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Design Windows of Candidate Fusion Structural Materials

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Requirements for Fusion Materials (1)

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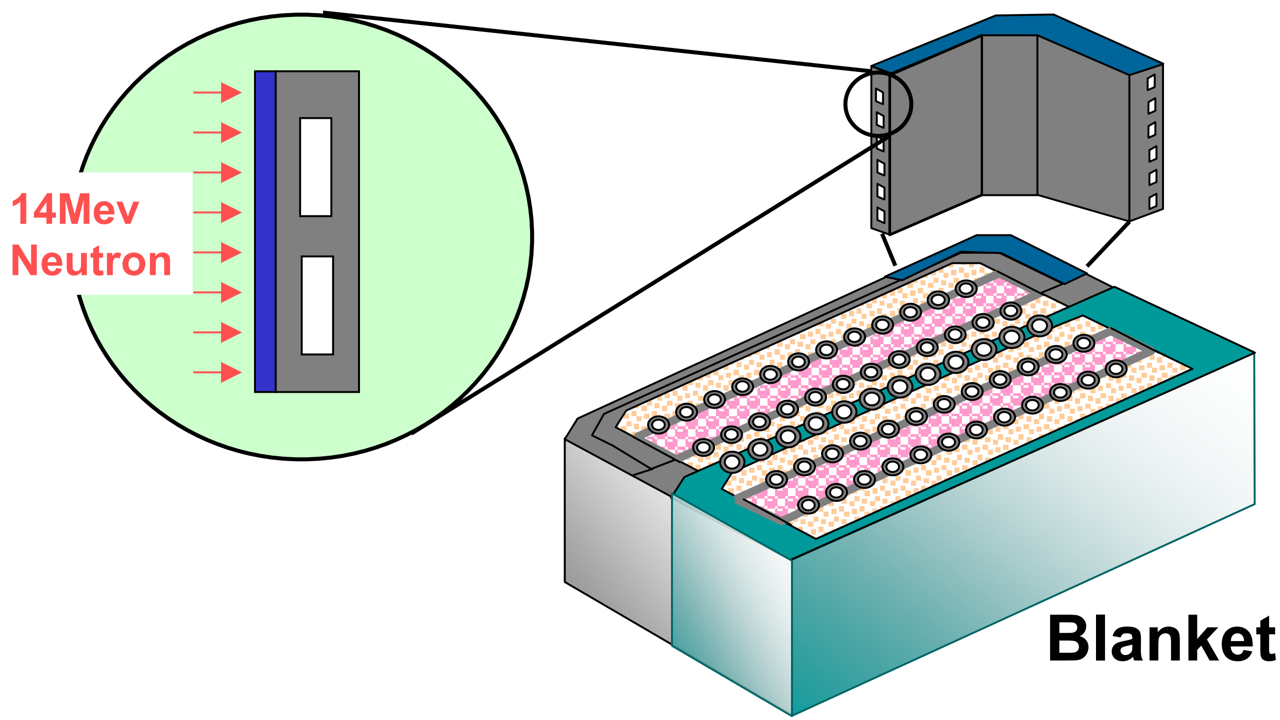
- **14MeV Neutron Irradiation (DT reaction)**
  1) Heavy displacement damage (200 dpa)
  2) High He and H concentration (0.5 at.%)
  3) Low activation

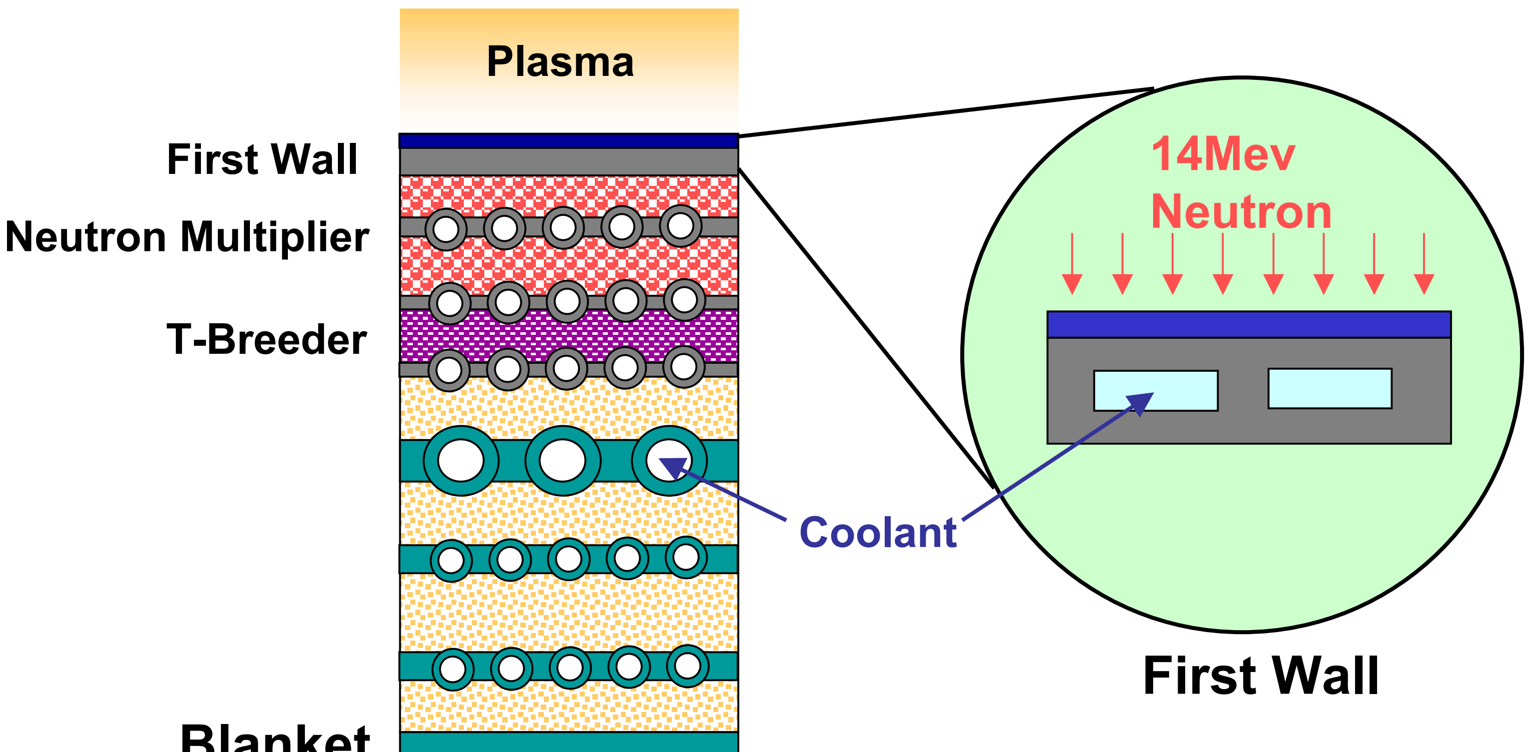


Requirements for Fusion Materials (2)

IAE, Kyoto University

● Blanket System Integration

1) Compatibility with coolant and breeder
2) Weld/Joint performance
3) Complex and synergetic effects

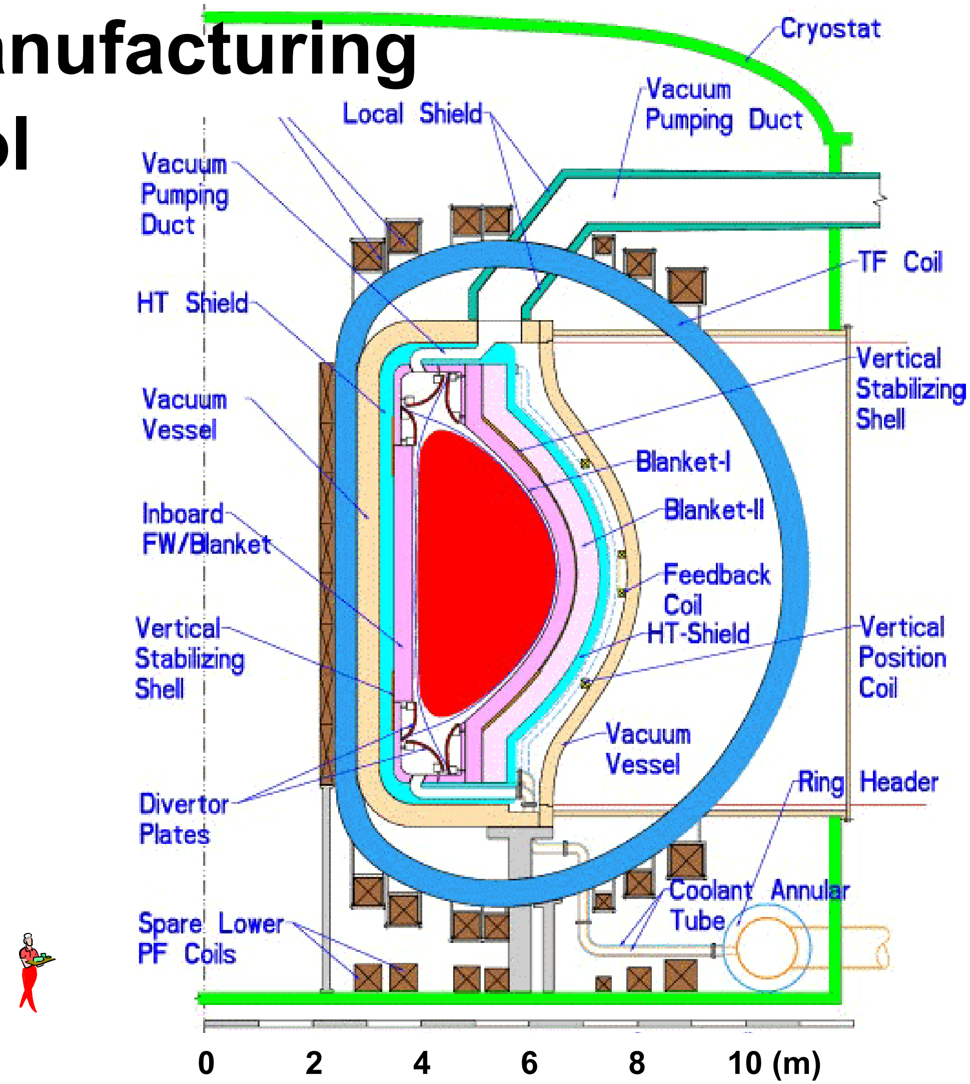


Requirements for Fusion Materials (3)

IAE, Kyoto University

● Industrial Engineering Basis

1) Large-scale manufacturing
2) Impurity control
3) Cost



Reduced Activation Materials

- **Safety and Environmental Performance**

  Reduction of radioactive waste

  Some elements, such as Mo, Ag and Nb are strictly limited to a level less than 5 wt.ppm.

