Progress of Reduced Activation Ferritic/Martensitic steel (RAF/M) development in Japan

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Specifications of RAF/M steel of JLF-1 and F82H developed in Japan

RAF/M steel is one of the leading candidate material categories for the Blanket of Fusion Power Demonstration Plant and ITER Test Blanket.

Table Chemical Composition of Japanese Reduced Activation Martensitic Steels

	C	Si	Mn	Cr	V	W	N	Ta
F82H[1]	0.09	0.10	0.21	7.46	0.15	1.96	0.006	0.023
JLF-1	0.1	0.2	0.45	9.0	0.25	2.0	0.05	0.07

[1] IEA-F82H (IEA heat of F82H, verified under IEA collaboration for Fusion materials development)

Heat Treatment F82H: Normalization;1040C for 38min, Tempering; 750C for 1h
JLF-1: Normalization;1050C for 1h, Tempering; 780C for 1h

‘60 ‘70- ‘80 ‘80 ‘80- ‘90

9Cr-1Mo → 9Cr-1MoNbV ---- MANET → F82H →

(British 9Cr) U.S. (ORNL) EU JLF-1 →

Optifer(EU) →

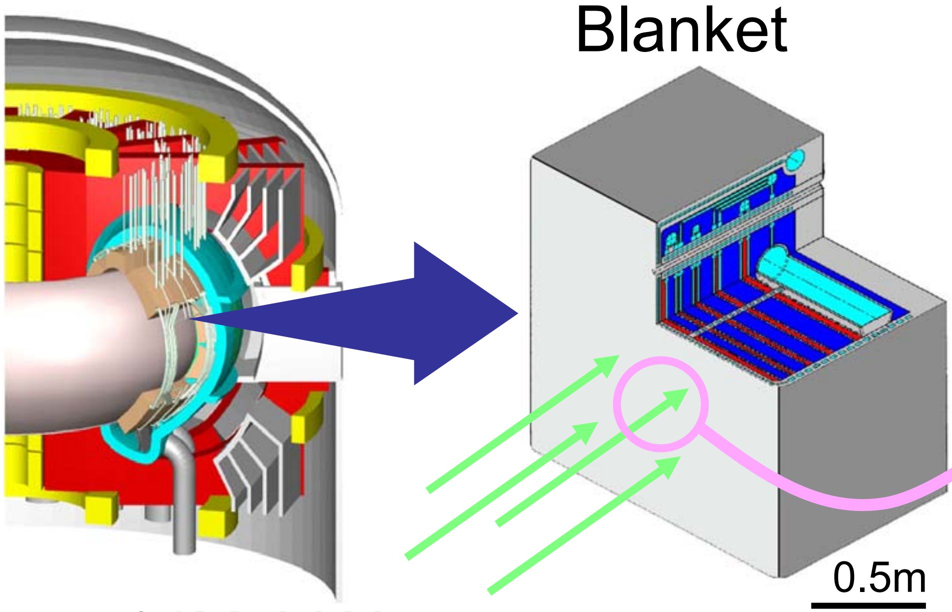
Eurofer(EU) →

JLF-1 and F82H have been developed for last 10 years in Japan.

Service Condition of the Blanket

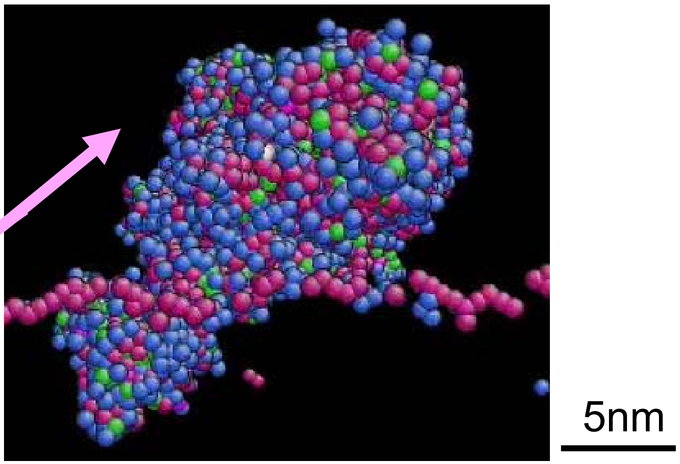
One of the most critical part of in-vessel components is the first wall of the blanket.

Collision of neutrons introduces;
- Displacement damages and
- Transmutation produced He atoms



14MeV Neutrons
Produce Damages

Cascade damage; MD simulation



Point defects are formed

RAF/Ms FW will be damaged to 150dpa (+1500appmHe) by fusion neutrons from plasma at temperatures ranging from about 300C to 500C or even higher.

In the following, the irradiation effects of the steels will be mainly introduced.

Progress of Radiation Damage Evaluation for DEMO and ITER blankets

Target and accomplised damage level in "displacement per atom (dpa)"

	2002		2004		Traget level	
	ITER TBM	DEMO	ITER TBM	DEMO	ITER TBM	DEMO
Short Term Mechanical Properties						
Tensile					>3dpa	>150dpa
Fracture Toughness				20dpa	>3dpa	>150dpa
Fatigue			4dpa		>3dpa	>150dpa
Creep					>3dpa	>150dpa
Compatibility						
Cracking (EAC)			2dpa		>3dpa	>150dpa
Corrosion					>3dpa	>150dpa
Materials Engineering	100%					
Joining	75%				>3dpa	>150dpa
Condition Change	50%		2dpa		>3dpa	>150dpa
Plasticity/Ductility	25%		5dpa		>3dpa	>150dpa
Codes						
Design						
Maintenance						

IFMIF

High Damage Levels

Fission reactor irradiation produces too small level of He atoms.
For evaluation with high enough accuracy, facility like IFMIF is needed.

