International Conference on Fast Reactors and Related Fuel Cycles (FR09)
Kyoto, Japan, December 7-11, 2009

Development of Structural Materials for JSFR
- Overview and Current Status -

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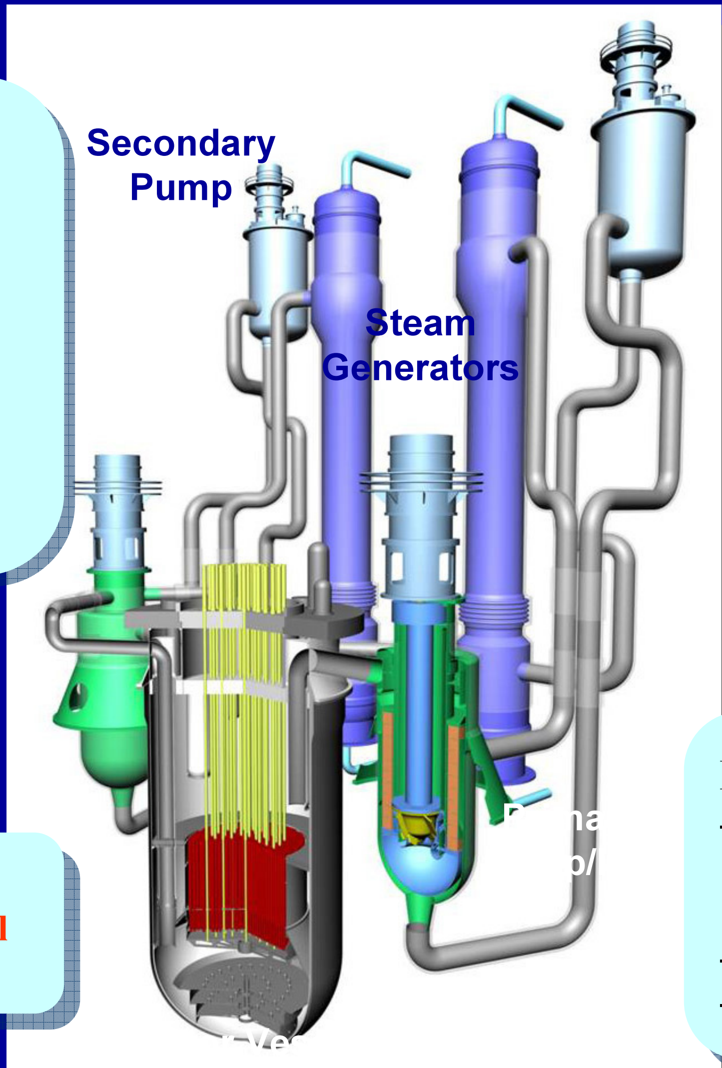
Background and Contents

- Development of new materials is an key issue to achieve innovative concepts of JSFR. R&Ds are being performed in an "All Japan" framework.
- Core materials
  - Oxide Dispersed Strengthened steel (ODS)
- Structural materials
  - 316FR (Low carbon nitrogen added 316SS)
  - Modified 9Cr-1Mo steel

JSFR - Innovative technologies -

Cost Competitiveness
- Simplified HTS with 2-Loop Arrangement
- Short piping with Modified 9Cr-1Mo steel
- Integrated heat exchanger and primary pump
- Compact and simple reactor block with 316FR
- Fuel handling system
- SC Containment structure



Prevention of Sodium Fire/Reaction:
Double-walled Sodium Piping

High Reliability:
Technologies for Inspection and repair tech under sodium

Enhanced Availability
- High bun-up fuel with ODS steel cladding

Enhanced Reactor Safety
- Passive safety by self actuated shutdown system and natural circulation decay heat removal
- Recriticality-free core
- Seismic isolation

