

# **Fracture toughness measurement using small specimens**

**M. Scibetta, R. Chaouadi and al.**

**SCK CEN, B-2400 Mol, Belgium**

**Presented in the Working Group :  
"European Hot Laboratories and  
Remote Handling"**

**Studsvick Nuclear, June 5-6, 1997**

*Working Group "European Hot Laboratories and Remote Handling"*  
*Topic II: Mechanical Testing of Structural Materials*  
*Fuel rods - Reactor Materials - Control Rod*  
*Studsвик Nuclear, June 5-6, 1997*

## **Fracture toughness measurements using small specimens**

M. Scibetta, R. Chaouadi and al.  
SCK•CEN  
Boeretang 200  
B-2400 Mol (Belgium)

Pre-Cracked Charpy V-notch (PCCV) and circumferentially Cracked Round Bars (CRB) are used to measure the fracture toughness of reactor pressure vessel steels. Both geometries are of practical interest for the nuclear industry as they only require a small amount of irradiated material.

This presentation describes experimental procedures to obtain fracture toughness from these two geometries. The PCCV specimens, in the baseline and irradiated condition, are precracked and tested in three point bending. CRBs are precracked using the rotating bending fatigue technique and are loaded in tension. Emphasis is put on the formulae used to analyse the load displacement trace of a fracture toughness test and on the applied correction to take the loss of constraint and size effect into account.

Promising results are obtained and show that both methods have the potential to measure fracture toughness in the lower shelf and in the transition region.

**KEY WORDS:** circumferentially cracked round bar, Pre-Cracked Charpy V-notch specimen (PCCV), fracture toughness, lower shelf, transition region, cleavage, precracking, rotating bending fatigue.

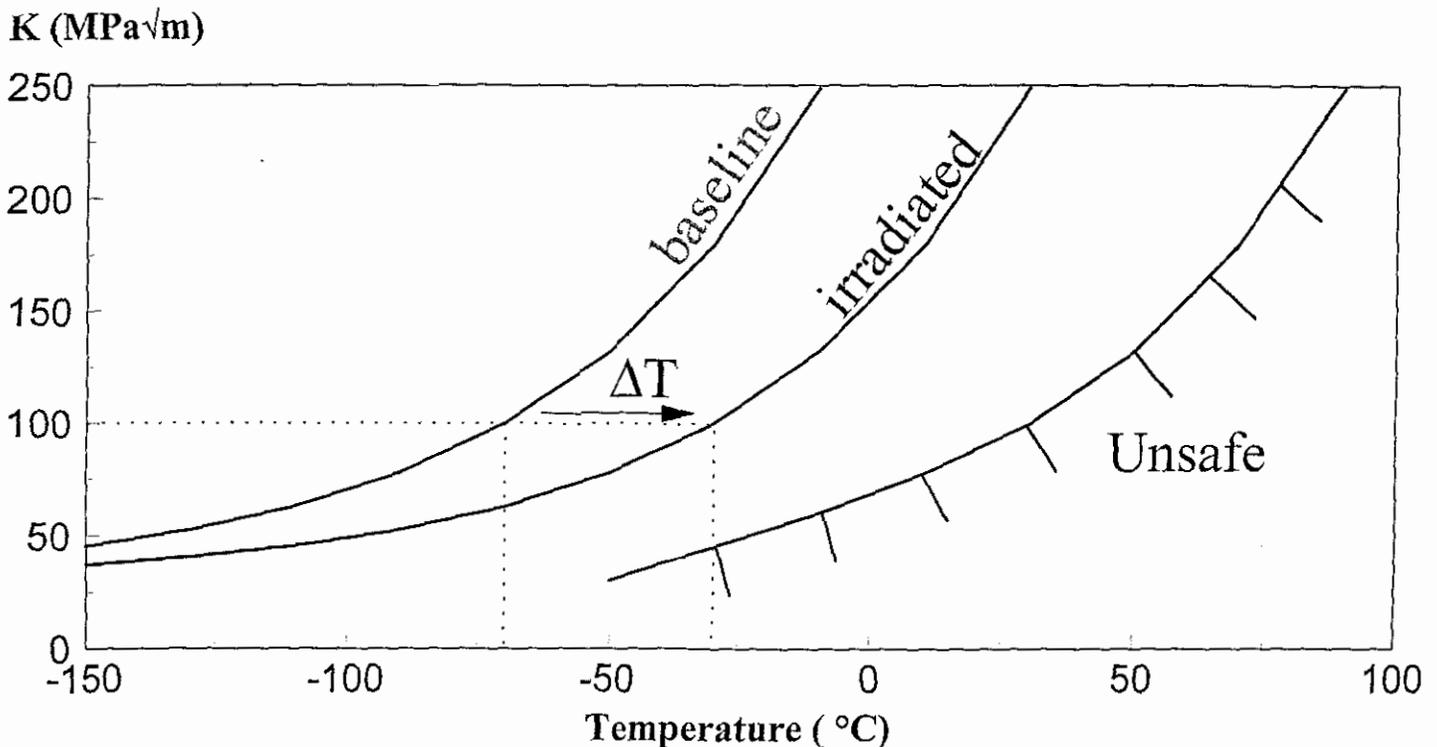
# Fracture toughness measurements using small specimens

