ABSTRACT

Several incidents about irradiated people, which took place worldwide at the beginning of the 2000s, reminded the utilities and the national safety authorities of the importance of the risk connected to the transport and the use of gamma-ray sources.

In regards with NDT, the results of an international Benchmark that EDF initiated in 2008 about the number of radiographic exposures on nuclear power plants during in-service inspection, and the place where they were performed (Controlled Area, Outside CA, Turbine building) led us to estimate the disparities between the international utilities and to identify the main causes of the risks which can lead to such an incident.

In this context, the initiative of EDF for the reduction of the risks connected to gamma radiography can be displayed in three main objectives:

- the search for alternative NDT in replacement of radiography,
- the optimization and the good practices where the radiography is still necessary,
- the limitation of the impact generated by the application of the national rules, and the optimization of the maintenance of the installations.

The main alternative for radiography is the use of the standard UT mono-elements, especially for the research of cracks in the welds made of low alloy steel in the secondary cooling system, which lead for our engineers to an important work in order to modify the existing NDT qualification. But radiography is also widely used in the turbine building for the research for Flow Accelerated Corrosion (FAC) in the parent metal (same risk as the incident at Mihama in 2004) as well as in the weld itself. For this type of degradation, the use of UT or digital radiography for wall thickness measurement can turn out to be a reliable alternative.

However, there are numerous configurations of the components where the replacement of the gamma radiography remains difficult with classic NDT (stainless steel welds, spin-dried molded steel, small diameters, connection with an isolation valve)

For the development and the optimization of good practices during radiographic exposures, working groups were launched in 2007 and 2008, including several companies using NDT (and not only utilities), and animated by the COFREND (French Confederation of Non Destructive Testing). The main conclusions of these groups have been published and are summarized in this article.

Furthermore, a partnership with a national industrial has lead to the development of a new type of attenuator made in an alloy of copper and tungsten (as a replacement of the bigger collimator made with Uranium) for the gamma exposures on the piping with small diameters.

Finally, our R&D department, in association with others NDT industrials, leads an action for the use of the Selenium 75 isotope or X-ray source for the examination of the piping of weak thicknesses.

As for the reduction of the impact in relation to the national rules, EDF began firstly a revision of its doctrine of maintenance of the NPP to decrease in a global way the NDT applied during in-service inspection, and secondly a globalization at a national level of the local choices of replacement of the RT by the other techniques outside the Reactor Building (UT, MT, PT between layers).

In conclusion, EDF undertook a global and fast initiative to reduce by 50 % the number of gamma exposures bound to NDT within 3 years (replacement, limitation of exposures...) and seized this opportunity to reduce the risks associated with radiography, to decrease the cost and to optimize the planning of in-service inspection.
INTRODUCTION

Gammagraphy testing is a very widely used process on welded steel constructions, pipings and pressure vessels, in order to survey the construction, the behavior and integrity of the components during a power plant lifetime. It fully contributes to the safety and to the availability of the means of production of electricity.

The major disadvantage of this NDT method lies in the risks due to ionizing radiations requiring a specific transport of the gamma-ray source (according to the national regulatory rules), the establishment of a safety perimeter being a constraint to the owner (no co-activity in this exclusion zone) or involving a shift schedule for the personnel.

In 2008, EDF has carried out about 16,000 gamma exposures for all French Nuclear Power Plants (NPP). This means that between ten to several hundreds of gamma exposures can be performed during a plant outage, with as much risk of accidental irradiation. In particular, the event of Blayais (French NPP) at the beginning of 2001 led to an overexposure of 15 mSv of one of the operators (source not fully re-entered in the gamma source container during a film replacement). The reduction of this risk is a major stake for EDF, the objective of which is to be no more confronted with such an accident of irradiation.

The question to settle, for each control of a NPP component, is to define clearly its objective and to know why the gammagraphy is rather used than another NDT. In numerous cases, the use of RT is more an historic choice or a question of ease of implementation than for considerations of detection performances. But in a certain number of configurations, RT is really the best technique to be carried out (general-purpose technique, no outside power source needed, important experience feedback…).

