
AREVA

Hot Laboratory Work for the CARINA project to Extend the Data Base for Fracture Mechanical Characteristics of Irradiated German RPV Materials – Status and Outlook

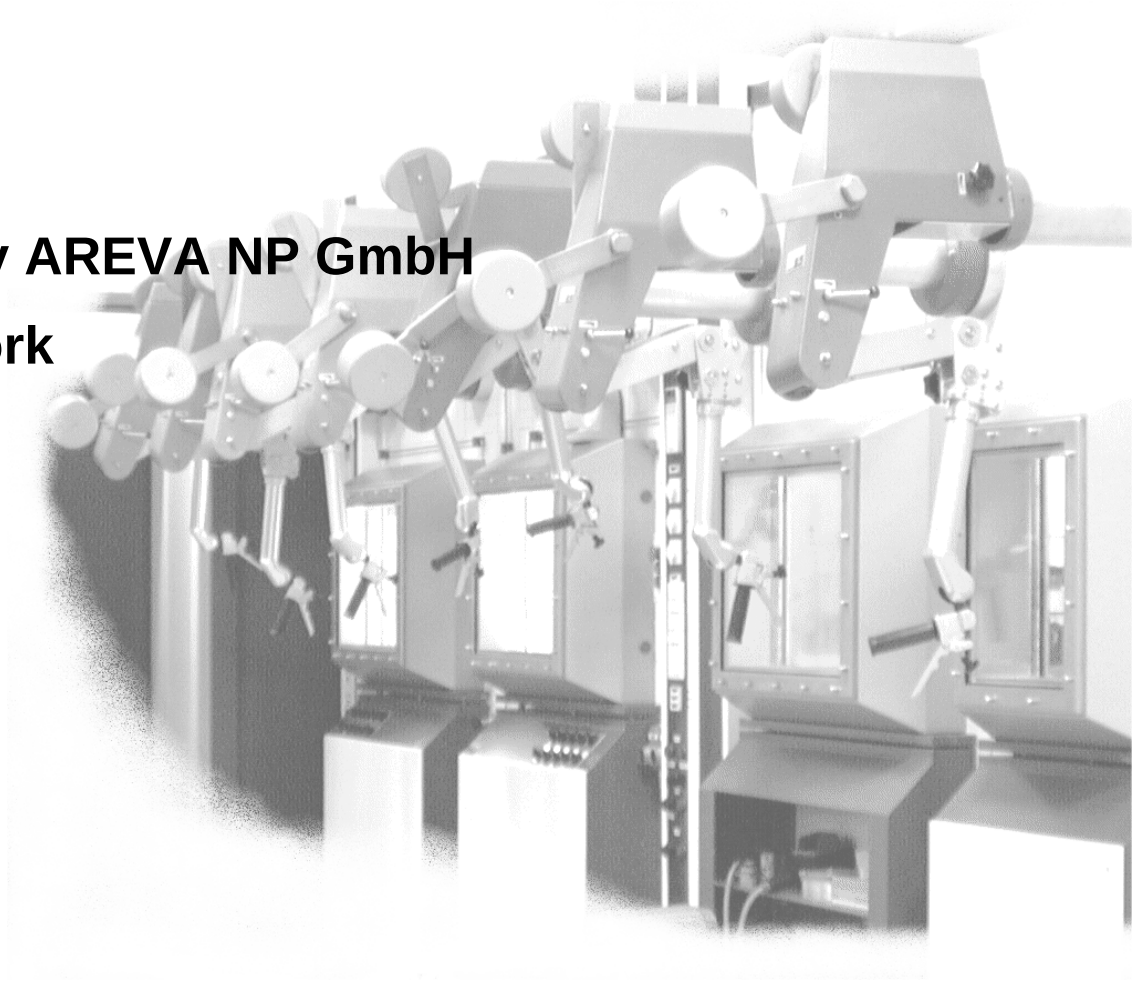
H. Hein, H. Schnabel, A. Gundermann, E. Keim
AREVA NP GmbH, Erlangen, Germany

46th Annual Meeting 'Hot laboratories and remote handling‘
Working Group, September 20-23, 2009, Prague, Czech Republic