M. Scibetta, R. Chaouadi and al.

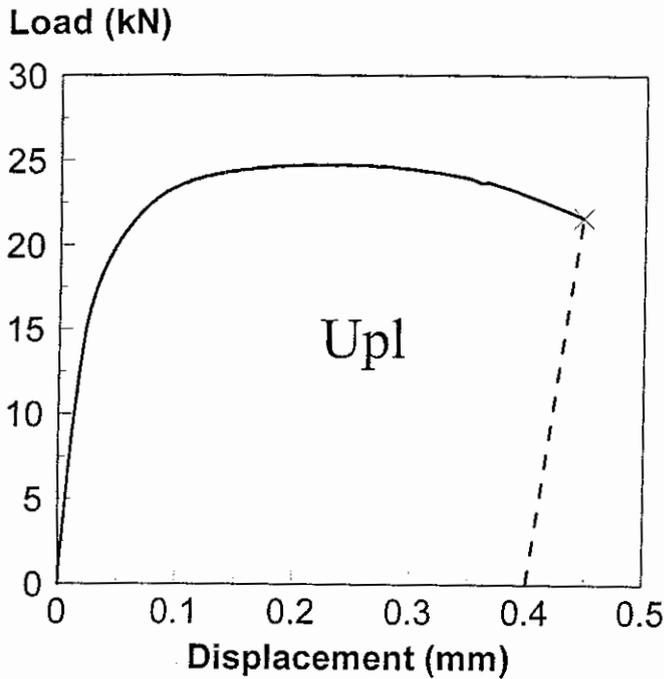
5-6 June 1997

Studsvik Nuclear

## RPVS is embrittled due to neutron irradiation and thermal ageing



# Load-displacement trace is used to derive the fracture toughness



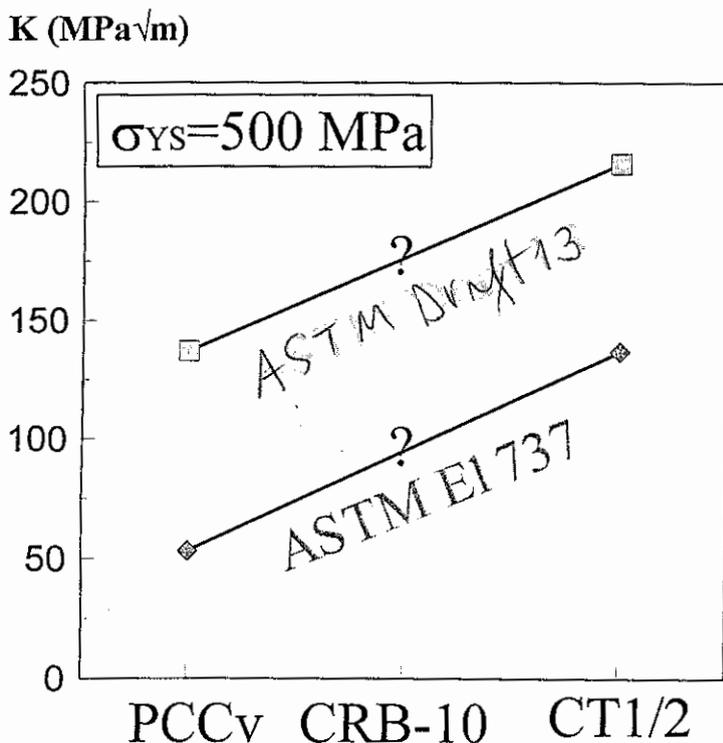
- $K(P) \begin{cases} \text{CT, 3PB} \Rightarrow \text{ASTM E399} \\ \text{CRB} \Rightarrow [\text{SCI} - 96] \end{cases}$

- $K = \sqrt{\frac{EJ}{1-\nu^2}}$  ASTM E1737

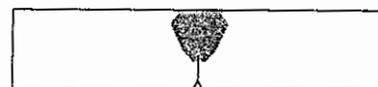
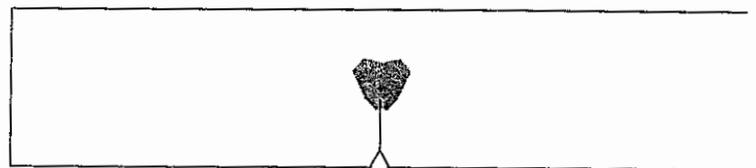
- $J = J_{el} + \eta \frac{U_{pl}}{\text{Ligament Area}}$

$$\eta = \begin{cases} \text{CT, 3PB} \Rightarrow \text{ASTM E813} \\ \text{CRB} \Rightarrow [\text{SCI} - 96] \end{cases}$$

