IRSN
INSTITUT
DE RADIOPROTECTION
ET DE SÛRETÉ NUCLÉAIRE

Enhancing nuclear safety

Carbon segregations in heavy forged components

IRSN assessment of non-conformances in French PWRs primary coolant system

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Content

- Context and safety issues
- Manufacturing conditions
- Justification file
- IRSN position

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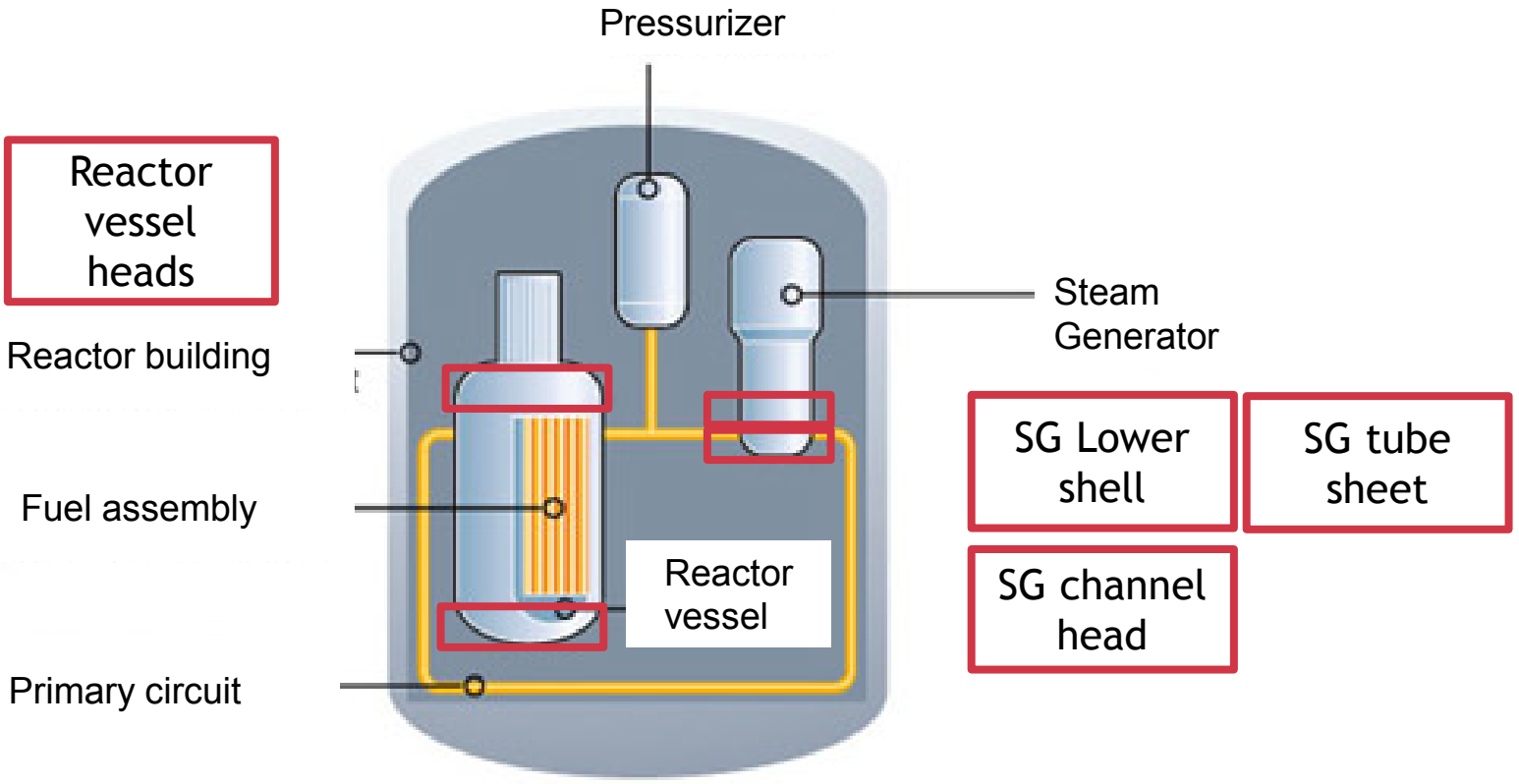
Context

