easy to see that the BUF is equal to SDR+1. Whereas SDR (or BUF) can only be determined experimentally in some very specific conditions, modelling gives an easy access to valuable SDR mappings. The local SDR around the defect indication is in fact one of the main parameters determining the defect indication visibility (the visibility decreases when the SDR increases, for a constant optical density) [1].

Table 1 shows the local SDR results on the film, at the defect indication location, for the different source and defect positions. Many of the results are close to a typical SDR value in the 0,75 - 0,76 range. They show that the impact of a little remaining water (less than 5 mm) can be neglected.

Some configurations show higher SDR values. They are highlighted in grey in the table. In these cases, the water in the piping generates some additional scattered energy on the film that decreases detection performance for a constant aimed optical density in the film region of interest.

One configuration, A-90°, leads to a lower SDR value. It is highlighted in black (with white typing) in the table. It is interesting to see that there is no symmetry between the A and B configuration. The explanation put forward is that a reasonable amount of water near the defect absorbs some scattered radiation, and therefore decreases the SDR value at the defect indication location. Water far from the defect only contributes in terms of additional scattered radiation and does not lead to this unexpected effect, so the mean behaviour is actually an increase of the SDR, ie a detection performance decrease. The decrease is however not very important and the visibility of the indication is confirmed by the dedicated MODERATO algorithm (all indications have a calculated visibility superior to the threshold value 0,013, the smallest value is 0,0143 for the full pipe configuration).

Table 1: Local Scattered / Direct Ratio on the film, at the defect indication location.

Water level (mm)	**Source - defect configuration**							
	A - 0°	**B - 0°**	**A - 45°**	**B - 45°**	**A - 90°**	**B - 90°**	**A - 135°**	**B - 135°**
empty	0,76	0,75	0,76	0,75	0,76	0,75	0,76	0,75
2	0,76	0,76	0,76	0,76	0,75	0,75	0,76	0,75
5	**0,78**	**0,78**	0,76	0,76	0,75	0,76	0,76	0,76
10	**0,81**	**0,81**	**0,77**	**0,77**	**0,73**	0,76	0,76	0,76
full	**0,99**	**0,99**	**0,99**	**0,99**	**0,99**	**0,99**	**0,99**	**0,99**

2. Results for the six inch butt-weld pipe

2.1 Simulated configurations

Five different situations, illustrated in Figure 4, were modelled with MODERATO: an empty pipe, a full pipe, and three partially empty pipes with a 51.81 mm remaining water level. The difference between the latter three situations is the angle of the source - film axis with respect to the water plane (perpendicular, parallel and with a 45° angle). The RT procedure parameters are specified in Table 2.

Table 2: RT procedure parameters

Simulation parameters	Values
Pipe Diameter	6" = 168,3 mm
Pipe Thickness	12,34 mm
Pipe Material	Stainless steel
Source-Film Distance	175 mm
Film Class	C2
Lead Filter Thickness	0,5 mm
Source	Iridium
Source dim. (height x diam.)	2 x 2 mm
Film fog	0,3
Film size (simulated)	20x10 cm (400x200 pixels)
Aimed optical density at film center	3.0
Water levels	empty, 51.81mm and full

All calculations were performed on a 600 MHz laptop PC. The design of the six configurations lasted about half an hour. The calculation time was 2 hours for each of the six configurations (on the author's quite ordinary laptop). The data post-processing and analysis took about one hour. It means that the results presented in this section were obtained within one working day.

2.2 Simulation results for the six inch butt-weld pipe

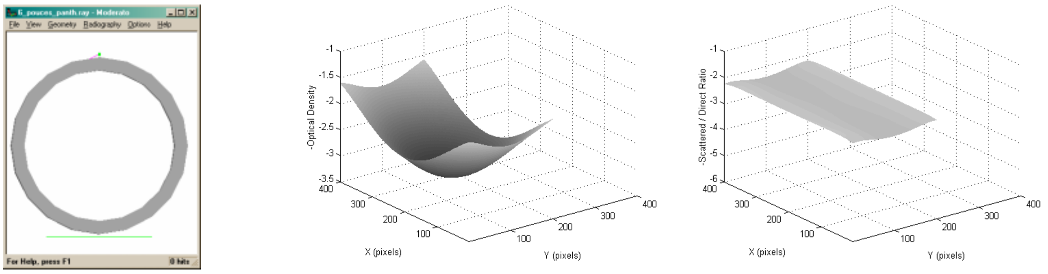
The optical density at the film centre is set as default to 3 for all simulations (the film fog is 0,3). Table 3 gives the optical density values in the film centre in case of constant exposition time (the reference is then the one of the empty pipe configuration).

Table 3: Optical density obtained in the film centres if the exposition time is the same for all configurations (the empty pipe configuration is the reference, the film fog is 0,3 for all configurations).