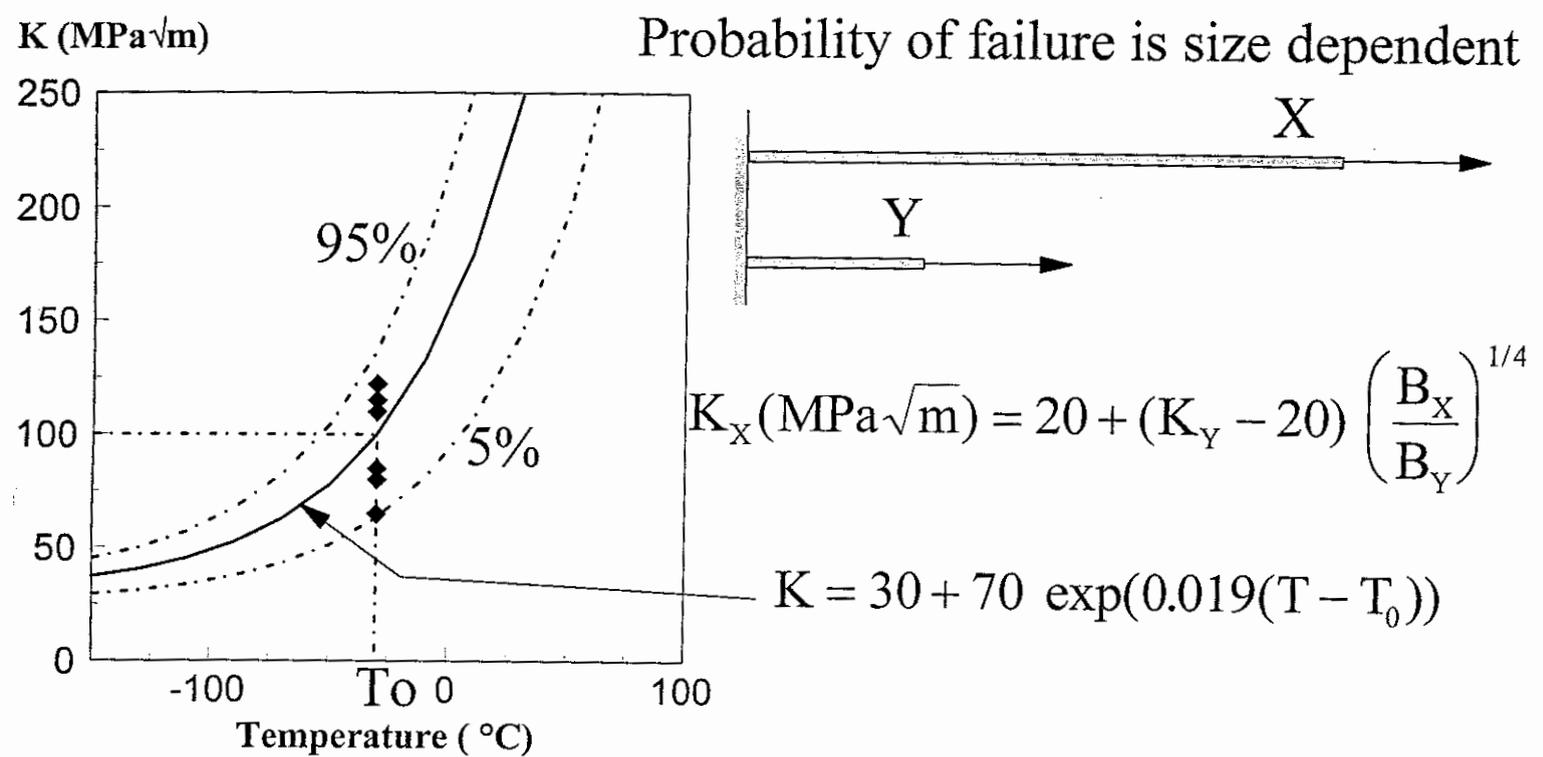
# Specimen size should be large enough to avoid loss of constraint



Largely spread plastic zone tends to decrease the constraint



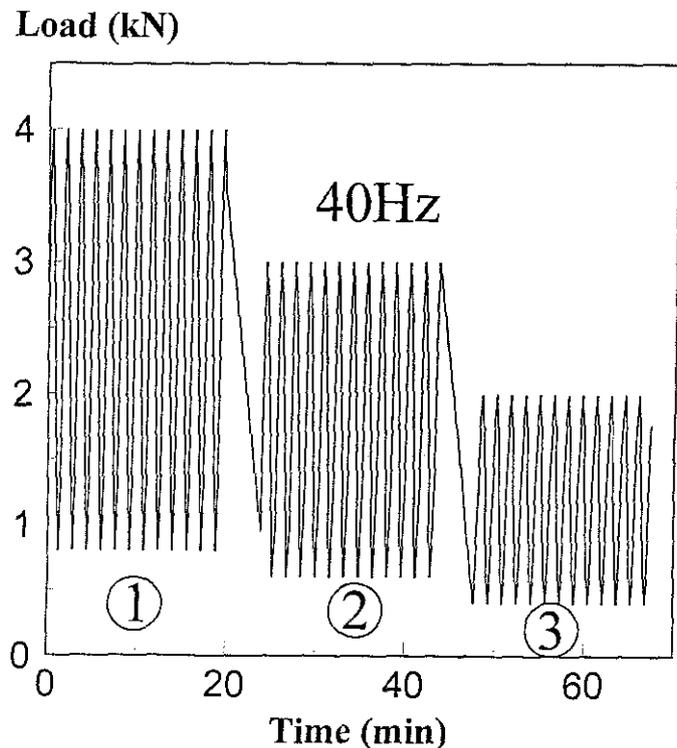
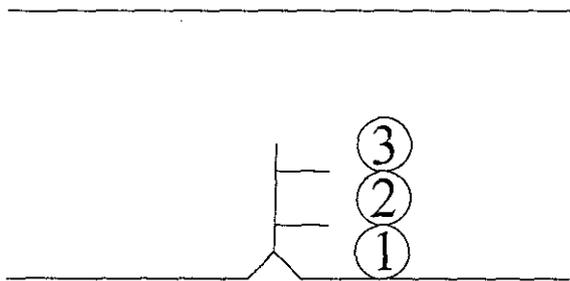
In the transition region the scatter is very large and a probabilistic approach leads to a size correction



CRB and irradiated PCCv are tested in 3 phases

- Precracking
- Testing
- Results

- Fatigue with visual crack growth monitoring
- Side groove machining (optional)



- Clip gauge installation
- Temperature stabilisation (30 minute) x-t recorder
- Analysis in Excel of previous test with hypothesis  $a=5\text{mm}$   $\Rightarrow$  choice of test temperature
- Coffee break
- Loading up to unstable fracture (cleavage) x-y recorder + data acquisition