Concerned components in France



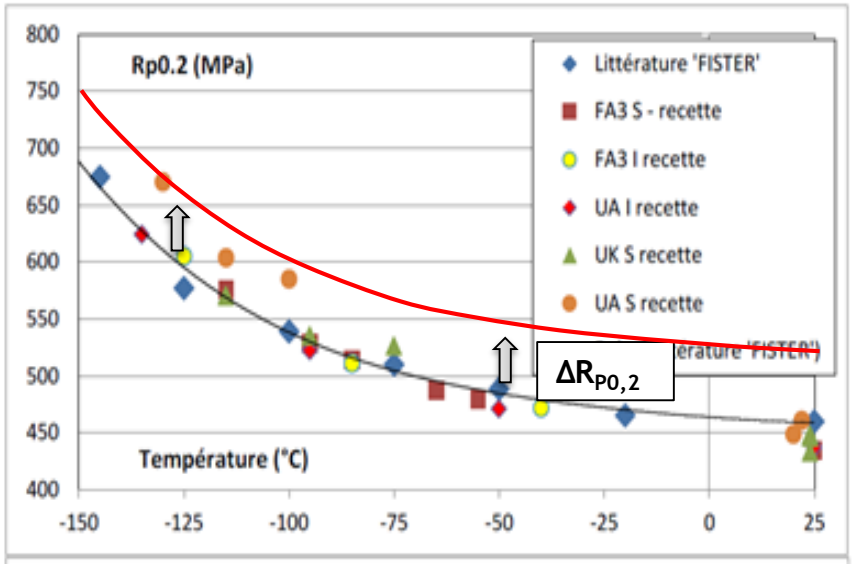
Context

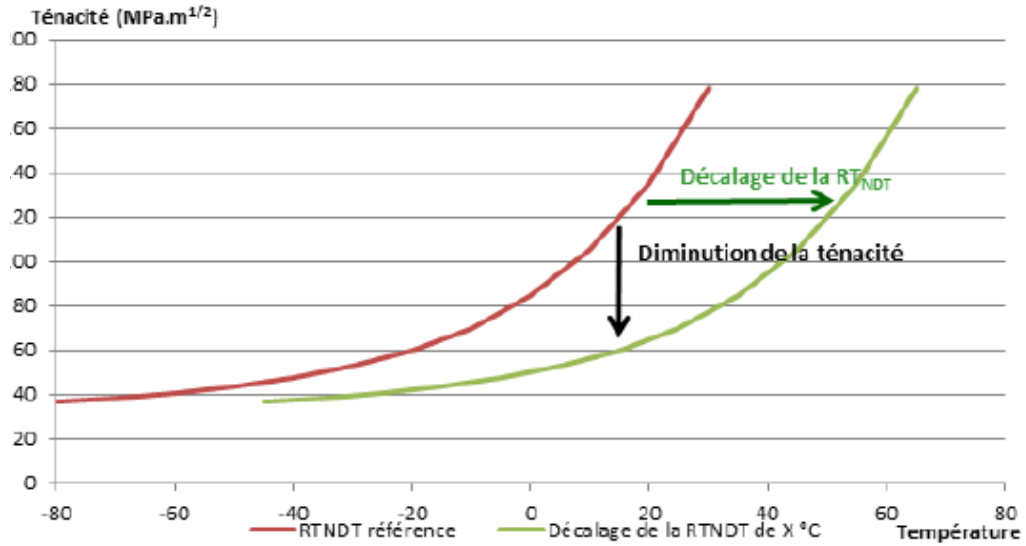
- Steel grade equivalent to A508
- RCC-M (French conception & manufacturing code) allows carbon content up to 0.25 % for this grade
- Carbon contents exceeding 0.3 % have been locally measured on some components during the technical qualification of heavy forged components (a French regulation requirement)
- Carbon contents exceeding maximum allowable values have been identified as the leading cause for low toughness values

↗ **A 508 mechanical properties considered in the code for design are questioned for these areas**

Safety issues

- A higher carbon content in A508 steels leads to :
  - An increase of tensile properties
  - A decrease of toughness properties => increase in DBTT





↗ What are the properties of this material ?

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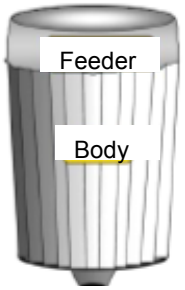
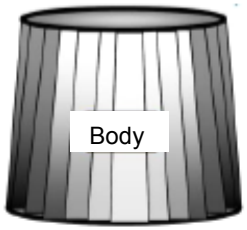
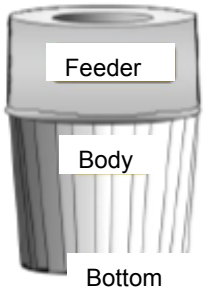
Manufacturing

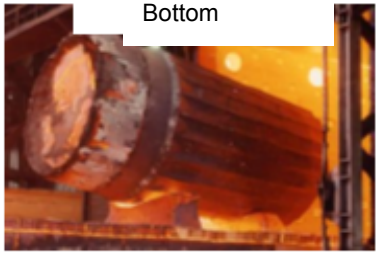
- Full ingot vs. Hollow ingot

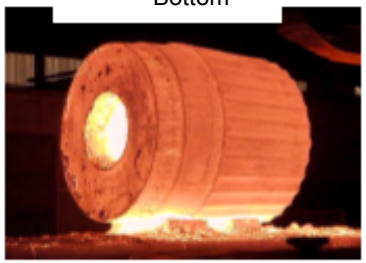
	Number of components
FA3 vessel heads	Full
SG channel heads	Full
SG lower shell	Hollow
SG tube sheets	Full