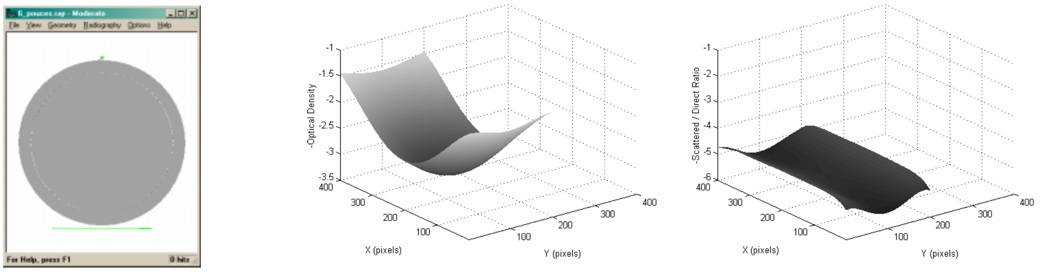
Configuration	Optical Density
(a) empty pipe	3,00 (reference)
(b) full pipe	1,32
(c) 51.81 mm water in pipe, water level parallel to film plane	2,14
(d) 51.81 mm water in pipe, water level perpendicular to film plane	3,02
(e) 51.81 mm water in pipe, water level 45° to film plane	2,24

Figure 4 shows that for the empty pipe, there is a small variation of the SDR even if the optical density varies from 1.5 to 3. The SDR of the full pipe configuration is also quite constant, even if it much higher than for the empty pipe (the water generates much photon scatter and absorption). The SDR of the (c) configuration is as expected intermediate to the two first cases.

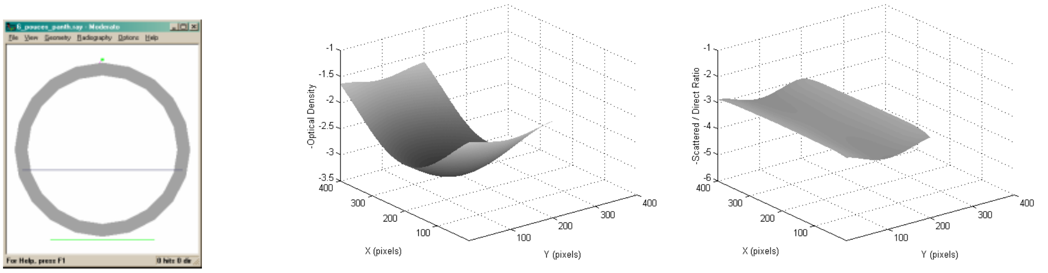
Configuration *Optical Density Mapping* *Scattered / Direct Ratio Mapping*



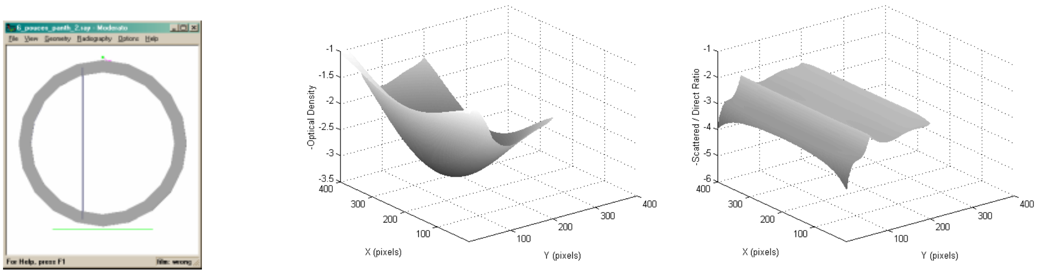
(a) empty pipe



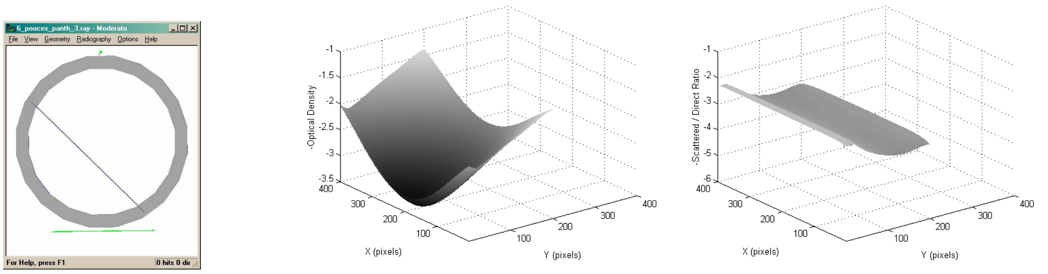
(b) full pipe



(c) 51.81 mm water in pipe, water level parallel to film plane



(d) 51.81 mm water in pipe, water level perpendicular to film plane



(e) 51.81 mm water in pipe, water level 45° to film plane

Figure 4: Configuration (left), Optical Density Mapping (centre) and Scattered / Direct Ratio Mapping (right) for the five configuration series. The vertical scales are oriented downwards in order to have a better correspondence between optical density and graph's gray-scale.

If the water level is not parallel to the film plane, as for the (d) and (e) configurations, the optical density and SDR mappings are no longer symmetric around the film centre. These SDR mappings cannot be guessed or obtained by analytical models. Also, only modelling codes able to calculate the scattered photon distribution can be used with satisfying results. This is why MODERATO is so handy and valuable to determine the detection performance of radiographic inspections.

3. Conclusion

The use of qualified RT procedures requires to limit non-conformities of unknown impact that may decrease the inspection detection performance. Whatever the work achieved during qualification, it happens that more or less unexpected parameters intervene during in-service inspections. This paper puts forward the advantages of using modelling codes to evaluate the impact of inspection parameters during RT procedure qualification or even during in service inspections. This paper gives some examples of how one can determine, with the help of the radiographic modelling code MODERATO, the impact of a qualified procedure non-conformity, remaining water in a pipe for instance.

References

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