However, the purpose of this article is not to establish an exhaustive list of alternative techniques, firstly because manufacturers of NDT equipments or working groups will constantly improve it and secondly because the radiography remains indicated in certain configurations of control (complex component, large surface with a high quality of image) and thus not replaceable.

The objective of this article is to present the global and coherent initiatives on a set of strengthened axes conducted within EDF to reduce the risk connected to the use of the gammagraphy, to replace gamma-ray sources where possibly or to implement a series of good practices and innovations to reduce the risk of irradiation.

INTERNATIONAL BENCHMARK

In the beginning of 2008, EDF has launched a benchmark with its international partners (China, Europe, Japan, USA…) in order to compare the use of radiography in NPP (number of gamma exposures and building where they are performed).
The caption of each column represents one utility of the country.
All the values have been normalized in comparison with the total RT exposures performed at EDF.

![Relative number of RT exposures per year for one NPP](image)

Figure 1 – Relative comparison of the average number of RT exposures performed during ISI, between international utilities (EDF is the reference at the value 1).

About ten answers from worldwide utilities – members of the EPRI at the USA, China and members of the European VGB (“Verband der Großkraftwerk-Betreiber” for Technical Association of Plant Operators) – have permitted a large comparison from which two important differences can be pointed out (see Figure 1):

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- Figure 1: European utilities seems to perform more RT than American or Chinese (note that Germany and Switzerland perform about 50 to 90% of their radiographic NDT with X-ray source), depending on the global number of NDT during ISI, on the regulatory authority and on the code referring to (ASME, KTA, RSE-M...)
- Some utilities perform most of the RT exposures in the turbine building, in order to find flaw-accelerated corrosion (FAC) in low alloy pipes, where the risk of irradiation is the highest (no wall to stop the radiation).

HOW TO REPLACE GAMMAGRAPHY DURING PLANT OUTAGE?

In France, most of the NDT performed during a plant outage are for In-Service Inspection (ISI) and the rest for replacements or repairs of components.

Alternative solutions are possible but their implementation depends: on the kind of component to be inspected, on the nature of materials, on the type of weld (butt-weld, nozzle...), on the orientation and position of the defects to be detected as well as their environment.

NDT for In-Service Inspection

First of all, the French regulatory requires that the NDT, carried out on the main primary system and the secondary cooling system of NPP, are qualified by an independent entity [1] (Qualification Body) according to strict rules of performance demonstration (based on the French RSE-M, the step of which is identical to that of ENIQ).

The simplest case to replace RT by manual UT is the butt-welds of the secondary cooling system: accessibility of the weld on both sides of the external weld bead, the low alloy steel convenient to the propagation of the UT and to the discrimination artifact / defect. Indeed, the new control should not produce more artifacts (geometry echoes, bound to the technique) than the existing RT.

But mono-element UT reach their limits, in case of a control of the volume, for non-grinding flush welds, for welds connecting to a valve, or for controlling a stainless steel weld (e.g. main primary system) and/or pipings of small diameters.

For those non-compatible geometries with standard UT, the use of more innovative techniques allows to solve the problem of replacement of the gammagraphy: UT phased-array which allows to control a vast volume of the weld even when the space around is reduced or when the access is possible only on one side of the weld.

Searching for Flow Accelerated Corrosion (FAC)

For the search for FAC in the turbine building, a very worrisome degradation (accident of Mihama in 2004), radiography is widely used, with many constraints on the schedule of plant outage, due to the absence of walls in the building (no radiation barrier) and to the need of evacuation of the staff in a wide exclusion zone. The replacement of gammagraphy as soon as possible allows important various gains: lower risk of irradiation, higher co-activity and lower cost.

For the current parts of the pipe, standard UT can easily replace RT for the measure of residual thickness in the pipings damaged by this type of degradation.
For the search of residual thickness around the welds of the pipings in the turbine building, several ways were or are still studied at EDF in order to replace the RT by other NDT (see Figure 2): TOFD (but without looking for diffraction signals) for simple geometrical configurations, standard UT around the internal weld bead (and a tube profilometry), and Selenium 75 (or X-ray source) associated with digital radiography (phosphor plate) which allows in certain cases to reduce the risk of irradiation (limited exclusion zone and reduced exposures time).

