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RPV integrity assessment – a comparison of regulatory approaches in nine ETSON member countries

Subject and aim

- Presentation of a report published in 2018
  - Available on the ETSON Website
- Written by ETSON EG2 „Mechanical Systems“
- Report describes approaches in 9 countries
  - Aspects of RPV integrity assessment
  - <u>Focus on brittle fracture assessment for PWR</u>
- Communalities and differences of approaches
  - Shall promote mutual understanding

Contents of the ETSON report

1. Introduction
2. Approach for integrity analyses
3. Scope and techniques of NDT
4. Content and scope of irradiation surveillance programmes
5. Specific aspects of fracture mechanical analyses
6. Preventive and mitigative measures
7. Conclusions
8. Annex 1: Abbrev, formulas for prediction of ΔDBTT and fracture toughness curves
9. Annex 2: Comparison of requirements of regulations

Introduction and General Approach

- Integrity analyses for pressure vessels:
- Strength and fatigue design analyses
- Brittle Fracture Analyses (BFA)
  - Most severe loading – including accidents
    - Mostly thermal shocks due to safety injection of cold water
    - And cold overpressure
  - crack postulated at most adverse location

for any pressure vessel

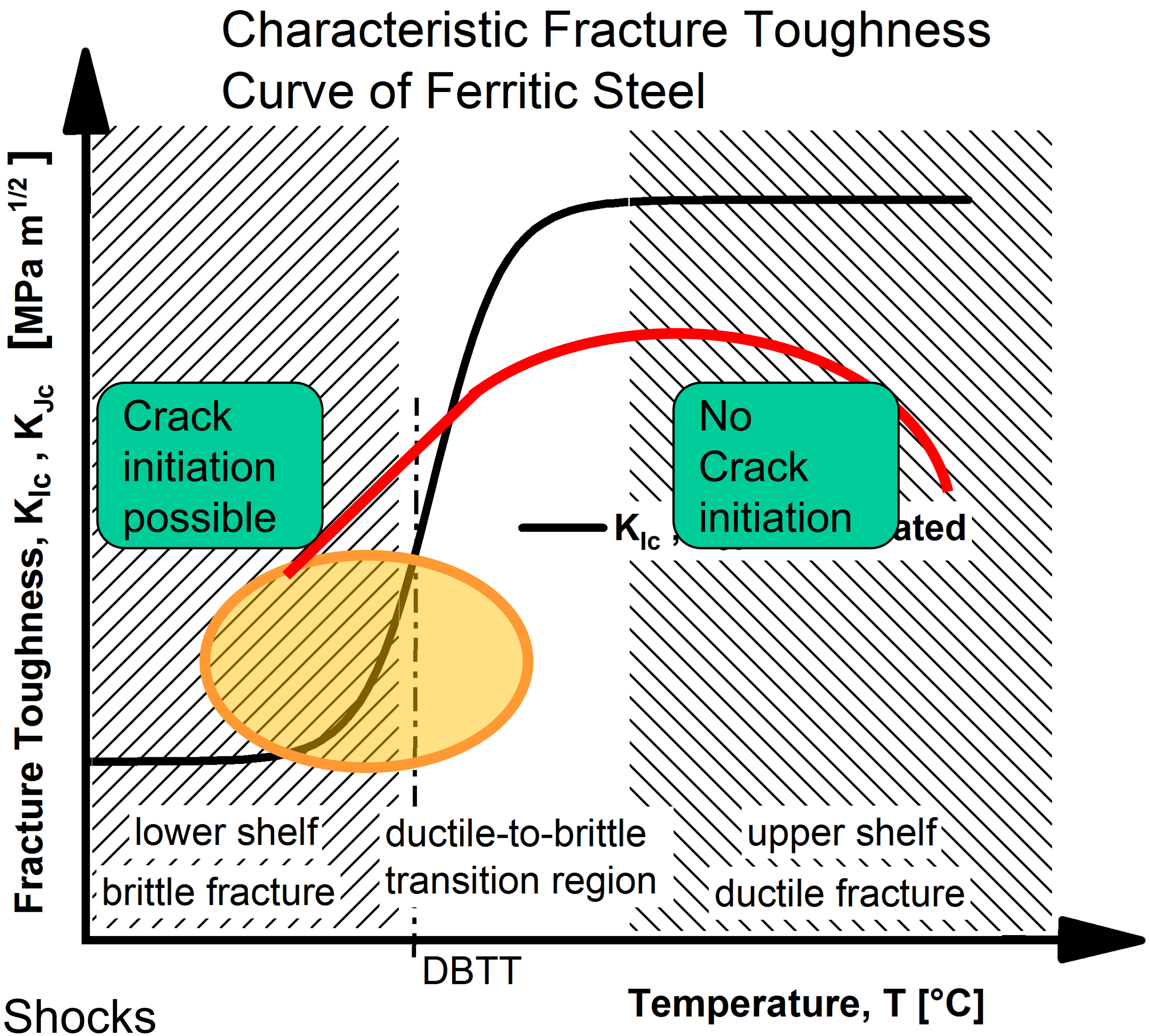
special for RPV due to neutron embrittlement