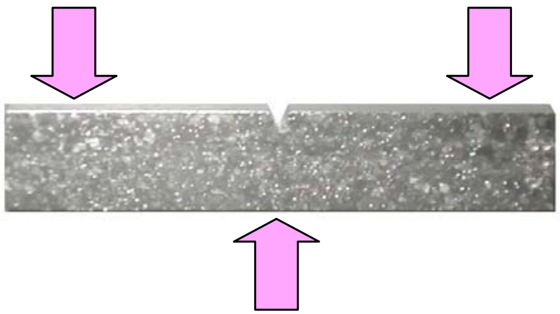
Effect of Irradiation on DBTT-Shift (1)

-Ductile to Brittle Transition Temperature; DBTT -
RAF/M exhibits “Embrittlement” at low temperatures.

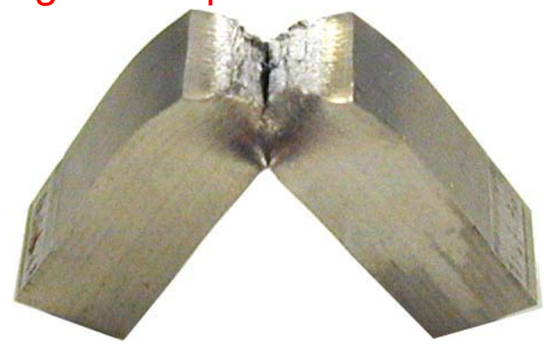
with Significant plastic deformation

Bend specimen

Load



Bend to fracture to evaluate fracture toughness and embrittlement.



-Ductile fracture (High toughness)

Higher temperatures

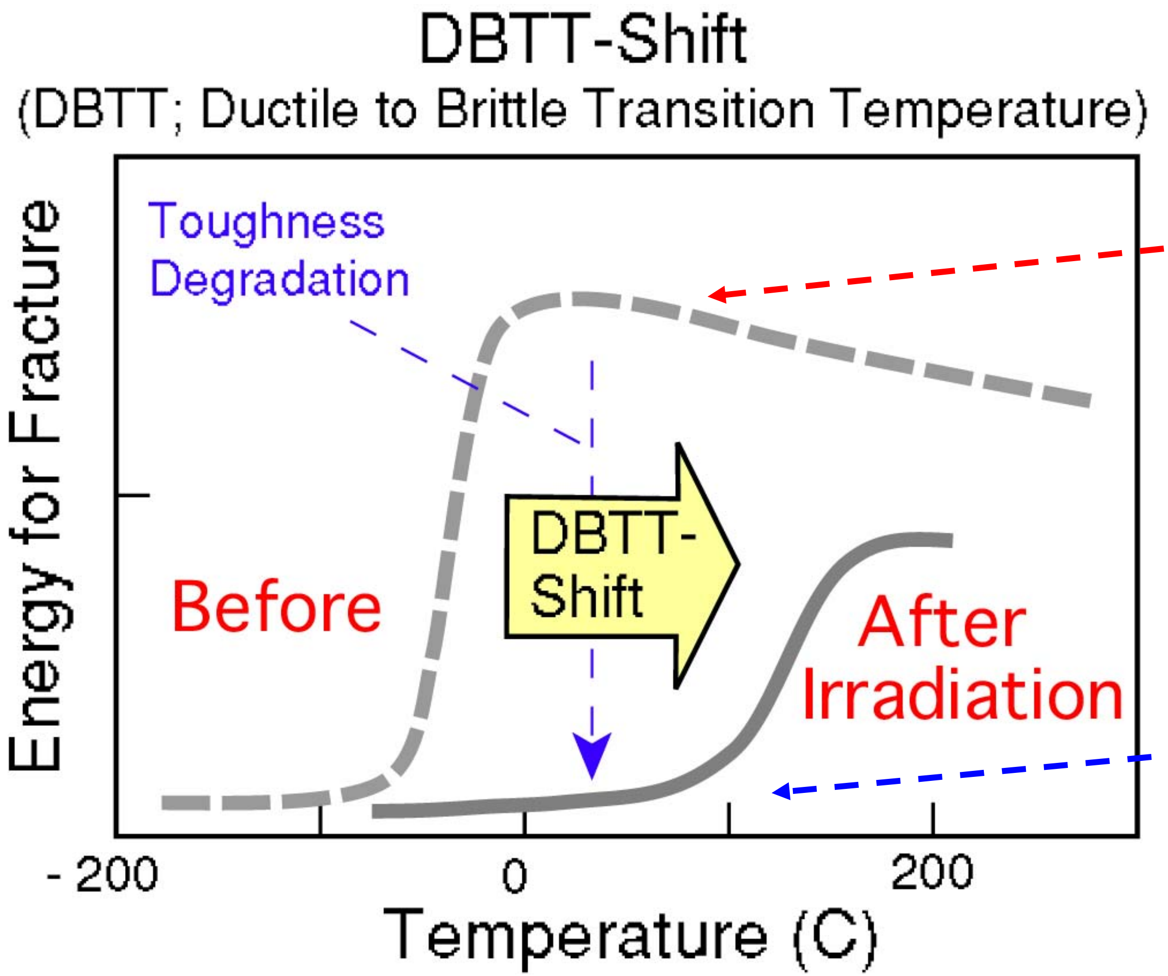
-Brittle fracture (Low toughness)

Lower temperatures

At low temperatures, steel fractures very easily;
out of service temperature

Effect of Irradiation on DBTT-Shift (2)

DBTT shifts by irradiation to higher Temperatures, and Reduce the margin to fracture



