In-Service Inspection of Bimetallic Welds of Steam Generator Qualification of Radiographic Examination

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Abstract: According to the French law issued by Safety Authorities all volumetric techniques implemented for in-service inspection of main primary components shall be qualified.
Applying a NDE method to a zone corresponds to an application which, depending to its impact upon the safety level is subjected to different qualifications types.
This paper details these different qualification types, "conventional, general or specific" according to the rules specified in French RSE-M code for In Service Inspection of Mechanical components of PWR nuclear power islands.
As an example, the approach followed, the results obtained and the modality of application on components, for the "general" qualification of radiographic examination of bimetallic welds of Steam Generator are presented.

1. In Service Inspection NDT qualification. Requirements applicable in France

1.1 Safety Authorities ("Arrêté d'exploitation")

The French law issued by Safety Authorities ("arrêté d'exploitation" dated 10 November 1999) has introduced by the article n°8 new concepts as the qualification of the non-destructive examination methods implemented in In-Service Inspection of PWR plants. The supervision of the qualifications is transferred to a Qualification Body chosen by the Utilities.
Applying such methods to a zone corresponds to an application which, depending on their impact upon the operation safety of the installation, could be subjected to different qualification types.

1.2. In Service Inspection Rules: RSE-M Code

The RSE-M (In Service Inspection Rules for the Mechanical components of PWR nuclear power islands) 1997 with 2005 addendum gives in chapter A 4300 the conditions for qualification of an application.

The different types of qualification defined in RSE-M depending of the probability of existence of defects induced in service and safety consequences are:

- Conventional qualification:
No specific defect is postulated. Justifying evidence (defects detected, precision of localization) shall be compiled in a technical file.

- General qualification:

The presence of specific defects is postulated. Justifying evidence (defects detected, localized and characterized) shall be based on a combination of technical justification and practical tests based on realistic defects.

- Specific qualification:
The presence of specific defects has been observed (for example under-clad cracking). Justifying evidence (defects detected over a given limit, localized and characterized) shall be based on a combination of technical justification and practical tests based on real or on similar defects.

The qualification includes the qualification of the examination technique and the qualification of the technique implementation using the carriage equipment.

2. General Qualification to an application: Example of the radiographic examination qualification of the Steam Generator (SG) nozzle to safe end bimetallic welds

2.1. Input information. Customer qualification requirements

This application concerning the radiographic examination of the bimetallic junction of the SG nozzle to safe end welds is subject to a general qualification as defined in the RSE-M. It concerns an application for which the presence of defects is supposed and which is likely to affect the safety of the installation. The postulated defect is a decohesion of the bimetallic junction. It has a planar geometry and is located along the bimetallic junction with a circumferential orientation.

This qualification covers the bimetallic junction of all the 900, 1300 and 1450 MWe types SG including the replacement SG. The area of the bimetallic weld subjected to examination is a width of 10 mm centered on the bimetallic junction between the ferritic steel SG nozzle and the stainless steel buttering. The remaining buttering and the homogeneous weld between the buttering and the safe end are concerned by the qualification of an other application. The stainless steel cladding is not in the scope of qualification.

The defects to be detected depending on their position in the thickness are detailed in table 1.

Position in the thickness	Definition of concerned areas	Dimensions of defects to be detected (mm) height x length x opening
Inner surface	from the uncladded inner surface up to 30 mm depth	6 x 20 x 0,1
Intermediate area	from 30 mm up to the outer surface minus 20 mm	9 x 20 x 0,1
Outer surface	from the outer surface up to 20 mm	6 x 20 x 0,1

Table 1: Definition of defects to be detected

These positions are illustrated on the figure 1.