Core materials

Target of ODS steel cladding development

Target Performance

■ High Burnup

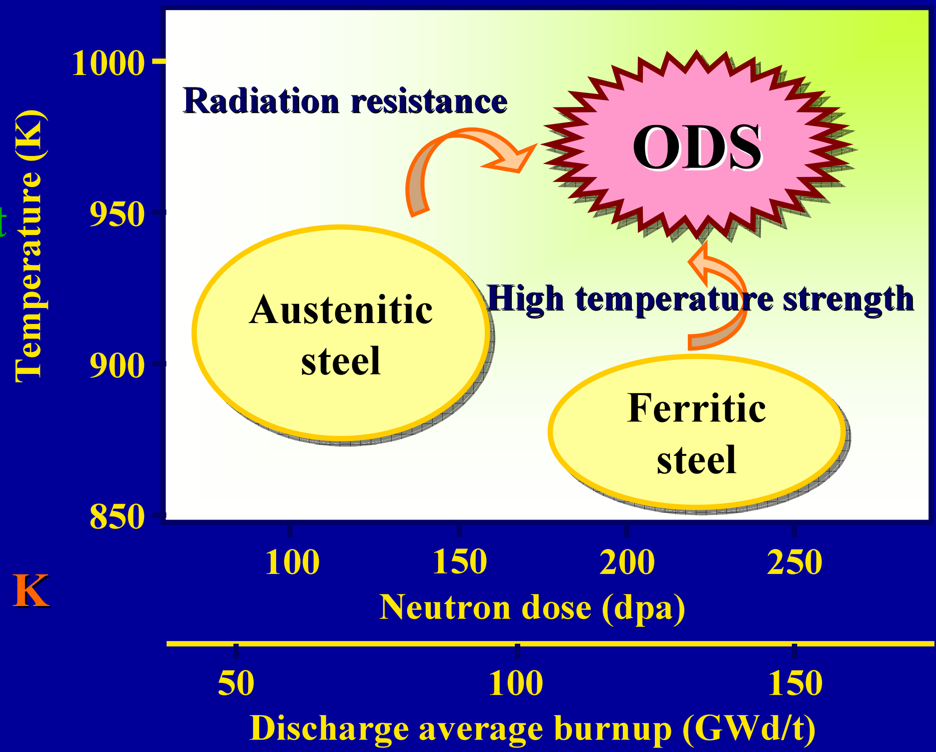
⇒Discharge average burnup : 150 GWd/t

- Peak burnup : ~250 GWd/t
- Peak neutron dose : ~250 dpa

■ High Temperature

⇒Coolant outlet temperature : 823 K

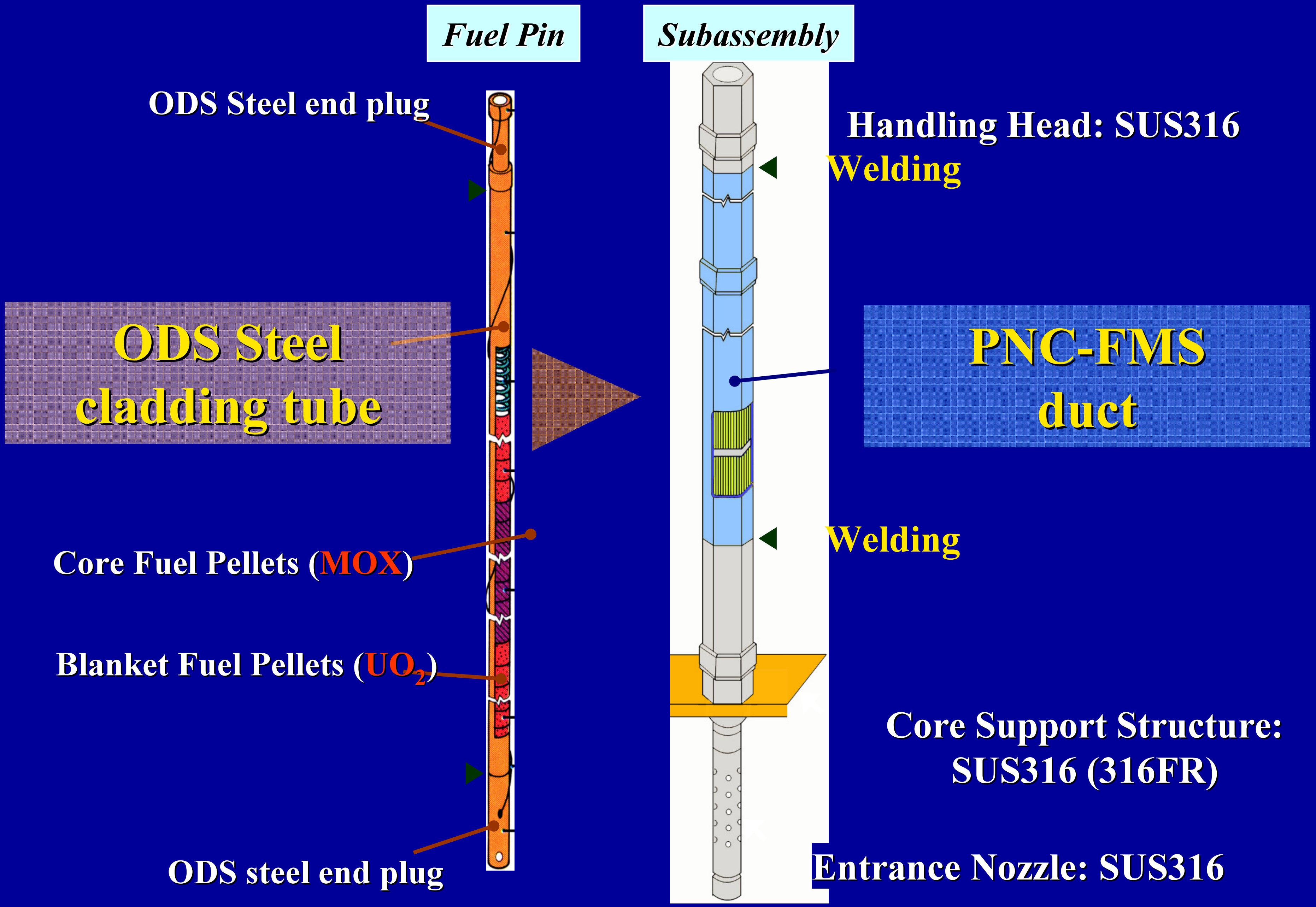
- Cladding mid-wall temperature : ~973 K



ODS Steel Cladding

- Ultimate tensile strength (UTS) : >300 MPa (973 K)
- Uniform elongation (UE) : >1%
- Internal creep rupture strength : 120 MPa (973 K × 10^4 hr)

Basic structure of fuel pin and subassembly



Alloy design and phases for candidate ODS Steels

mass%	C	Cr	W	Ti	Y_2O_3	Excess O
	M	M	S	D	D	D
9Cr-ODS	0.13	9.0	2.0	0.20	0.35	0.07
12Cr-ODS	0.03	12.0	2.0	0.26	0.23	0.07

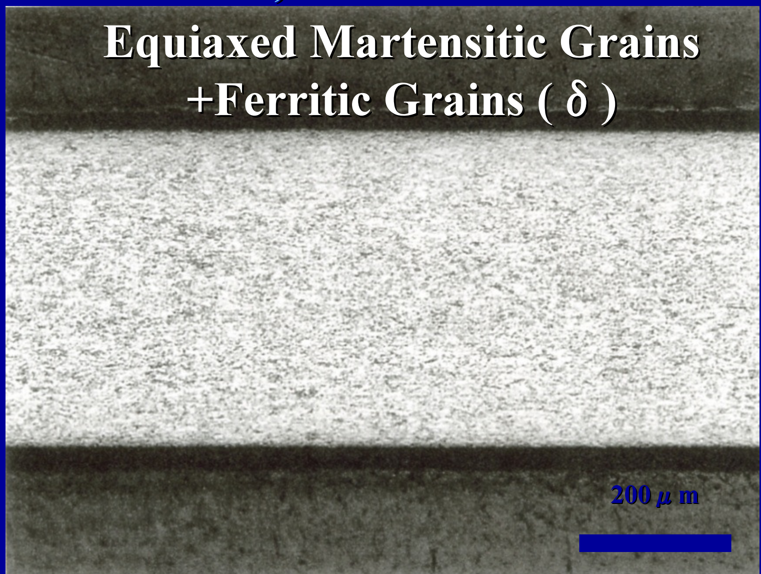
M: Phase Control
S: Solution Hardening
D: Dispersion Hardening

