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New Advances in the Development of MODERATO

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Introduction and context

MODERATO is a radiographic Monte-Carlo simulation software developed at EDF [1-3]. It simulates images obtained on photographic films during radiographic inspections with γ sources. A simulation tool is very useful to help finding the best configuration before on-site inspection, especially in nuclear power plants. It can also be used for training. However the simulation must produce images similar to real ones, which must reflect configuration changes and detector composition. Such requirements have motivated the use of a Monte-Carlo model also for the detector.

In this paper, we present the physical model of MODERATO, and results that show the influence of radiographic configuration on images.

Physics of the simulation

In MODERATO, the complete radiographic system is modeled according to the underlying physical processes [4-5]. Each photon's or electron's behavior is computed one after the other. Sources are Ir or Co sources, and objects and flaws are described by their CAD. Objects can be of any shape and material, and different objects can be inspected on the same simulated radiography. Detectors are cassettes containing metallic screens and films, because such detectors are widely used at EDF. Filters can be used in front of the cassette.

The peculiarity of MODERATO is to simulate detectors consisting in metallic screens and argentic films with a Monte-Carlo model. The advantage of such a model for the detector over a refined analytical model is to enable to simulate any radiographic configuration. This model takes into account the specificity of front and back screens, and can simulate different kind of films according to their parameters. The model of detector is very flexible, as any combination of filters, screens and films can be simulated.

The simulation of particle interactions is more complex in the detector than in the objects. In the objects and in the flaws, inelastic and elastic collisions (Compton and Rayleigh interactions) and photoelectric absorption of photons are taken into account, whereas the electrons are neglected.

However electrons cannot be neglected in the detector because they are responsible for the formation of the image. In the detector, MODERATO simulates the generation of electrons by the photons (during photoelectric absorption and Compton scattering) and their own interactions.

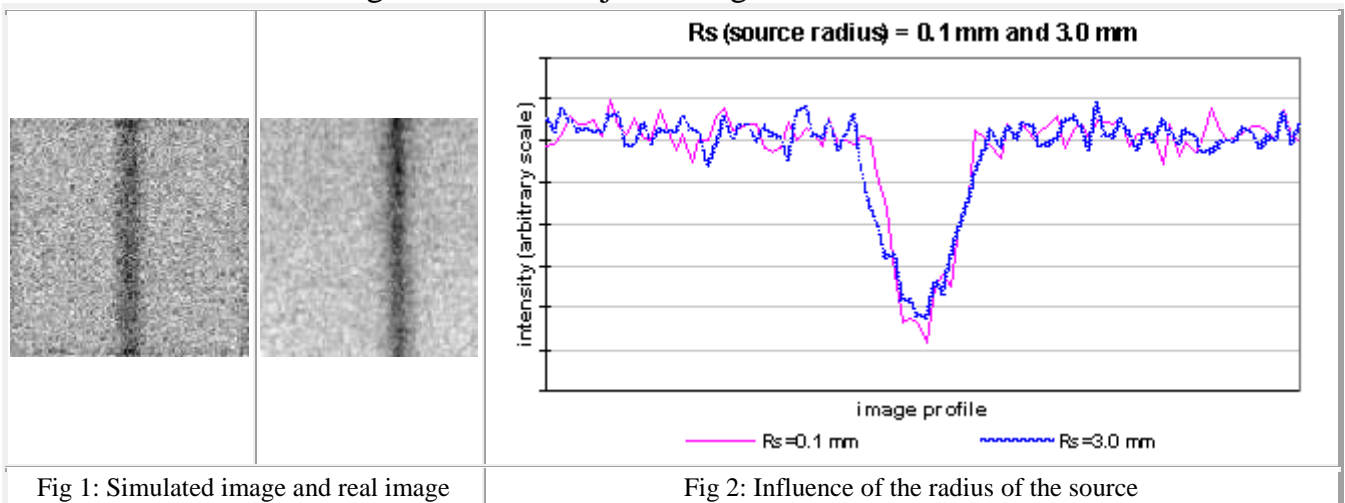
Electrons can encounter many different interactions, and we have designed models for filters, screens and photographic films. We have developed a simplified model for ionization by neglecting ion formation. Coulomb diffusion, that is mainly responsible for backscattering of electrons, is only simulated in back screens.