- **Low-activation elements:**

  C, Cr, W, V, Ta, Ti, Mn, Si, B, Fe

  Fe-9Cr-2W reduced activation ferritic steels
  V-4Cr-4Ti reduced activation vanadium alloys
  SiC/SiC composites

Candidates for Fusion Structural Material (1)

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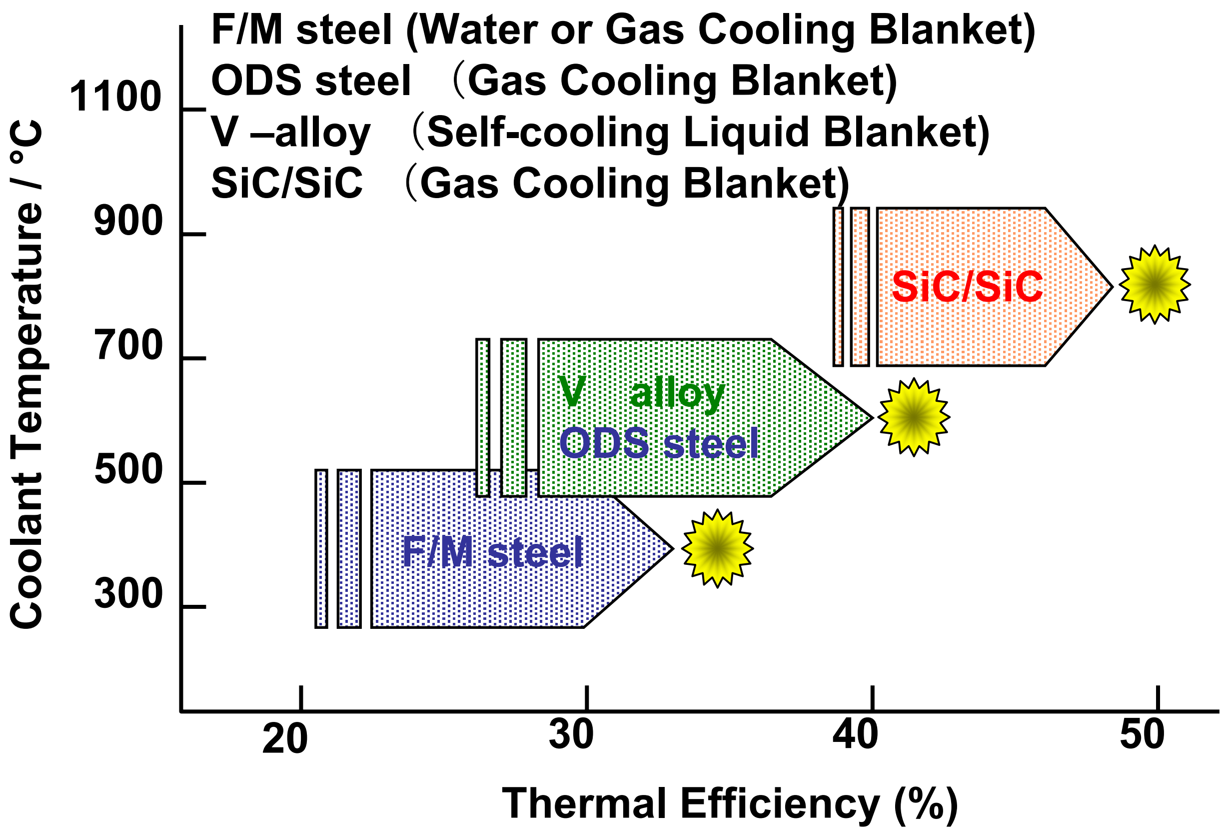
1. Fe-9Cr-2W reduced activation ferritic steels
2. V-4Cr-4Ti reduced activation vanadium alloys
3. SiC/SiC composites



Achievements of the Candidates

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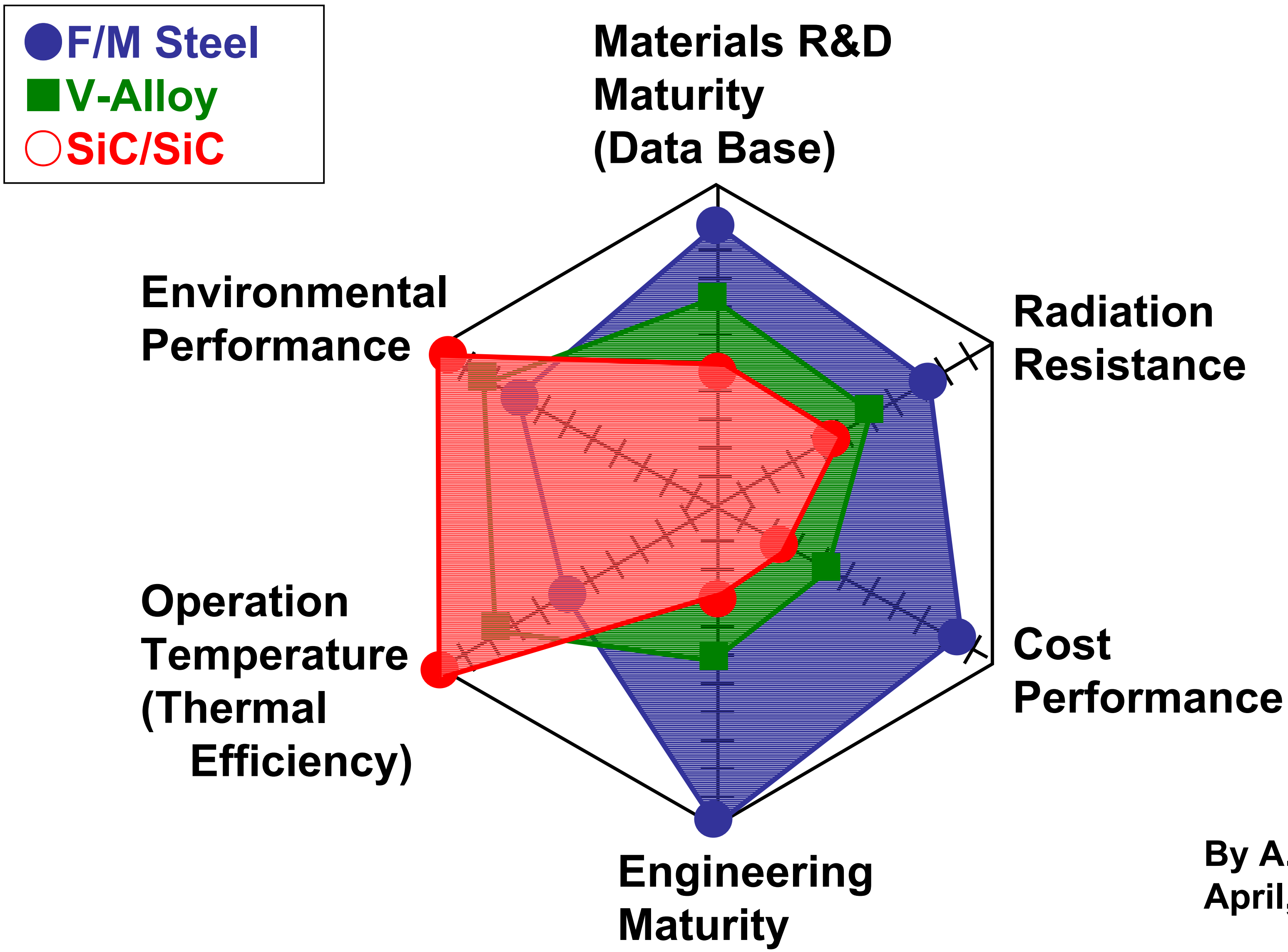
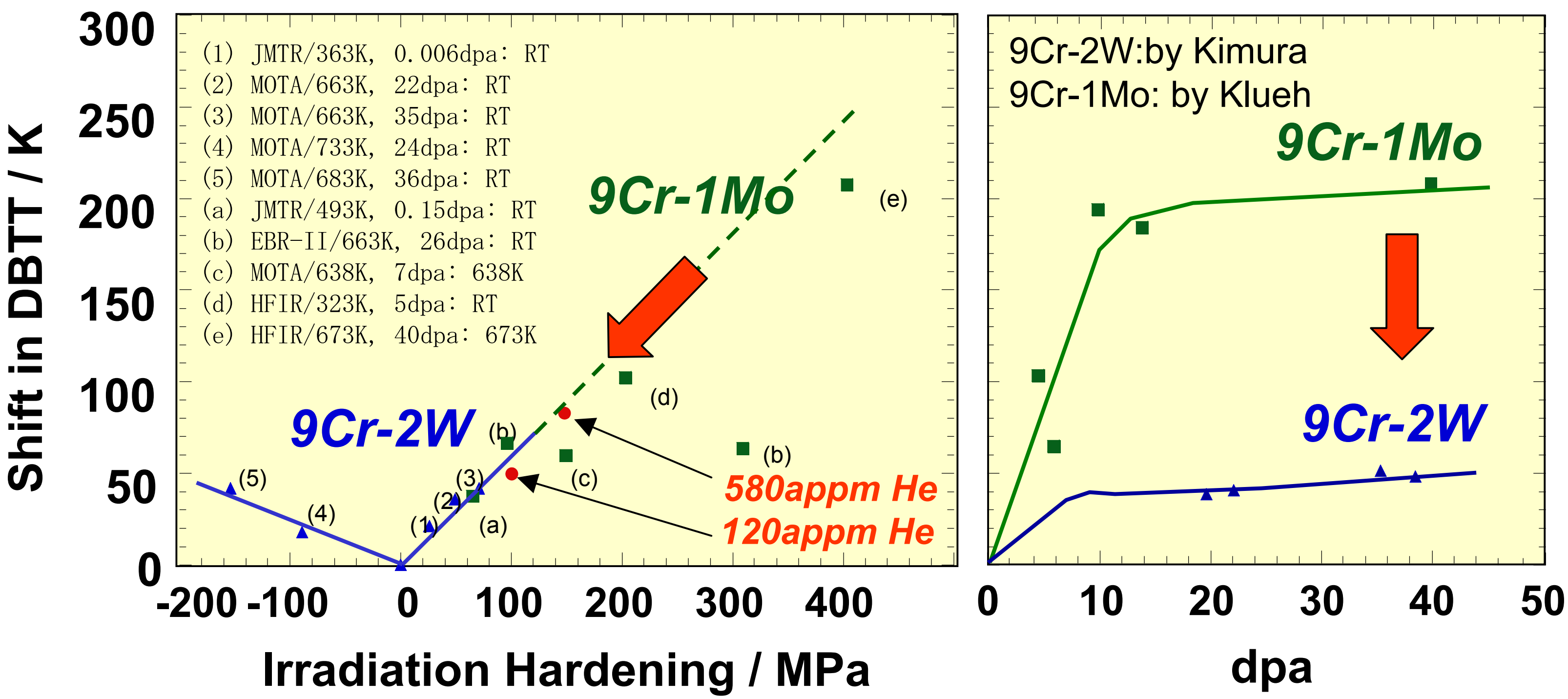