Oxygen in Y_2O_3 ≒ Excess Oxygen

Primary Candidate

9Cr-Martensitic

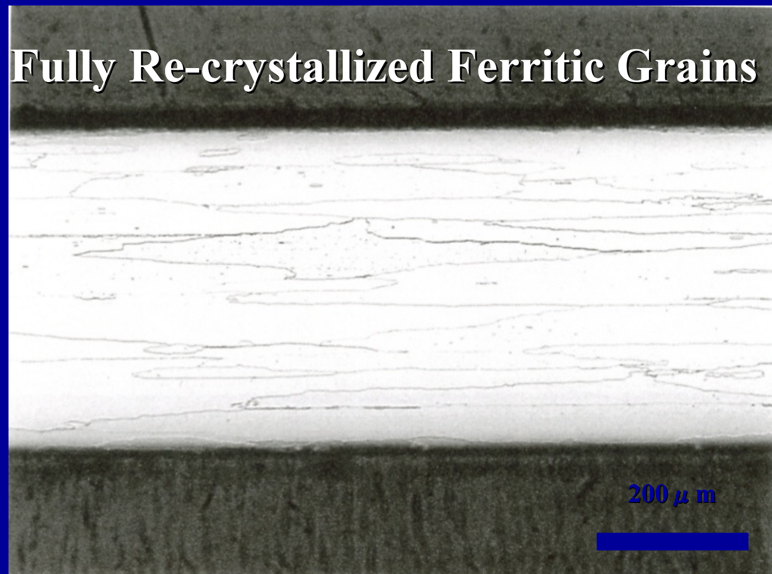
=> Fabrication, Irradiation Resistance



Secondary Candidate

12Cr-Fully Ferritic

=> Corrosion Resistance



Manufacturing process of ODS pins

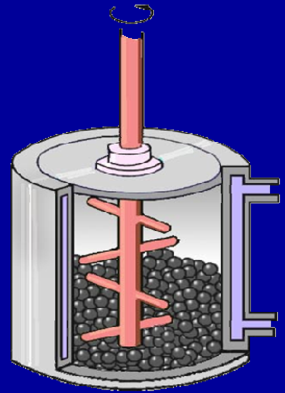
Powder Metallurgy Process

Raw Powders

Gas-Atomized Prealloyed Powder

Y_2O_3 Powder

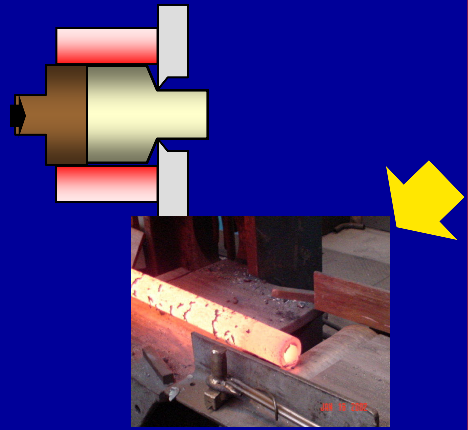
Mechanical Alloying (MA)