Films are described by their physical properties (number of grains, distribution of grain sizes, etc.) so that different films can be simulated. They are considered to be composed of silver-halide grains in gelatin.

The detector has just been completed and is now thoroughly assessed. The simulation is rather time-consuming if we simulate actual exposure times. However the dynamic of the simulated images is much wider (255 gray levels at least for simulated images, around 50 in photographic images), so that less photons (i.e. shorter exposure duration) are necessary to obtain comparable images.

Influence of the geometric configuration

We performed tests on MODERATO to check that geometric parameters have the same influence on simulated images than during real inspections [6]. Our test object is a steel bloc with an electro-eroded notch. All test images are obtained with the same exposure. We present a simulated image and a real image of such an object in Figure 1.



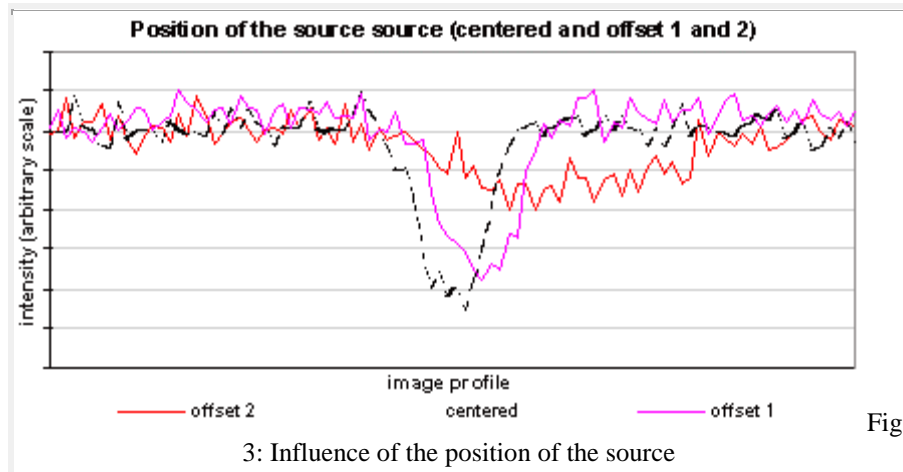
Source width

The image profiles of Figure 2 show an increase of geometric unsharpness with the source radius. Due to film unsharpness, the profiles are not smooth

so it makes interpretation harder. However the difference of slopes of flaw profiles indicates that the image of the flaw is sharper with a smaller source.

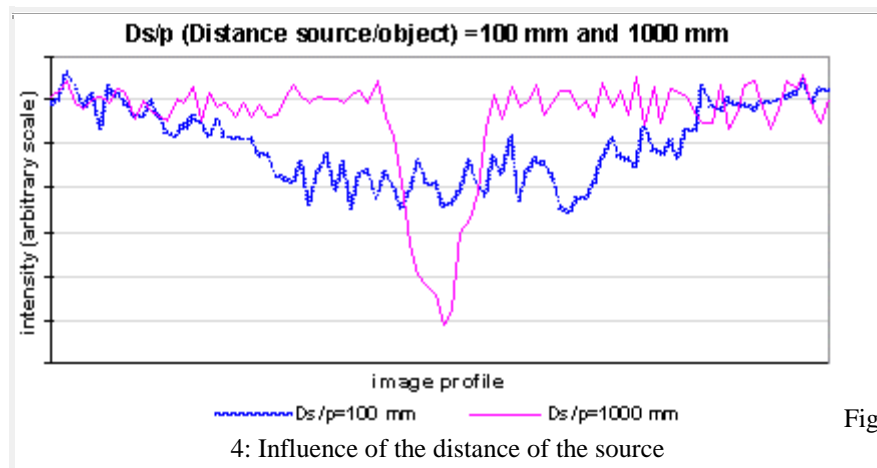
Source position

An offset of the position of the source leads to a less contrasted image, and a wider flaw image. We compare on Figure 3 the profiles obtained with a centered source, and two offset sources.