By A. Kimura
April, 2002

Ferritic Steels R&D (1)

IAE, Kyoto University

● Improvement of Impact Properties

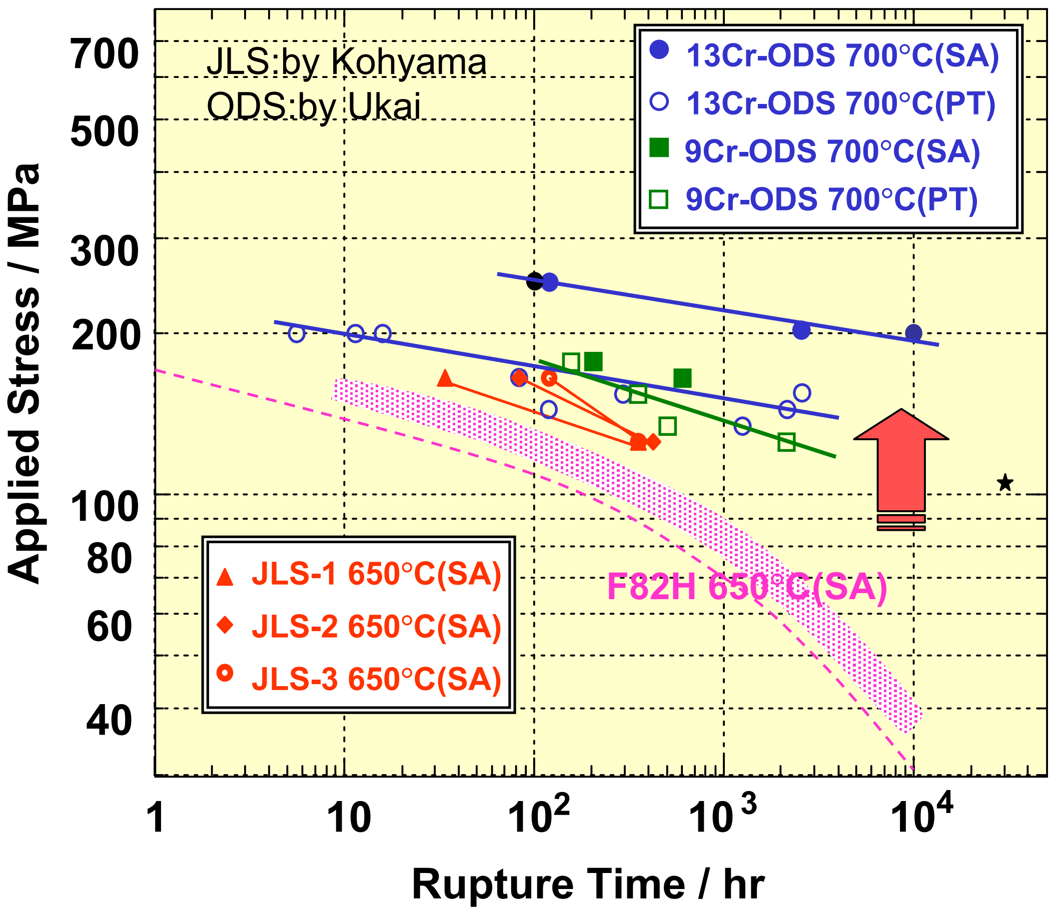


1) Higher resistance to irradiation embrittlement.
2) Saturation of irradiation embrittlement at 10 dpa
   (above 100 dpa?)

Ferritic Steels R&D (2)

IAE, Kyoto University

● Improvement of High Temperature Strength



A significant increase in the creep strength has been obtained by increasing W conc. and/or mechanical alloying method.

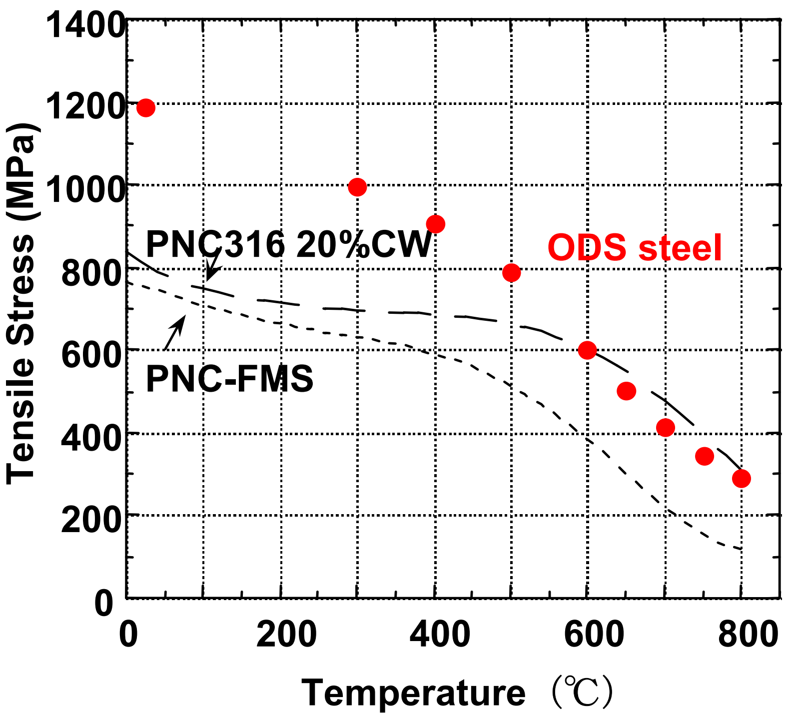
Irradiation study is in progress.

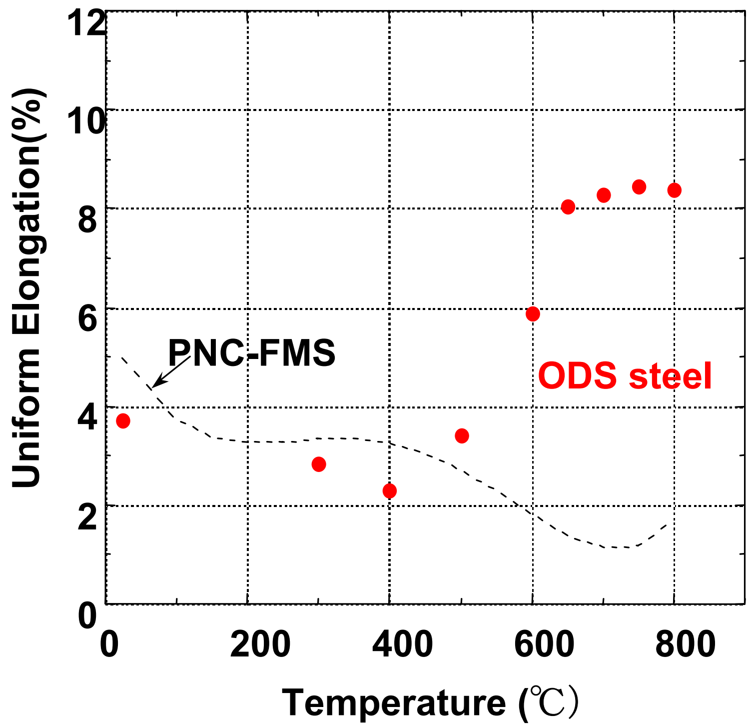
Ferritic Steels R&D (3)

IAE, Kyoto University

● Improvement of High Temperature Strength

ODS steel (JNC)





Ferritic Steels R&D (4)

IAE, Kyoto University

● Improvement of Creep Property

Basic Chemical Composition

- 9Cr-Martensitic ODS

$9Cr\text{-}0.12C\text{-}2W\text{-}0.2Ti\text{-}0.35Y_2O_3$
Advanced radiation resistance due to reduced Cr content

- 12Cr-ferritic ODS

$12Cr\text{-}0.03C\text{-}2W\text{-}0.3Ti\text{-}0.25Y_2O_3$
Advanced corrosion resistance

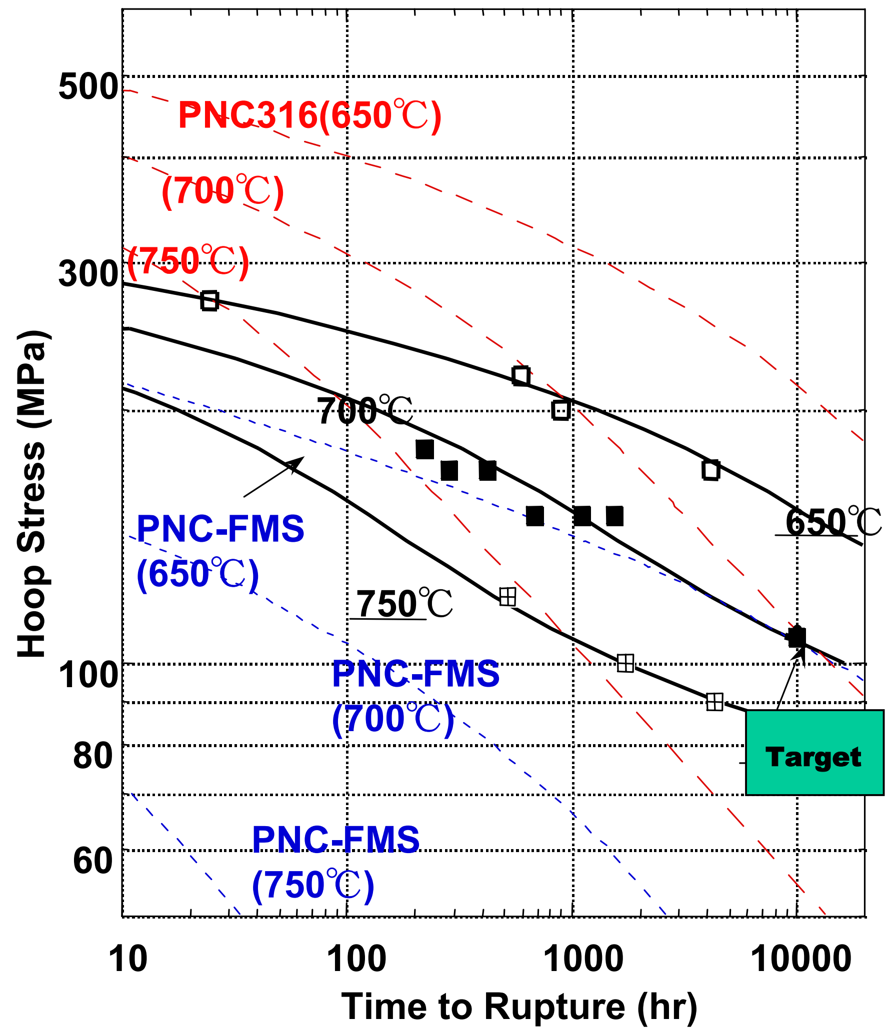
- Claddings manufactured by cold-rolling

