РОСАТОМ

Russian Federation
Bochvar Institute
of Inorganic Materials

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Requirements&Problems for Structural Materials for Fusion and Fast Power Reactors (the RF R&D)

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THE RF NUCLEAR POWER REACTORS: GOALS&REQUIREMENTS

- **Nuclear power reactors:**
  - **F**ast**B**reeder**R**eactors:
    - Na-Coolant: (BN-350↓), BN-600 (2020 ↓), BN-800 (2012↑), BN-K (commercial type BN-1200, 2020↑).
    - Pb-Coolant: BREST (under elaboration),
    - He-Coolant: HTGR (under elaboration).
  - Fusion: DEMO-RF (2035↑) and FPP (2050↑) .
  - Dreams: Cosmic Reactor for the Mars Expedition (2030).

- **Requirements for the Structural Materials (SMs):**

- FBRs (Na) – the fuel burning are (12)16-20-25 % ha, (80)100-200 dpa,
- Fusion (type TOKAMAK) - 10-15 MW year/sq.m, 100-200 dpa.
- Wide Temperature window ∆Tmax = (Tmax – T min) with high energy efficiency.

The RF Way to **BN-K** (commercial FBR) and **DEMO-FusionPowerPlant**

Conception, Design, Materials, Technology, Manufacturing

Materials &Technology:

Core SMs:

RAFMS: Fe-12Cr-2W-V-Ta-B-C,

FMS: Fe-12Cr-W-Ni-Mo-Nb-V-N-B-C

Austenitic SS:

Fe-16Cr-(15-19)Ni-2Mo-2Mn-Ti-V-Nb-B-P-Ce

LA Alloys:

V-(8-4)Ti-(5-4)Cr

Functional Materials:

- Superconductivity Materials for Magnetic Systems,
- Beryllium,
- Tritium Systems.

TBM DEMO in ITER.

V-4Ti-Cr (Li)

Reactor Tests: IVV-2M, BOR-60

2008-2015

Basic R&D.

Radiation Damage.

Modelling.

2008-2020

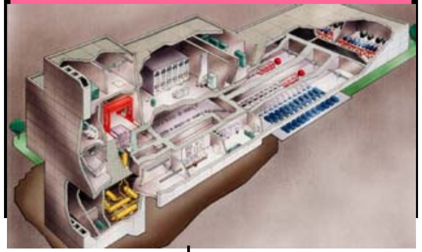
FBRs (Na): (BN-350↓) BN-600, BN-800 (2012 ↑)

High Dose Reactor Tests.

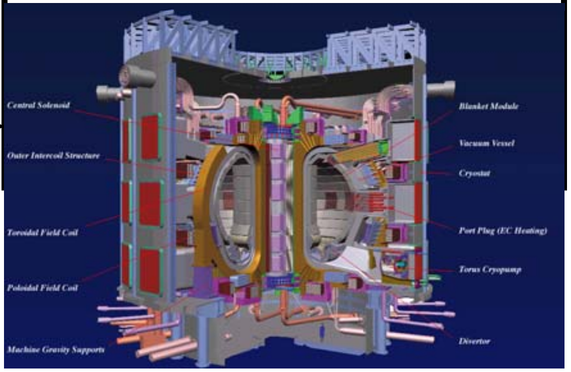
Data Bases

2008-2020

IFMIF (2015-2016)



ITER (2018-2020)



CONCEPTION

DEMO-FPP, 2015

Materials. Technologies.

Industry

2020-2025

FBR

BN-K (Na)

2020

DEMO

2035

FPP

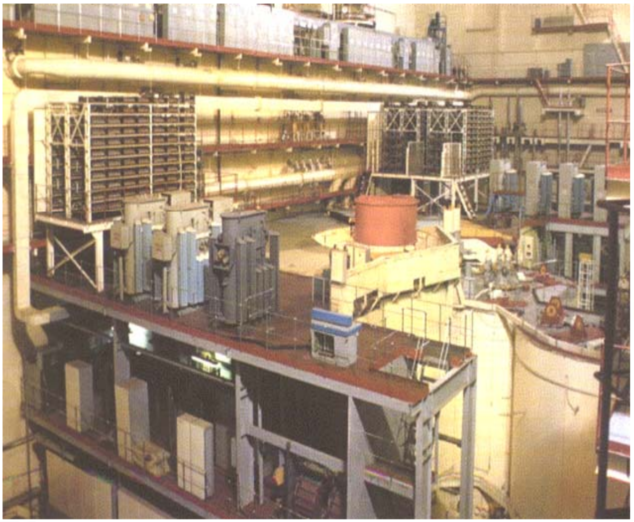
2050

The RF way to the FBR BN-K (type BN-1200)