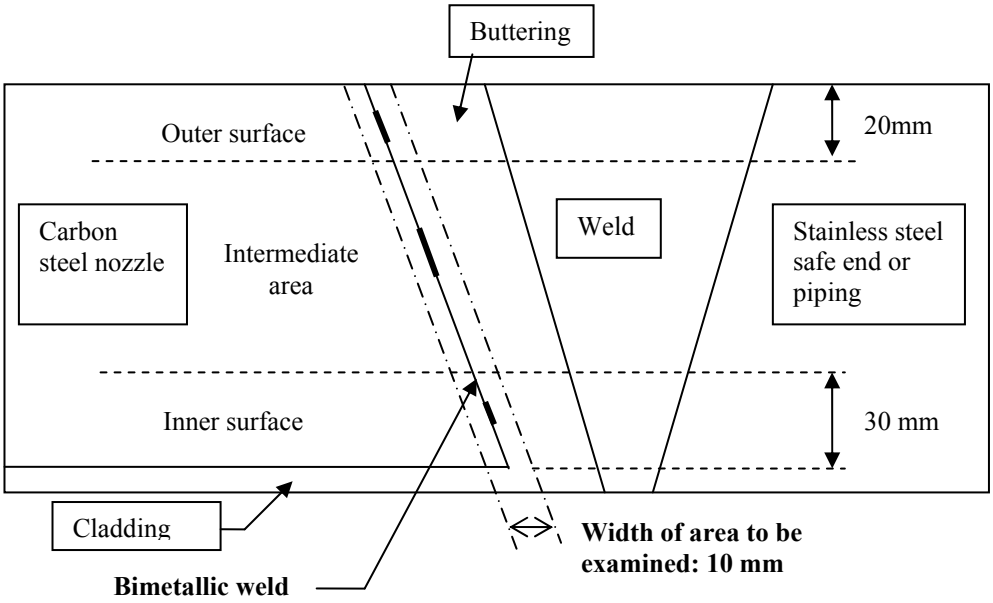

Figure 1: Area to be examined

2.2 Qualification approach

The qualification approach adopted for the evaluation of the examination technique performances is based on the results of tests carried out on qualification blocks containing a postulated defect located in the configurations to be evaluated.

The qualification test conditions are defined after identification of the "influential parameters" and justification, for each of them, of the retained nominal values. For the "essential parameters", for which their variation in the range modifies the performances, the nominal values are chosen in their most unfavorable values for the detection.

This qualification process is completed by the utilization of the results obtained on mock-ups representative of Steam Generator bimetallic welds configuration with implanted artificial flaws. They allow the validation of the transposition of the mock-ups results to the equipments to be in service inspected.

Then, the qualification of the implementation is carried out in order to verify the assembly operating condition including the previously qualified technique, the carriage equipment and the industrial NDE equipment under representative operating conditions.

2.3 Qualification of the examination technique. Input information

2.3.1 Description of the component to be examined

The figure 2 illustrates an example of the 1300 MWe type SG connection welds configuration with its different geometrical characteristics.

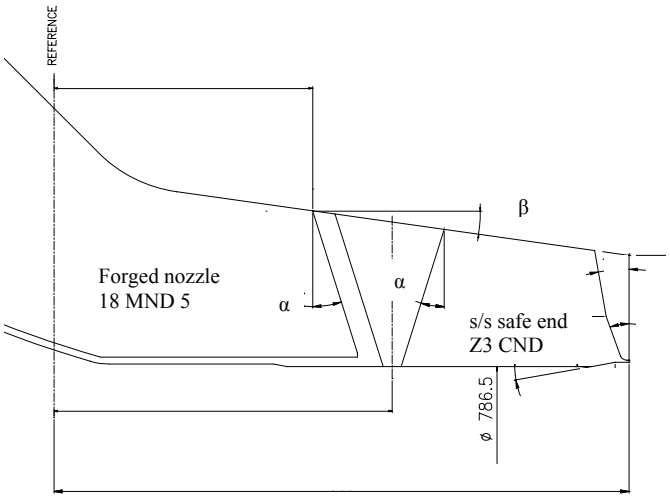

Figure 2: Example of 1300 MWe type SG configuration

The main values of the geometrical characteristics applicable to each SG type are listed in table 2.

SG Model	Type	Inner diameter (mm)	Outer diameter (mm)	Bimetallic junction Bevel slope	Outer surface slope	Bimetallic weld length (mm)
900	51	785,6	969,8	17,5°	3° to 15°	96
	51 B	785,5	961	17,5°	4°	91
	47/22 - 55/19	785,5	981,7	10°	5°	100
1300	forged	786,5	1012,5	17,5°	8°	118
	Cast	786,5	1000,5	17,5°	10°	112
1450	Chooz	786,5	1016,5	13°	3°	116
	Civaux	786,5	1016,5	10°	3°	119

Table 2: Geometrical characteristics

So the range of the bimetallic junction slope with the normal to the pipe is 10° to 17,5° and the outer surface slope 3° to 15°. The inner diameter is 786 mm. Depending on these values and on the nozzle thickness, the range of the bimetallic length is 91 to 96 mm for the 51 type SG and 100 to 119 mm for the 47/22, 55/19 type SG (900 MWe), 1300 MWe and 1450 MWe SG.

The materials of the SG nozzle is either carbon steel casting (AFNOR grade 20MN5M) or forged material (AFNOR grade 18MND5). The first welding run of the buttering is carried out by manual arc welding with covered electrodes or automatic TIG welding with stainless steel (Z2 CN 24-12) filler material. The run penetration at interface for these 2 welding processes remains in a 1 mm width area.