**NDT for repair of components**

Even if gammagrophy for repair or replacement of components is not the mostly used NDT during a plant outage, its impact can be important especially during non-planned repairs. However, the use of gammagrophy in that case is often bound to the application of codes and standards. Thus, the replacement of RT by an innovative technique collides with the absence of normalized acceptance criteria (for example, there is not yet an European standard for TOFD).

Often, the applicable codes and standards recommend the use of radiography as a volume technique, but leave at the same time the door opened to the use of UT under reserve of compatibility of the couple diameter / thickness or of an agreement between the utilities and the manufacturers. In this context, EDF is raising awareness among its staff for advocating specifications for repair or replacement components compatible with the implementation of UT during a plant outage.

In some specific cases, it was even possible to abandon the classical control volume recommended (RT or UT) with the replacement by a surface technique as PT between layer for austenitic stainless steel welds, thanks to qualified welding processes and adequate justification on the holding in the service of components with defects volume size below 3 mm, the size of the electrode for Tungsten Inert Gas welding (standard NF EN ISO 6520-1).
GOOD PRACTICES TO OBSERVE WHEN RADIOGRAPHY IS THE ONLY OPTION

The search for best practices that can reduce the risk of irradiation related to the use of a gamma-ray source led our teams as a first step to the specific analysis of the radiographic significant events, which record the non-conformities during exposures, as well as their real or potential consequences.

The result of this analysis, conducted annually, led to identify the problems of zone beaconing as the most important (incomplete zone, operators trapped into the marking or voluntary crossing it). An action implemented since 2007 is the exhaustive inventory of the buildings maps and their reliability for each of 58 NPP in France, to make it available in a common IT base for the stakeholders (EDF staff or service providers) who perform radiographic exposures.

The feedback of this analysis towards the various actors showed a first slow decrease of this type of significant events for the past 2 years.

Advocate of good practices in industrial gammagrapy

On the proposal of the French Nuclear Safety Authority (ASN), the COFREND has initiated workshops bringing together a large number of industrials from fields of gas, oil and nuclear power to define best practices to propose and deploy nationally to operators using radiography, to standardize practices and provide a common reference, in addition to national regulations on the use of gamma-ray sources.

The main themes and results of these workshops are [2]:

- the national feedback from non conformities and its exploitation: bad control of the exclusion zone, a source locked outside a gamma source container due to the presence of dust into the sheath, lack of training for new operators and more generally the human factor (constraints on personnel, work night...),
- the book review of all the hardware used in industrial radiography (gamma source container, zone marking...), their study and areas for improvement for safety: using a different gamma source container than the GAM80 and 120® which is heavy, such as the GAMMAMAT SE ® lighter and adapted to Selenium 75, the systematic use of collimator or equivalent attenuator (see below § New type of attenuator), advocating for the amendment of codes and standards to take into account the use of Selenium 75, advocacy of the mark out “sentinelle” ® (CARMELEC Cie) or other light and sound signals that are already in place on the French nuclear power plants (see Figure 3),
- detailed analysis of the sequences and conditions of work of the personnel involved in radiography to determine the risky jobs – high dosimetry, lack of attention at night, and finally setting up a guide for self-evaluation of radiological risk.

Figure 3 – Mark out “Sentinelle” ® (on the left side) and other light and sound signals.
New type of attenuator

The use of a collimator can significantly reduce the irradiated area upstream of the source, and thus reduce the exclusion zone marked, allowing a more important potential co-activity. However, the current collimators are difficult to implement while maintaining precise known gamma-ray source position compatible with qualified NDT. In addition, the material used is impoverished uranium, whose transport in Europe has to be done under strong constraints (declaration of transport of radioactive material).