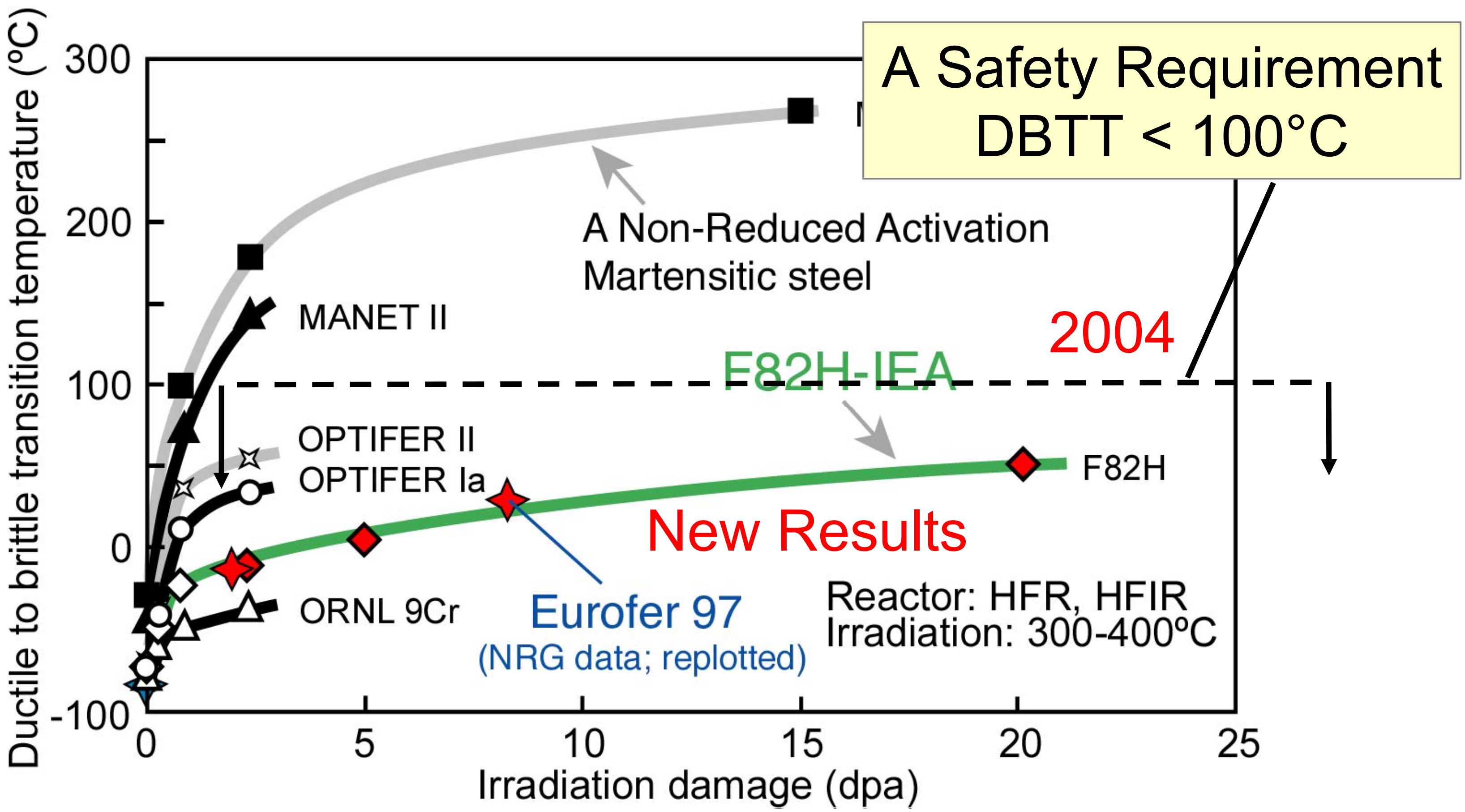
Unirradiated

Irradiated

The temperature shift (DBTT-shift) is used as an indication of embrittlement.

Effect of Irradiation on DBTT-Shift (3)

Evaluation to higher damage levels has been conducted.



- DBTT-shift tends to saturate with damage level.

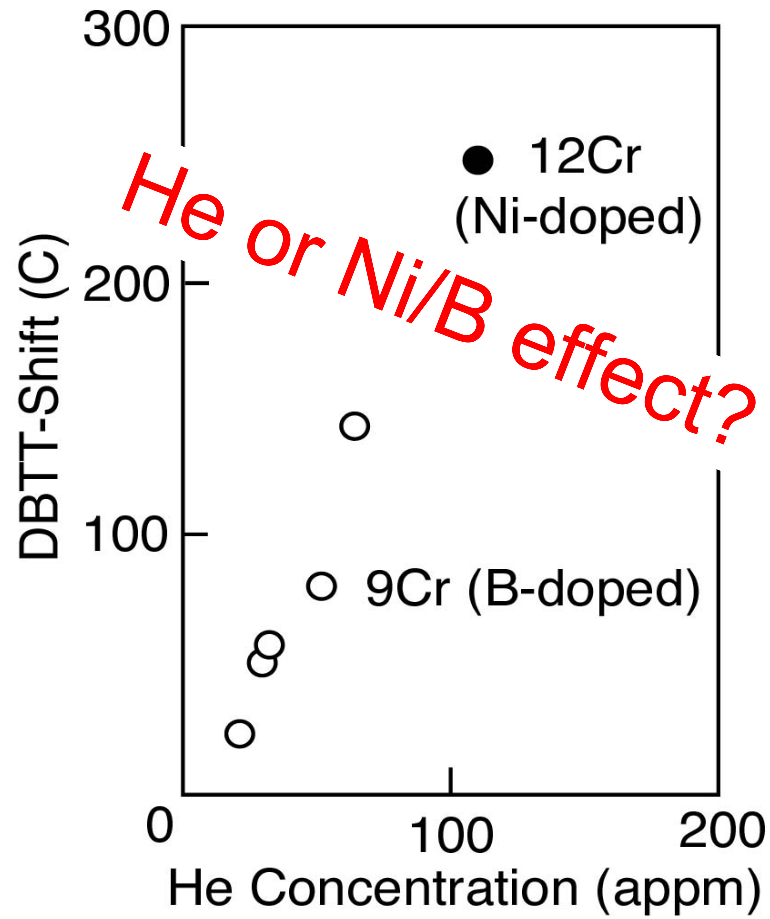
F82H maintains <100°C to Some Tens of dpa level, except He effect.

