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Carbon content anomalies in large forged components in France

NRC/RIC – 16 March 2017

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EPR FA3 RPV lessons learned

End of 2014: Discovery of anomalies in the composition of the steel in certain parts of the reactor pressure vessel of Flamanville EPR reactor

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    graph TD
      A[Flamanville 3 RPV anomalies] --> B[Same anomaly in other components]
      B --> C[CFSI  
Creusot Forge]
      subgraph Note
      D[Technical anomaly : carbon segregation]
      end
  
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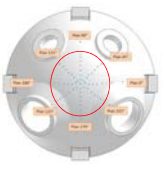
Review of all the forged heavy components

- Pressurizer domes
- Pressurizer shells
- SG tubesheet
- SG channel head
- SG elliptical head
- SG shells
- RPV closure head
- RPV bottom head and transition zone
- RPV shells

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asn **Steam generator channel heads**

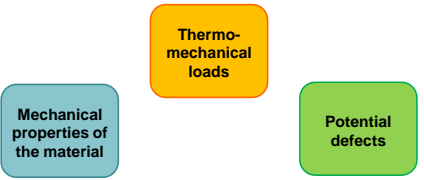
- The review identified several SG bottom channel heads
- High probability of carbon segregation
- Manufactured by Creusot Forge and Japan Casting & Forging Corp. (18 PWR units in France)
- Charpy V-notch tests results (approximately 30J at 0°C) : no compliance with French regulation on a qualification component

- ASN asked EDF to justify the structural integrity of these components
- Analysis aim is to confirm the absence of potential risk of fast fracture

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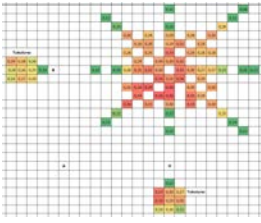
asn **EDF safety file: Fast fracture analysis**



Analysis to check that the thermo-mechanical loads can't initiate the propagation of the biggest potential defect, that can not be detected by NDE

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asn **EDF safety file: Fast fracture analysis**



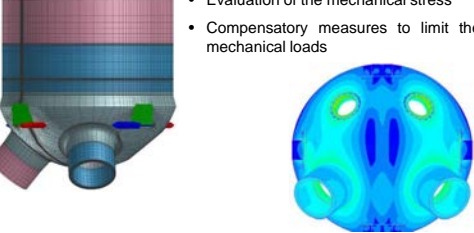
- Carbon measurements on the outer surface (optical emission spectroscopy): high carbon content up to 0.39% for JCFC channel heads (RCC-M code limit : 0.22%)
- Estimation of the depth of the segregation
- Mechanical tests on segregated materials

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asn EDF safety file: Fast fracture analysis

Thermo-mechanical loads

- Identification of the thermo-mechanical loads on channel heads : hot and cold thermal shocks and overpressures
- Evaluation of the mechanical stress
- Compensatory measures to limit thermo-mechanical loads




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asn EDF safety file: Fast fracture analysis

Potential defects

- Review of NDT performed during manufacturing
- New additional NDT (Penetrant and ultrasonic testing)



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asn ASN stances – December 2016 and January 2017

ASN considers acceptable the methodology and hypotheses proposed by EDF

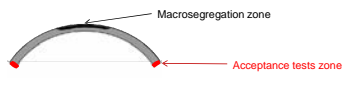
- Additional information about thermo-mechanical loads
- Additional operating compensatory measures
- Hypotheses about material properties to be confirmed by a testing program on representative channel heads

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asn **Past regulation**

Order of February 26th, 1974 and RCC-M code

- Risk of heterogeneities in materials controlled by applying the RCC-M M140 requirements
 - RCC-M M 143.1: *“ the qualification shall ensure that the component is capable of being suitably operated and controlled. In this context, the manufacturer identifies the particularities of the component, especially, his controllability and unusual zones ”.*
- Heat analysis and product analysis of the chemical composition
- Compliance with minimal mechanical properties required in acceptance tests zone (surface to be welded)



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asn **Past regulation**

Order of February 26th, 1974 and RCC-M code

- M140 qualification usually leads the manufacturer to adjust its testing program from expert elicitation by comparing with an existing similar manufacturing process.
 - Ex: the M140 qualification of the EPR RPV cover head (forged from a 150T conventional ingot) was based on the M140 qualification program of a smaller replacement RPV cover head (forged from a 50T “LSD”, directional solidification ingot) with addition of some mechanical test in the zone to be welded to the flange.

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asn **New regulation**

Orders of December 12th, 2005 and December 30th, 2015 “ESPN”

- “ESPN” Technical Qualification
- Objective:
 - to identify the parts of the component with a risk of heterogeneity
 - to assure the component get the required characteristics
- Systematic analysis of the risk of heterogeneities
- Achieving objectives can lead the manufacturer to proceed to adequate tests in order to qualify the process on a full-size mock-up.

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Lessons learned – Conclusions (1/2)

- Carbon positive macrosegregation phenomenon is not well understood and mastered by the forge industry
- Its impact on mechanical properties is not well known, specially in case of high carbon content (> 0,30%)
- Due to carbon segregation some components may be susceptible to fast fracture whereas they are generally not considered so
- Operating compensatory measures necessary, based on current knowledges, to limit the impact of the potential fast fracture risk
- Carbon positive macrosegregation can cause difficulty of weldability, if close to surface to be cladded or welded
- Residual carbon segregation can lead to generic anomalies

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Lessons learned – Conclusions (2/2)

- New French regulation highlighted the risk of heterogeneities.
- French code (RCC-M) does not address adequately carbon segregation, despite the implementation of M140 qualification.
- RCC-M derives from ASME III.
- Regarding risk of heterogeneities, codes and industrial practices must continue to evolve in order to enhance quality and thus safety.

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