Mechanical Properties

- Advantageous at higher temperature over 700 ℃ in creep rupture and tensile strength, comparing with PNC316
- Maintain good ductility

Irradiation

- Up to 15 dpa at 400 ℃ to 530 ℃
- Maintain strength and ductility without α'



Design Windows of RAFS

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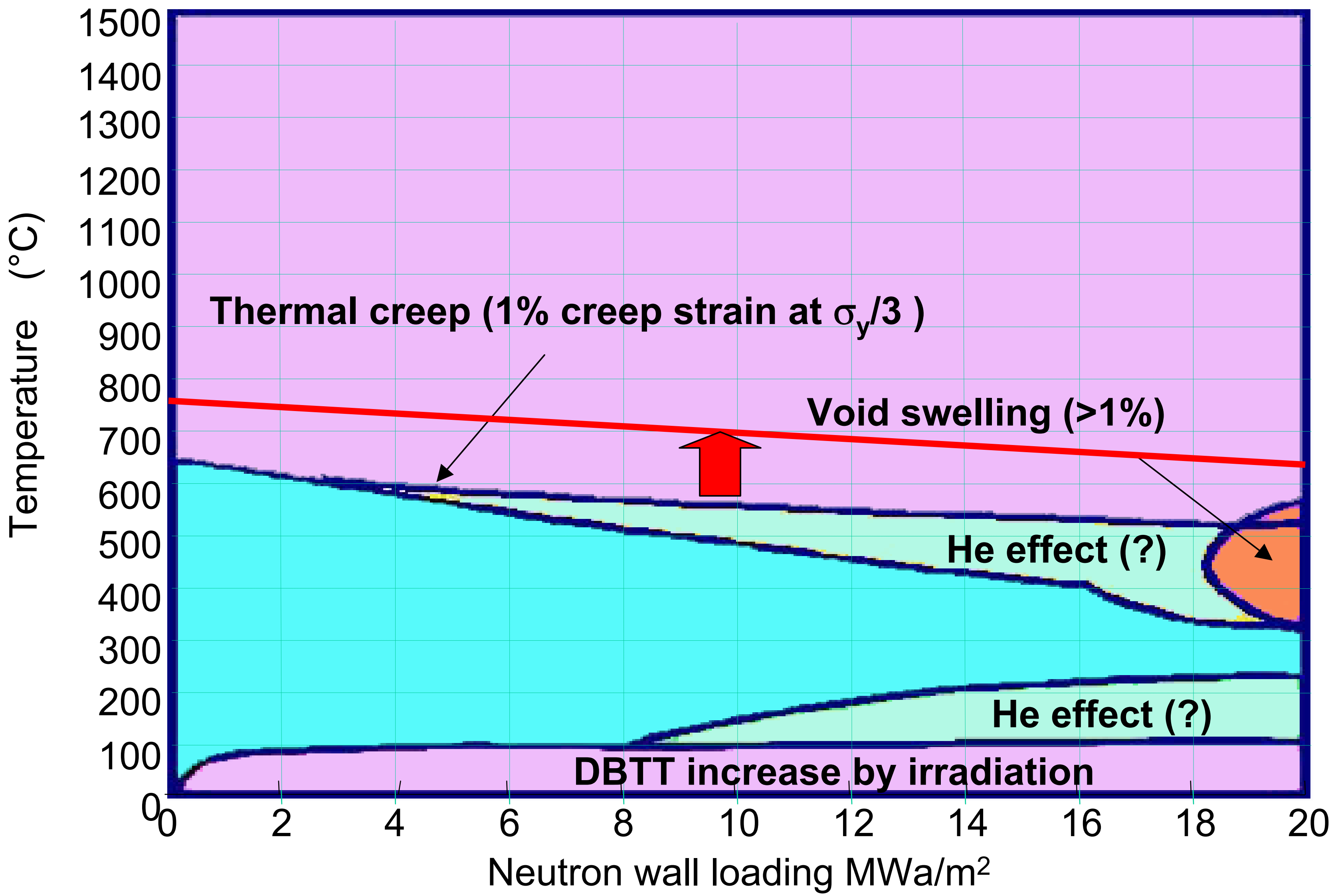


And More for Ferritic Steels

◎Toward DEMO

- ●Data base
- ●Helium and hydrogen effects
- ●Compatibility issues

◎Toward Power Reactor

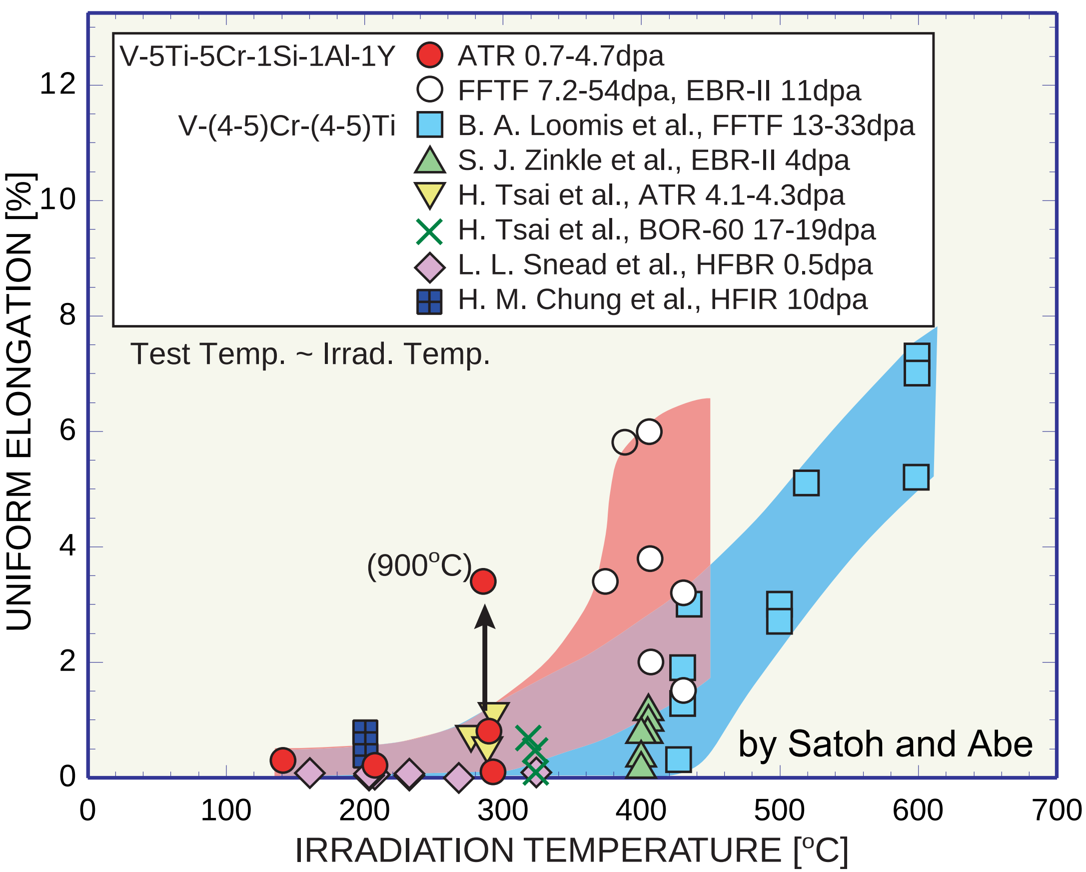
- ● All the above
- ● RAFS/ODS combination design

Vanadium Alloys R&D (1)

IAE, Kyoto University

● Ductility Improvement by Alloying

◎ **Marked ductility loss by irradiation**



◎ **Internal oxidation technique**

Al, Si, Y addition
Al_2O_3, SiO_2, Y_2O_3

Reduction of O in the matrix of vanadium

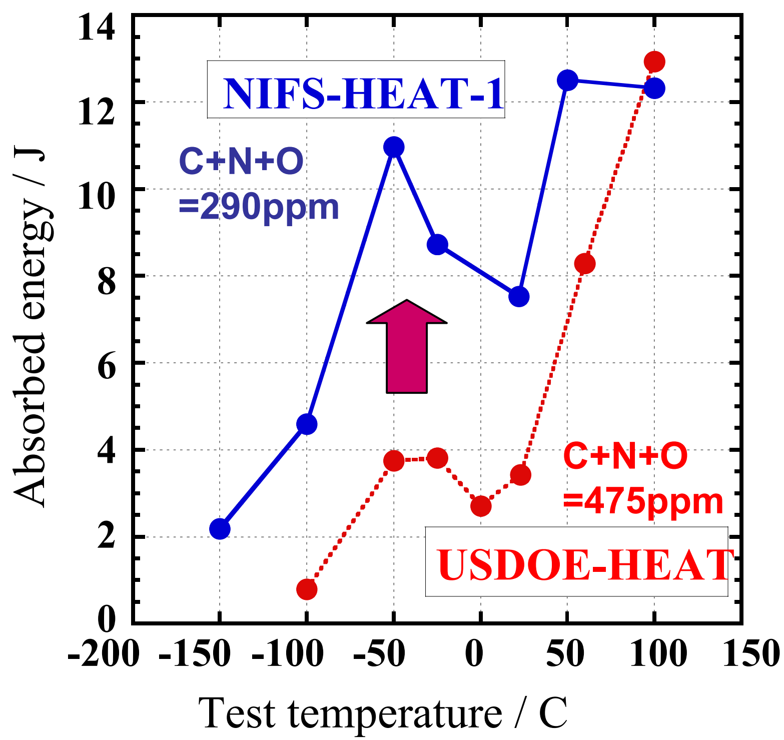
Heat treatment condition is another concern.