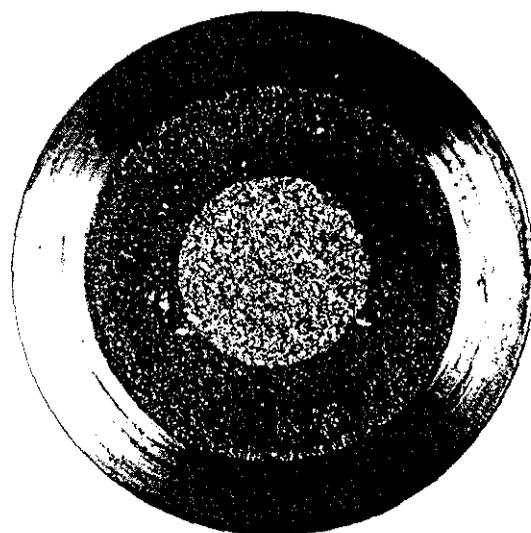
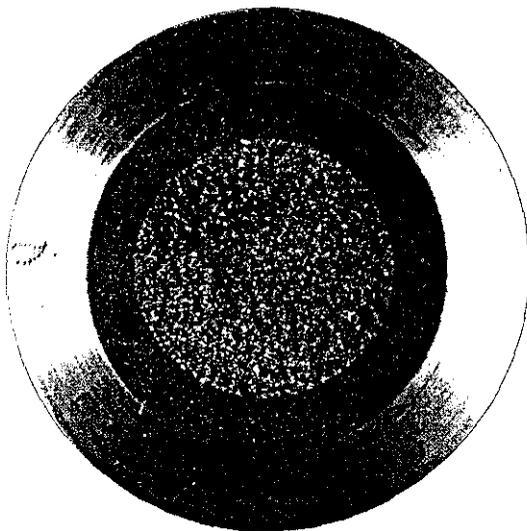
## Result: Definitive result are obtained after fracture surface analysis

---

- Heat tinting
- Load up to rupture at  $-170^{\circ}\text{C}$
- Specimen thickness measurement
- Photo of fracture surface
- Measurement of crack length (and crack growth if any)
- Excel => reanalysis of data
- Final evaluation and storage