Similar in all countries

Approach to integrity analyses

More Communalities

- Fracture toughness:
  - Resistance against crack propagation
  - For real or postulated cracks
- DBTT:
  - Ductile Brittle Transition Temp.
- Most severe loading:
  - High stress in the RPV wall at low T
  - Highest during Pressurized Thermal Shocks



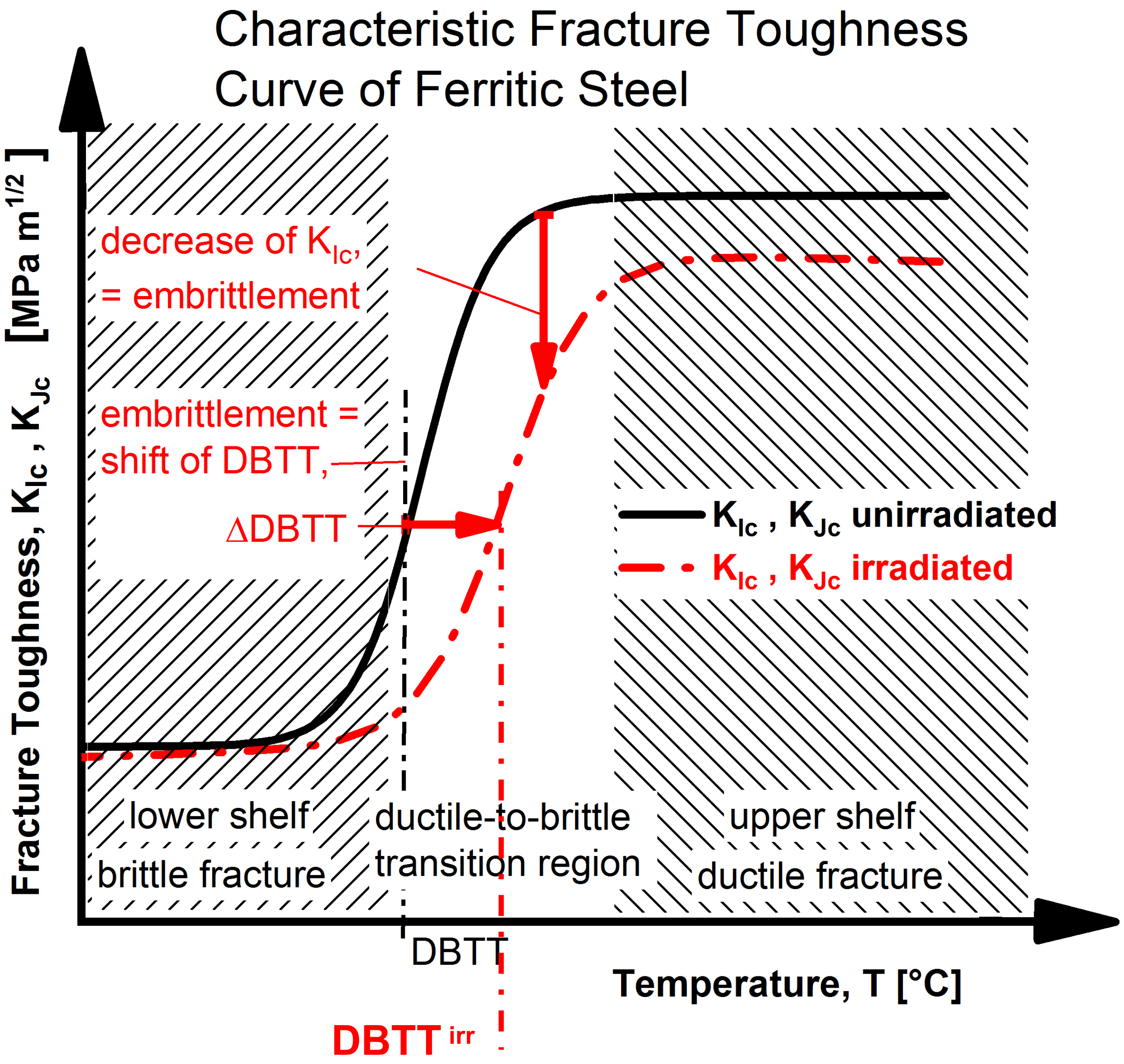
Approach to integrity analyses

More Communalities

- Effects of neutron irradiation
  - Shift of DBTT
  - Decrease of upper shelf

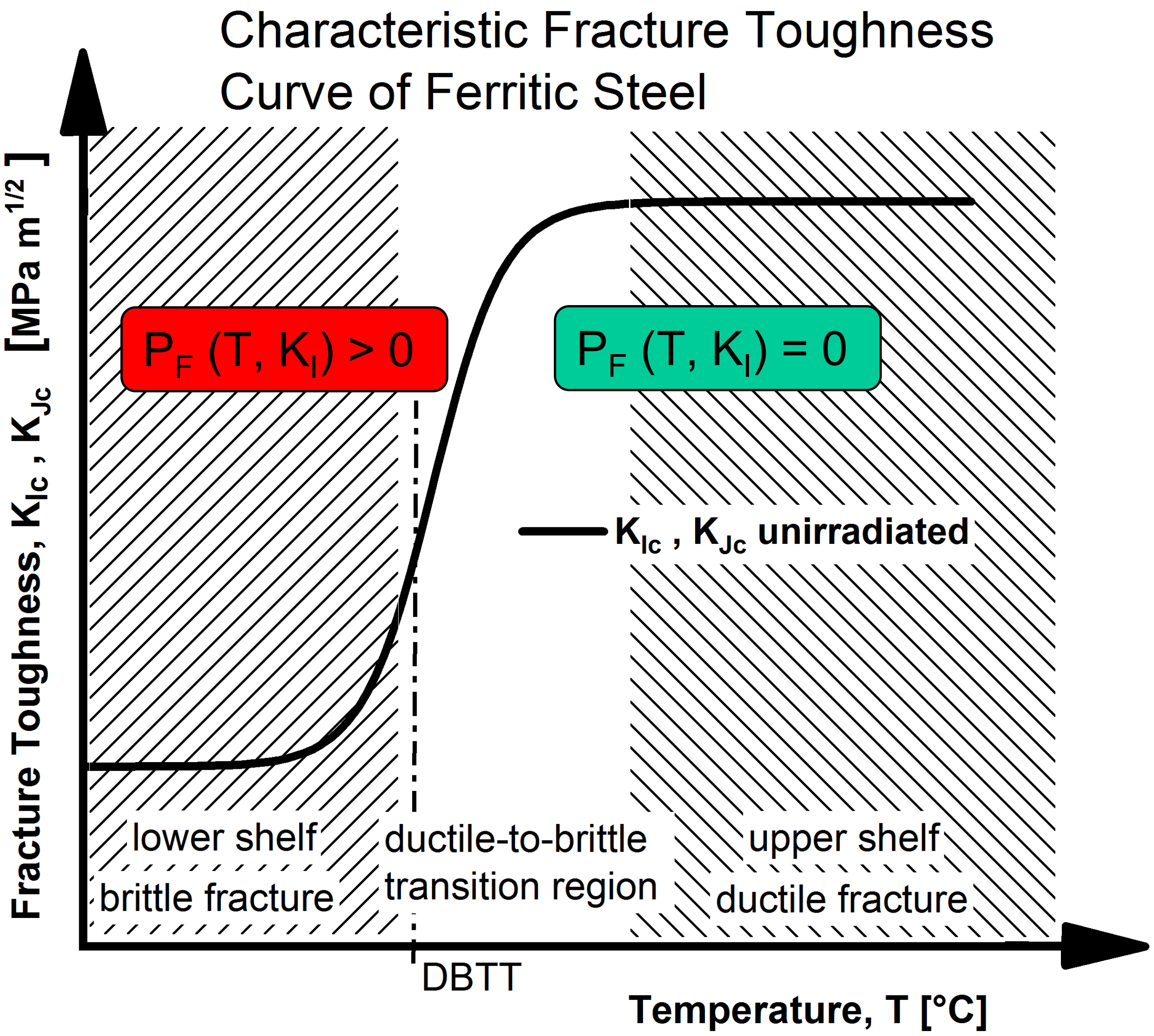
And now:

Differences



Fracture toughness curves

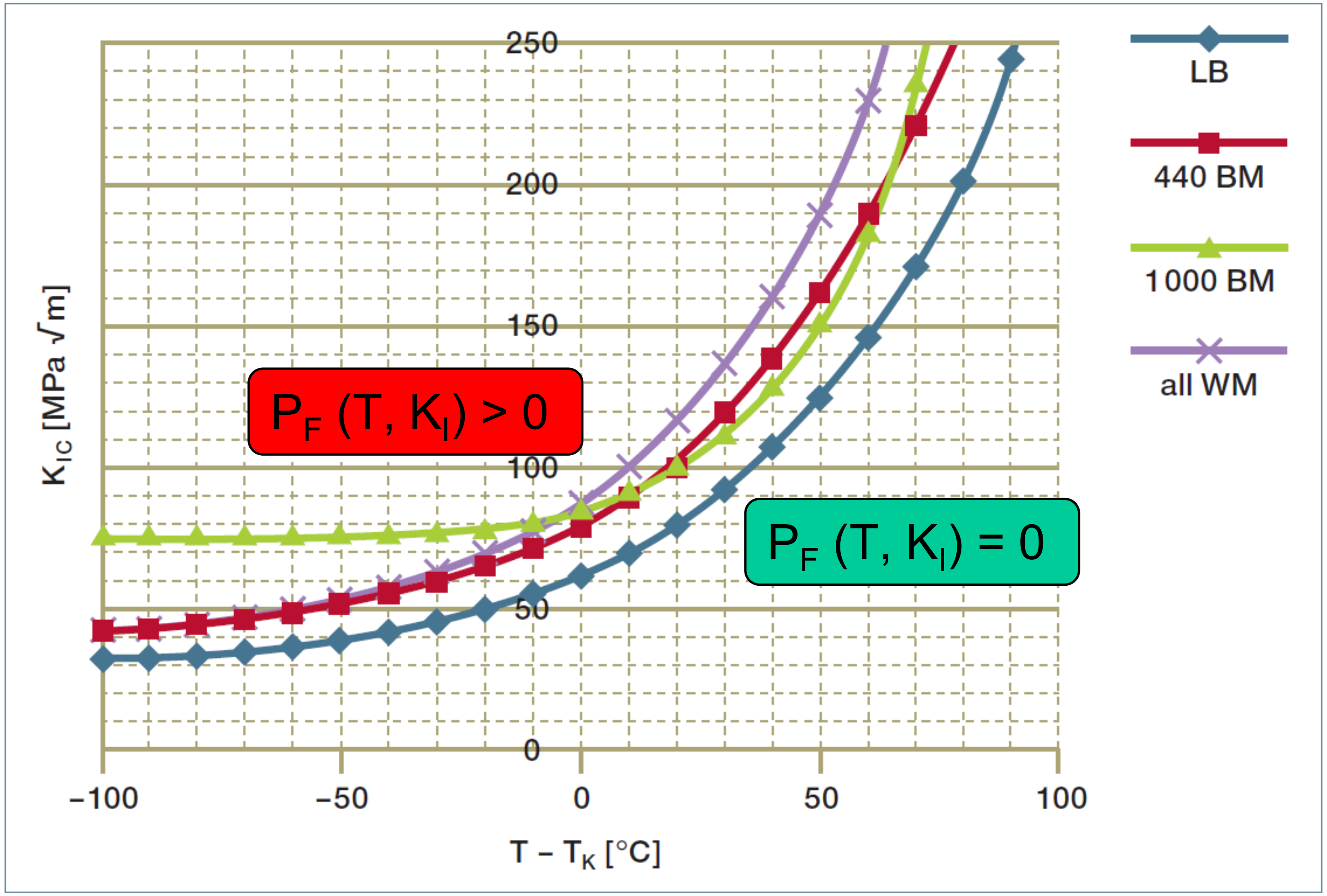
- Reference curves in the codes
- Assumed to be “lower bound” curves for specific material(s)
- ➤ Deterministic approach



More fracture toughness curves

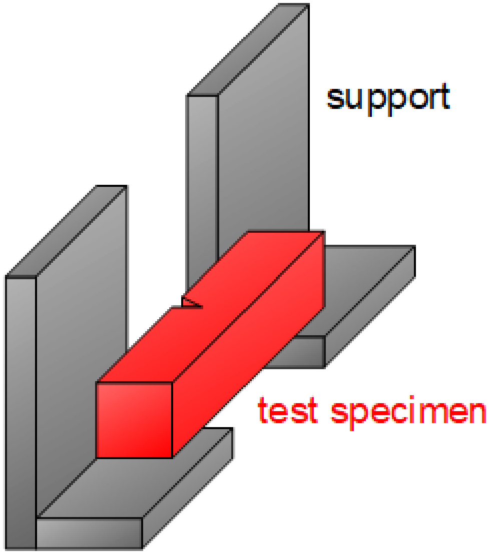
- Reference curves in the codes
- Assumed to be “lower bound” curves for specific material(s)
- ➢ Deterministic approach
- Examples:

1. Curves in Ukrainian code - f(T_K)
2. Master Curve - f(T_0)
   - independent of specific material
     - i.e. ferritic steel
   - Probabilistic curve - fractiles