AREVA

Contents

- Introduction
- CARINA Overview
- Hot Cells Laboratory AREVA NP GmbH
- CARINA Hot Lab Work
- Status and Outlook
- Summary



Introduction

- **RPV safety assessment in Germany**
  - **Beside RT_{NDT} approach, German regulation accepts use of measured fracture toughness values and RT_{T0} for establishing a K_{Ic},T-curve**
  - **RT_{T0} (Master Curve) approach allows direct determination of reference temperature by fracture mechanics tests**
  - **More realistic transfer to the component behavior**
- **CARISMA "Determination of Fracture Mechanics Values on Irradiated Specimens of German PWR Plants" finished in 2008**
  - **Data base on 7 pre-irradiated materials being representative for the four German PWR construction lines**
  - **Irradiation at 283 °C to 288 °C and 6×10^{18} to 4×10^{19} n/cm^2 (E>1 MeV)**
  - **Application of RT_{NDT} and Master Curve based reference temperature RT_{T0}**
  - **Determination of Crack Arrest characteristics, some remaining issues**

» Initiation of follow-up CARINA due to need for more data

CARINA Overview Objectives

- **Follow-up project CARINA "Extension of the Data Base for Fracture Mechanical Characteristics of Irradiated German RPV Materials - Application of the Master Curve Approach for Neutron Fluences in the Upper Bound"**
  - **2008 to 2012**
  - **Support by VGB (German utilities), the German Ministry of Economics and Technology (sponsorship number 1501357), NPP Gösgen (Switzerland) and NPP Ringhals/Vattenfall (Sweden)**
- **Objectives**
  - **Extension of already existing CARISMA data base by additional materials irradiated to higher neutron fluences and different irradiation conditions (beyond 5×10^{19} n/cm², E > 1 MeV)**
  - **Study of possible specific irradiation effects such as Late Blooming Phases and Neutron Flux by specimens irradiated in gradient capsules**
  - **Application of Master Curve approach to RPVs with longer operation times and beyond EoL, respectively**

CARINA Overview Materials

Project	Material	Code	Type	Cu [%]	P [%]	Ni [%]
CARINA	22NiMoCr3-7 JSW (3^{rd} generation, Pre Convoy)	P150	BM	0.05	0.008	0.83
CARINA	22NiMoCr3-7 JSW (3^{rd} generation, Pre Convoy)	P150	HAZ	0.05	0.008	0.83
CARINA	22NiMoCr3-7 Klöckner (1^{st} and. 2^{nd} generation)	P151	BM	0.09	0.007	0.97
CARINA	22NiMoCr3-7 Klöckner (1^{st} and. 2^{nd} generation)	P151	HAZ	0.09	0.007	0.97
CARINA	Molytherme Electrode Sulzer (1^{st} generation)	P152	WM	0.03	0.015	0.08
CARINA	20MnMoNi5-5 JSW (4^{th} generation)	P142	BM	0.06	0.009	0.8
CARINA	S3NiMo1/OP41TT GHH (4^{th} generation)	P142	WM	0.06	0.012	0.9
CARINA	S3NiMo3/OP41TT Udcomb (3^{rd} generation)	P16	WM	0.08	0.012	1.69

CARINA Overview
Test Matrix

Code	Type	Estimated fluence [n/cm^2] (E> 1 MeV)	Tensile test irradiated	Charpy-V irradiated	KJc,=f(T), T_0 unirradiated	K_{Jc} =f(T), T0 irradiated	Crack Arrest K_{Ia}
P142	**BM**	4.3×10^{19}	yes	yes	yes	yes	yes
P150	**BM**	4.6×10^{18} 1.1×10^{19} 2.6×10^{19}	data available	data available	yes	yes yes yes	-
P150	**HAZ**	4.6×10^{18} 1.1×10^{19} 2.6×10^{19}	data available	data available	yes	yes yes yes	-
P151	**BM**	4.6×10^{18} 1.1×10^{19} 2.6×10^{19} $\sim3\times10^{19}$	data available	data available	yes	yes yes yes yes	-
P151	**HAZ**	4.6×10^{18} 1.1×10^{19} 2.6×10^{19} $\sim3\times10^{19}$	data available	data available	yes	yes yes yes yes	-
P142	**WM**	4.7×10^{19}	yes	yes	yes	yes	yes
P152	**WM**	4.6×10^{18} 1.1×10^{19} 2.6×10^{19} $\sim3\times10^{19}$	data available	data available	yes	yes yes yes yes	-
P16	**WM**	4.62×10^{19} - 5.22×10^{19}	yes	data available	data available	yes	yes