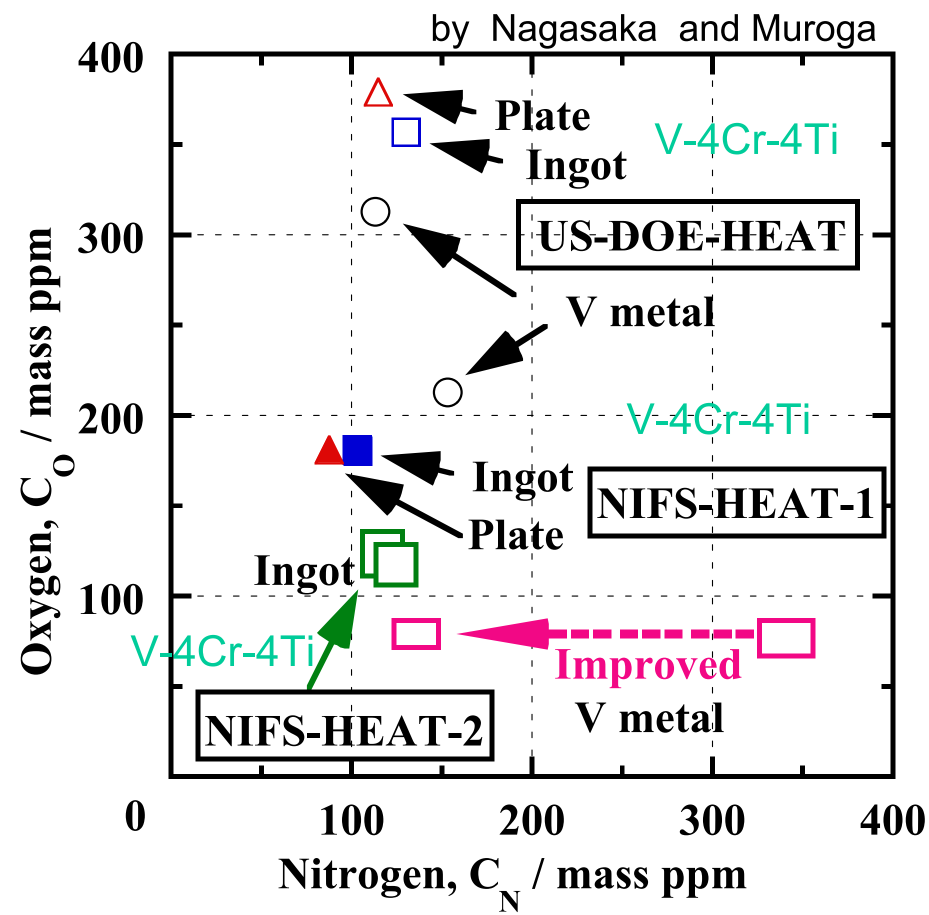
Vanadium Alloys R&D (2)

IAE, Kyoto University

● Ductility Improvement by Purification

◎ **Oxygen: 80 wt.ppm**
Nitrogen: 130 wt.ppm





Vanadium Alloys R&D (3)

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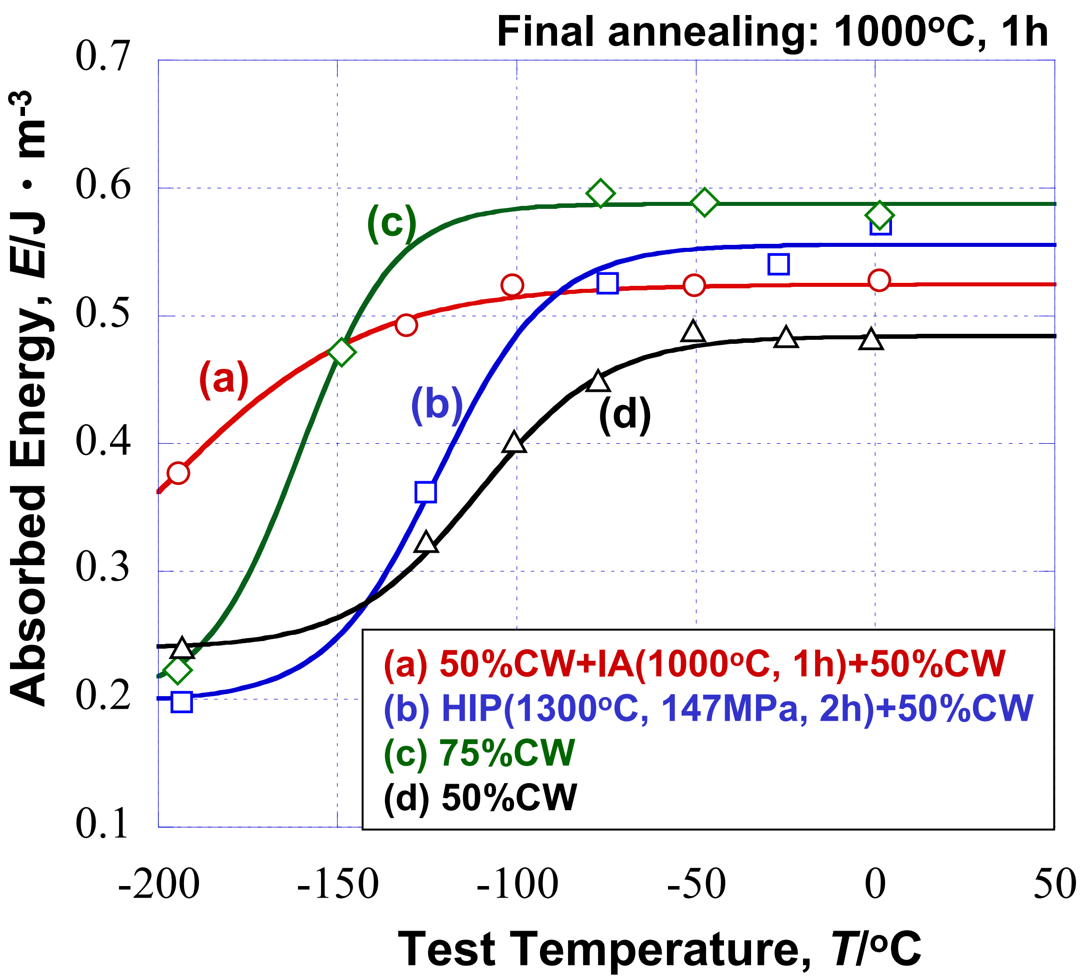
● Ductility Improvement by Processing



◎ **Thermo-mechanical treatment**

lowering DBTT

by Satoh and Abe

Vanadium Alloys R&D (4)

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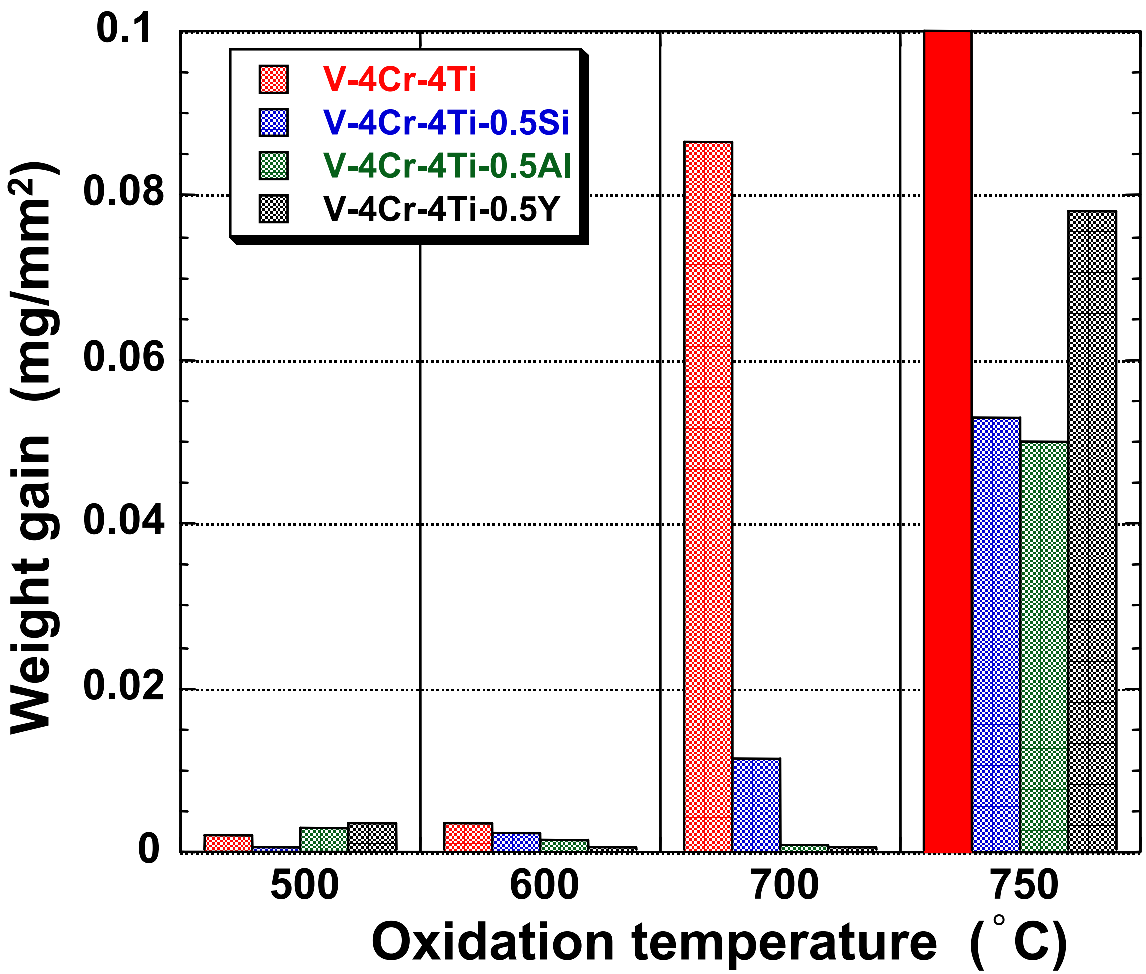
● Improvement of Oxidation Resistance