## Precracked specimen

---



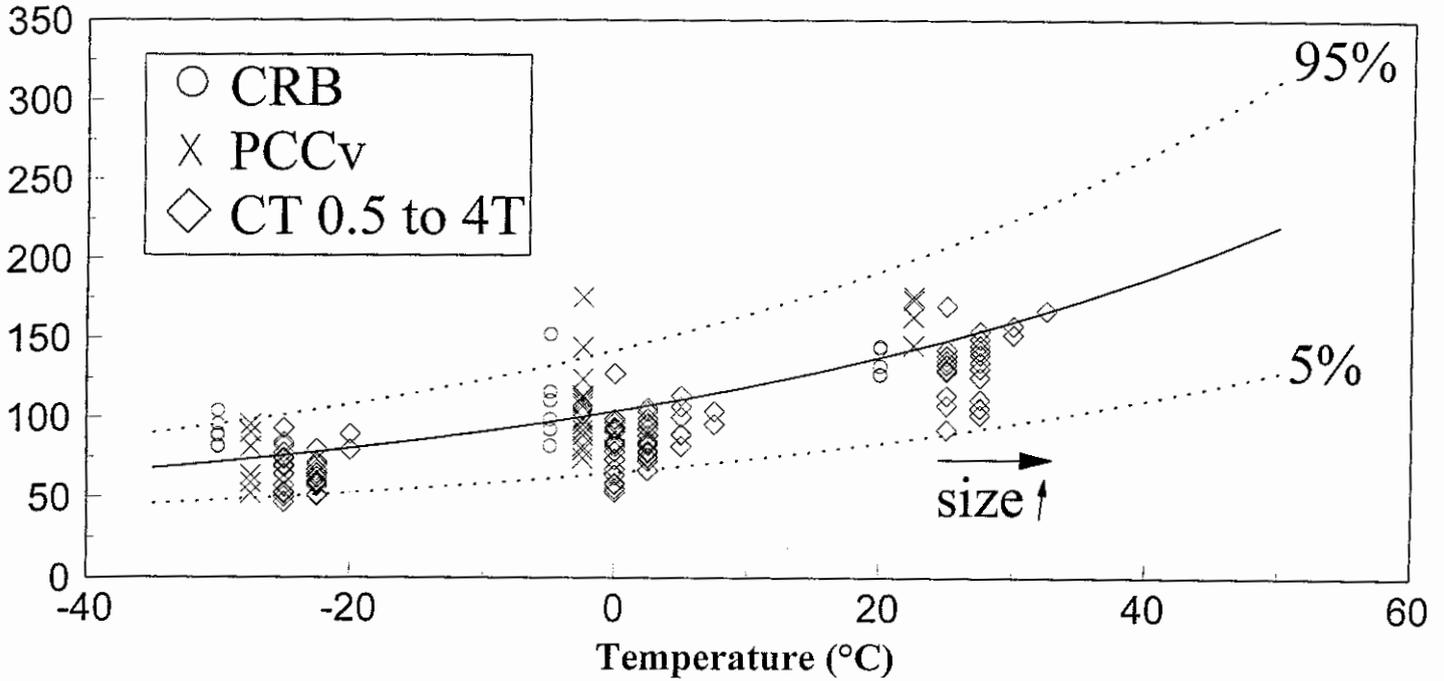
■  $a/R = 0.501 \pm 0.13$

■  $e = 0.07 \text{ mm}$

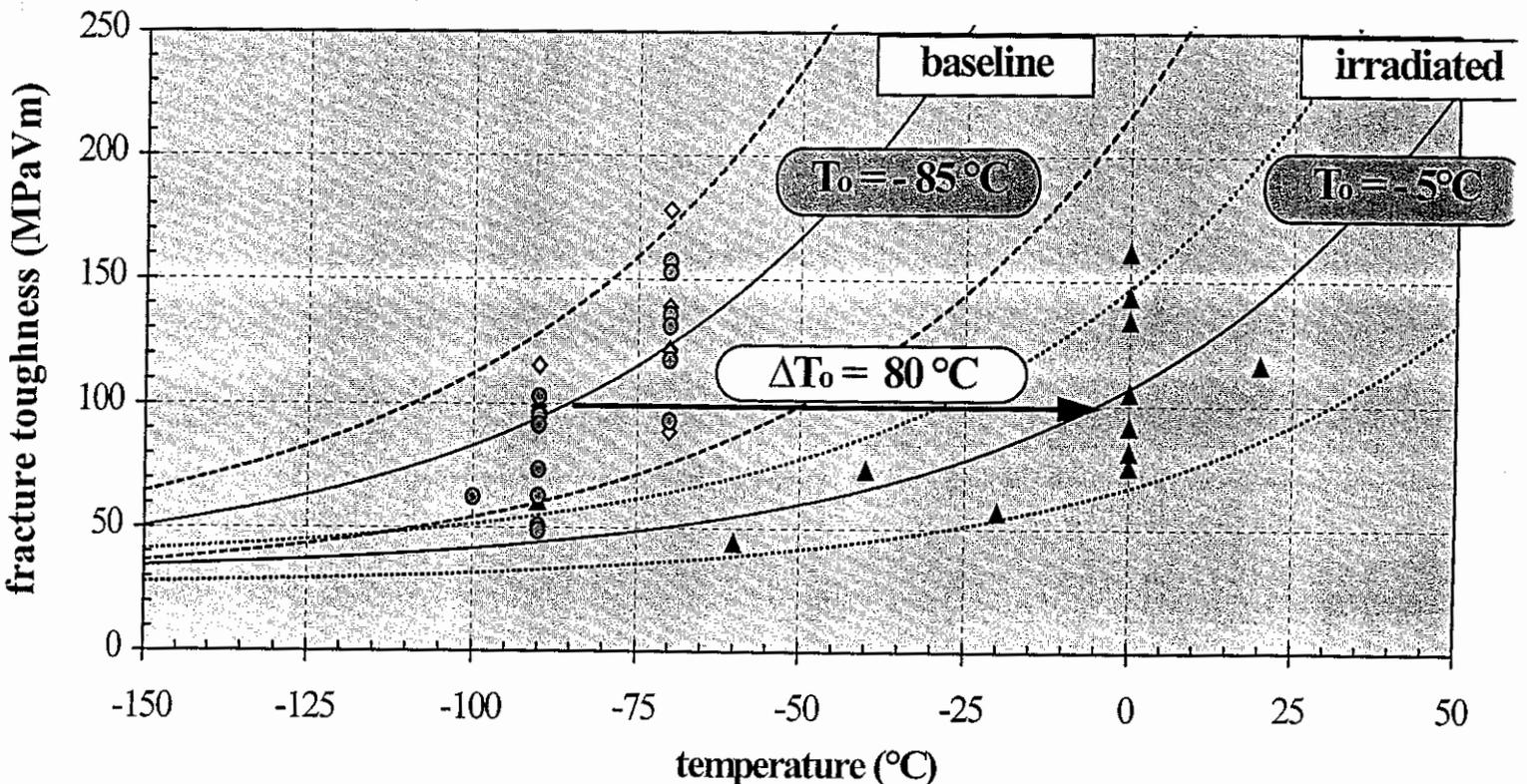
■ Time = 60 min.

# Characterisation of the transition behaviour based on 6 PCCv tested at $-25^{\circ}\text{C}$ for a A533B (JSPS)

K normalised to 1T ( $\text{MP}\sqrt{\text{m}}$ )



## Results obtained on a RPVS



- 
- ASTM E399-83 "Test Method for Plane Strain Fracture Toughness of Metallic Materials"
  - ASTM E813-83 "Test Method for  $J_{Ic}$ , a Measure of Fracture Toughness"
  - ASTM E1737-96 "Test Method for J-integral Characterisation of Fracture Toughness"
  - ASTM DRAFT-13 "Test Method for the Determination of Reference Temperature,  $T_0$ , for Ferritic steels in the Transition Range"
  - [CHA-97] Chaouadi, R., "Fracture Toughness in the Transition Regime from Precracked Charpy Samples", ASTM STP 1329, 1997
  - [SCI-97] Scibetta, M. and Chaouadi, R., "Fracture Toughness Derived from Small Circumferentially Cracked Bars", ASTM STP 1329, 1997