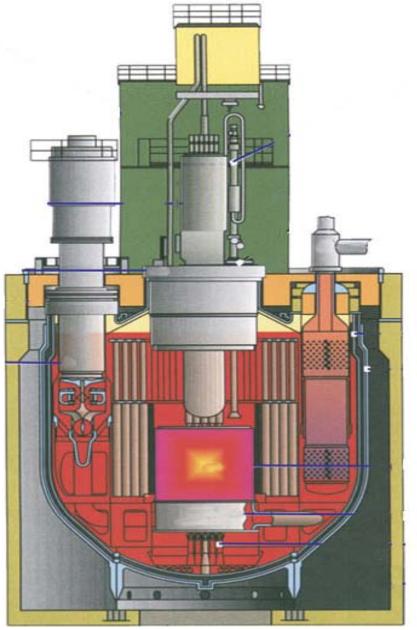
The RF Core SMs:

AS:	FMS (12%Cr):
OX18H10T	ЭП-450
ЭИ847 A	ЧС-139
ЭИ847 CW	ЭК-181 (RA)
ЧС68 CW	
ЭК164 CW	

1974↑, BN-350↓



1980, BN-600, 2020↓



2012↑, BN-800

2020↑, BN-K

- **Electric Power: 350 - 600 – 800 - (1200) MW**
- **Fuel Burning: 7-12-16-(25) % ha**
- **Core SMs: 70-90-110- (200) dpa**

The FBR BN-800 (Na): a key part of Russia's nuclear strategy of closed fuel cycle

The BN-800 project meets the stringent requirements – including non proliferation – for nuclear power in the 21st century.

- Attention is currently focused on the tasks of

  (1) **attaining economic competitivenes** of this type reactors,

  (2) **creating a closed fuel cycle industry (2035)**.

  BN-800 is currently under construction at Beloyarsk plant in the Urals (2012↑) and it will play an important role in the solution of both tasks.

- The future of the FBRs in Russia is conceived as **design of a commercial reactor BN-K (type BN-1200, 2020↑) meeting requirements for advanced nuclear power technology.**

Durable and high-performance the Structural Materials (mainly for cores) are the backbone for all innovative nuclear power reactors (fusion and fission)

There are many commonalities in the SMs R&D issues for fusion (DEMO-FPP) and fast (BN-K) power reactors.

There are many similarities in the chemical compatibility issues for proposed coolants, which include alkali metals (Na, Li), and Pb-based alloys (Pb, Pb-Li, Pb-Bi) and inert gas (He) systems.

Substantial improvement in the performance of the SMs can be rapidly achieved with a science-based materials development approach.

There are clear advantages for both BN-K and DEMO-FPP to coordinate fundamental R&D programs on the SMs in order to expeditiously bridge the gap from current operating conditions to future higher dose and higher temperature operating conditions and to speed the development of fusion and fast fission nuclear technology.

The SMs PROPERTIES (1):

PHYSICAL-MECHANICAL and THERMO-PHYSICAL

(yield strength, fracture toughness, creep rates, void swelling rates, creep rupture times and strains, fatigue stress and strain limits, thermoconductivity).

RADIATION SWELLING - VOID SWELLING RATES

The increasing of the volume of irradiated SMs: $(\Delta V/V)$max = 5-6 %.

The unsolved problem for the FCC SMs (austenitic steels and alloys) and no optimism for the advanced FCC SMs (> 100 dpa).

LOW TEMPERATURE EMBITTLEMENT of the BCC SMs (ferritic-martensitic steels, vanadium alloys, etc.).

A shift of the ductile-to-brittle transition temperature T_{dbtt} under the low temperature neutron irradiation ($T_{\mathbf{irr}}$ < 350-400 ^{0}C). The reason for the restriction of the minimum temperature under operation $\mathbf{T_{min}}$ (T ≈ 300 ^{0}C is BN-600 refueling temperature).

CREEP AND HEAT RESISTANCE DURING OPERATION.

The reason for the restriction of the maximum temperature $\mathbf{T_{max}}$ and the mechanical stresses under operation (for FM steels $\mathbf{T_{max}} \leq 700\ ^{0}$C).