The repair process is included in the qualification scope. After repair, the ferritic nozzle to buttering junction location is at a maximum distance of 3 mm from the original junction otherwise is repositioned to the original position by carbon steel welding. The examination area, 5 mm width from each side of the bimetallic junction, covers the repair interface.

2.3.2 Description of the examination technique

Two γ sources are used depending on the radiographied thickness: Iridium 192 for the thicknesses < 100 mm and Cobalt 60 for the thicknesses ≥ 100 mm. The minimum activity of Ir 192 source is 2,96TBq (80 Ci) and 1,1TBq (30 Ci) for Co 60 source.

The single wall exposure is carried out with a gamma source centered on the axis of the pipe and placed in the plan of the bimetallic junction. The geometrical unsharpness (Ug) is calculated with the conventional formula, so taking into account by convention the defect located on the inner surface and the maximal source to film distance. For all the involved configurations the Ug range is 0,70 to 1,44 mm.

Gamma source positioning in the nozzle axis is carried out by a carriage equipment. Their conception allows the positioning within the tolerances of +/- 20 mm in the axial direction and of +/- 10 mm in the radial direction.

The films cassettes are placed all around the external circumferential of the weld for a panoramic exposure. The content of the cassettes - double film (C2 system film), reinforcing screens and filters - is in conformance with the RCC-M requirements. The density range of the bimetallic area to be interpretated is 3,0 to 4,5.

The image quality is attested by indicators located on inner and outer surfaces.

2.3.3 Influential / essential parameters. Identification and retained values

The parameters having influence on the performances of the technique are identified in table 3 and their nominal values adopted for the qualification tests are justified.
From these parameters, the essential parameters identified by a mark (*) in table 3 are retained in their most unfavorable value for the detection. They are reminded here after:

- Radiographied thickness equal to 120mm,
- Cobalt 60 source (4,7 mm x 4,7 mm) with stainless steel screens,
- Source to film distance corresponding to the maximal geometrical unsharpness value (1,44),
- Source to defect plans disorientation equal to 6° for a defect located on the external surface and 9° for a defect located on internal surface,
- Film density ≥ 3 in double film,
- Inclination of films cassettes with external surfaces: 27°.

For parasite exposure evaluation, tests have been carried out on SG bimetallic welds representative of the most exposed PWR plants to parasite scattering radiations. For the maximal exposure time, parasite exposure density has been found < 0,1 in double film.
So, no additional parasite density is added to the qualification test. On site, specified total fog density (film base + scattering radiation densities) is limited to 0,5.

GROUPS OF PARAMETERS	PARAMETERS	NOMINAL VALUE FOR THE QUALIFICATION TEST
CONCERNING THE EQUIPMENT	MATERIALS	Involved materials identical for all configurations Parameter not considered as a variable
	THICKNESS (*)	Directly linked to the detection performances Thickness of blocks: maximum bimetallic length 119 mm
	SLOPES OF OUTER SURFACE	Outer surface (15° max): taken into account by the radiographied length, the optical density and the films cassette inclination.
	SLOPES OF BEVEL	Misalignment of γ source with bimetallic junction (*) taking into account the maxi tolerances of parameters for the technique
	RUN FORM AT INTERFACE (BUTTERING WELDING PROCESS)	For any welding process, the interface area width is within 1 mm
	REPAIR	The bimetallic junction position (3 mm displacement) in case of repair remains included in the defined area to be interpreted (10 mm)
CONCERNING THE TECHNIQUE	GAMMA SOURCE	Co 60 with stainless steel screens as equivalent performance (image quality) to Ir 192 with lead screens has been demonstrated for radiographied thickness > 70 mm
	GEOMETRICAL UNSHARPNESS (*)	Source to film distance calculated for the maxi value of Ug (1,44) applicable to Co 60 exposure
	POSITION OF THE SOURCE	Source positioning with the maximum axial direction tolerance (20 mm) of the carriage equipment. Insignificant consequence of the radial shifting
	INCLINATION OF FILMS CASSETTES	Inclination 27° from outer surface covers the maxi slope of bimetallic junction 17,5° and an outer surface slope mean value (10°)
CONCERNING THE RADIOGRAPH	DENSITY (*)	Performance to be established for the minimum density 3 +0/-0,2
	IMAGE QUALITY	Defined by the performance demonstration and the feed back experience on site
CONCERNING THE DEFECT	POSITION IN THICKNESS, DEPTH AND LENGTH (*)	3 positions in the thickness : Inner and outer surfaces : 6 x 20 mm Intermediate area : 9 x 20 mm
	OPENING (*)	>= 0,1 mm

Table 3: Influential / essential parameters. Nominal values for qualification tests

2.4. Qualification tests for the technique. Qualification block

Tests are carried out with a reference mock-up containing electro eroded defects as represented in fig. 3. The defect defined for the performance demonstration is 5 mm high, 20 mm long with an opening equal to 0,1 mm.