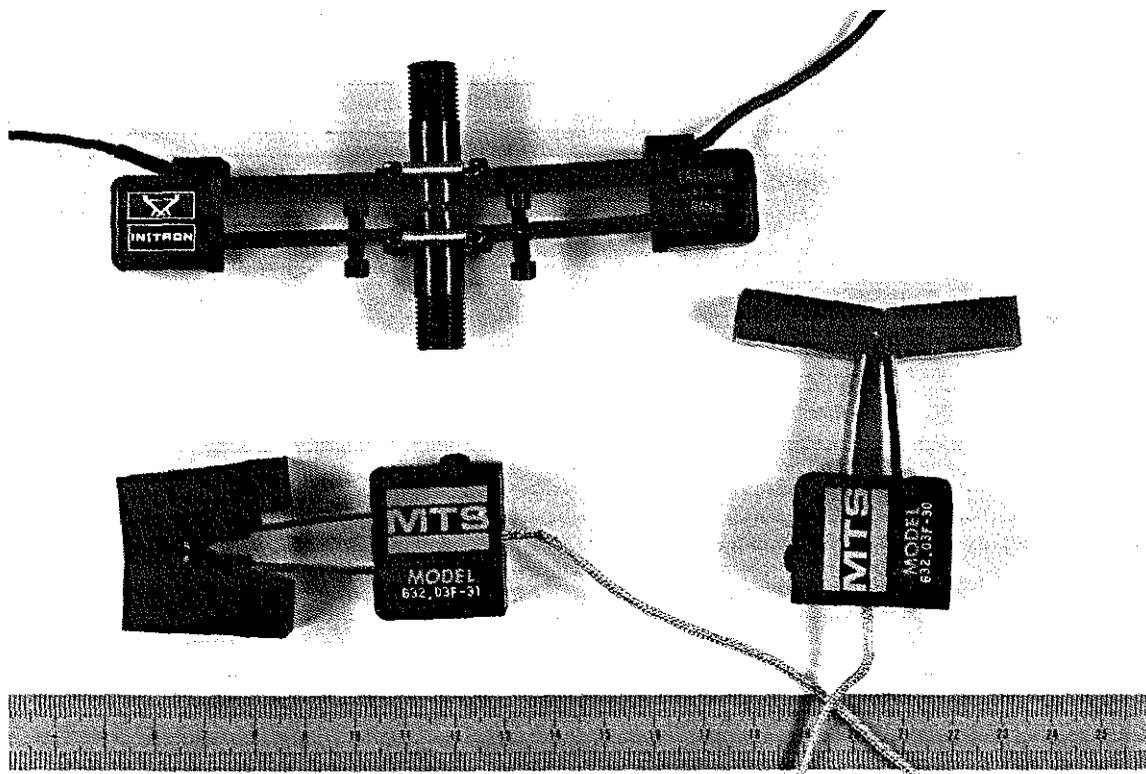
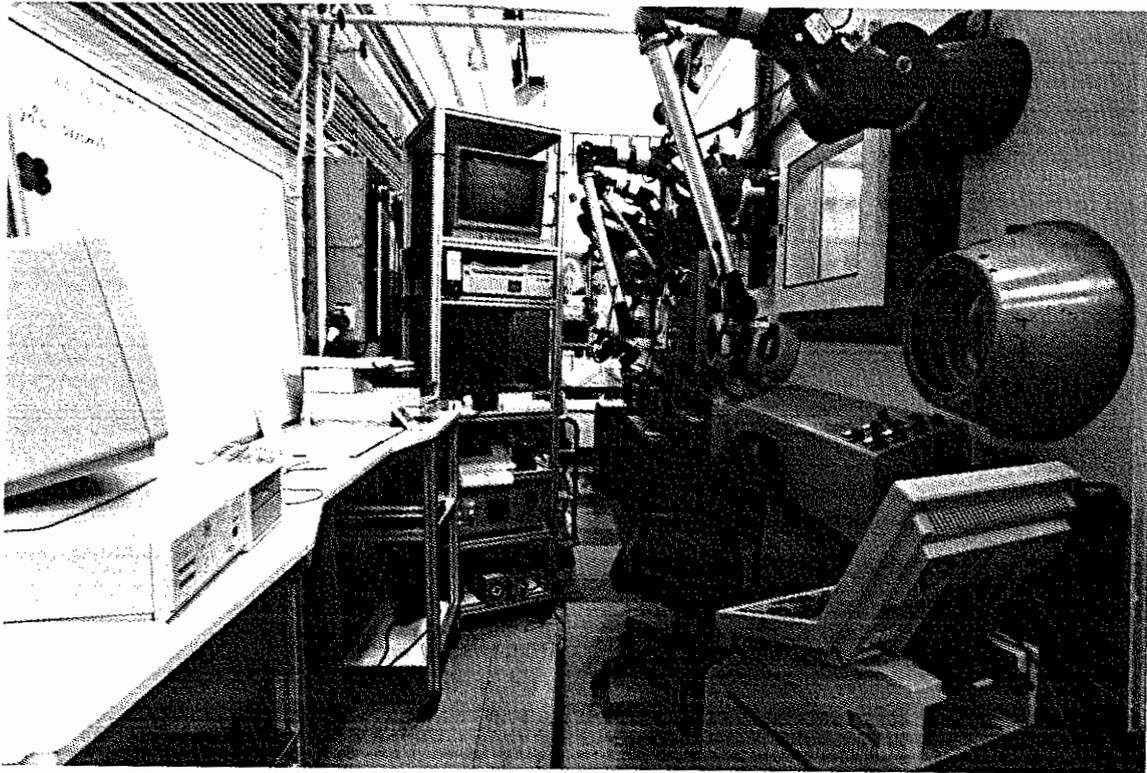


Photo 1: Instrumented Fracture Toughness specimen. The circumferentially Crack Round Bar diameter 10mm (CRB) is equipped with two extensometers, the Precracked Charpy V-notch (PCCv) loaded in three point bend is instrumented with a clip gauge and the 1/2 inch thickness Compact Tension CT-1/2T is equipped with a clip gauge.



*Photo 2: Hot cell 14 is used to test irradiated PCCv loaded in three point bend. The cell is equipped with a 50kN (static) - 25kN (dynamic) servo hydraulic tensile machine controlled by a PC and a user friendly control panel. A camera connected to a monitor allows a visual monitoring of the crack growth during fatigue.*