Effect of Irradiation on DBTT-Shift (4)

- Extra DBTT-shift by He atoms (1) -

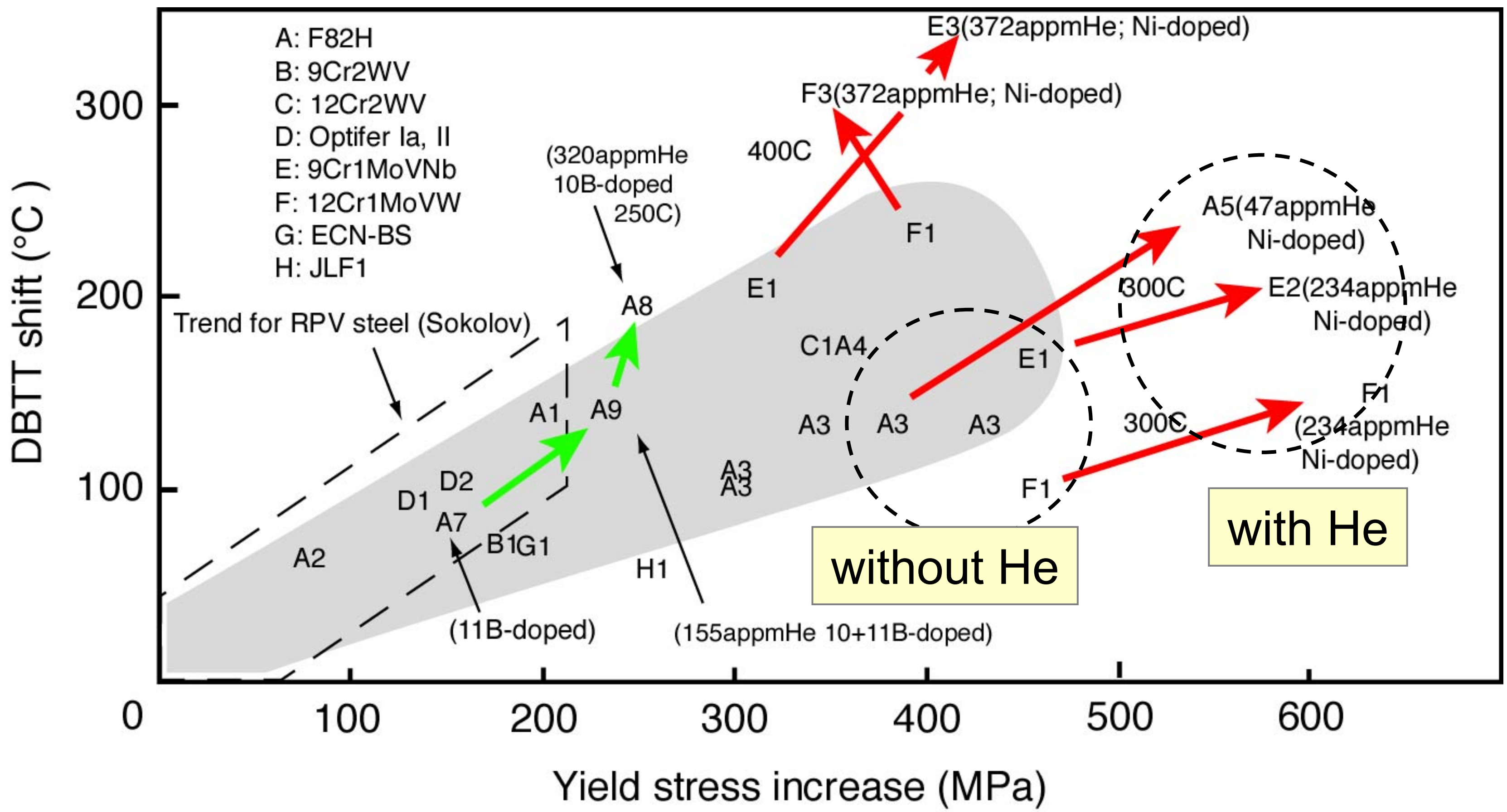
Transmutation reaction by 14MeV fusion neutrons produce He atoms.

- A large extra DBTT-shift by He is suggested.
- Data translation to estimate He effect is complicated.
- To examine He Effect by Fission Reactor irradiation, B/Ni doping have been applied, --- needs analysis to evaluate the "He effect".
- IFMIF is needed for accurate enough evaluation.



Effect of Irradiation on DBTT-Shift (5)

- Extra DBTT-shift by He atoms (2) -



- No obvious He effect was observed.
- DBTT-shift mainly follows hardening; Ni also enhances hardening
- Reduction of hardening is effective to reduce DBTT-shift.

Evaluation for DEMO Blanket Application

Fracture Toughness (DBTT-Shift)

-DBTT-shift saturated with dose
And, satisfies the requirement to 150dpa (DBTT < 100C).

-No obvious He effect was seen.

-Reduction of hardening is effective to reduce DBTT-shift
(e.g. Stronger tempering reduces hardness after irradiation.)

Tensile

-Irradiation hardening saturated with dose.

-Considerable level of residual ductility was remained even after severe irradiation hardening.

→Components with RAF/Ms may be designed based on the current design methodology with a limited modifications to accommodate irradiation effects, as far as the effects on the short term mechanical properties are concerned.