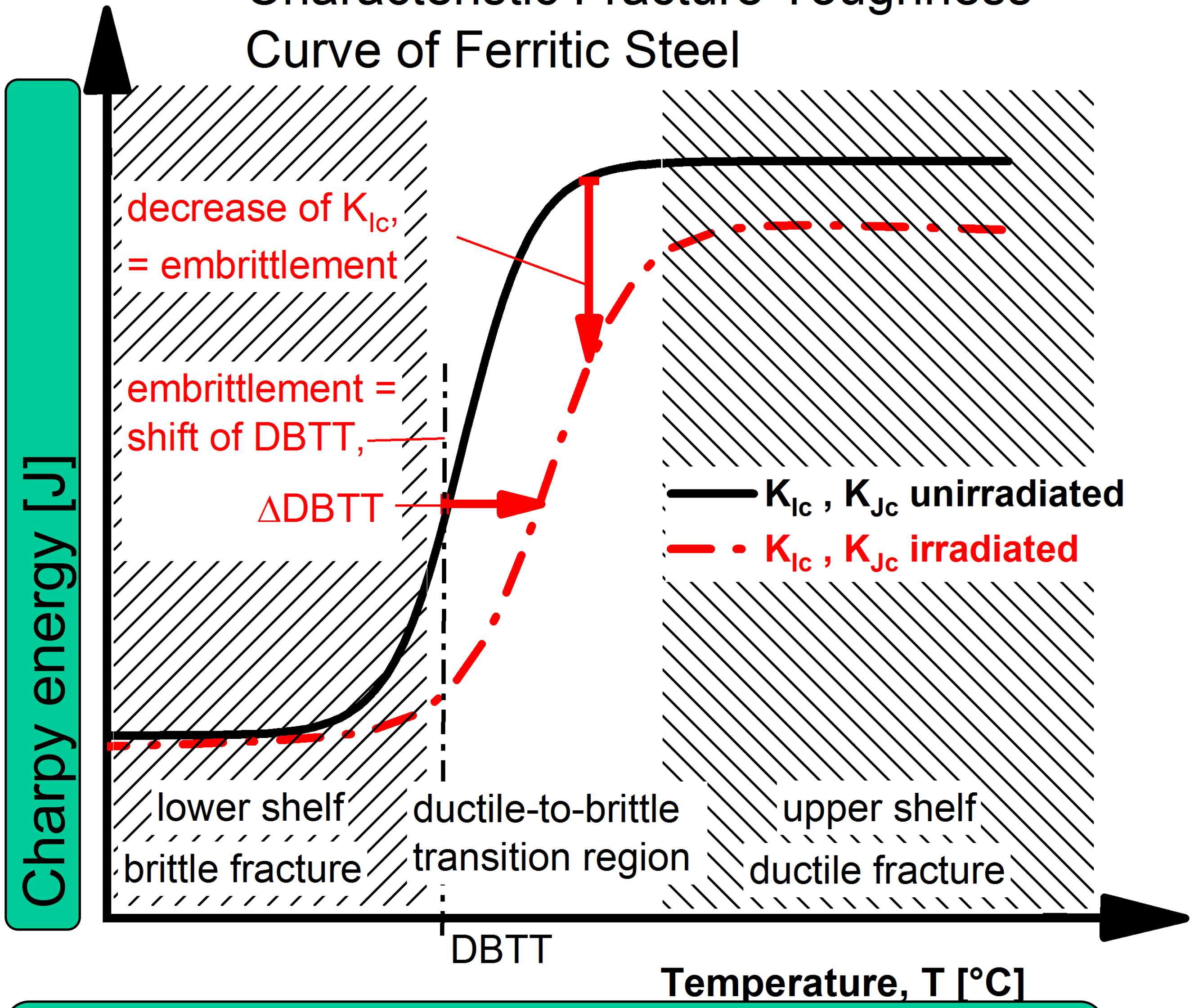


Definitions of DBTT

- RT_{NDT}: Based on Charpy & Pellini
- T_K based on Charpy only
- Shift based on Charpy energy
- Slightly different criteria



Characteristic Fracture Toughness Curve of Ferritic Steel



Fracture toughness curves are correlated to Charpy curve via DBTT

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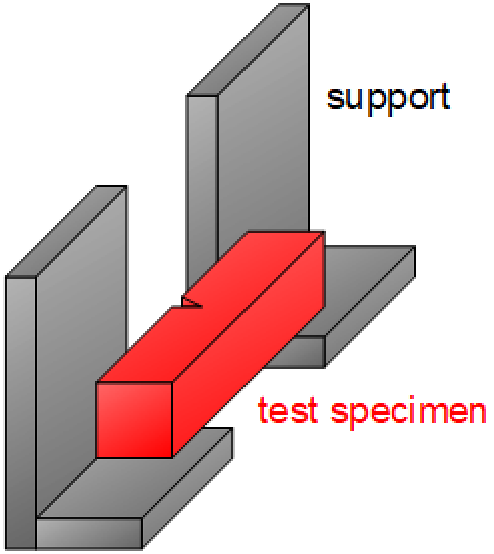
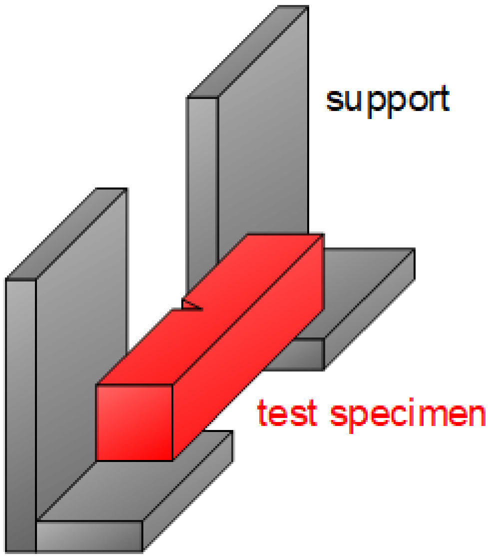
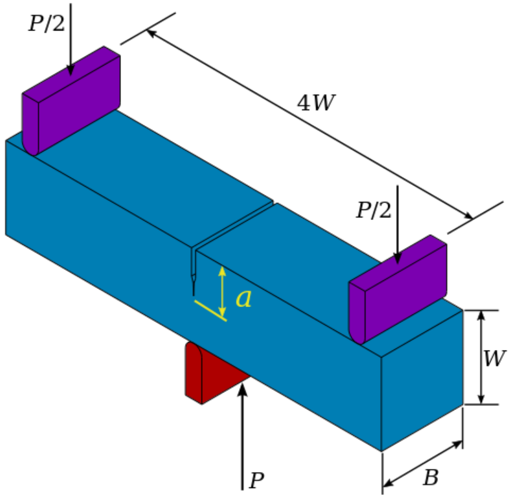