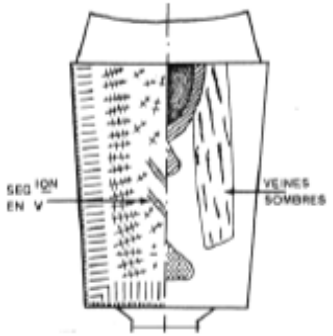


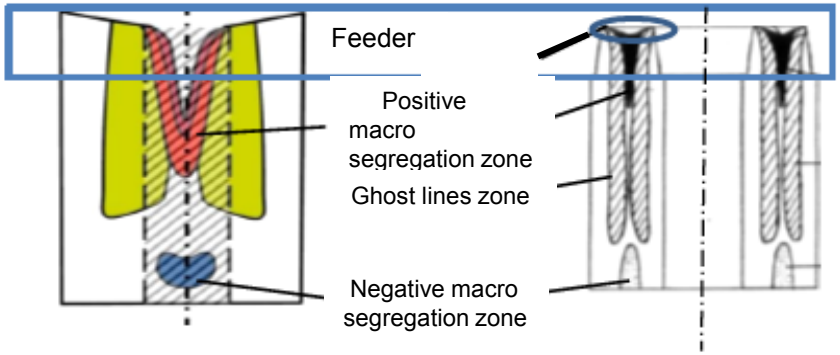






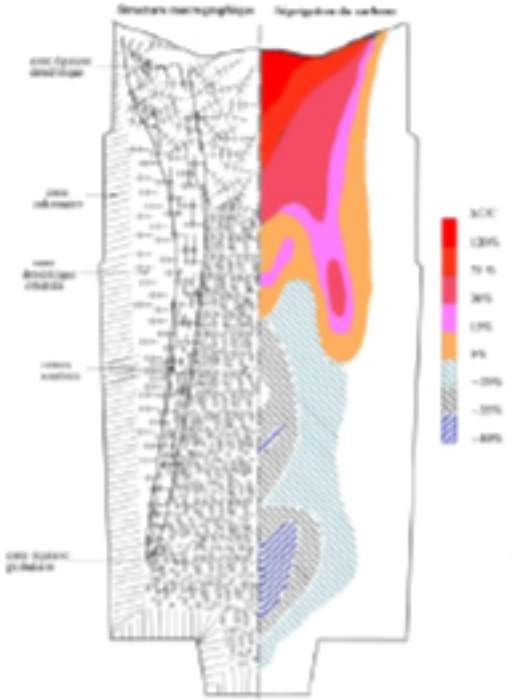


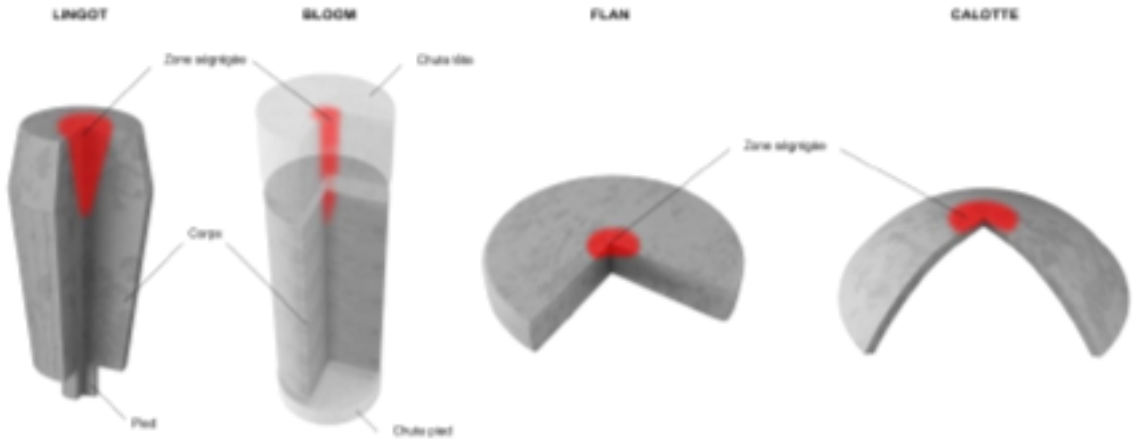




Manufacturing

- Full ingot – final localization of carbon segregation





Further manufacturing steps

- Manufacturing parameters have a major effect on final maximum carbon content
  - Ingot type and geometry (H/D ratio)
  - Feeder discard ratio
  - Machining