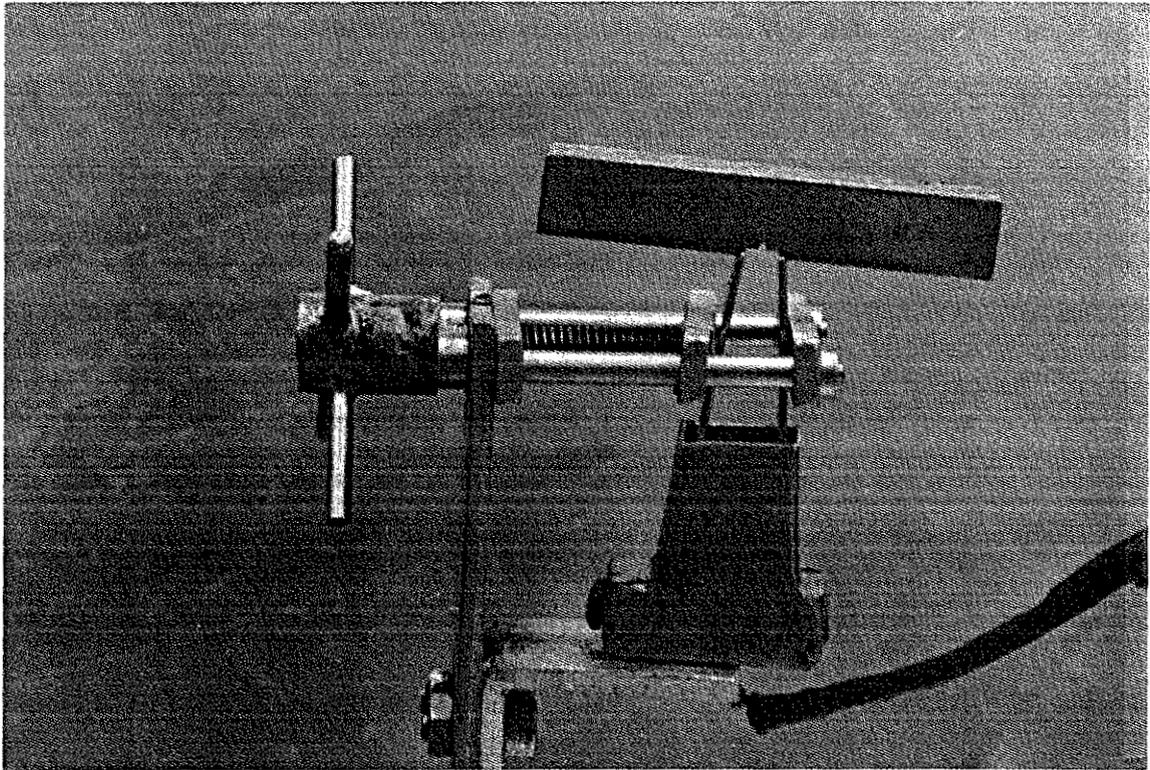


Photo 3: *A simple mechanism allows the positioning of the clip gauge on the specimen.*

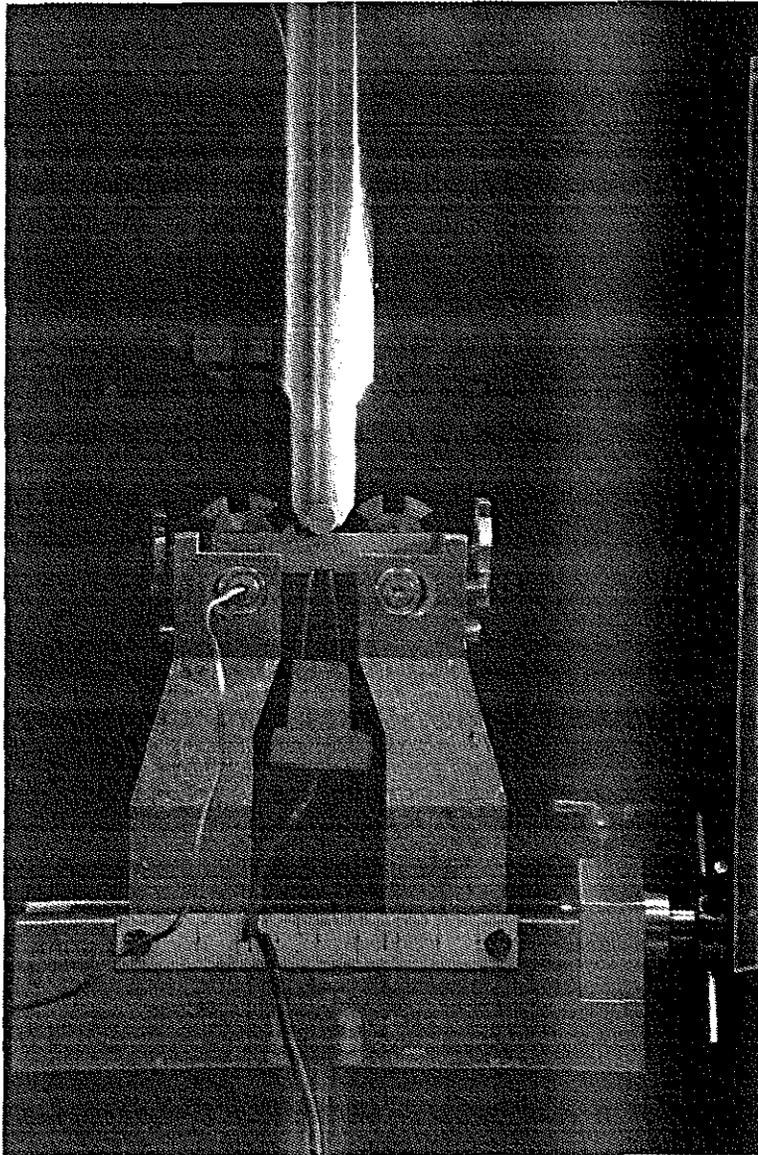


Photo 4: *Three point bend fixture mounted on the tensile test machine is contained into an oven allowing different test temperature from  $-170^{\circ}\text{C}$  to  $600^{\circ}\text{C}$ .*