More definitions of DBTT



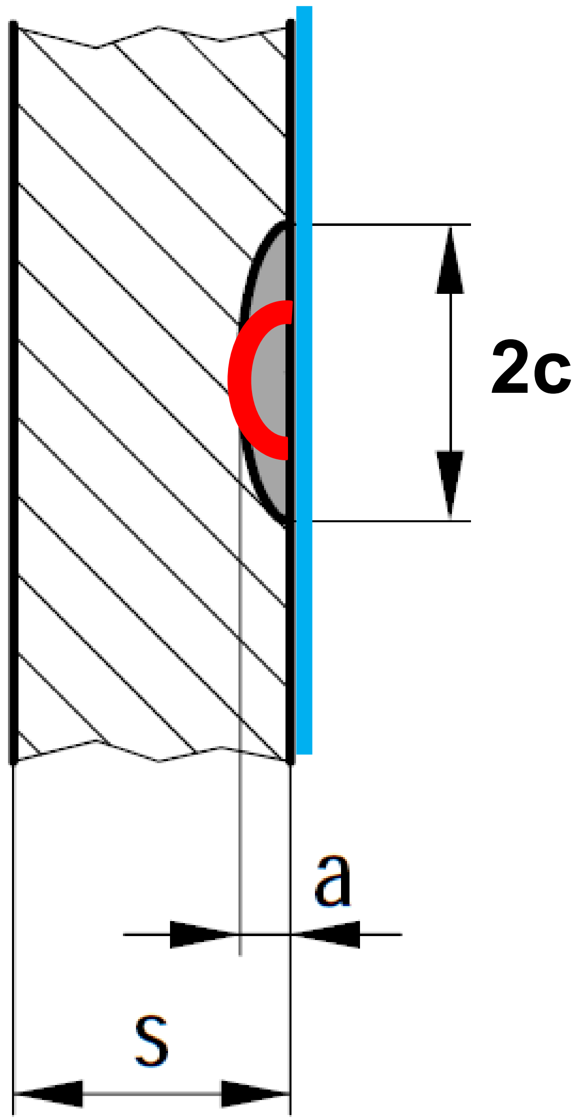
- RT_{NDT}: Based on Charpy & Pellini
- T_K based on Charpy only
- Shift based on Charpy energy
- Slightly different criteria
- **More recent definitions**
  - Allowing direct evaluation of fracture toughness
  - e.g. T_0 based on 3-point bending tests
    - "Master Curve": Probability of failure P_F (T, K_I)
  - Experimental correlation: $RT_{T0} = T_0 + 19.4K + \text{Margin}$



Picture below: By Bbanerje - Own work, CC BY-SA 3.0, https://commons.wikimedia.org/w/index.php?curid=15933571

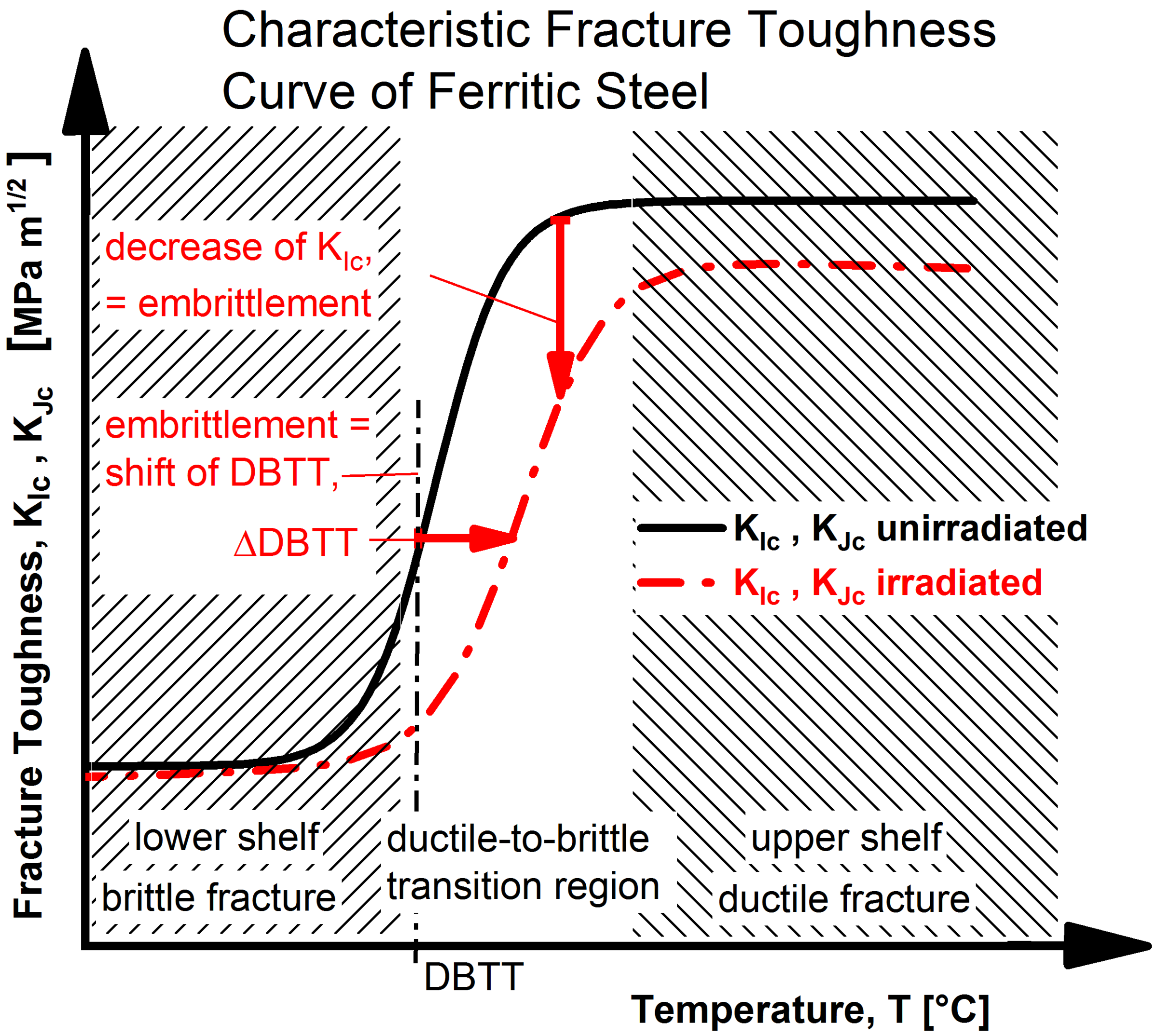
Postulated cracks – size, form and location