- Full ingot : evolutions of ingot type in the 90's led to larger and deeper segregation zone not sufficiently limited by subsequent manufacturing steps

- Hollow ingot :
  - Mistakes in feeder discard ratio and consequent machining (only 1 case in France i.e. SG lower shell)

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Justification file

- French safety authority demanded to determine the toughness of the segregated areas based on sacrificial components characterization

- Reactor vessel heads : 3 components

- SG lower shell : 2 components

- SG primary heads
  - Justifications issued by EDF and accepted by French safety authority
  - Sacrificial components under characterization

- SG tube sheets
  - Justifications issued by EDF

Justification file

- Type of investigations
  - Carbon content mapping to identify the extension and intensity of the segregated area
  - Tensile tests
  - Toughness tests
    - Charpy V notch samples
    - CT samples

- Objectives :
  - Determine the potential shift in mechanical properties
  - Determine the risk of cold cracking in case segregated material is located in the vicinity of welds (case of SG lower shell)

Results – RV heads

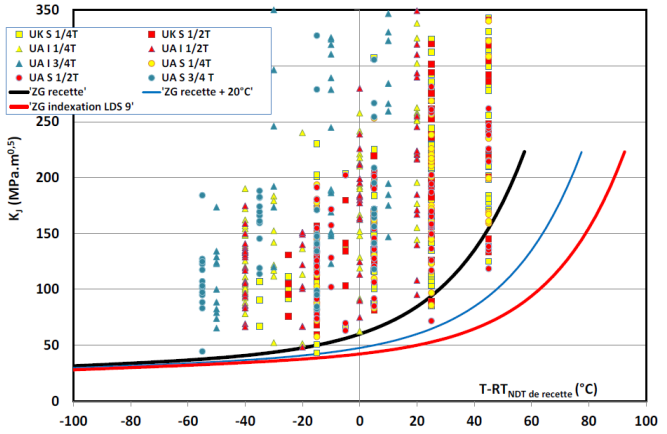
- Segregated area extent

	Component #1		Component #2			Component #3		
Zone	¼ T	½ T	¼ T	½ T	¾ T	¼ T	½ T	¾ T
C% (avg)	0,25	0,22	0,27	0,25	0,22	0,28	0,27	0,23

- Mechanical properties

	ΔRp0,2 (Mpa)	ΔRm (Mpa)	A %	ΔT68 (°C)	Upper shelf (J)	ΔRTNDT (°C)
Number of tests	145			574		96
	≤ 55 (1/4 T)	≤ 74 (1/4 T)	≥ 20	50<Δ<58 (1/4 T)	> 172	45 (1/4T)

- Toughness
  - Ductile tearing results are in conformance with RCC-M specifications
  - Fracture toughness : not all results are covered by RCC-M minimal value curve when indexed to acceptance tests RTNDT
  - A shift of 20 °C is necessary to cover the results



Results - SG lower shell

- Segregated area extent

Configuration	Max %C	Position
Discarded + machined	0.28	Between ½ T and int. ¼ T

- Manufacturing data show that no segregated material is in contact with the fluid → no corrosion issue

- Mechanical properties

	Rp0,2 (Mpa)	Rm (Mpa)	A %	ΔT68 (°C)	ΔRTNDT (°C)	Toughness
Number of tests in segregated area	30			183	48 drop weight tests	150 CT(0.5T)
	In conformance with requirements			45	10	All results are covered by RCC-M indexed to acceptance tests RTNDT

- HAZ properties (1 mm and 4 mm to fusion line)
  - No deviation to mechanical properties requirements
  - Implant tests showed no risk of cold cracking on segregated material

Results

- Mechanical properties in fast fracture studies were based on these results

- The difference of DBTT shift between each justification file is linked to the localization of the segregated area, i.e distance to quenched surfaces

Global view

	Justifications issued by EDF	Justifications accepted by ASN	Sacrificial components characterization	Safety body decision
RV heads	☑	☑	☑	☑
SG lower shell	☑	☑	☑	☑
SG Channel heads	☑	☑	ongoing	
SG tube sheets	☑	ongoing		

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IRSN position

- Justification method based on sacrificial components
  - Necessary approach as calculation approach would raise uncertainties and representativity issues
  - Representativity is key
  - Additional conservatism on material properties to integrate representativity and variability issues

- Type of tests supporting the demonstration
  - IRSN recommends the use of drop weight tests in addition to CVN and CT tests
    - CT tests are necessary but not sufficient especially to justify the integrity of components whose manufacturing process has little OPEX (hollow ingot for instance)
  - CT tests provide information at a local scale on heterogeneous materials
  - Drop weight tests provide information at a mesoscopic scale

↗ **Both types of tests are complementary**

Thanks for your attention