CORROSION, OXIDATION AND COMPATIBILITY WITH COOLANTS

The SMs PROPERTIES: (2)

NUCLEAR - PHYSICAL: NEUTRONICS, NEUTRON ACTIVATION AND TRANSMUTATIONS, COOLING

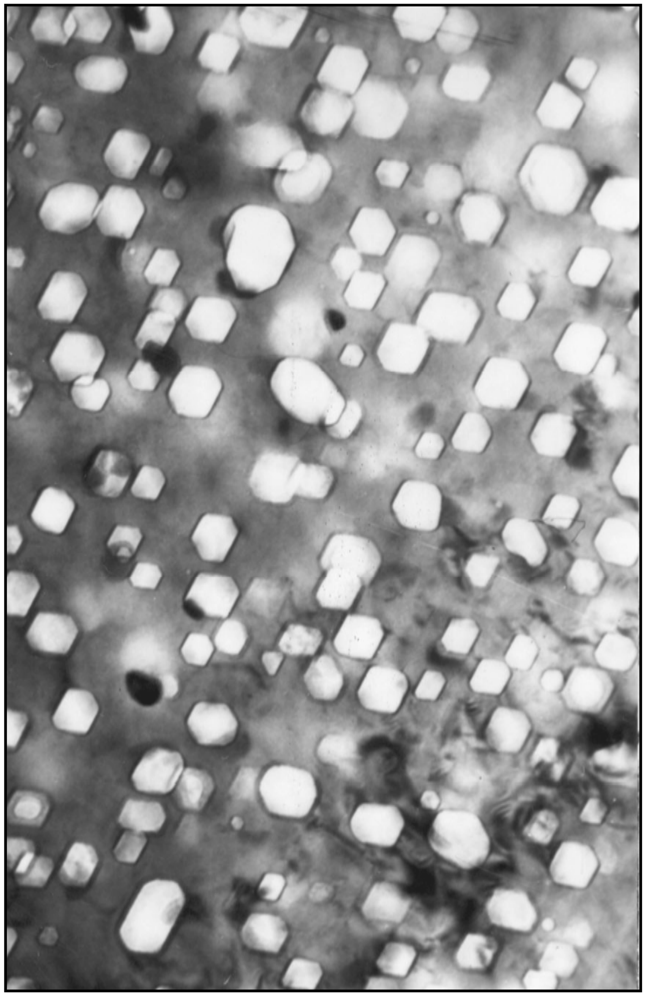
Burn-in and burn-out of essentially all elements. Nuclear alloyage and the degradation of the functional properties (fa, via H and He formations).

Fast decay of radioactive inventory. THE LOW ACTIVATION REQUIREMENTS: the cooling to the level of 10^{-2} Sv/h ("remote level") with the possibility of recycling of irradiated SMs for the time 100 years at the most after neutron irradiation.

NUMEROUS EXTRINSIC FACTORS (and ACCIDENTS) related to the size, geometry, stress-state, temperature, loading rate that are imposed on the specimens or structures, potentiality leading to a variety of degradation mechanisms and to failure.

Industrial manufacturing & joining SMs (good rolling, welding and tubing) with technologies based on their highly competitiveness in engineering properties for power reactors.