- Semi-elliptical cracks with different depth a shall be analyzed
  - underclad (UCC) and/or through clad cracks (TCC)
  - Even cracks within or into the cladding
- Different sizes are prescribed in the codes
  - Absolute values: e.g. 5 x 25mm
  - Relative to wall thickness s: e.g. a=0.07s to 0.125s (+ s_{clad})
  - different aspect ratios a/c: Mostly 1/3, sometimes 1/2 or 2/3
- Prescribed size may depend on ISI performed
  - E.g. depending on specified size found by ISI
  - if no ISI performed → assume larger crack and/or TCC



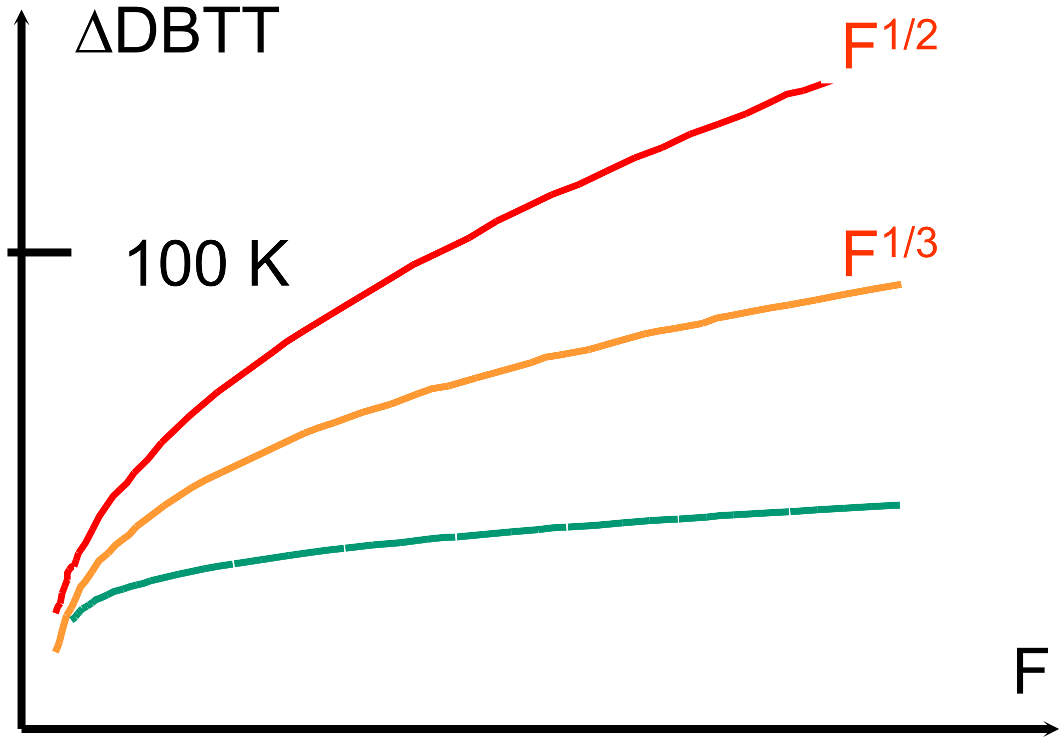
Shift of DBTT by irradiation

- Shift is predicted by formula
- ΔDBTT = CF·F^n with
  - "chemical factor" CF
  - Fast neutron fluence F
  - CF may depend on Cu, P, Ni, Mn
  - exponents n between 0.28 and 0.6