CARINA Overview
References

- **Detailed project description and first results presented on PVP 2009 ASME Pressure Vessels and Piping Division Conference, July 26-30, 2009, Prague, Czech Republic**
  - **PVP2009-77035: CARINA: A NEW PROJECT TO EXTEND THE DATA BASE FOR FRACTURE MECHANICAL CHARACTERISTICS OF IRRADIATED GERMAN RPV MATERIALS AT HIGH NEUTRON FLUENCES**
    H. Hein, AREVA NP GmbH, Erlangen, Germany; J. Ganswind, VGB PowerTech e. V., Essen, Germany; A. Gundermann, E. Keim, H. Schnabel, AREVA NP GmbH, Erlangen, Germany
  - **PVP2009-77025: DEVELOPMENT OF DUPLEX SPECIMENS FOR POTENTIAL APPLICATION IN TESTING OF HIGHLY IRRADIATED WELD METALS**
    A. Gundermann, E. Keim, H. Hein, H. Schnabel, AREVA NP GmbH, Erlangen, Germany

Hot Cell Laboratory
AREVA NP GmbH

- **Radiochemical Laboratory**
  - Radiochemistry
  - Analytical chemistry
  - Radiation metrology
  - Hot Cells
- **Hot Cells Laboratory**
  - Material Testing
  - Specimens manufacturing
  - Metallographic examinations
  - All-included Service
  - DAP accreditation according to DIN EN ISO/IEC 17025:2005

DAP Deutsches Akkreditierungssystem Prüfwesen GmbH

Signatory to the Multilateral Agreement of EA for mutual recognition and to the Mutual Recognition Arrangement of ILAC

represented in the

Deutschen AkkreditierungsRat

Accreditation

The DAP Deutsches Akkreditierungssystem Prüfwesen GmbH herewith confirms that the

AREVA NP GmbH

Freyeslebenstraße 1
91058 Erlangen

with its

Testing Laboratory „Heiße Zellen"

is competent under the terms of DIN EN ISO/IEC 17025:2005 to carry out tests in the fields of

mechanical-technological testing (including fracture mechanic and hardness tests), metallography and non-destructive test methods (penetration test) of metallic materials

in accordance with the test methods lited in the annex. The annex forms part of the certificate and comprises 8 pages.

The accreditation is valid from 2008-04-04 to 2009-09-08.

DAR registration number: **DAP-PL-3500.80**

Berlin, 2008-04-04

Deutscher Akkreditierungs Rat

Hot Cell Laboratory AREVA NP GmbH

- **Hot Cells Laboratory**
  - **Material Testing**
    - Irradiation surveillance programs for LWR and research reactors
    - Post irradiation examinations
    - Failure analysis
    - Radiation resistance (e.g. cables)
  - **Specimens manufacturing**
    - Tensile, Charpy, fracture mechanics (with mechanical and fatigue cracks) specimens
    - Test pieces from tested specimens
    - Reconstituted specimens with EBW
    - Dimension measurements by digital phototechnique

Hot Cell Laboratory AREVA NP GmbH

Hot Cells Laboratory

Metallographic examinations

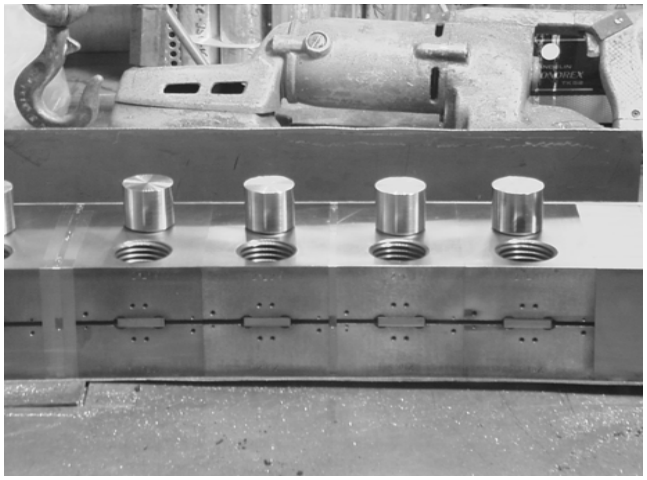
- Failure analyses, e.g. SG tubes, springs, screws, center ring pins
- Microstructure examinations on metallic materials and nuclear fuel
- Material development (e.g. for spacer grids) with examination of oxide layer, hydrogen content distribution and geometric change of components
- Specimen preparation for SEM and TEM examinations