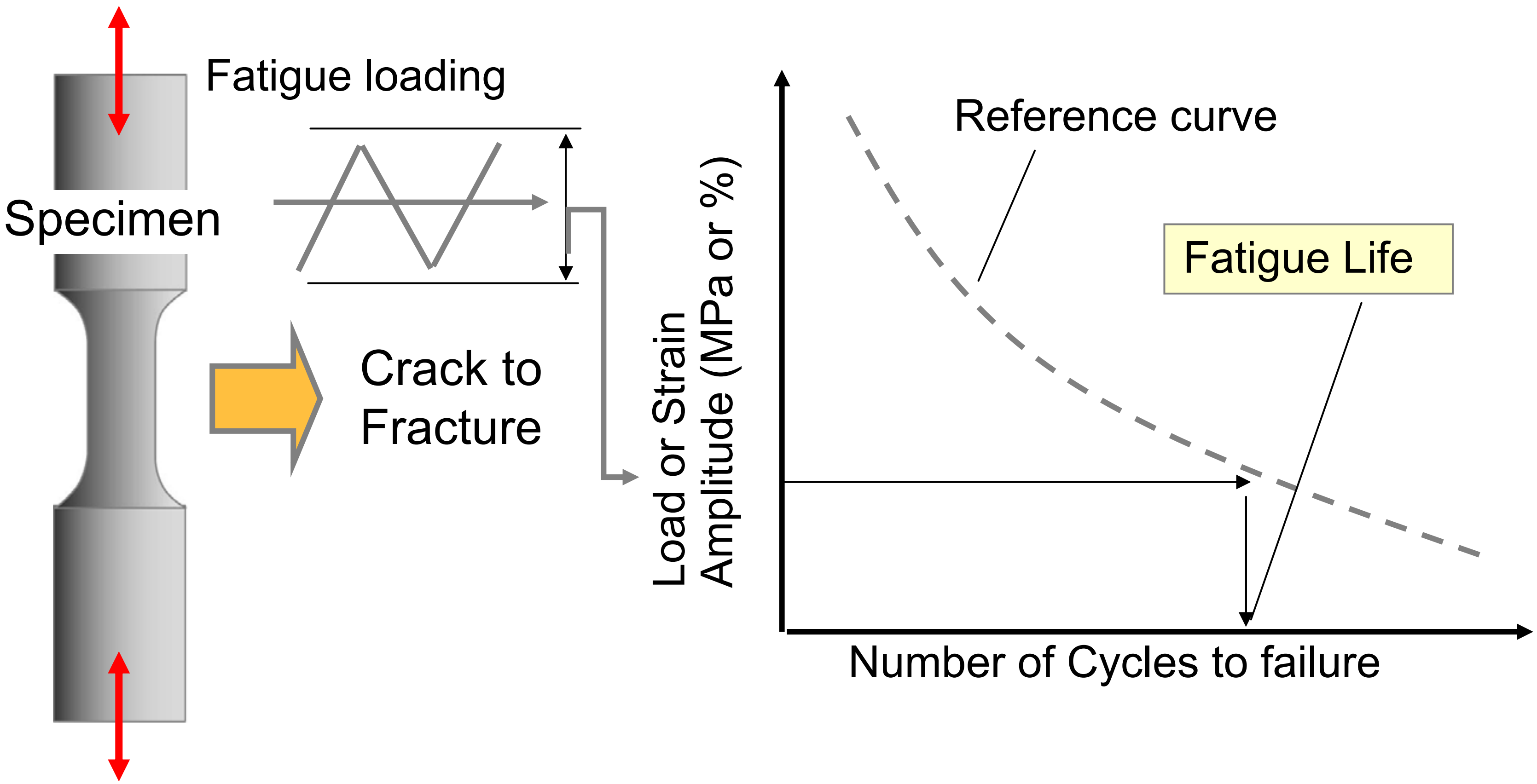
List of Properties to be evaluated for ITER TBM Application

- Short Term Mechanical properties (Fracture Toughness, Tensile)
- → Fatigue
- Creep
- Compatibility
  - → Environmentally Assisted Cracking
  - Corrosion
- Materials Engineering
  - Joining
  - Effect of Temperature, Stress and Damage Rate Change
  - Plasticity/Ductile Fracture Condition
    - → Irradiation Effect on True Stress-Strain Curve

\- These need to be evaluated for Design methodology preparation.