SWELLING OF NEUTRON IRRADIATED AUSTENITIC AND FERRITIC-MARTENSITIC STEELS



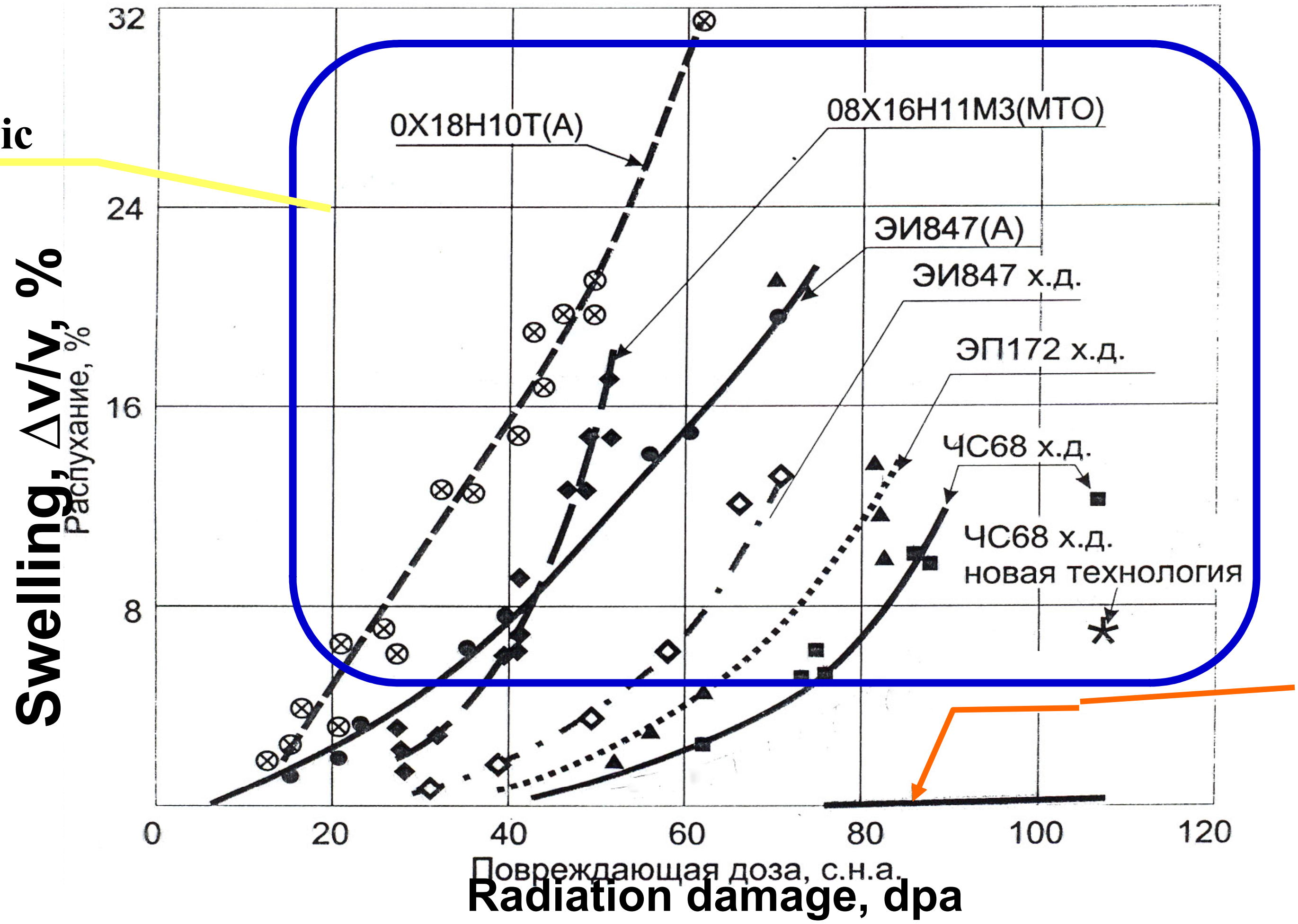
Austenitic SS: ChS-68 CW (ЧС 68 ХД), Very high swelling (many big voids)

12%Cr FMS: EP-450 (ЭП 450), Very low swelling (seldom and small voids)

RADIATION SWELLING AS BASIC CRITERIUM FOR THE CHOICE OF SMs FOR CORES: $(\Delta V/V)_{max} < 6\ \%$

Austenitic and Ferritic-Martensitic Steels: SWELLING DOSE DEPENDENCES

Austenitic Steels



FMS (<1%)

THE RF REACTOR CORE SMs

The priorities are the heat resistance and low (reduced) activation SMs. New SMs are required for further widening of temperature, mechanical and dose application windows.

AUSTENITIC STEELS:

- **ChS68** (ЧС68): Fe-16Cr-15Ni-2Mo-2Mn-Ti-V-B → 95 dpa (max)
- **EK-164** (ЭК164): Fe-16Cr-19Ni-2Mo-2Mn-Ti-V-Nb-B-P-Ce→110 dpa (max)

ADVANCED SMs: → 100-200 dpa:

1. **12% Cr FMS**:
   - **ChS-139 (ЧС-139)*:*** Fe - 12Cr-W-Ni-Mo-Nb-V-N-B-0,2C.
   - **RA RUSFER-EK-181**: Fe -12Cr-2W-V-Ta-B-C.
2. **LA Vanadium alloys:**
   - V-(5-4)Ti-(5-4)Cr ,
   - V-(8-4)Ti-(5-4)Cr (Me).