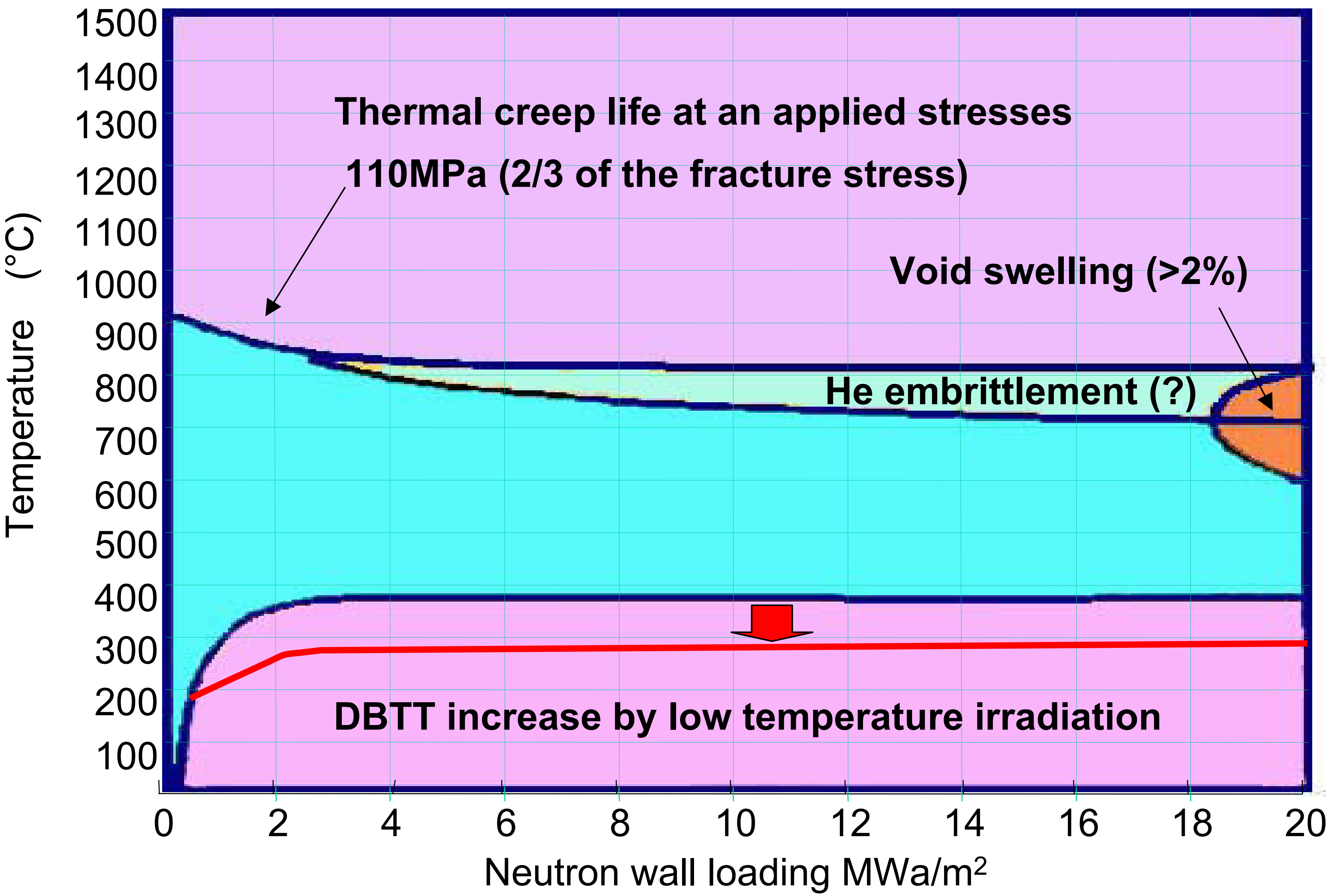


◎ **Addition of Al and Y appears to be effective to increase oxidation resistance at 700°C.**

by Fujiwara and Abe

Design Windows of V Alloys

IAE, Kyoto University



And More for Vanadium Alloy

◎Toward DEMO

- Data base
- Helium and hydrogen effects
- <u>Coating technique</u>

◎Toward Power Reactor

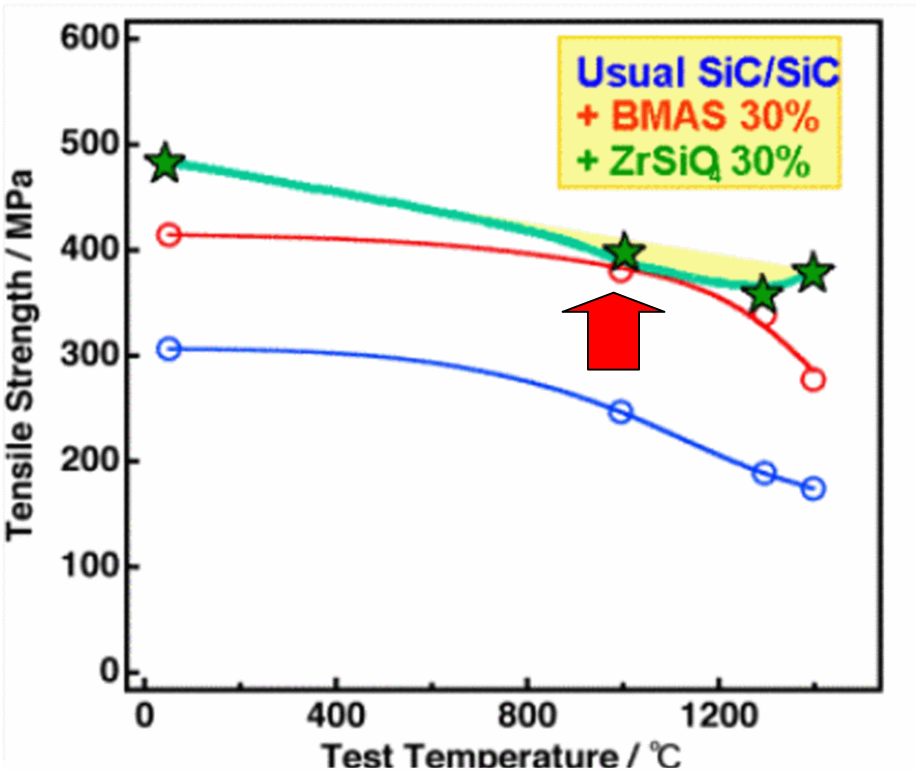
- All the above
- Industry engineering basis (Spin-off to non-nuclear)

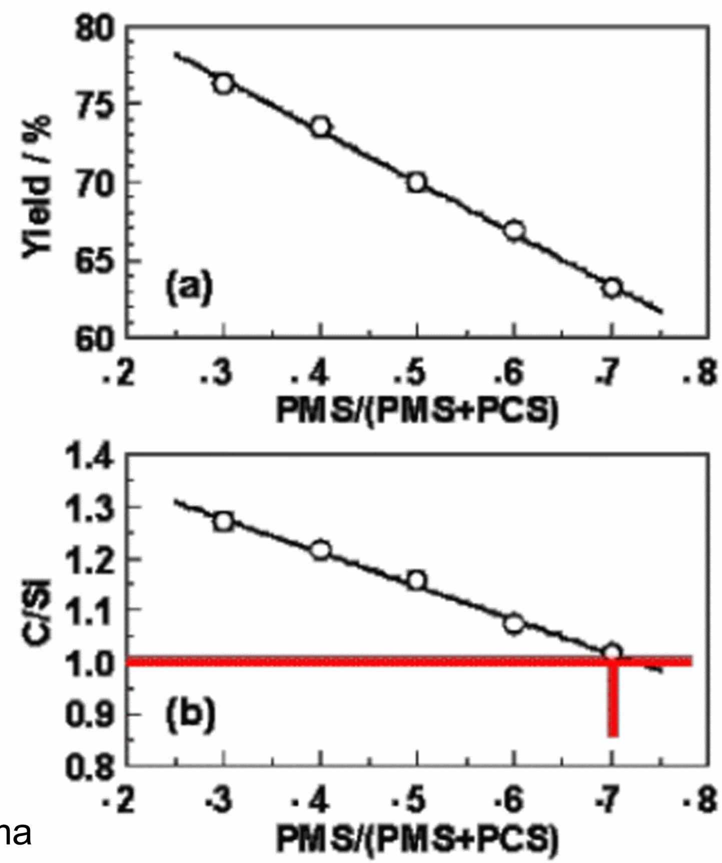
SiC/SiC Composites R&D (1)

IAE, Kyoto University

● Improvement of Tensile Stress

(PIP:Polymer Impregnation and Pyrolysis)





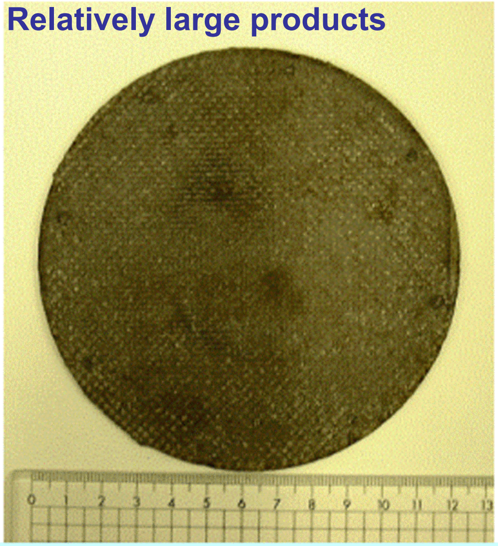
by Kotani and Koyama

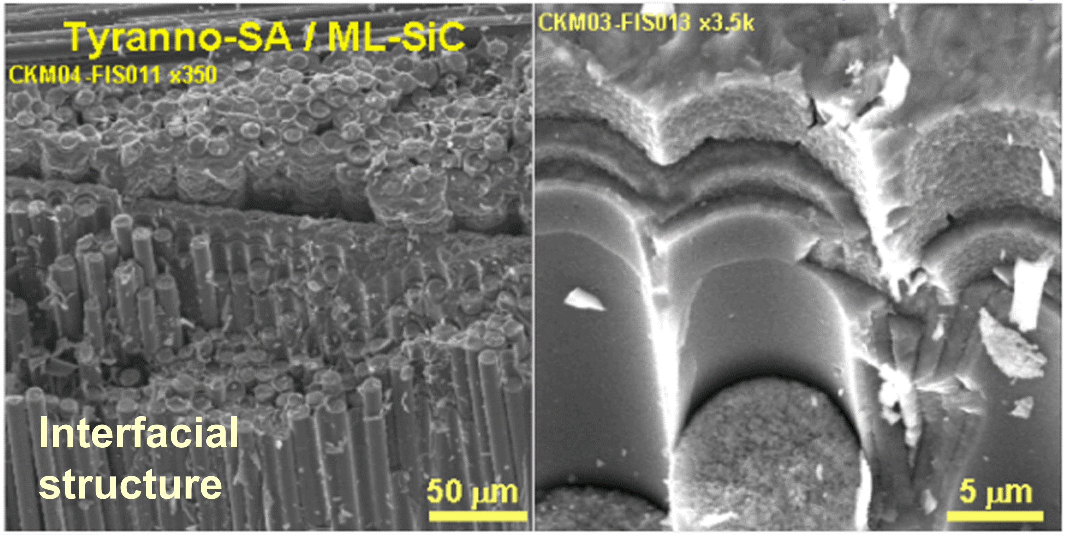
◎ **Good performance at stoichiometric composition**