Irradiation Effect on Fatigue Life 1

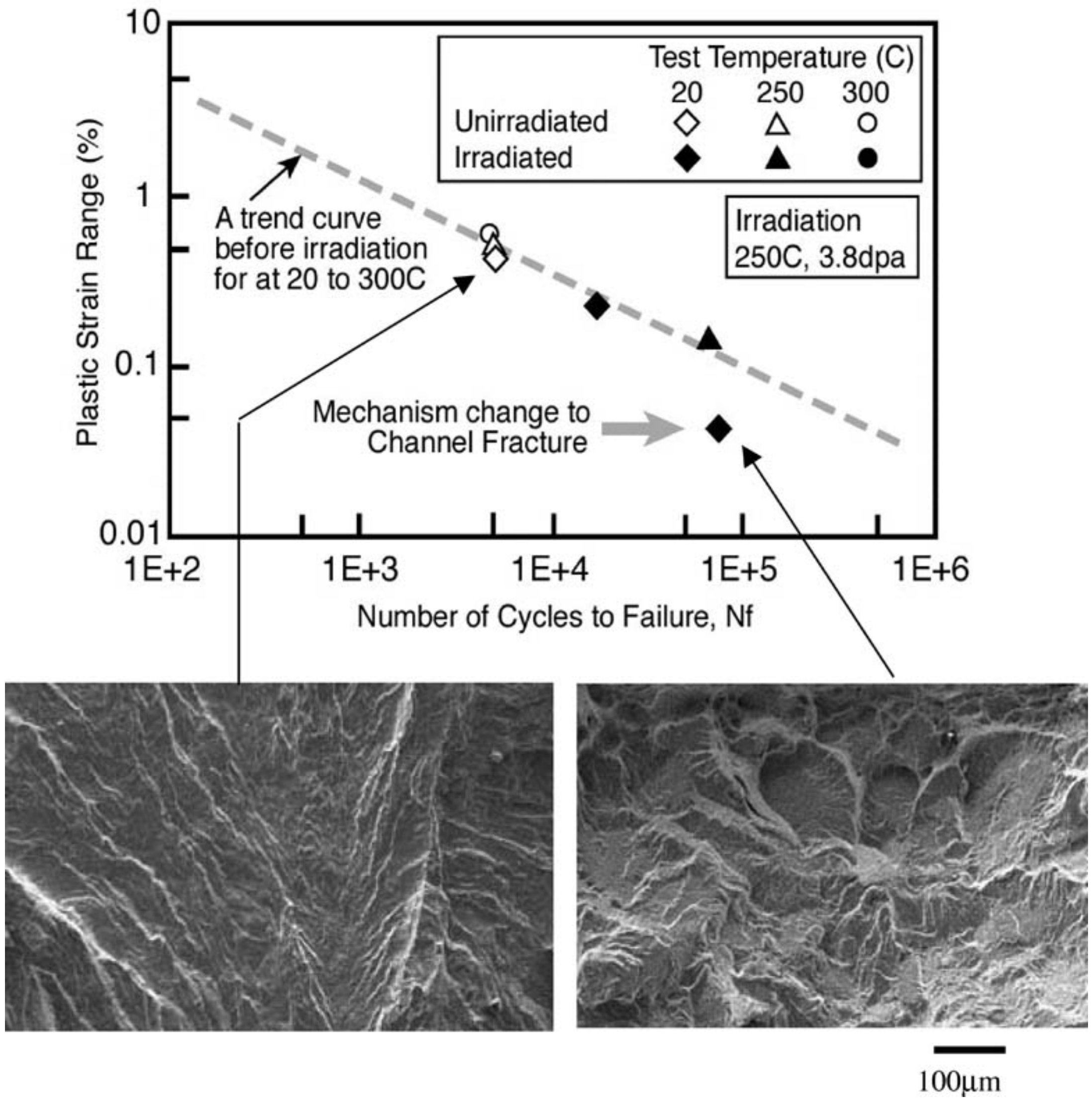
- Fatigue Damage and Fatigue Testing -



- Because ITER is a pulse operating machine, effect of irradiation on fatigue behavior has some importance.

Irradiation Effect on Fatigue Life 2

Irradiation did not reduce fatigue life, except for that of smallest strain range.

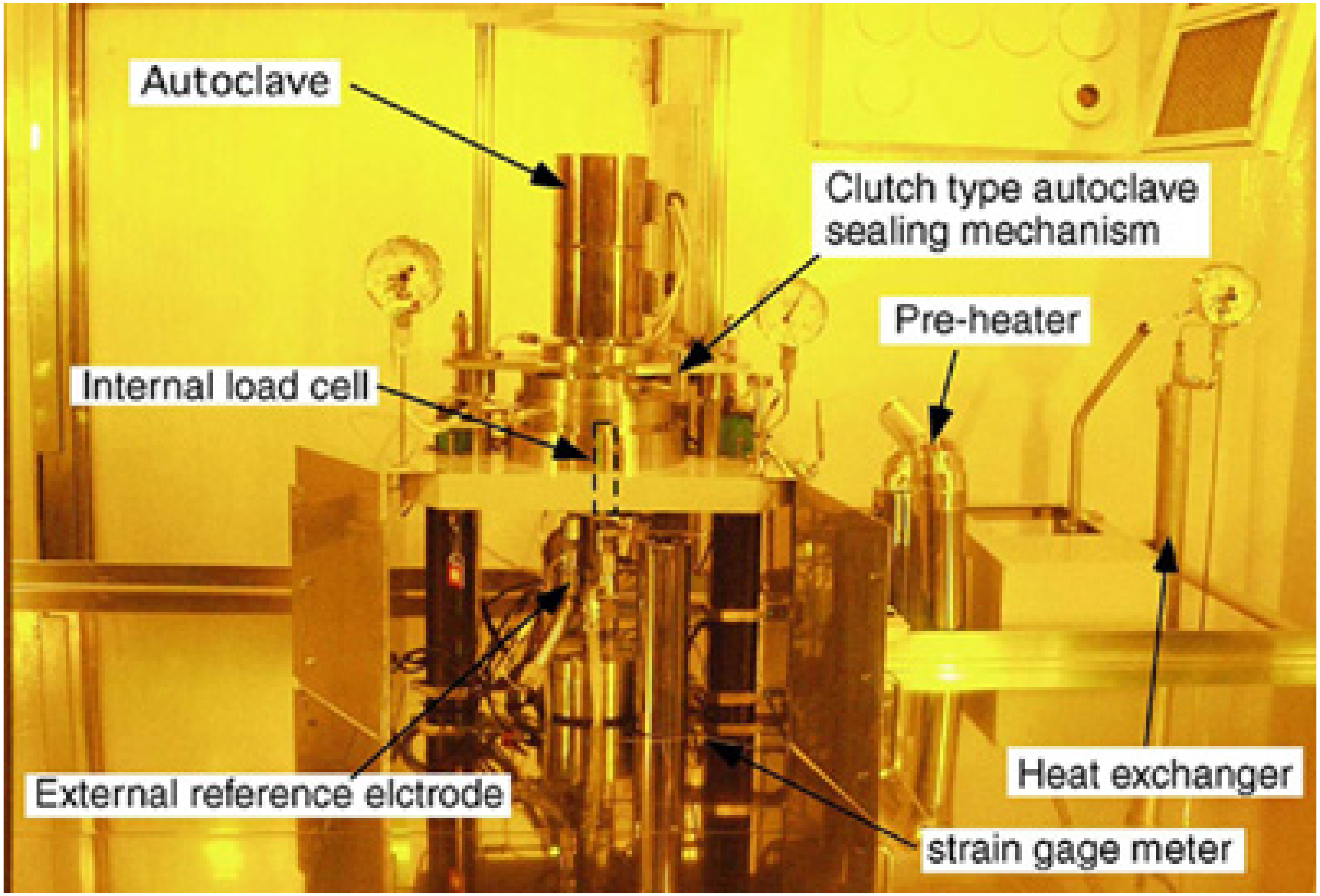


Small irradiation effect on fatigue property may allow application of current Design methodology.

Nf decreased to one seventh at the plastic strain range of 0.04%.
The reduction might be attributed to channel deformation under cyclic stress.