Source-to-object distance

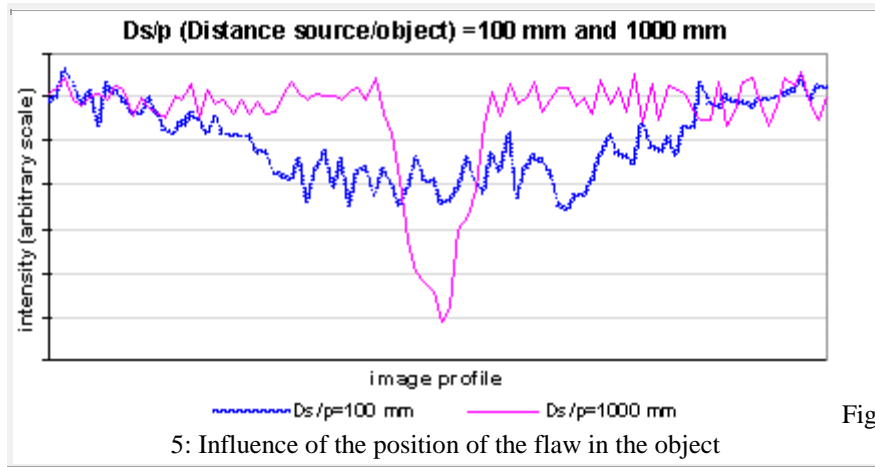
In Figure 4 we notice that magnification varies with the distance between the source and the object.



Position of the flaws

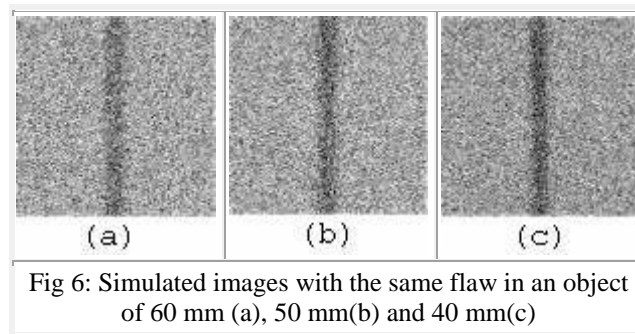
In Figure 5 the position of the flaw varies perpendicularly to the film (40 mm off the film and 70 mm off the film). Profiles are quite similar. We know that the depth of the profile depends on the ratio flaw/object, that does not vary with the position of the flaw in the object. We present radiant image profiles to suppress the effect of film unsharpness because differences are difficult to detect. On these profiles, we notice that the definition of the flaw

image is better when the flaw is close to the film ($Z_{\text{def}}=40$ mm), which is natural.