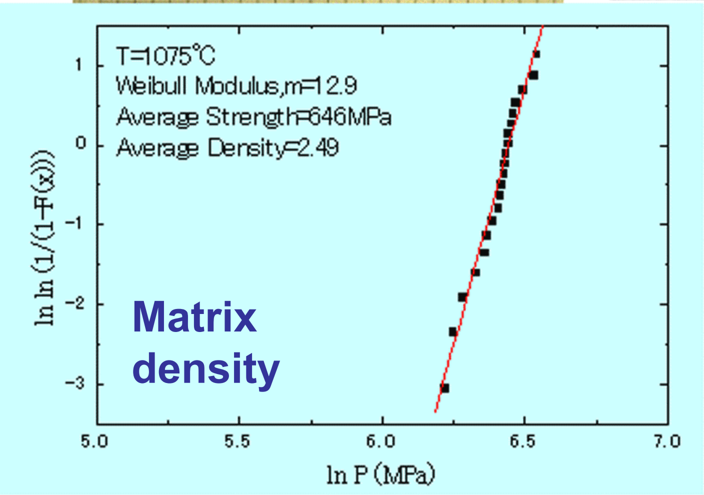
SiC/SiC Composites R&D (2)

IAE, Kyoto University

● Improvement of Fabrication Technique







Optimization of ;

Interfacial CVI-coating
Matrix Infiltration (reduce porosity/micro crack)

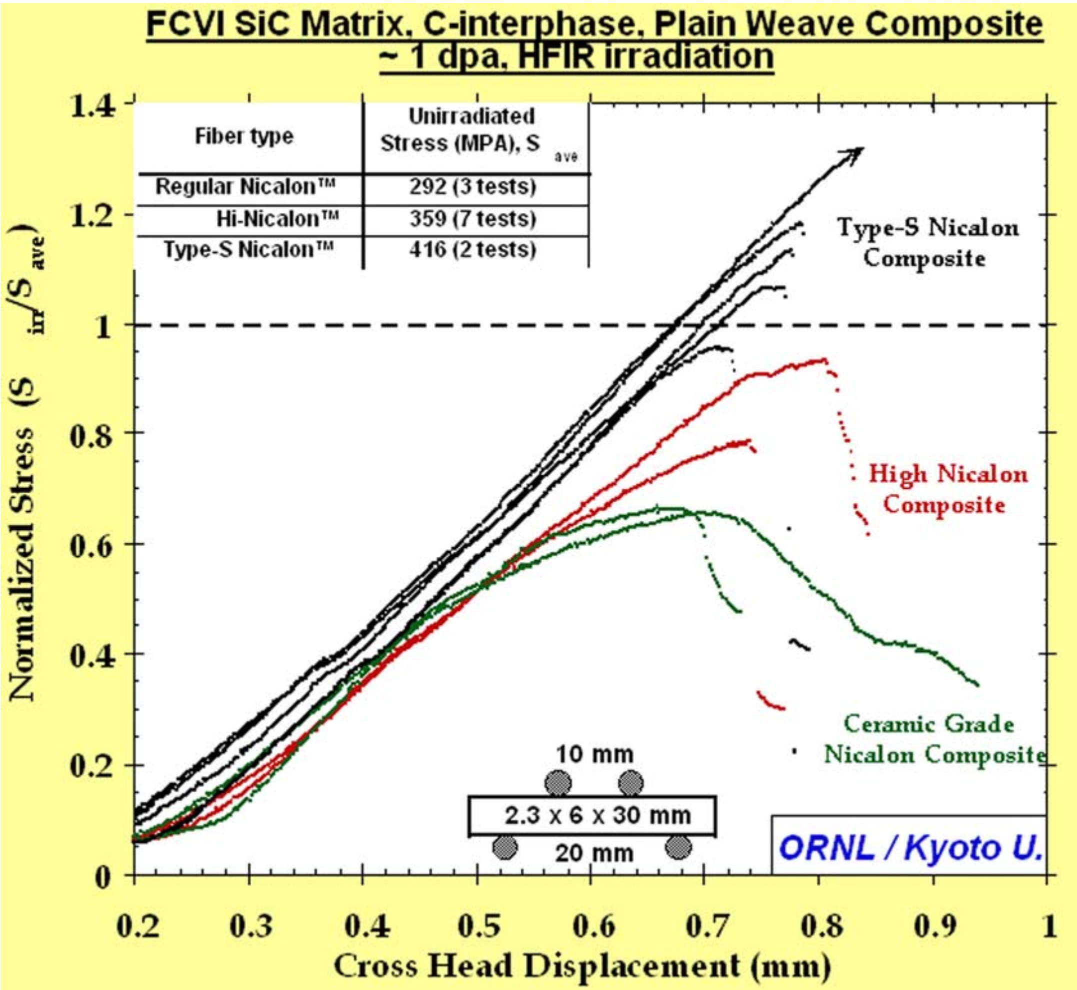
High reliability (m>12)
High strength (σ_b > 700MPa)
High proportional limit (σ_{pl} > 500MPa)

by Yang and Noda

SiC/SiC Composites R&D (3)

● Improvement of Irradiation Response

by Kohyama



◎ Development of new fiber (Type-S Nicalon) improved response of mechanical properties to neutron irradiation.

The advanced fiber has an almost stichiometric composition.

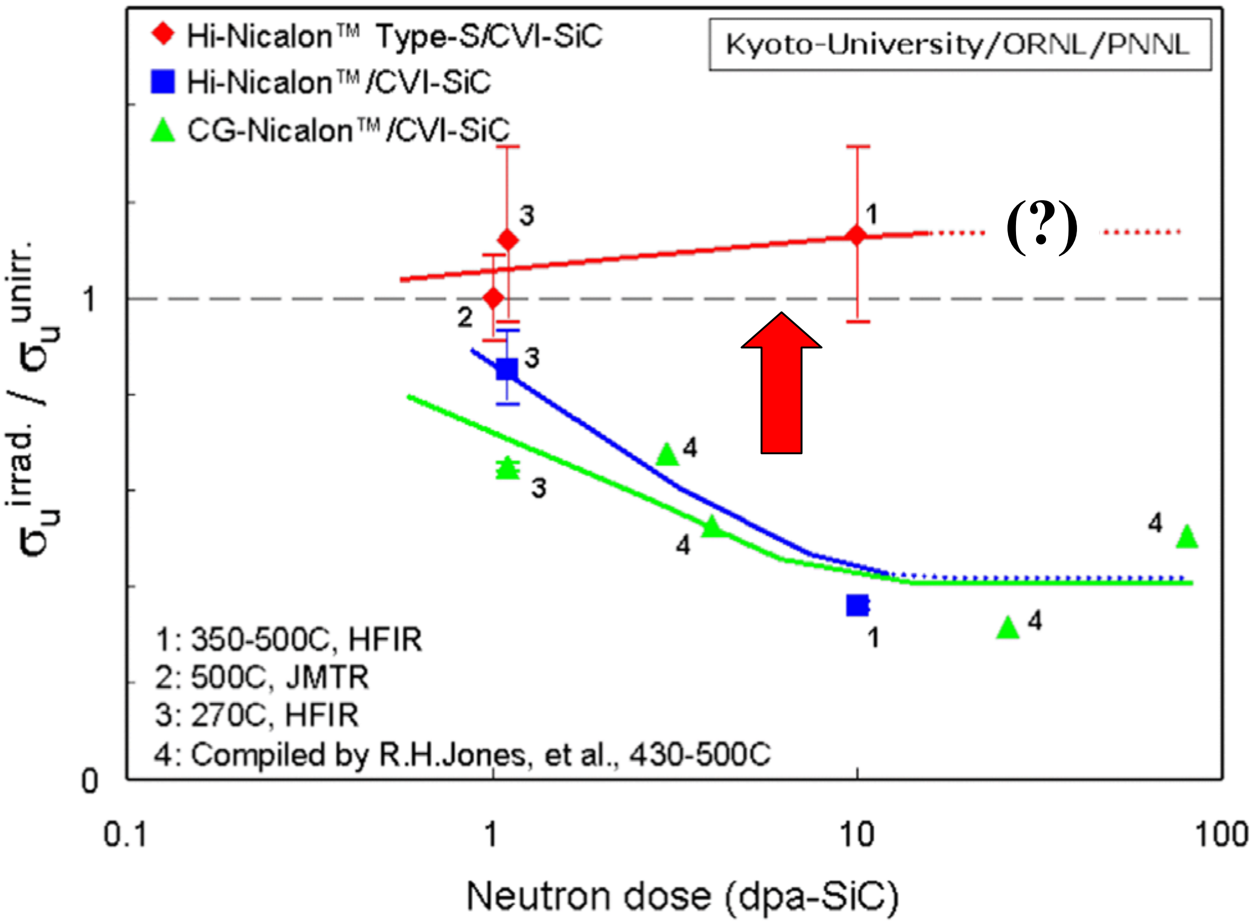
R&D of stoichiometric matrix SiC and appropriate interfacial structure.

SiC/SiC Composites R&D (4)