All-included Service

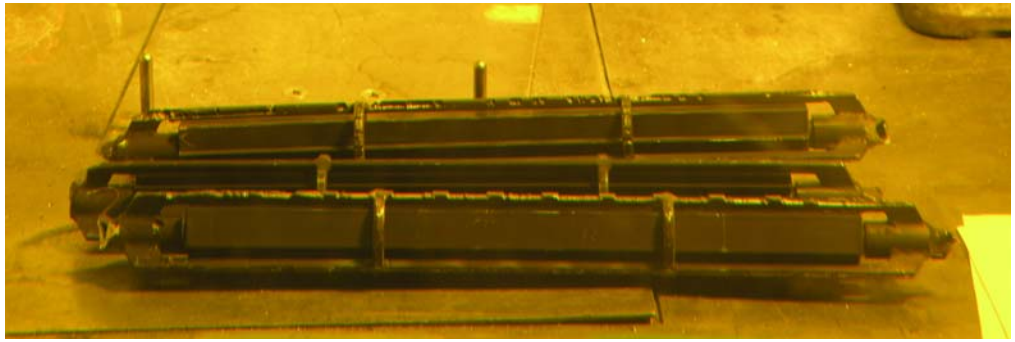
- Provision of transport packages for highly radioactive specimens
- Organization and execution of transports
- Performance of examinations, evaluation and documentation
- Return/disposal of waste

CARINA Hot Lab Work
Disassembling of Capsules

- **Opening of Capsules**
  - **VAK and surveillance capsules**
  - **Temperature monitors**
  - **Fluence detectors**
- **Radiochemical analysis**
  - **Activity of neutron fluence detectors**



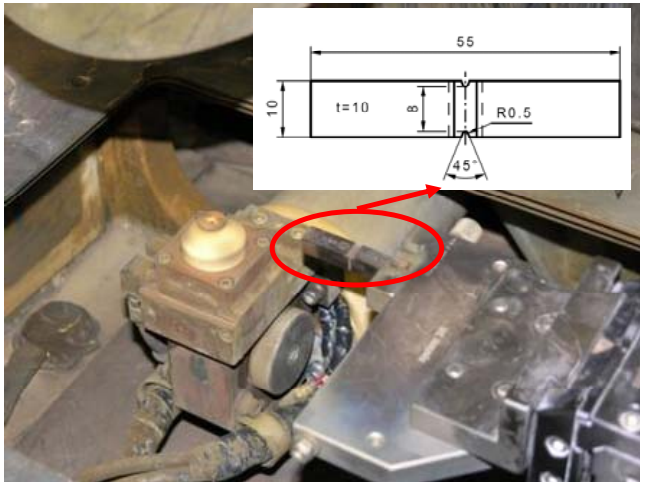
Dismantled VAK capsule



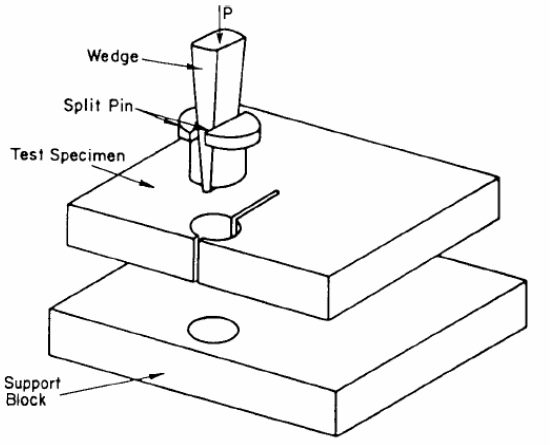
Surveillance capsules, state of delivery