<table>
<thead>
<tr>
<th>New Attenuator</th>
<th>Standard Collimator</th>
</tr>
</thead>
<tbody>
<tr>
<td>Materials</td>
<td>Copper and Tungsten alloy</td>
</tr>
<tr>
<td></td>
<td>Impoverished Uranium</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>2.3</td>
</tr>
<tr>
<td></td>
<td>1.1</td>
</tr>
<tr>
<td>Power of attenuation</td>
<td>1 ( \times ) 250</td>
</tr>
<tr>
<td></td>
<td>1 ( \times ) 250</td>
</tr>
<tr>
<td>Conical beam irradiation</td>
<td>60 degrees</td>
</tr>
<tr>
<td></td>
<td>120 degrees</td>
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<td>Fits on the sheath of irradiation</td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td>No</td>
</tr>
<tr>
<td>Radiography Technique</td>
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<tr>
<td></td>
<td>Plane on plane and double-wall</td>
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<td>Regulatory audit</td>
<td>No</td>
</tr>
<tr>
<td></td>
<td>Yes, every year</td>
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<tr>
<td>Declaration of mass Uranium transport</td>
<td>No</td>
</tr>
<tr>
<td></td>
<td>Yes</td>
</tr>
<tr>
<td>Help with settings</td>
<td>Laser Pointer</td>
</tr>
<tr>
<td></td>
<td>Self-tightening clamp setting</td>
</tr>
<tr>
<td></td>
<td>No</td>
</tr>
</tbody>
</table>

Figure 4 – Comparison between a new Copper-Tungsten attenuator and a standard collimator

In this context, for exposures realized on small diameters and thicknesses pipings, EDF has developed the use of an attenuator in copper-tungsten, with an industrial partnership (CICO Center ®), with the same power of attenuation (about 250) than collimators made of Uranium but without the regulatory constraints associated to the transport (see Figure 4). In the year 2009, all the French NPP and the industrials, which perform gamma exposures on NPP, will be equipped with this kind of attenuator.

Other possible approaches to decrease the risk of irradiation

When radiography is still necessary, the replacement of the gamma-ray source (Iridium 192) with Selenium 75 (less powerful) or X-rays, and the replacement of the standard films by a digital detector are under study by various groups, which EDF is part of (ALTERX [3]), to define the hardware configurations and the appropriate conditions of use for this change.
This is a kind of continuation of the studies conducted at the EPRI [4] on the digital radiography with a reference block, of which EDF owns a copy.

**REDUCING THE TOTAL AMOUNT OF NDT TO REDUCE RT**

It is obvious that NDT is only part of the global maintenance strategy of the utilities. The main gain for reducing the use of radiography is to reduce the NDT carried out on NPP.

In France, EDF is presently the only utility operating nuclear power plants, involving a total of 58 reactors. This large feedback from more than 30 years is used by EDF to change the strategy of maintaining its power plants. The additional justifications made to change the doctrines of maintenance should reduce the total volume of NDT performed for ISI and at the same time reduce the number of radiographic exposures on the pipings.

In that way, EDF has used its knowledge to build a huge program to reduce the amount of NDT on the main primary and secondary systems by 10% for the 10 years to come.

In addition, optimization of the maintenance, use of surface examination techniques and material change of some components have reduced by 90% the number of radiographic exposures carried out in the nuclear island.

**CONCLUSION**

In conclusion, EDF undertook a global and fast initiative to reduce by 50% the number of gamma exposures bound to NDT within 3 years (replacement, limitation of exposures...) and seized the opportunity to reduce the risks associated with radiography to decrease the cost and to optimize the planning of in-service inspection.

Furthermore, there are many situations where radiography is the most appropriate and most efficient NDE technique. For these cases, the use of less powerful gamma-ray or X-ray sources and the implementation of good practices by the operators can highly reduce the risks of irradiated people.

**ACKNOWLEDGEMENTS**

EDF thanks the international partners that have transmitted in 2008 and 2009 the information about the way they perform radiography during ISI: USA, China, Switzerland and Germany.

**REFERENCES**

1) Blin P, *NDE qualification process at EDF*, 5th International Conference on NDE, San Diego (USA), 10-12 may 2006, p59-71