The RF referenced and advanced compositions of the SMs and neutron spectra are sufficiently typical for the international nuclear community for power nuclear fission (FB) and fusion (DEMO) reactors.

The RF 12% Cr FMS

FMS ChS-139 (ЧС-139) - Fe-12Cr-W-Ni-Mo-Nb-V-N-B-0,2C.
RAFMS RUSFER-EK-181 –
Fe-12Cr-2W-V-Ta-B-0,16C-(0,08-0,11)N.
Industrial Steel: Any ingots, Any products.
Today's recommendations (300)350-670(700) ^{0}C.
***+ Low activation, No swelling (<98 dpa), Ductile, Industry* fabrication.**
- Low heat resistance, No high dose tests (>100 dpa),
Ferromagnetism (fusion plasma configuration ?).
Applications: TBM DEMO in ITER, DEMO-FPP (He, Pb-Li).
FBRs: BN-600, BN-800, BN-K (Na),
BREST (Pb).

The R&D Goals:

- Precipitation hardening (nanostructuring) industrial steels.
- More Homogeneity, Thermal Stability of Solid Solutions and Strengthening Precipitations and Phases.
- Improving Radiation and Heat Resistant Properties **(100-200 dpa, $T_{max} \leq 700\ ^0C$).**
- Decreasing Effect of the LTRE (**$T_{min} \leq 300\ ^0C$**).
- Improving the Low Activation Properties under Long Time Neutron Irradiation (to reduce the concentration of impurities).
- Industrial manufacturing & joining (good rolling, welding and tubing)

Chemical composition of RUSFER-EK-181 (Fe-12Cr-W-V-Ta-B)

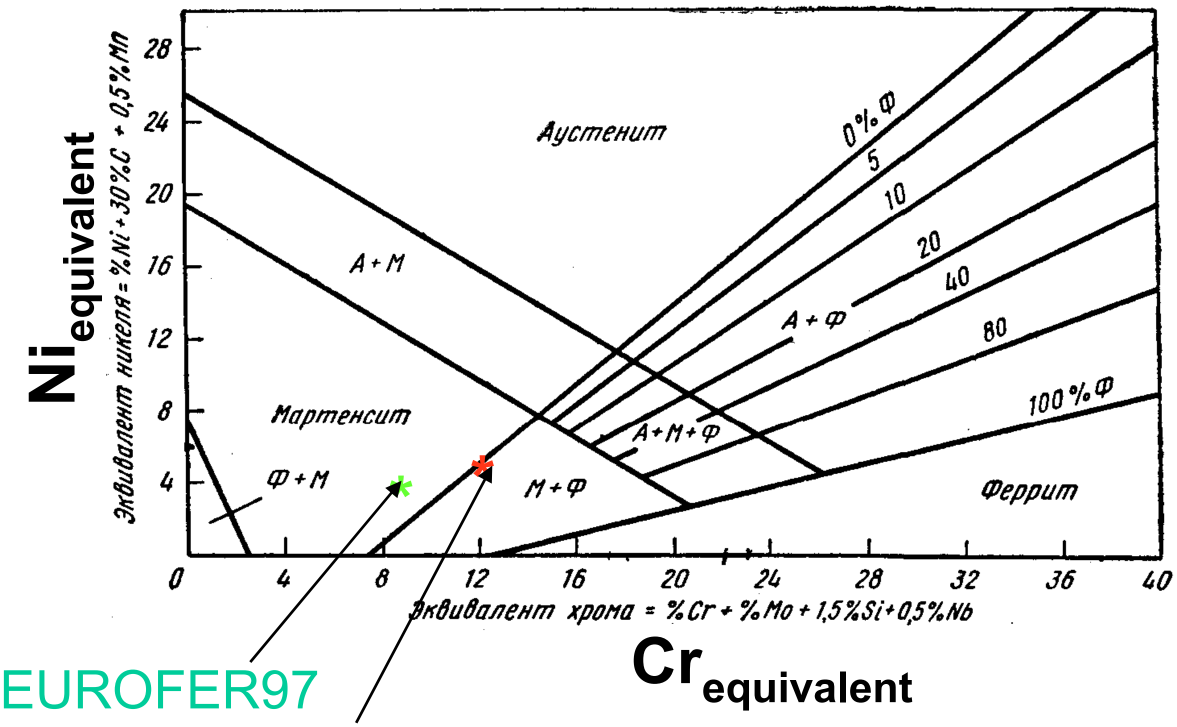
Element	Recommendation	Goal (Fe-opt)	Heat 191/ Heat 536
B	0.001-0.008	0.003	0.003 / 0.004
C	0.010-0.210	0.160	0.130 / 0.140
N	0.020-0.150	0.070	0.020 / 0.044
Cr	10.00-13.50	12.00	11.250/11.170
V	0.050-0.400	0.400	0.280 / 0.290
Ta	0.050-0.200	0.150	0.170 / 0.180
W	0.800-2.500	1.300	1.170 / 1.100
Mn	0.500-2.000	0.600	0.670 / 0.940
Fe	Balance	Balance	Balance
Co	0.010 (max)	0.002	0.002 / 0.003
Ni	0.100 (max)	0.030	0.035 / 0.030
Nb	0.010 (max)	0.005	0.005 / 0.010
Mo	0.010 (max)	0.010	0.023 / 0.040
Cu	0.100 (max)	0.010	0.010 / 0.010
Ce	0.001-0.100	0.050	0.010 / 0.010