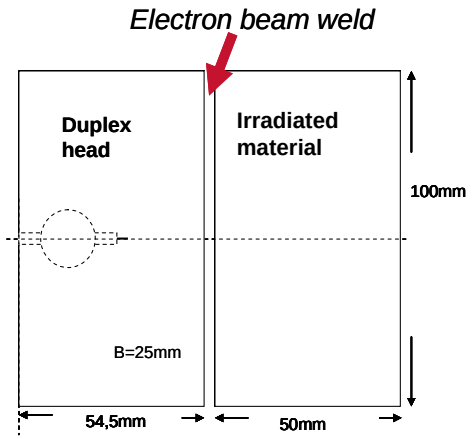
CARINA Hot Lab Work
Manufacture of Specimens

- **PCCV specimens used for T_0 testing**
  - **Manufactured by EDM**
  - **Fatigue crack introduced by a high-frequency vibration load using a resonance testing machine**
- **Compact Crack Arrest (CCA) and Duplex specimens for Crack Arrest testing**



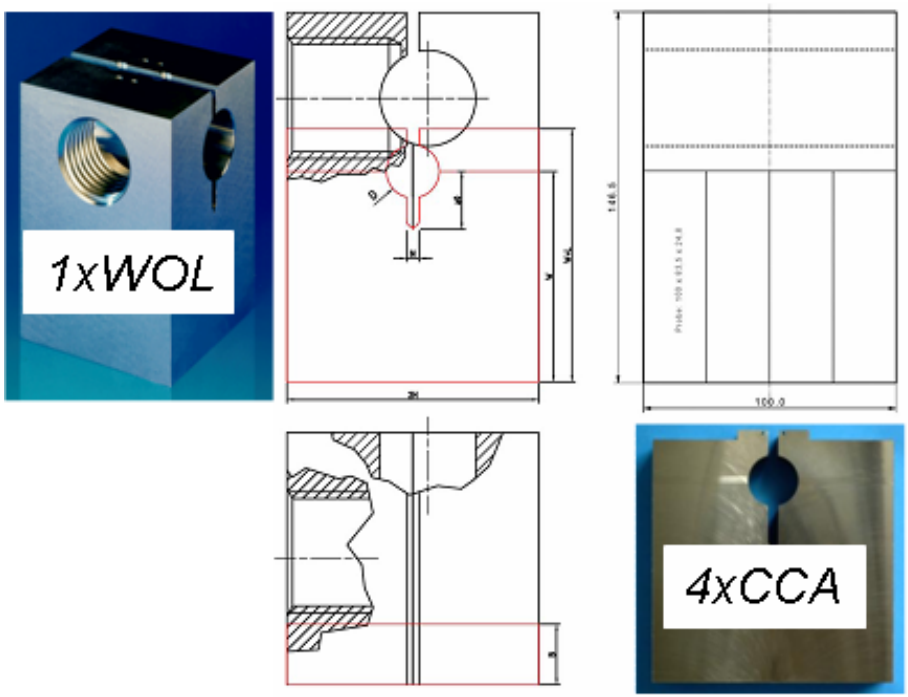
Manufacture of PCCV specimen