Shift of DBTT by irradiation

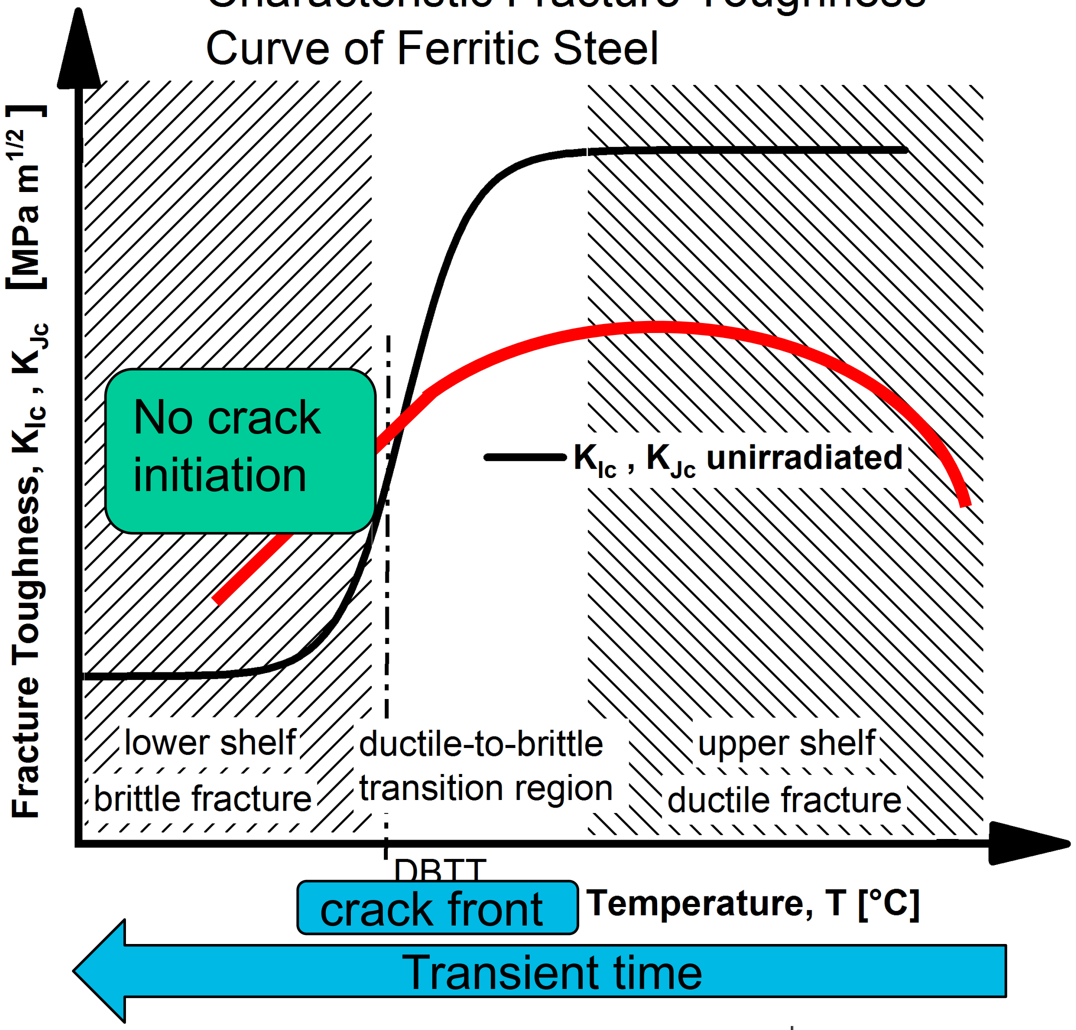
- Shift is predicted by formula
- $\Delta DBTT = CF \cdot F^n$ with
  - "chemical factor" CF
  - Fast neutron fluence F
  - CF may depend on Cu, P, Ni, Mn
  - exponents n between 0.28 and 0.6
- Experimentally determined parameters
  - from data base for specific materials
  - ➢ should not be simply transferred to other materials



Specific aspects of BFA: Crack arrest and Warm-Prestress (WPS)

- Mostly: BFA → No (instable) crack initiation
- Some countries: Integrity might be proven by crack arrest after initiation
  - E.g. for large LOCA
- **WPS:** Pre-stressing steel with a crack at high T
  - ➢ Will increase the K_{Ic} at low T after cooling
  - Generally accepted for decreasing load $K_I(t)$
  - Additional margins for fast transients
  - Application under discussion in some countries

Characteristic Fracture Toughness Curve of Ferritic Steel



Chosen as next topic

Conclusions

- RPV integrity analyses are based on similar principles in all countries
- The approaches differ significantly in many details
- A direct comparison should always consider the impact of these details
- Many details of BFA are described in our report Annexes
- We hope improving mutual understanding of analyses from different countries
- Finally, I want to acknowledge…

Contributors to the report / ETSON EG2 “Mechanical Systems“

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