Canning

Degassing@400℃

Hot Extrusion@ 1,150℃

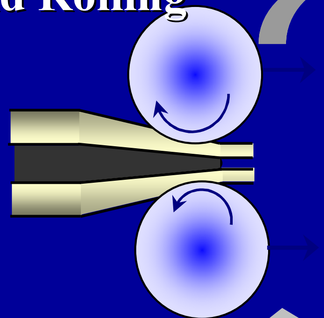


Thin Wall Precise Tubing Process

Mother Tubes

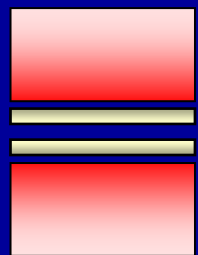
PD18mm×ID12mm×L180mm

Cold Rolling



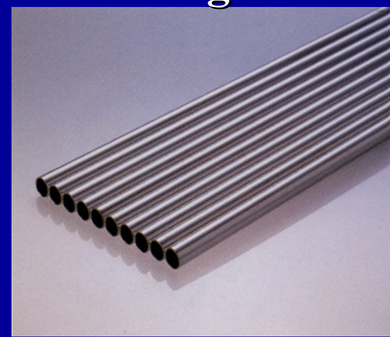
Pilger

Intermediate/ Final Heat Treatment



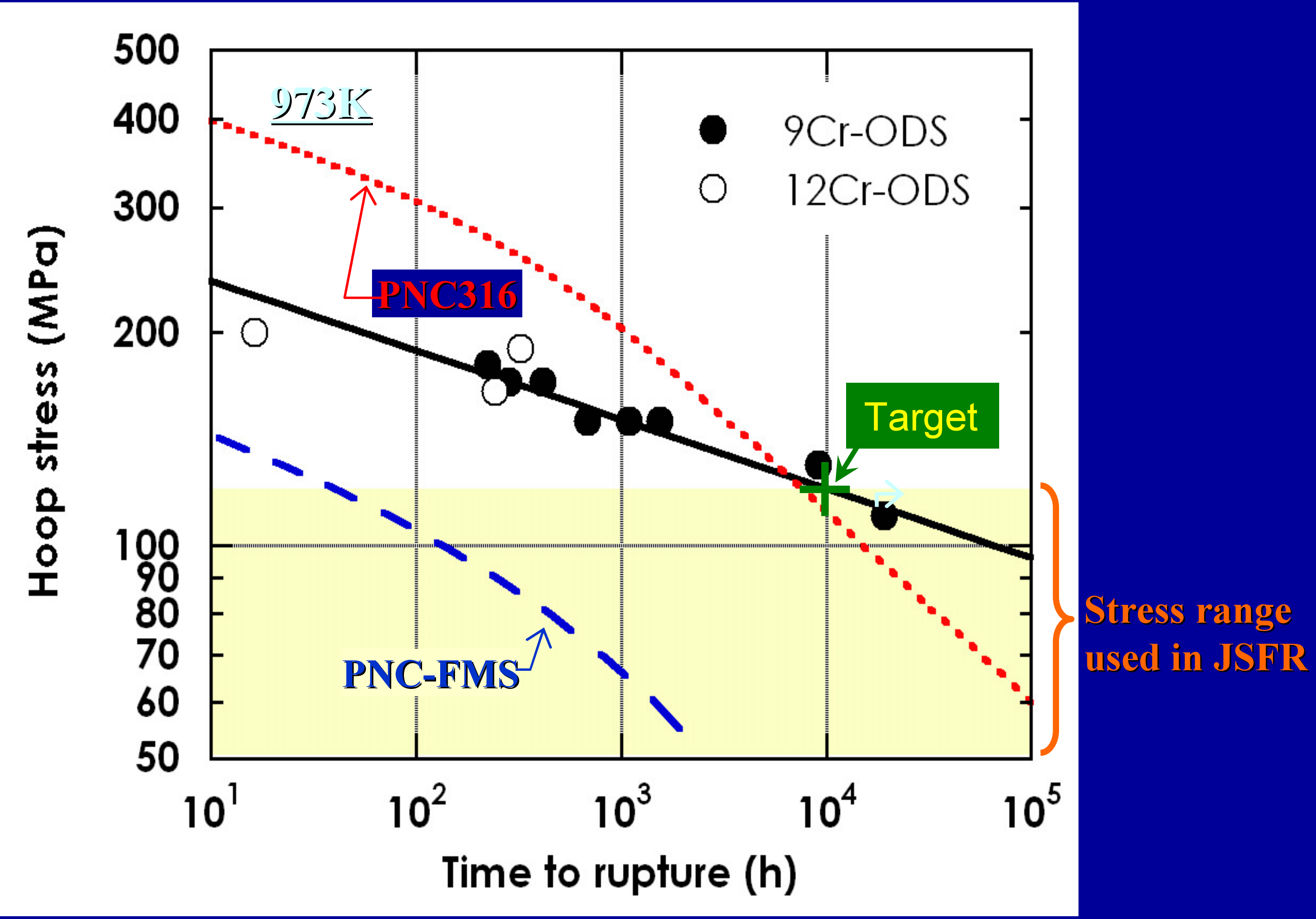
4 Times

Cladding Tubes



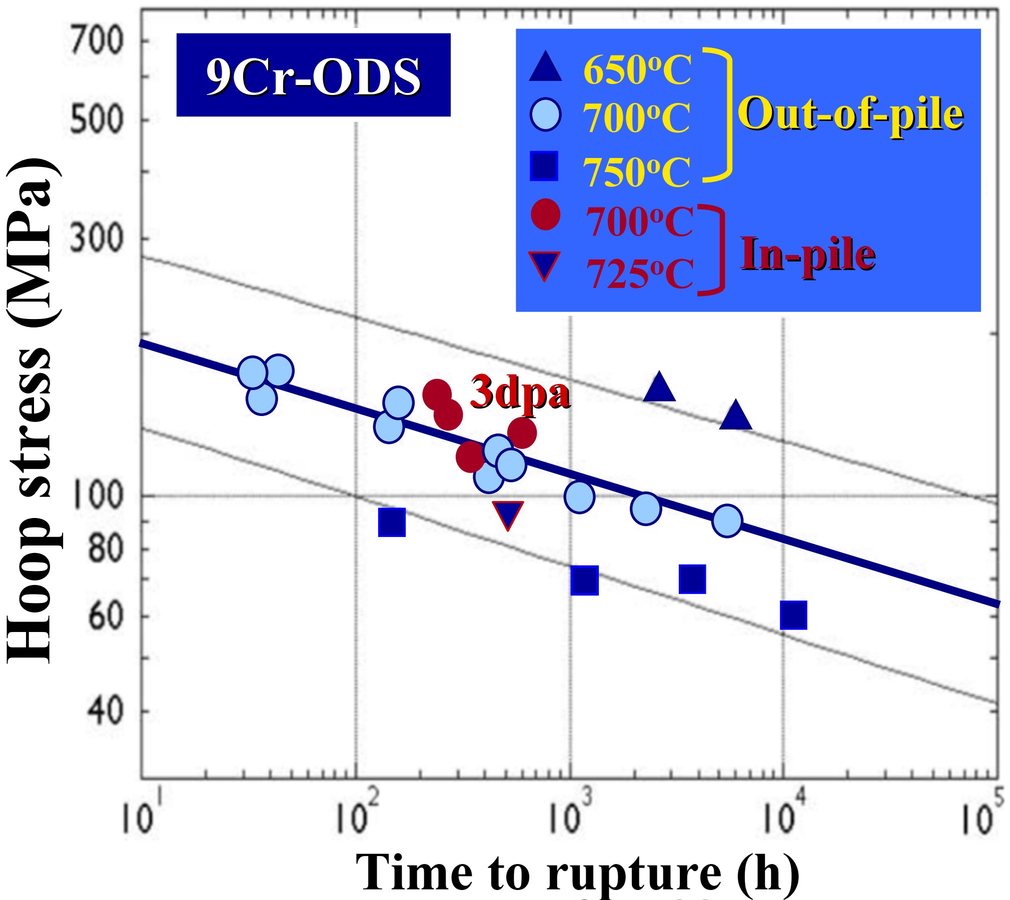
OD8.5mm×ID7.5mm ×L1,850mm

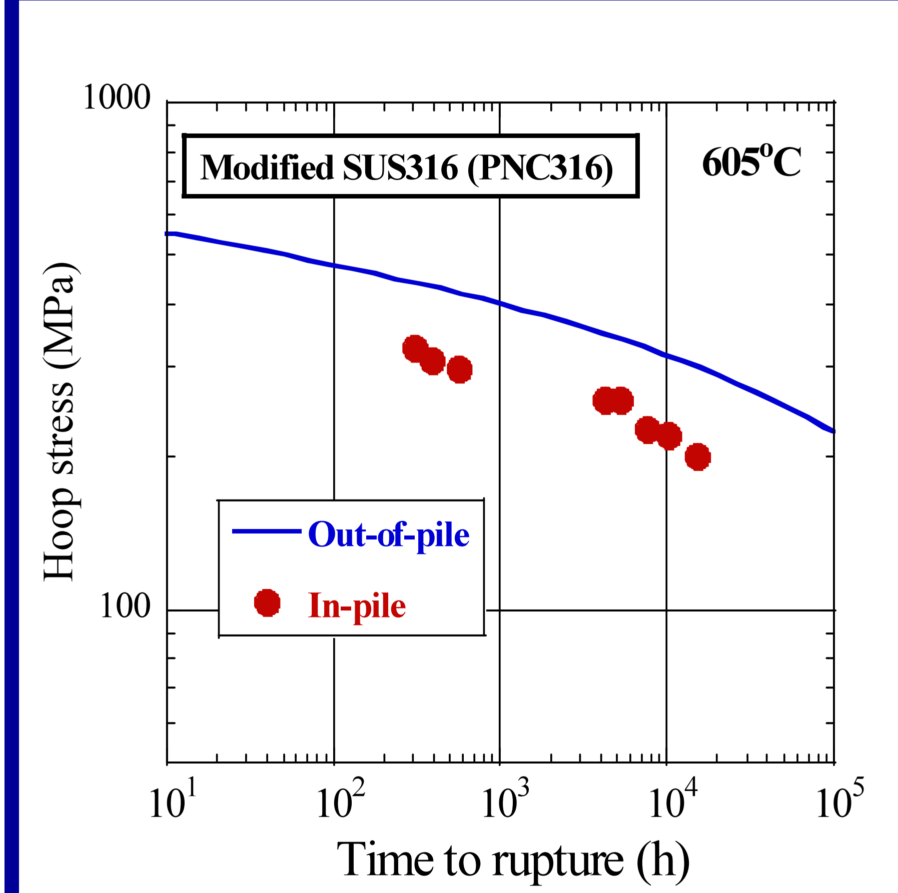
Out-of pile creep rupture strength of ODS steels



✓High-strength ODS steel cladding tube achieves the target out-of-pile creep strength, i.e. 120 MPa for 10,000 h at 973 K.

In-pile creep rupture strength of 9Cr-ODS steel





✓No irradiation-induced degradation of creep rupture strength of 9Cr-ODS steel in contrast to the modified SUS316.

Structural materials

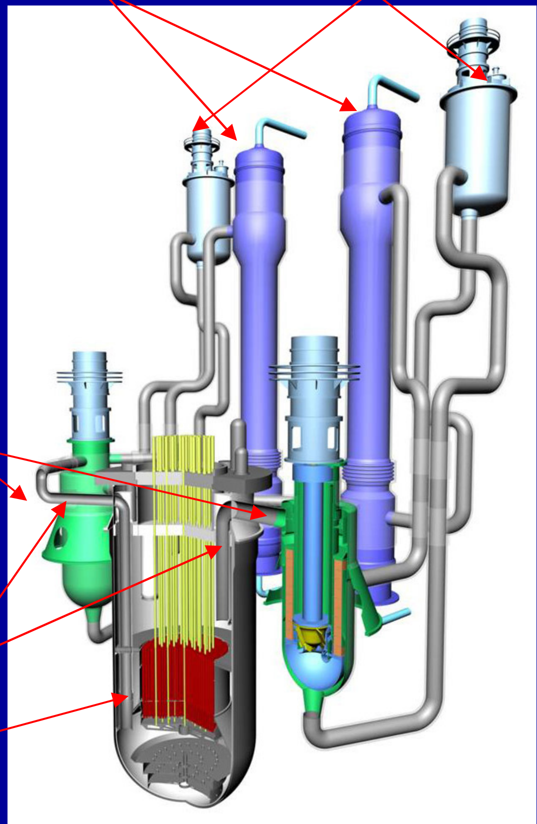
Target of structural materials development

Reactor Vessel and Internals = 316FR

Coolant Systems = Mod.9Cr-1Mo