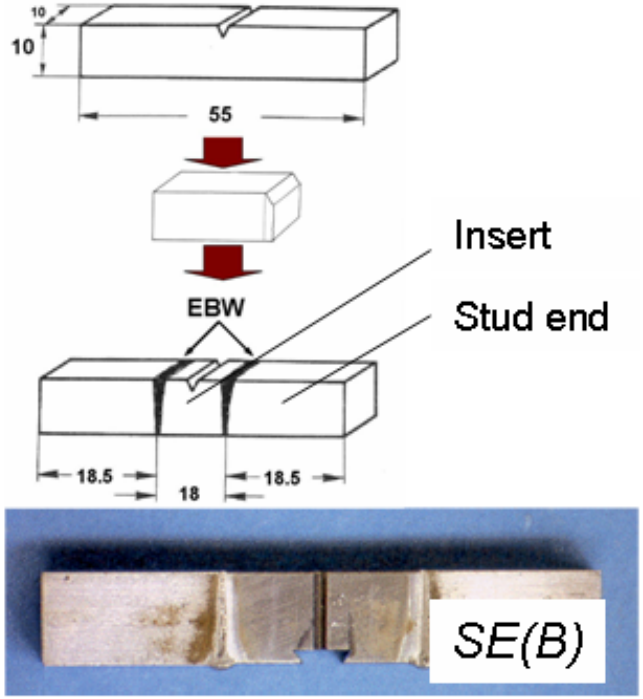




CARINA Hot Lab Work
Manufacture of Specimens

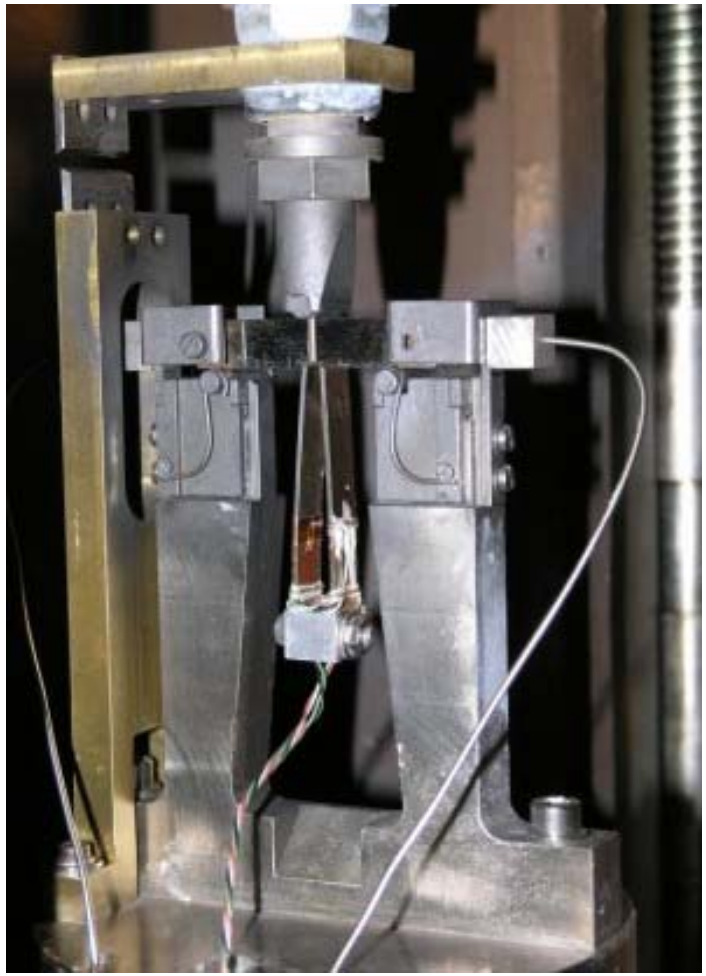
Reconstitution technique





CARINA Hot Lab Work
Testing of Specimens

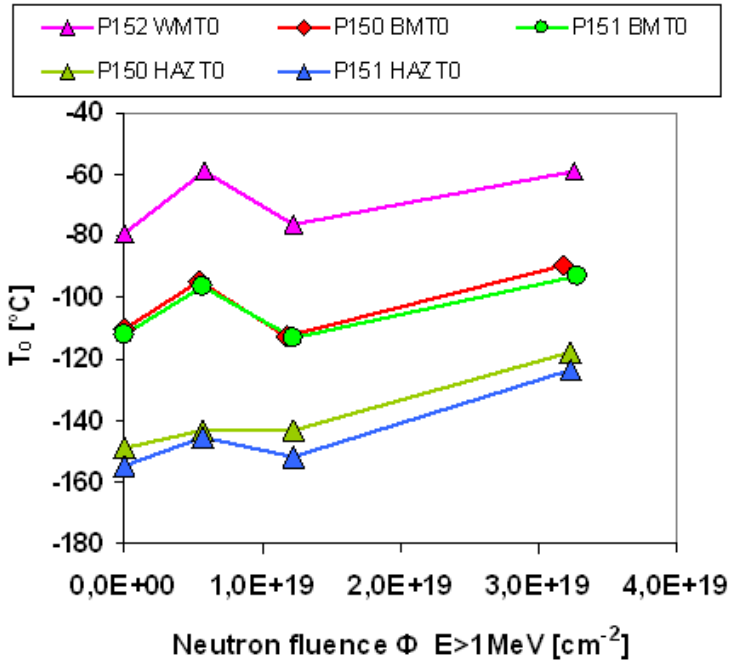
- Tensile
  - DIN EN 10002
- Charpy-V
  - Instrumented DIN EN 10045
- Crack initiation
  - PCCV according to ASTM E-1921
- Crack Arrest
  - CCA according to ASTM E-1221
  - Duplex (ongoing qualification)