Alloying by Cr-W-V-Ta-B under the certain C and N concentration relates RUSFER-EK-181 steel to ferrite-martensite class with percentage of δ-ferrite no more than 5%.

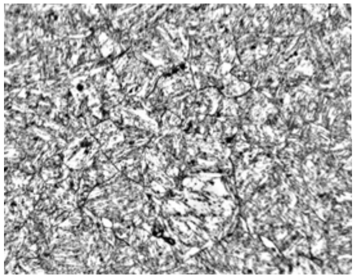
Selected composition and regimes of thermomechanical treatments put the steel in to the class of dispersion (precipitation) hardening materials with good technological and mechanical properties in the temperature range (300-700) ° C.

Impurity and alloying content (technological purity) provides fast induced activity decay of RUSFER-EK-181 steel.

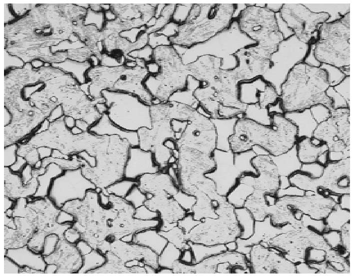
Structure States of Cromium Steels



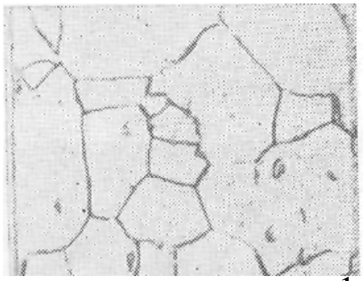
- ☐ Martensite Microstructure



- ☐ Ferritic-Martensitic Microstructure



- ☐ Ferritic Microstructure



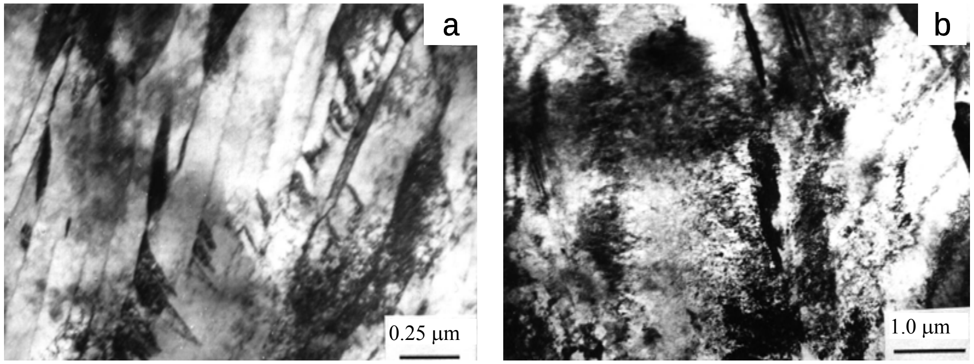
Sheffler Diagram:

$$Cr_{equivalent} = \%Cr + \%Mo + 1{,}5 \times \%Si + 0{,}5 \times \%Nb$$

$$Ni_{equivalent} = \%Ni + 30 \times \%C + 0{,}5 \times \%Mn$$

Structure of RUSFER-EK-181 in the initial state (before irradiation)