Steam generators

Secondary Pump Mod.9Cr-1Mo



IHX = Mod.9Cr-1Mo

Primary and secondary piping systems = Mod.9Cr-1Mo

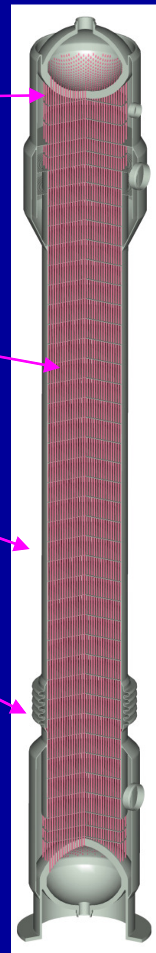
Reactor Vessel and internals = 316FR

Tubesheet = Mod.9Cr-1Mo

Tube = Mod.9Cr-1Mo

Vessel = Mod.9Cr-1Mo

CSEJ (Bellows) = Mod.9Cr-1Mo



Steam generator (SG)

- Coolant outlet temperature = 550 C
- Design life = 60 years

Current status and path forward

- **R&Ds are progressing step by step towards licensing process:**
  - Material development
  - Data acquisition and evaluation methods
  - Development of fabrication technologies for products for the JSFR
  - Codification for elevated temperature design
- **R&Ds are based on the efforts being continued since before the FaCT project.**

Material Development

- **316FR**
  - Developed in Japan within the specification of SUS316 (Type 316 SS) of Japanese Industrial Standards (JIS) with stronger requirements for carbon, nitrogen and phosphorus.
  - Material development completed.