Irradiation Effect on Compatibility 1

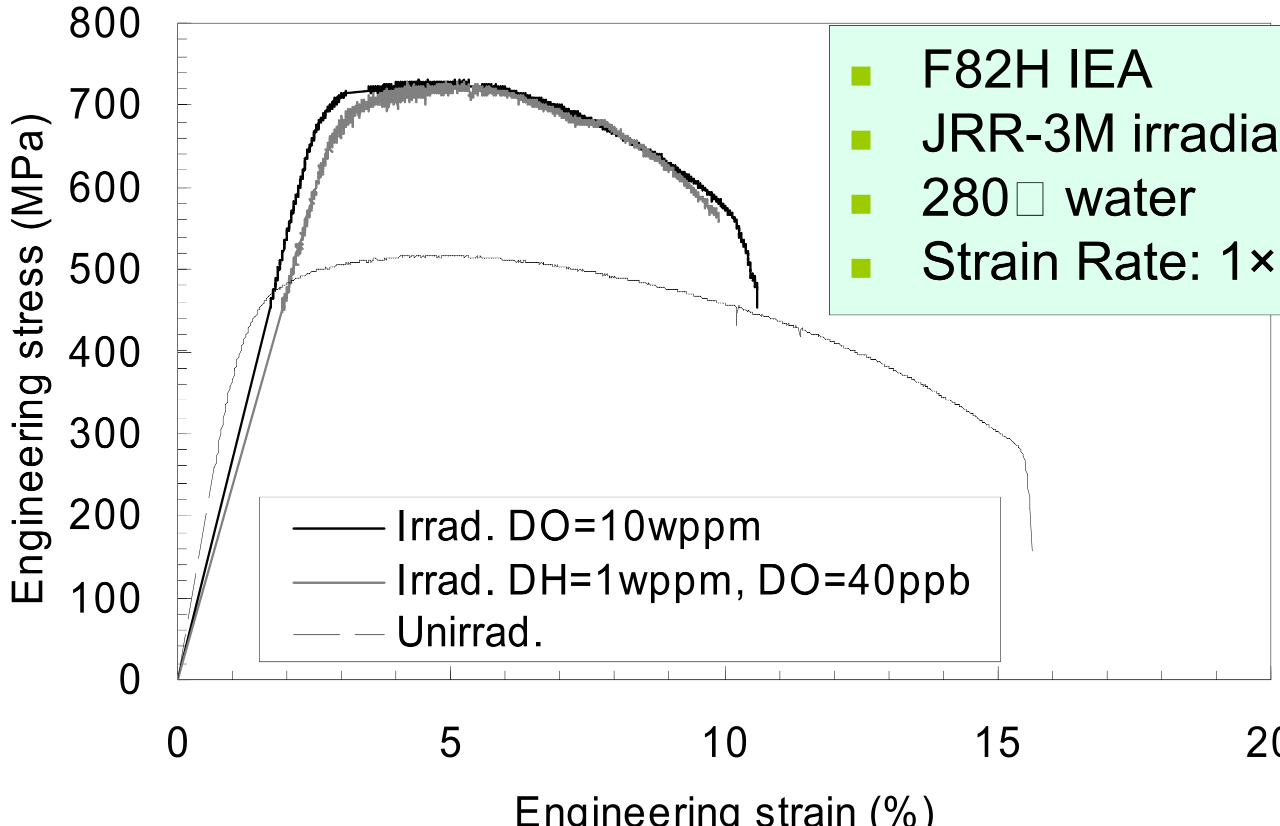
SSRT Tests on Irradiated Tensile Specimen



Slow Strain Rate Tensile test machine equipped in a hot Cell.
SSTR tests were performed at 280°C after Irradiation to 2 dpa.

Irradiation Effect on Compatibility 2

EAC susceptibility in high temperature water was examined.
Hardening caused to increase EAC susceptibility → Tests was conducted.



- F82H IEA
- JRR-3M irradiation(250□, 2dpa)
- 280□ water
- Strain Rate: $1\times10^{-7}s^{-1}$

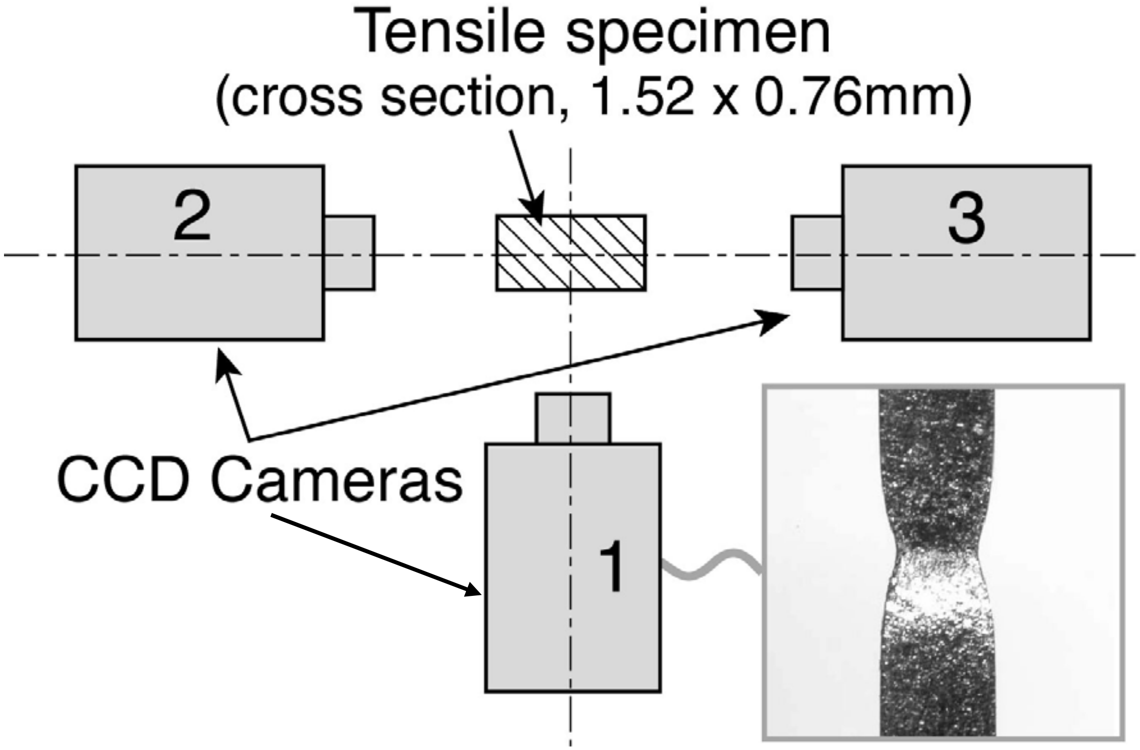
Elongation (%)