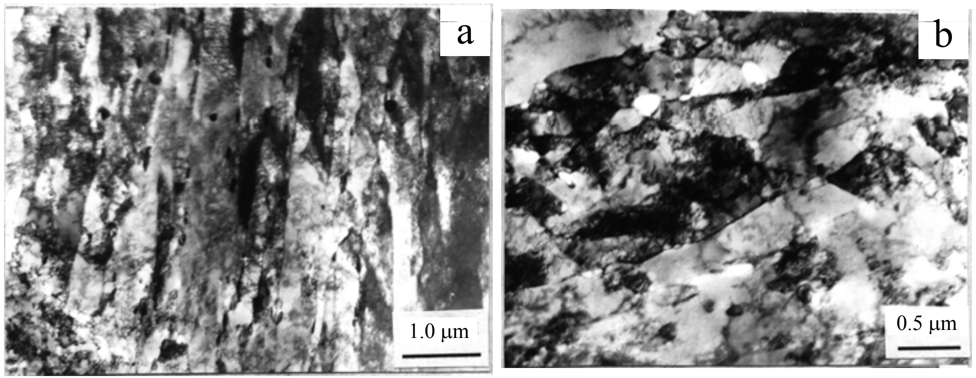
Structure of quenched steel from 1070-1100 °C



lath martensite

laminated martensite

Typical structure of quenched and tempered steel



transformed
lath martensite

transformed
laminated martensite

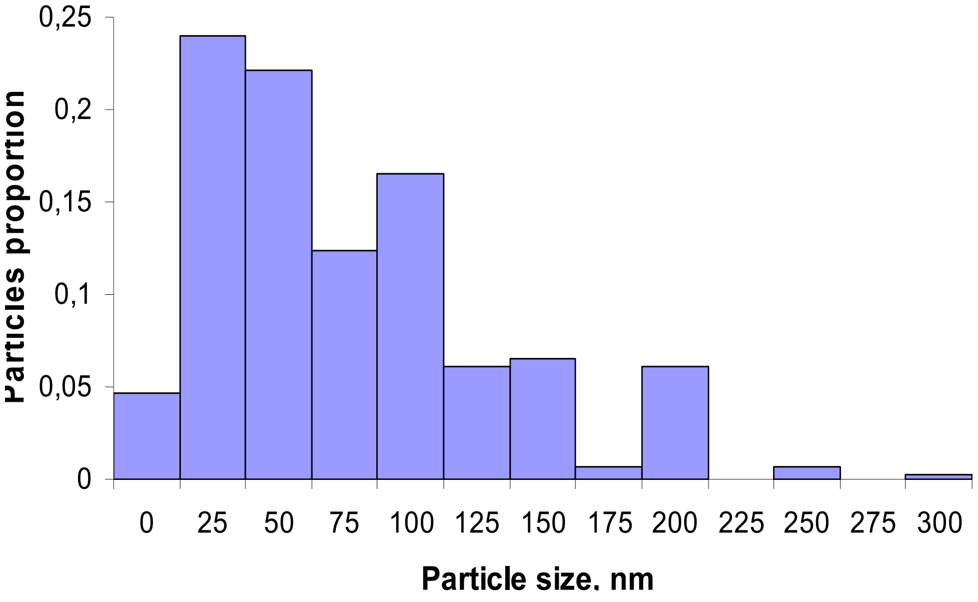
High level (700 ^{o}C) of heat resistance of RUSFER-EK-181 steel is maintained by:

- specific structure of matrix phase (ratio 1:3 of laminated martensite and lath martensite);

- heightened grain-size and sub grain-size stability as a result of precipitating of carbide and carbo-nitride phases (grain boundary engineering).

RUSFER-EK-181: Basic phase particles

Size distribution histograms of phases particles after air quenching and tempering



VC and $M_{23}C_6$ phases providing precipitation hardening of the steel after quenching and tempering

Carbide phases precipitate during tempering with different compositions and sizes:

$M_{23}C_6$, M_6C, M_3C, TaC, VC;