C	Si	Mn	P	S	Ni	Cr	Mo	Al	N
≦0.020	≦1.00	≦2.00	0.020—0.045	≦0.030	10.00—14.00	16.00—18.00	2.00—3.00	≦0.05	0.06—0.12

- **Mod.9Cr-1Mo steel**
  - Basically, ASTM/ASME code material (Grade 91)
  - Material development completed

C	Si	Mn	P	S	Ni	Cr	Mo	V	Nb	Al	N
0.08—0.12	0.20—0.50	0.30—0.60	≦0.020	≦0.010	≦0.40	8.00—9.50	0.85—1.05	0.18—0.25	0.06—0.10	≦0.04	0.030—0.070

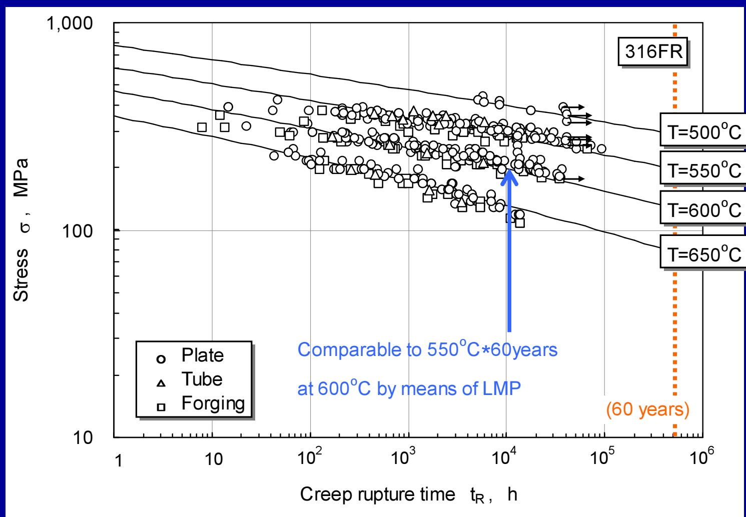
Data acquisition and development of evaluation methods

- **Key factor: 60-year design at 550 C**
  - Acquisition of material data
    - Long-term creep, long-term creep-fatigue, environmental effects (aging, sodium, irradiation)
    - Base metals, welded joints
  - Modeling based on better understanding of degradation mechanisms
    - Creep-fatigue evaluation methods for welded joints
    - Possible "Type IV damages (Mod.9Cr-1Mo steel)" at long-term regions taken into account
  - Extrapolation based on models needs to be implemented in code development

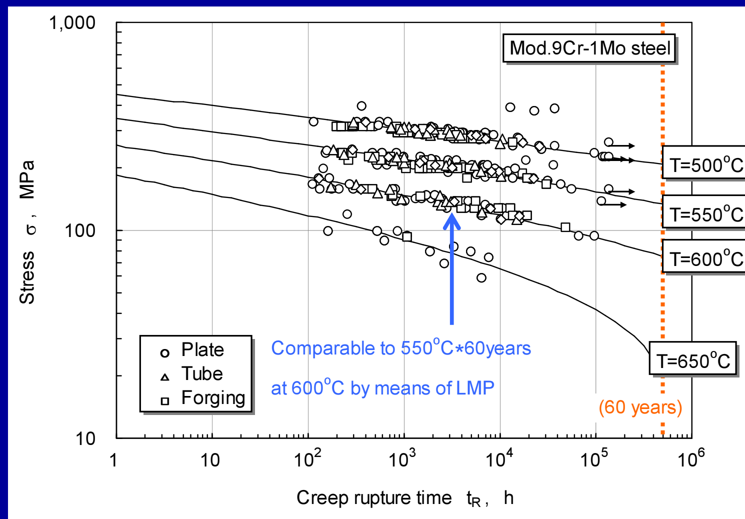
Acquisition of long-term creep data

- Creep tests including long-terms ones have been performed and being continued, and data are stored in **Database "SMAT"** which has been developed by JAEA.
- Collaborative study with National Institute of Material Science (NIMS)