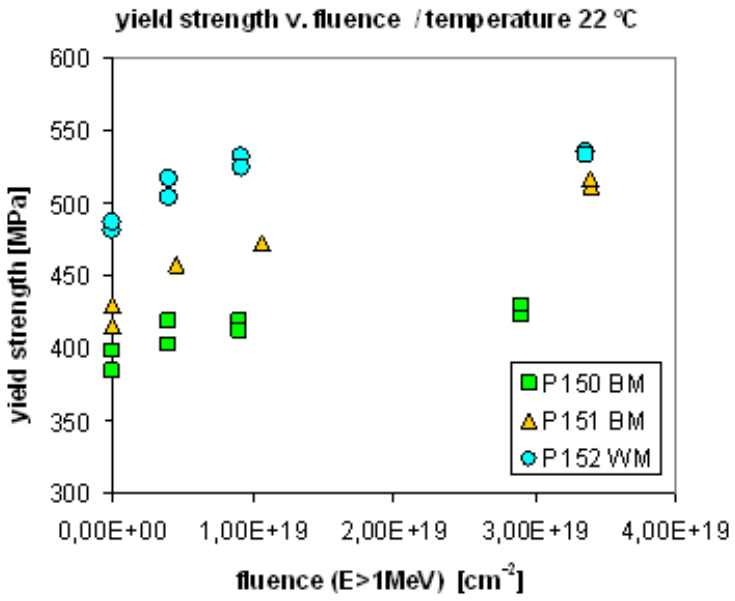


Testing of PCCV specimens

CARINA Hot Lab Work
Analytical Examinations

- **Unexpected low irradiation embrittlement of P15X materials at 1.2×10^{19} n/cm² (E > 1 MeV)**
  - **Activity measurements (Co-60 in P150 BM) ➔ activity follows the fluence**
  - **Chemical analyses by Spark Emission Spectroscopy ➔ no significant deviations**





CARINA Hot Lab Work
Metallographic Examinations

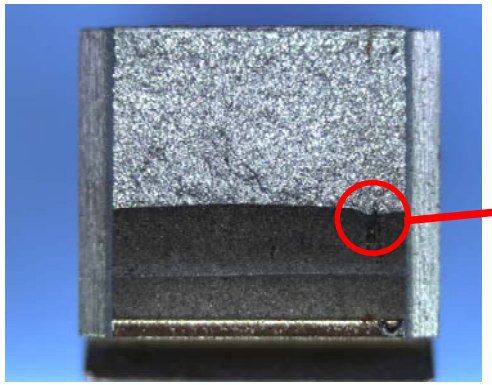
- **22NiMoCr3-7 steel: Broken surfaces of the tested unirradiated P150 BM and P151 BM specimen materials**
  - **P151 BM (Klöckner) is more coarse-grained than the P150 BM (JSW)**
  - **Underlines the impact of the manufacturing process on the microstructure**