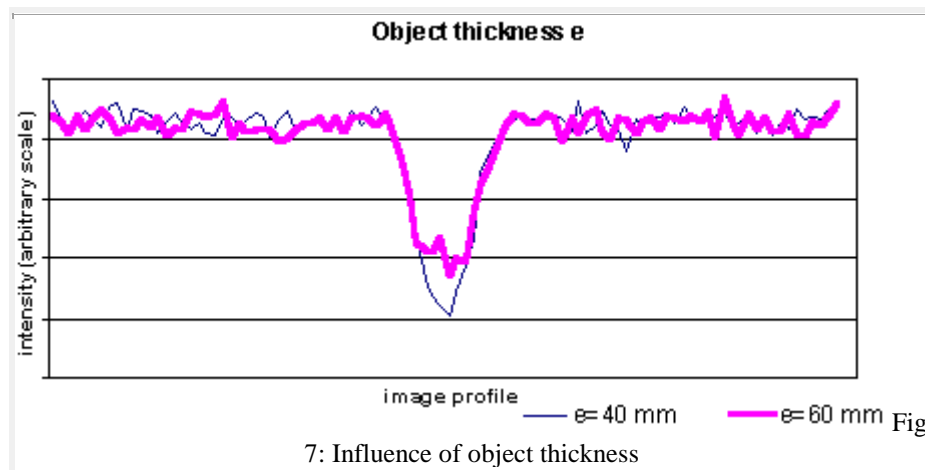


Object thickness

In Figure 6, we show three simulated images with the same flaw and similar object of different thickness. The thinner is the object, the sharper is the profile of the flaw because the ratio flaw/object increases from (a) to (c).



We present the corresponding profiles in Figure 7 for image (a) and (c). The profile of the sharpest image is deeper.



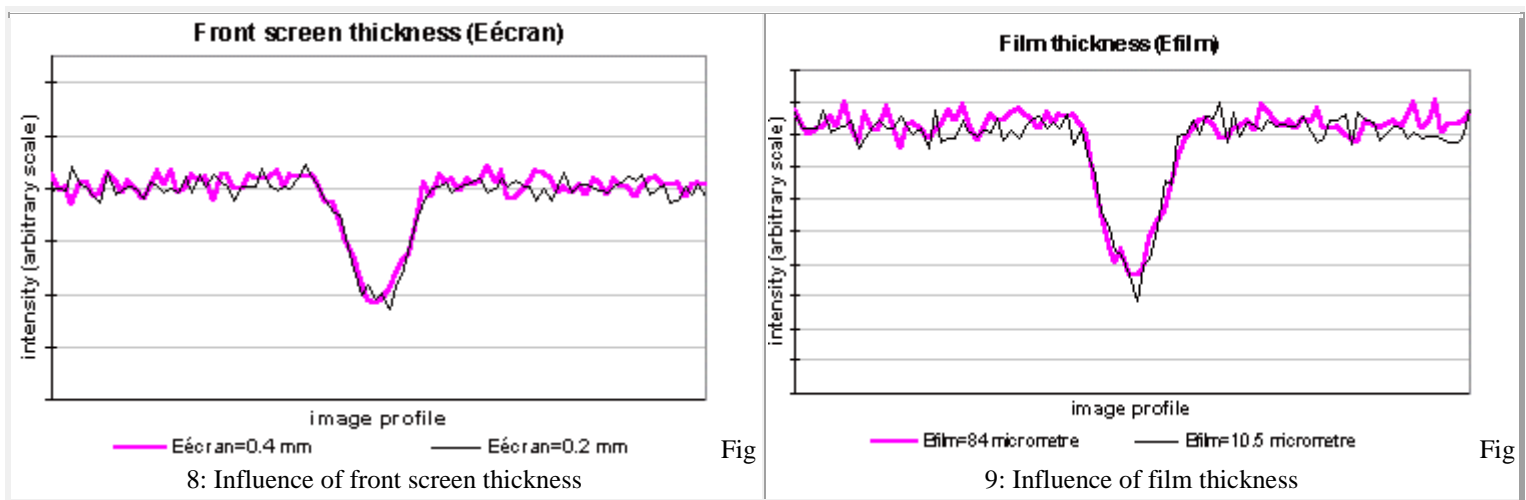
Influence of the detector composition

Screen thickness

We see on the profiles of Figure 8 that the image is slightly smoother with a thicker front screen. We checked also by simulation that for important thickness the screen behaves like a filter. The threshold value between reinforcement and filtering that was determined by simulation is similar to the one experimentally determined at EDF.

Film Thickness

The film thickness has influence on the smoothness of the image which is shown on Figure 9. We also observed that, as one electron can only darken a few grains, there is a threshold above which the film thickness does not have any influence.



Conclusion

The complete radiographic system gives images very close to real ones. The results of the tests demonstrate the influence of the configuration of the inspection. This makes MODERATO suitable for helping to determine the best configuration for a given inspection. The simulation software can also be used for training.

MODERATO is an efficient simulation software for γ radiographic inspection.

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