316FR

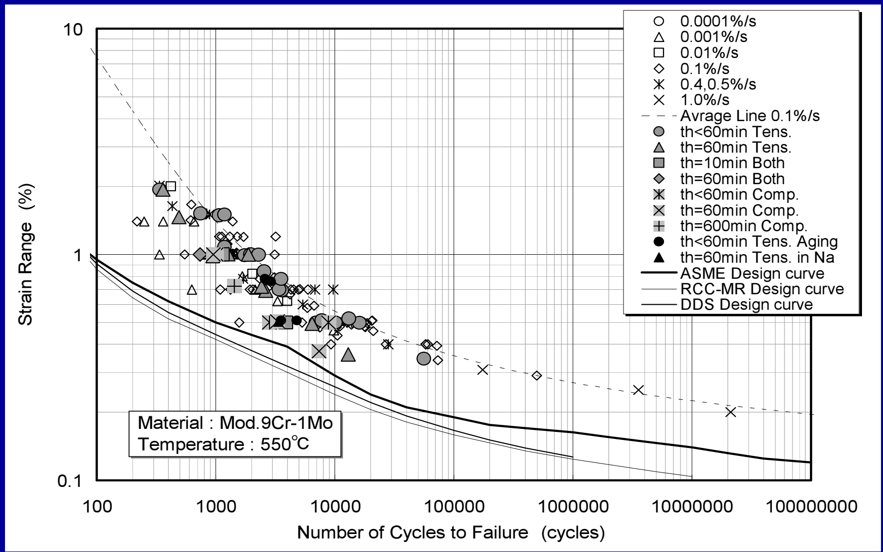


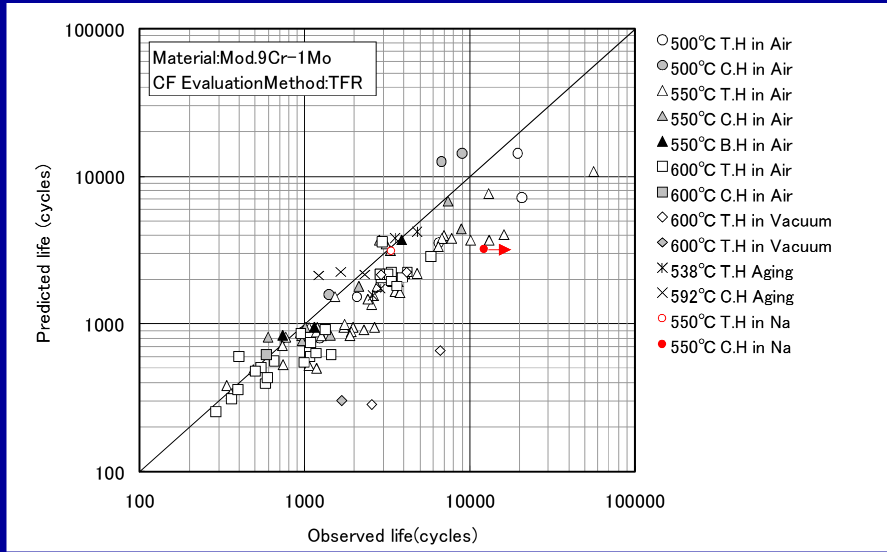
Mod.9Cr-1Mo



Acquisition of long-term creep-fatigue data and evaluation

Mod.9Cr-1Mo

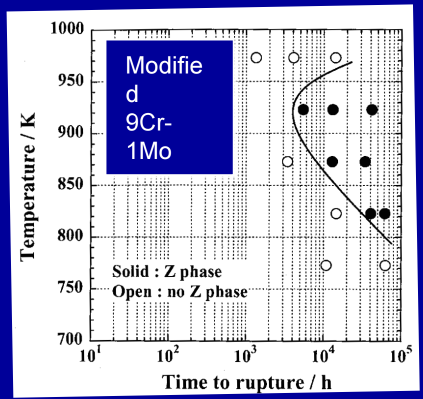




- **Creep-fatigue test data have been generated in air, sodium and vacuum.**
- **Time fraction linear damage rule gives reasonable life prediction.**
- **Long-term tests are being continued.**

Strategies for extrapolation and verification

- Example: Extrapolation of creep strength
  - Metallurgical investigation to support temperature acceleration



Metallurgical Investigation

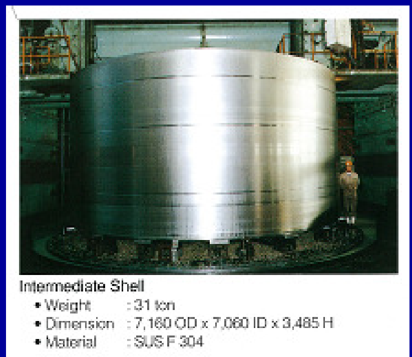
Ex.
TTP diagram of “Z-phase” for modified 9Cr-1Mo steel

(K.Sawada et al., ISIJ International, Vol.47(2007) 733-739)

  - Investigation of newly developed extrapolation methodologies such as “region split method”
  - Monitoring of integrity of materials to verify design margins
    - Technologies to ensure integrity of materials during operation such as monitoring, surveillance and non-destructive examination technologies should also be explored in light of 60-year design.

Fabrication technologies for products specific to JSFR

- Fabrication technologies for products such as large-scale forgings and heat exchanger tubes are being developed by collaboration with Japanese steel manufacturers



316FR: Large scale forged ring for reactor vessel (photo: Monju)

Modified 9Cr-1Mo: Large scale test forging for tubesheets of steam generators

Modified 9Cr-1Mo: Heat exchanger tubes

Code development for JSFR

- **Technologies for Elevated Temperature Design Codes are being developed within the framework of FaCT project.**
- **They are reviewed by "All Japan" specialists.**
- **Based on the above, codes for JSFR will be published as a 2016 version of the Japan Society of Mechanical Engineers (JSME) codes for fast breeder reactors.**
- **The codes will involve material strength standards, design code, and fitness-for-service code including in-service inspection requirements.**

JSME Subgroup on Elevated Temperature Design

- JSME Sub Committee on Nuclear Power - Subgroup on Elevated Temperature Design is intensively working on the code development for JSFR
  - WG on Material Standards
  - WG on Design Standards
  - TF on System Based Code
  - TF on Fitness-for-Service Code
  - TF on Seismic evaluation
- Code development closely tied with technology development in FaCT project. Codes also cover Monju.