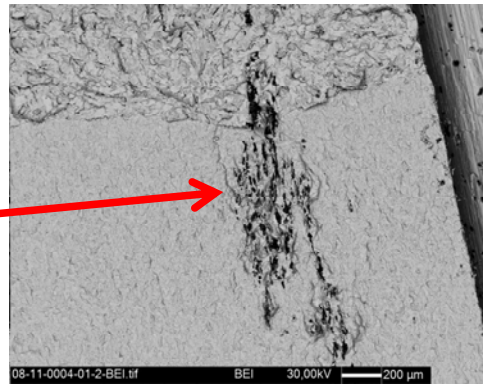
P151 BM 140B

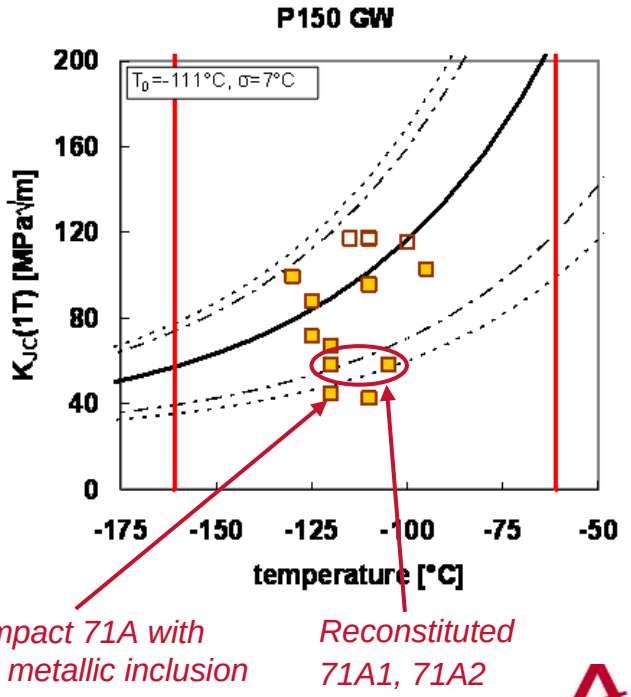
P150 BM 71A

CARINA Hot Lab Work
Metallographic Examinations

- **Impact of non-metallic inclusion (found on surfaces of the unirradiated broken P150 BM PCCV specimens) on K_{Jc} data studied by reconstituted specimens ➔ no significant impact**

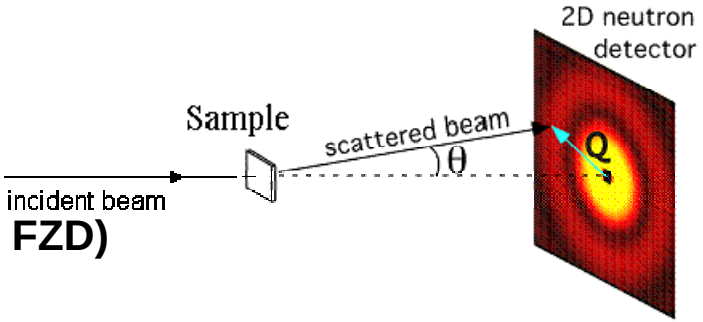






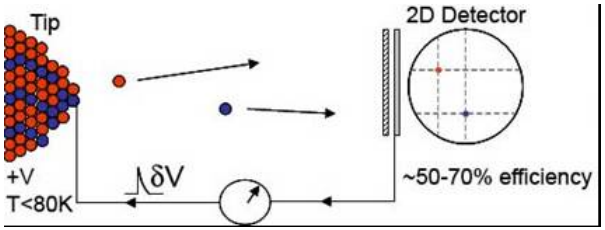
CARINA Hot Lab Work
Microstructural Examinations

- **SANS**
  - CARISMA materials (by FZD)
  - CARINA materials planned (by FZD)



10 mm x 10 mm x 1 mm

- **APT**
  - Planned in LONGLIFE (FP7)



- **TEM**
  - Planned in LONGLIFE (FP7) and by own R&D

- **FIB**
  - Dual-beam focused-ion-beam (FIB) microscope
  - Feasibility study

AREVA NP GmbH

Status and Outlook

- **Status**
  - **First results from fracture toughness testing and T_0 data from specimens irradiated in PWR standard surveillance capsules are available (low irradiation embrittlement)**
  - **CARINA specimens irradiated in the VAK reactor will be tested next**
  - **Ongoing qualification of Duplex specimens for crack arrest testing**
  - **In general progress of the work is on schedule to finish the project by 2012**
- **Outlook**
  - **Enhanced activities for microstructural studies (SANS, APT, TEM)**
  - **FIB**
  - **Installation of a new EBW machine**

Summary

- In the research project CARINA the experimental data base for both the safety concepts RT_{NDT} and Master Curve will be extended by additional representative materials irradiated under different conditions and with respect to “Upper Bound” accumulated neutron fluences and specific impact parameters (neutron flux, chemical composition, manufacturing effects).
- Focal point on Hot Cells work
  - Capsule opening
  - Radiochemical analysis
  - Specimen manufacture
  - Material testing
  - Analytical, metallographic and microstructural examinations
- In general the progress of the work is on schedule to finish the project by 2012.