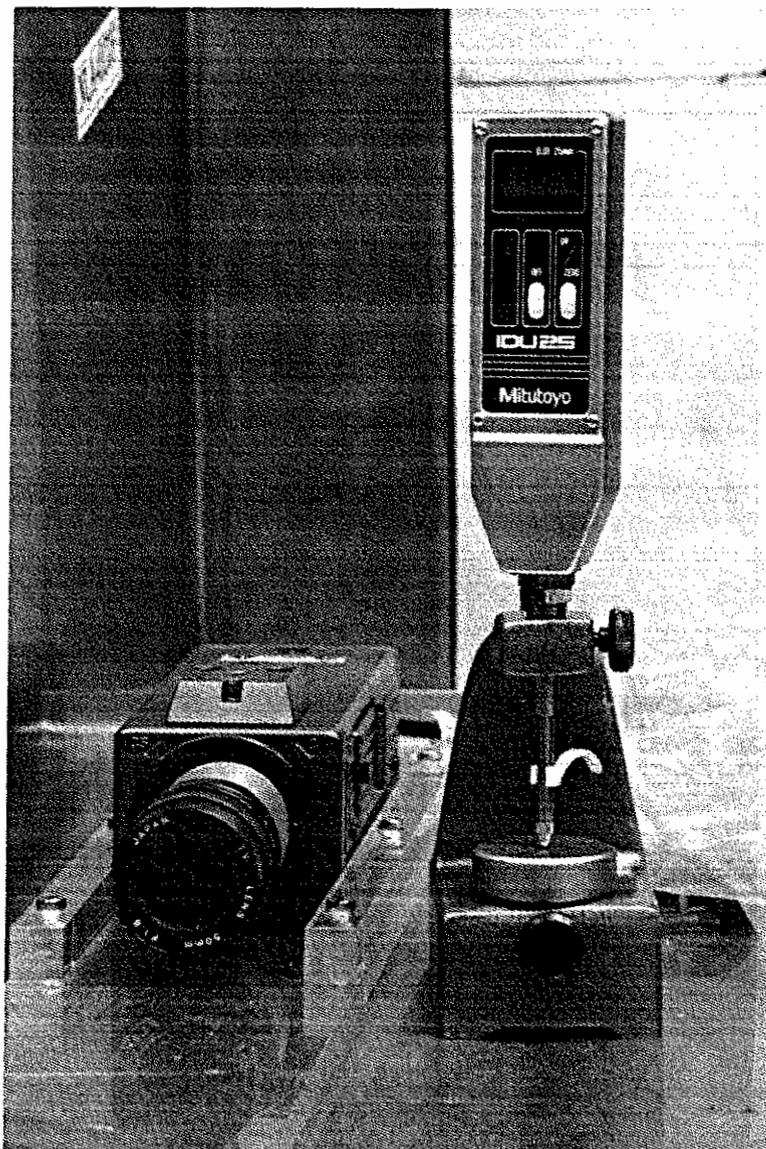
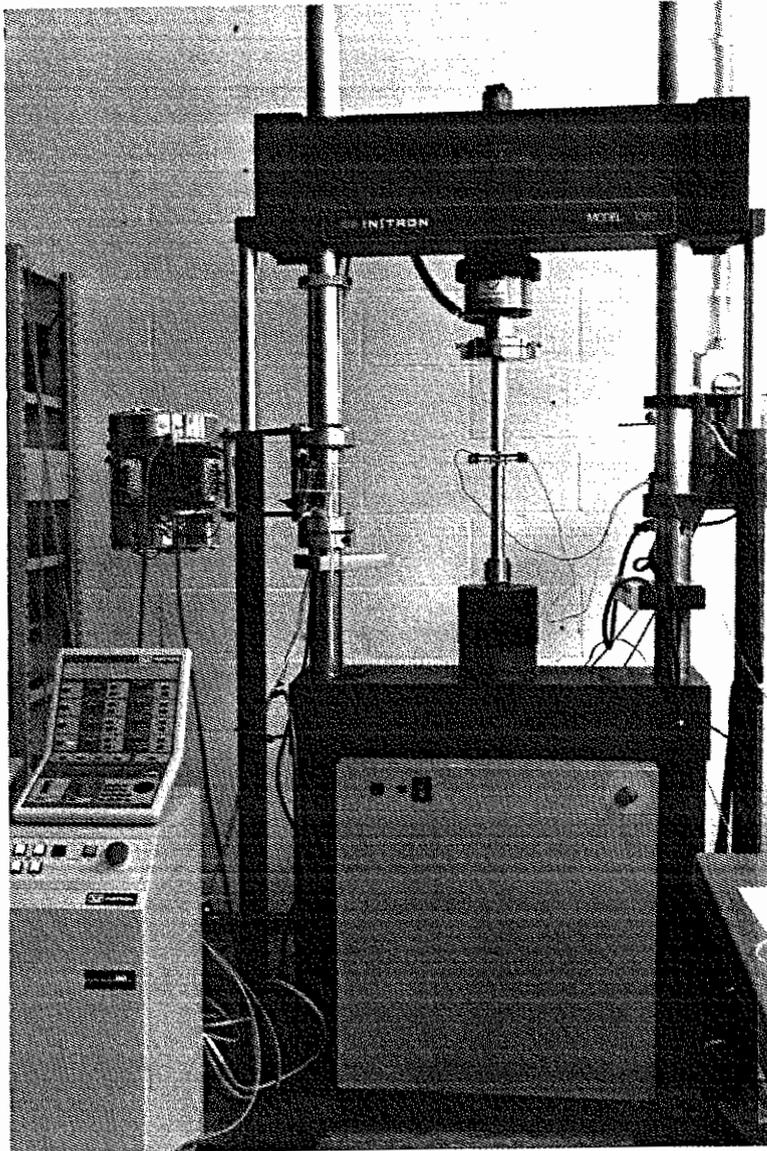


Photo 5 : A in cell camera and a micrometer allows the measurement of the crack length by the 9 point averaging method.



*Photo 6: CRB mounted on a tensile machine. Special attention is paid to avoid and evaluate the bending component.*