JSME Material code for JSFR

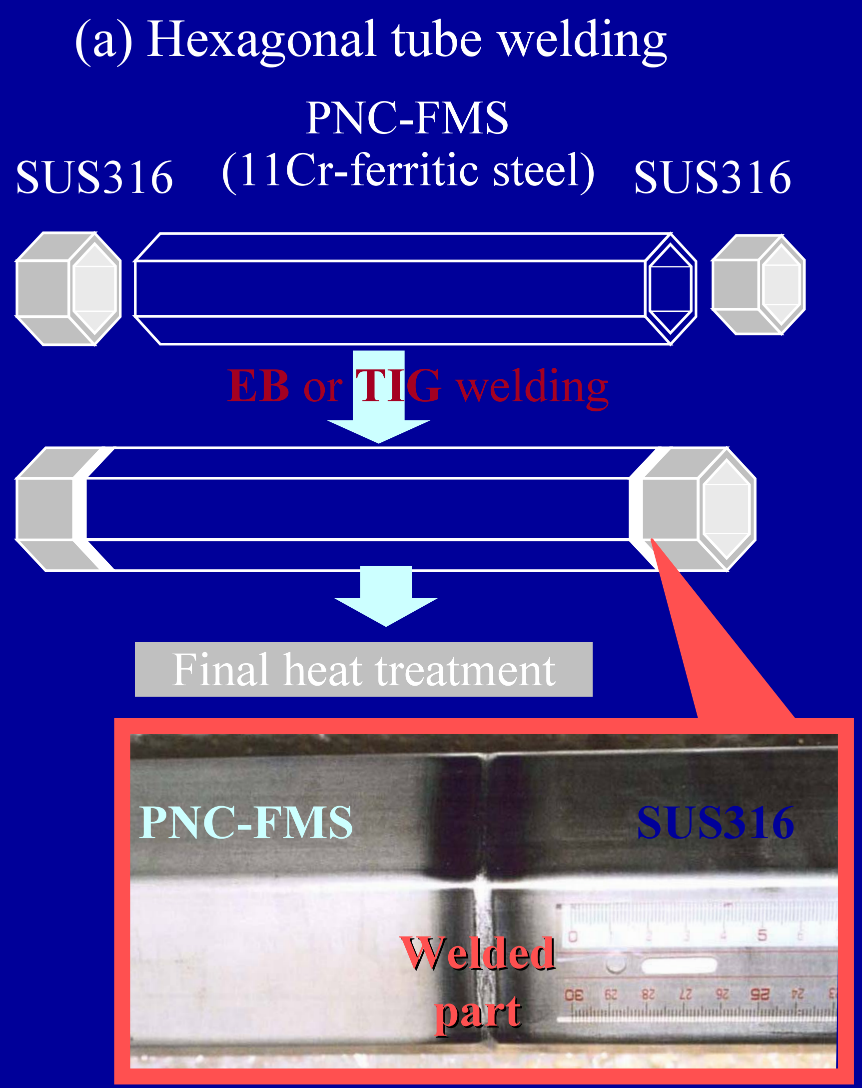
- Allowables for 316FR and Mod.9Cr-1Mo steels covering 60-year design will be determined based on statistical analysis of generated data and associated investigations
- Allowables for products specific to JSFR will also be included
- Equations that describe material properties such as creep strain evolution will be given
- Provide detailed technical backgrounds will be provided for further optimization

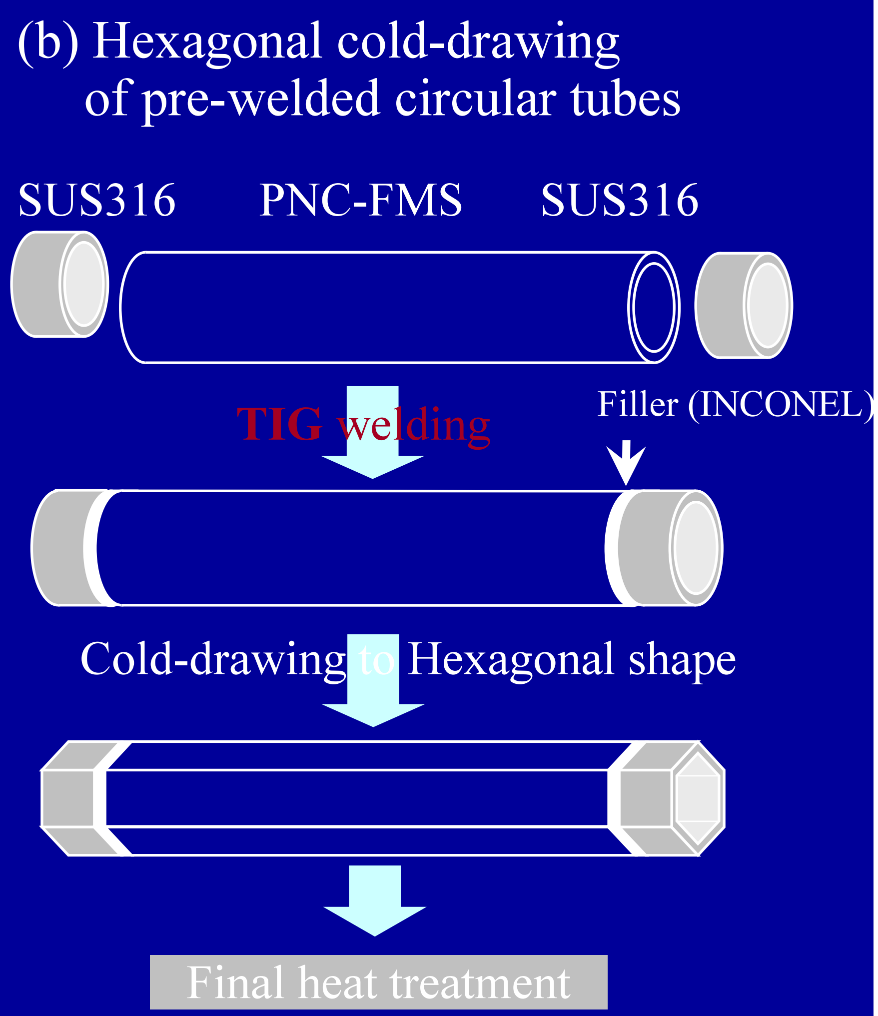
Summary

- Material development is intensively performed to achieve the innovative concepts of JSFR
- Basic material development has been completed
- Data acquisition particularly that in conditions close to practical applications is being continued and development of evaluation models are accordingly performed.
- Fabrication technologies are being developed by collaboration with steel manufactures
- Codes and standards will be developed by 2016 when licensing process for JSFR is envisioned.
- International collaboration will accelerate understanding and development of materials.

Appendix

PNC-FMS duct with SUS 316 short joint





✓**Adequate strength at FMS/316 dissimilar-welded part has already been proved by high-temp. tensile tests in both cases.**