The radiographied thickness is obtained by fitting this 8 mm high reference mock-up to an additional ferritic block, alternatively on the outer and inner surfaces. Qualification block with outer surface defect is given in fig. 4 as example.
Intermediate area defect detection performance is covered by inner surface defect location due to the geometrical unsharpness value.

Qualification blocks gather the essential parameters with the most unfavourable value as defined in § 2.3.3.

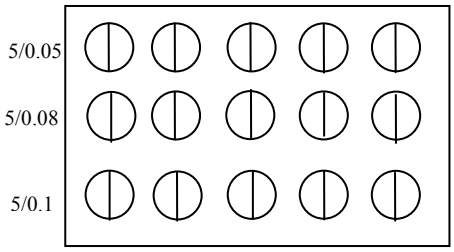

Fig. 3: Reference mock-up with calibrated electro eroded defects, 20 mm long
(height / opening in mm)

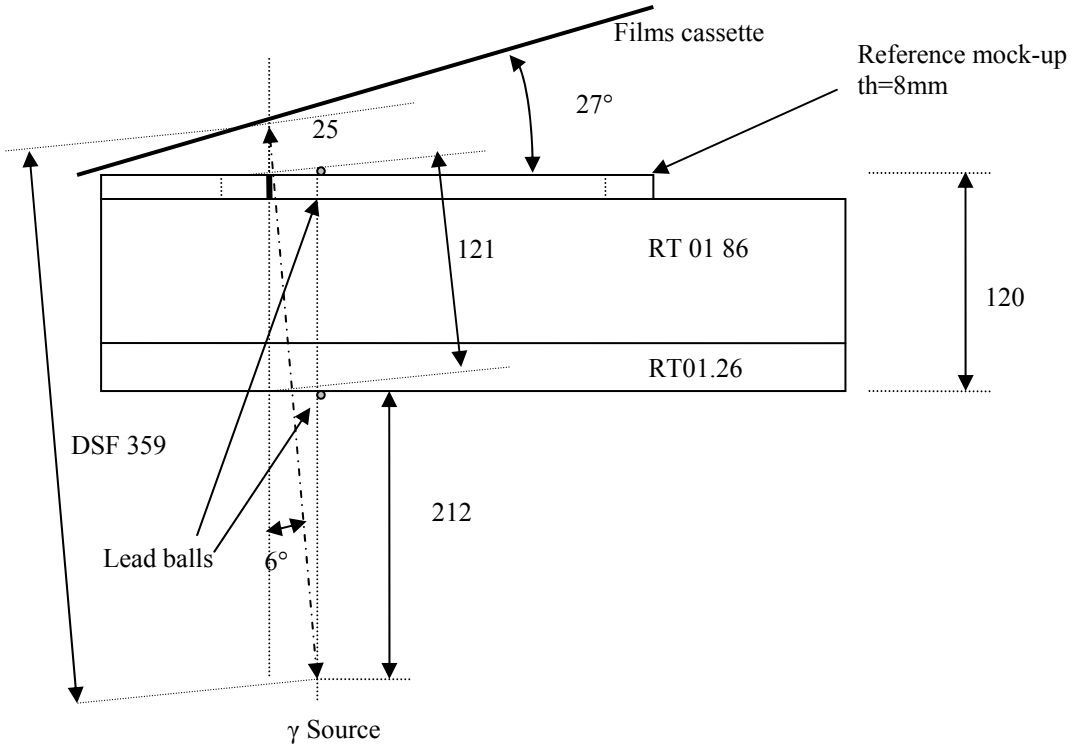

Fig. 4: Qualification block with outer surface defect

3. Results of the qualification tests

The following performances are validated by the tests:

- on inner surface: the reference defect (height 5mm, length 20mm, opening 0,1 mm) is detected as a well contrasted linear defect with an interpretated length equal to 26 mm.

- on outer surface: the reference defect (height 5mm, length 20mm, opening 0,1 mm) is detected as a sharp and high contrasted linear defect with an interpretated length equal to 20 mm. One notes that a defect with identical dimensions but finer opening (0,08 mm) is still clearly detected with the same interpretated length.