IAE, Kyoto University

● Good Performance to 10 dpa

by Katoh and Koyama



◎ **No degradation of strength of stoichiometric Hi-Nicalon Type-S fibers.**

Design Windows of SiC/SiC

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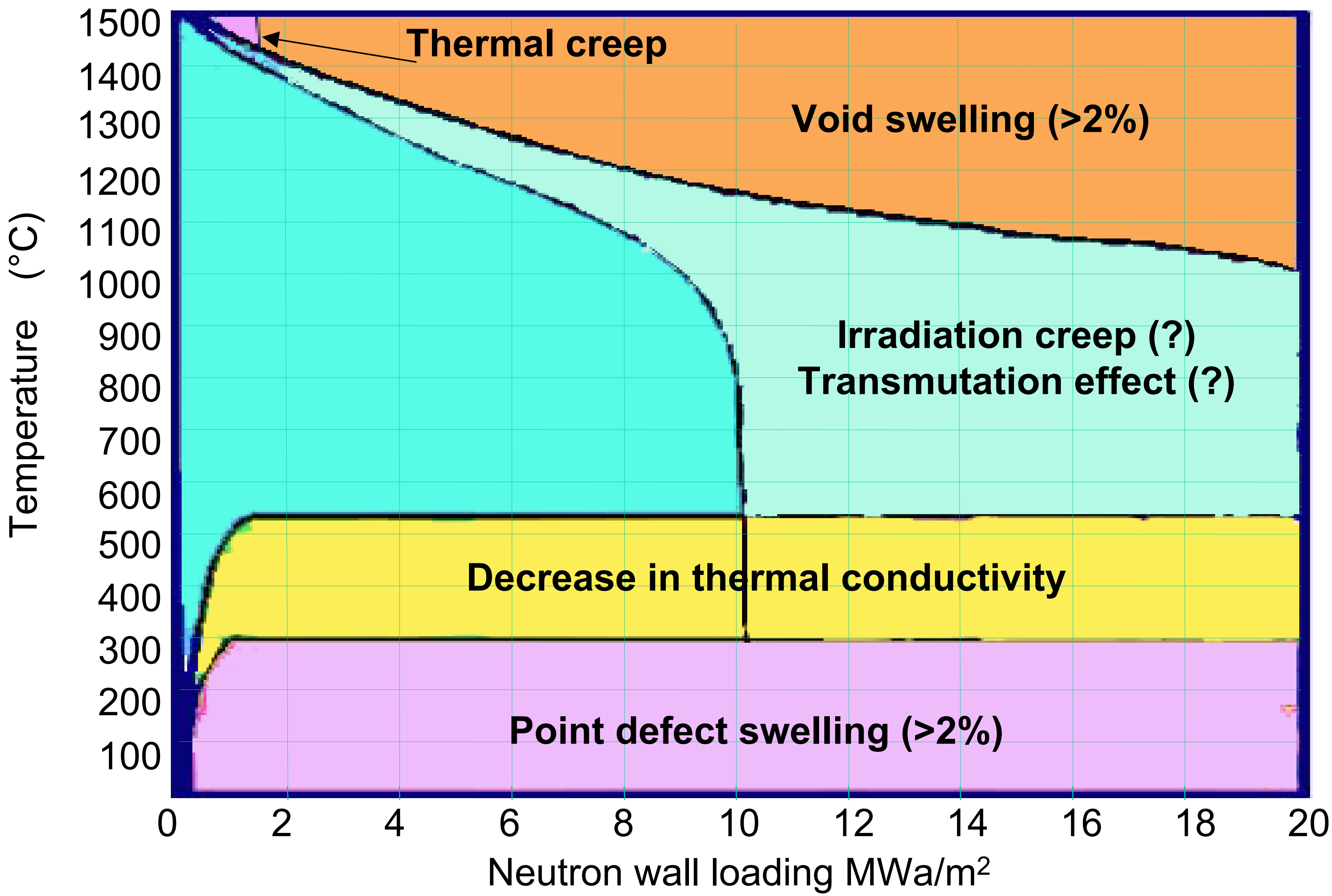

And More for SiC/SiC

◎Toward DEMO

- Data base
- Helium and hydrogen effects
- Fracture toughness (Interfacial structure)

◎Toward Power Reactor

- All the above
- Radiation resistance
- Production of large components

R&D Roadmaps

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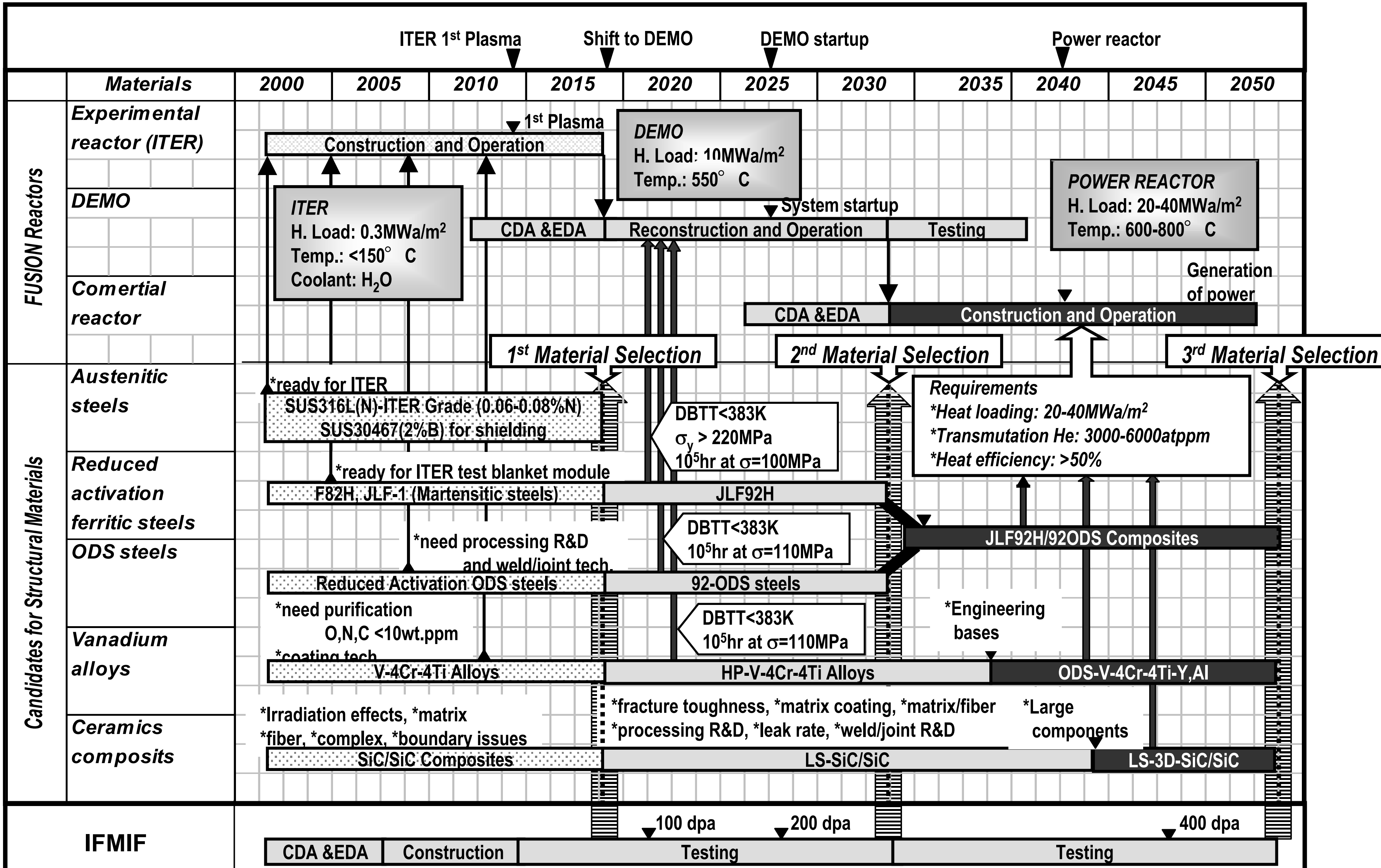
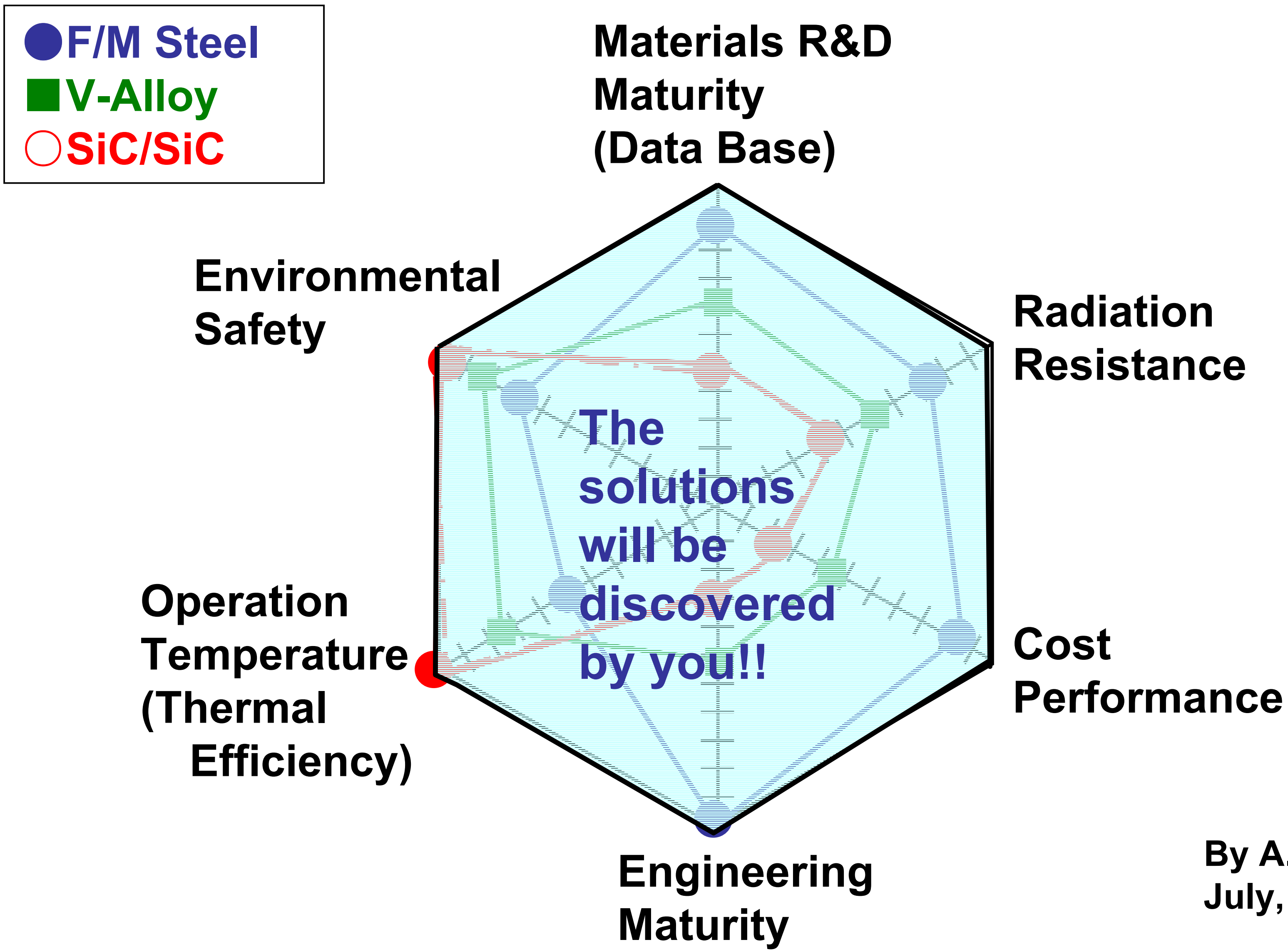


Summary

1. **Ferritic steel is the first candidate of fusion blanket structural materials. The issue of high thermal efficiency can be solved by application of ODS steel. Combined utilization of ferritic steel and ODS steel is quite promising for power reactor.**

2. **Vanadium alloys and SiC/SiC composites are also desirable for fusion power reactors. Extensive improvements have been achieved so far.**
   R&D of material processing for production of large-scale component is strongly demanded.

Conclusion



By A. Kimura
July, 2001