- No cracking was formed, although strong hardening is occurred. □ No large EAC Susceptibility

This indicates no particular methodology to prevent cracking in water is required so far

Effect of Irradiation on the Margin to Ductile Fracture 1

- To evaluate the condition for the ductile fracture, True stress-strain relation need to be obtained.
- Approximate True stress-strain relation after irradiation was obtained.



To measure the strain distribution in the neck at the gage section of the specimen, images of the specimens have been recorded continuously during the tensile test. Tensile direction is perpendicular to the sheet.

Effect of Irradiation on the Margin to Ductile Fracture 2

Post-irradiation Plastic Flow Property (true stress-strain relation)

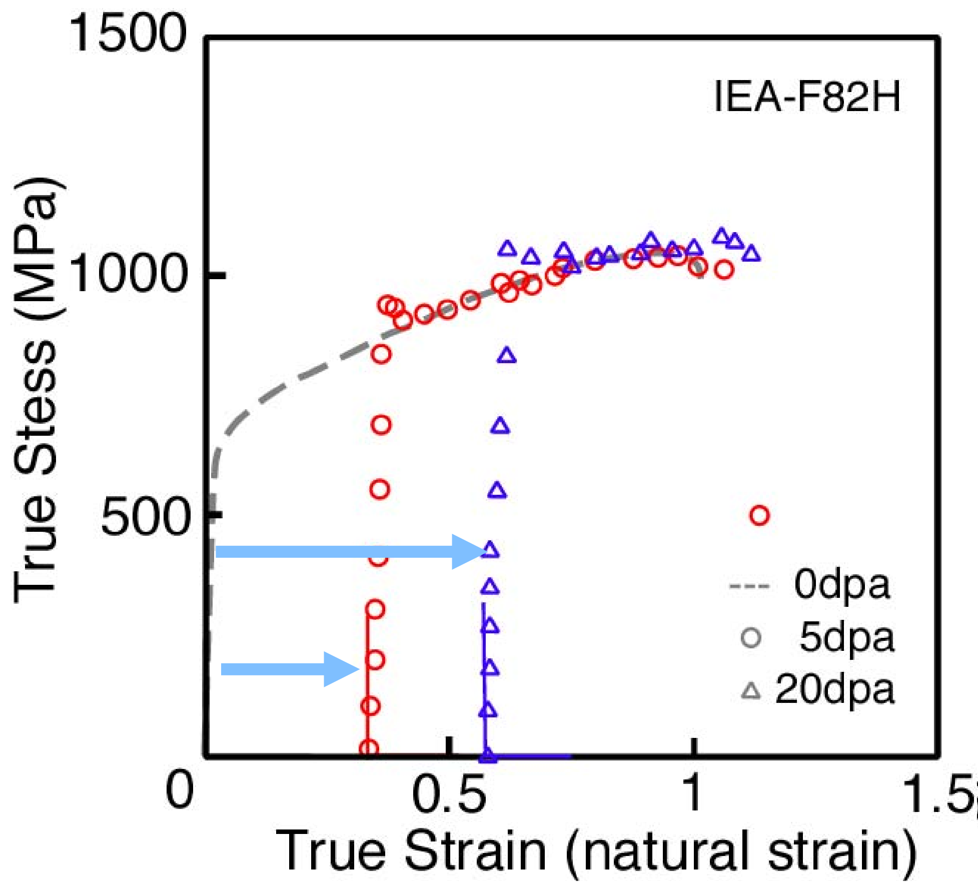
A simple relation was obtained;

before $\sigma_{un} = f(\varepsilon)$ and

after $\sigma_{irr} = f(\varepsilon_0 + \varepsilon)$

Irradiation.

ε_0 corresponds to Irradiation Hardening.



Curves after irradiation overlaps well with that before irradiation by shifting the curve along the strain axis.

Results suggest that cold worked hardened material may be used to estimate the deformation and fracture of the irradiated component under monotonic loading.

Evaluation for ITER TBM application

- No strong irradiation effect on fatigue property was obtained.
- No enhancement of EAC sensitivity was detected.

- These suggests no large change is required for Design method about fatigue and compatibility with water.

- Plastic property after irradiation may be expressed with that before irradiation by introducing the equivalent strain for hardening.
- Results suggest that cold worked hardened material may be used to estimate the deformation and fracture of the irradiated component under monotonic loading.

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Design						
Maintenance						

IFMIF

High Damage Levels

A large progress in materials property evaluation for ITER TBM application has been accomplished

Summary

for DEMO Blanket Application

- Examination of the irradiation effects on the short term mechanical properties are in progress.
- Based on the results, it may be said that the in-vessel components with RAF/Ms are possible to be designed based on the current design methodology with a limited modifications to accommodate irradiation effects.

for ITER TBM Application

- Considerable level of progress about the examination of the irradiation effects on fatigue, EAC and other materials engineering properties have been accomplished.
- Results also indicate that no large change is required for Design method about fatigue and EAC.

- One of the remaining issues is the He effect on mechanical properties with enough accuracy → IFMIF.

IFMIF Layout

International Fusion Materials Irradiation Facility