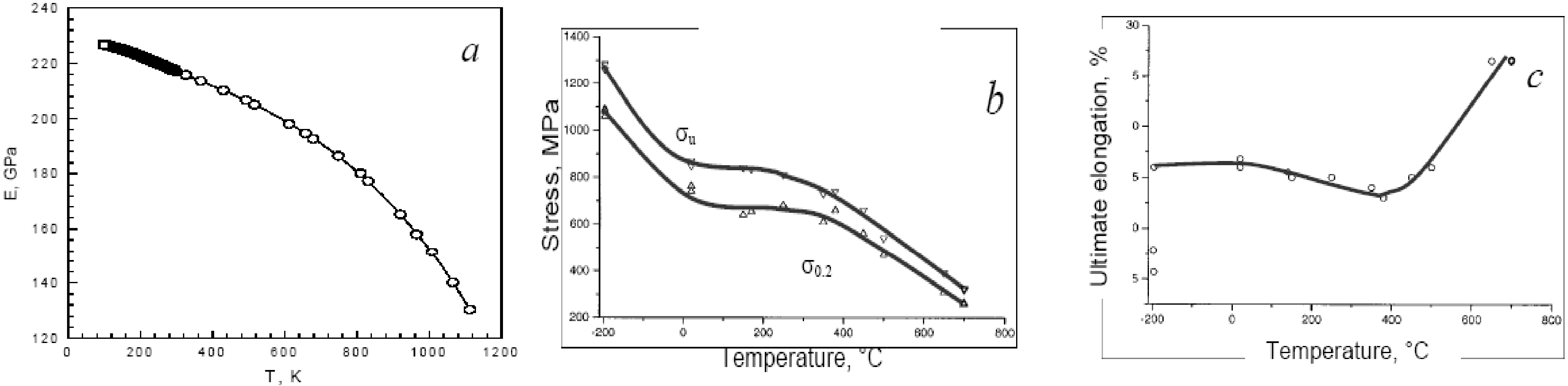
Mean particle size is

75.1±7.4 nm (TEM).

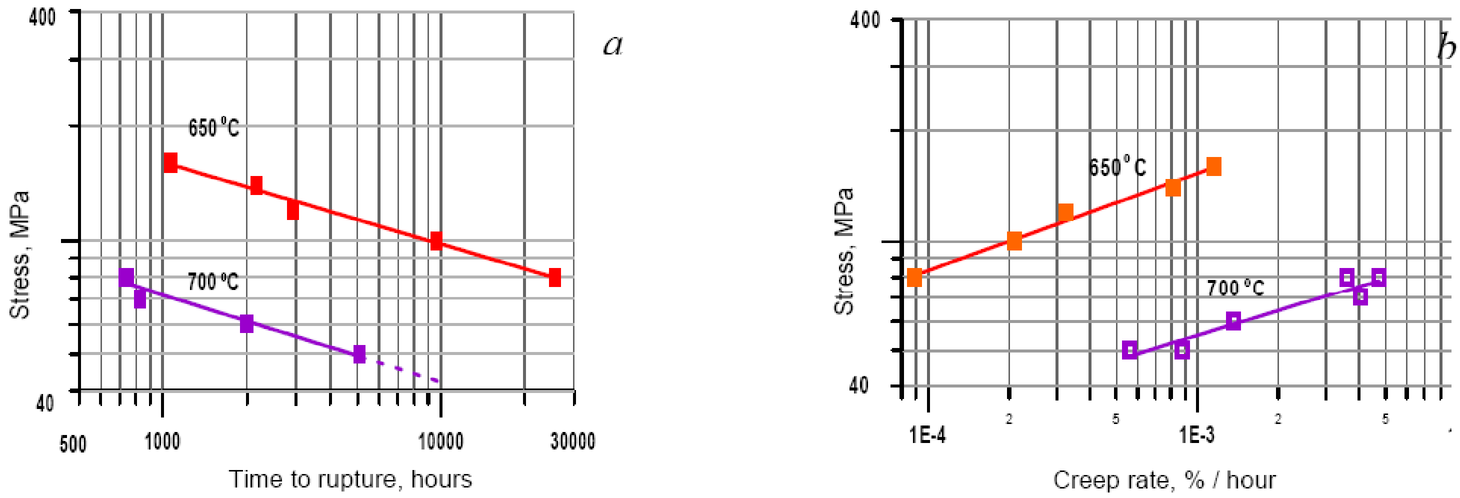
- Carbides provide precipitation hardening of the steel and fixation of low- and large-angle boundaries (grain boundary engineering).

- VC / TaC and $M_{23}C_6$ of 3–5 nm size constitute an appreciable part of the carbide phase.

RUSFER-EK-181 (Traditional Thermal Treatment): Initial Properties

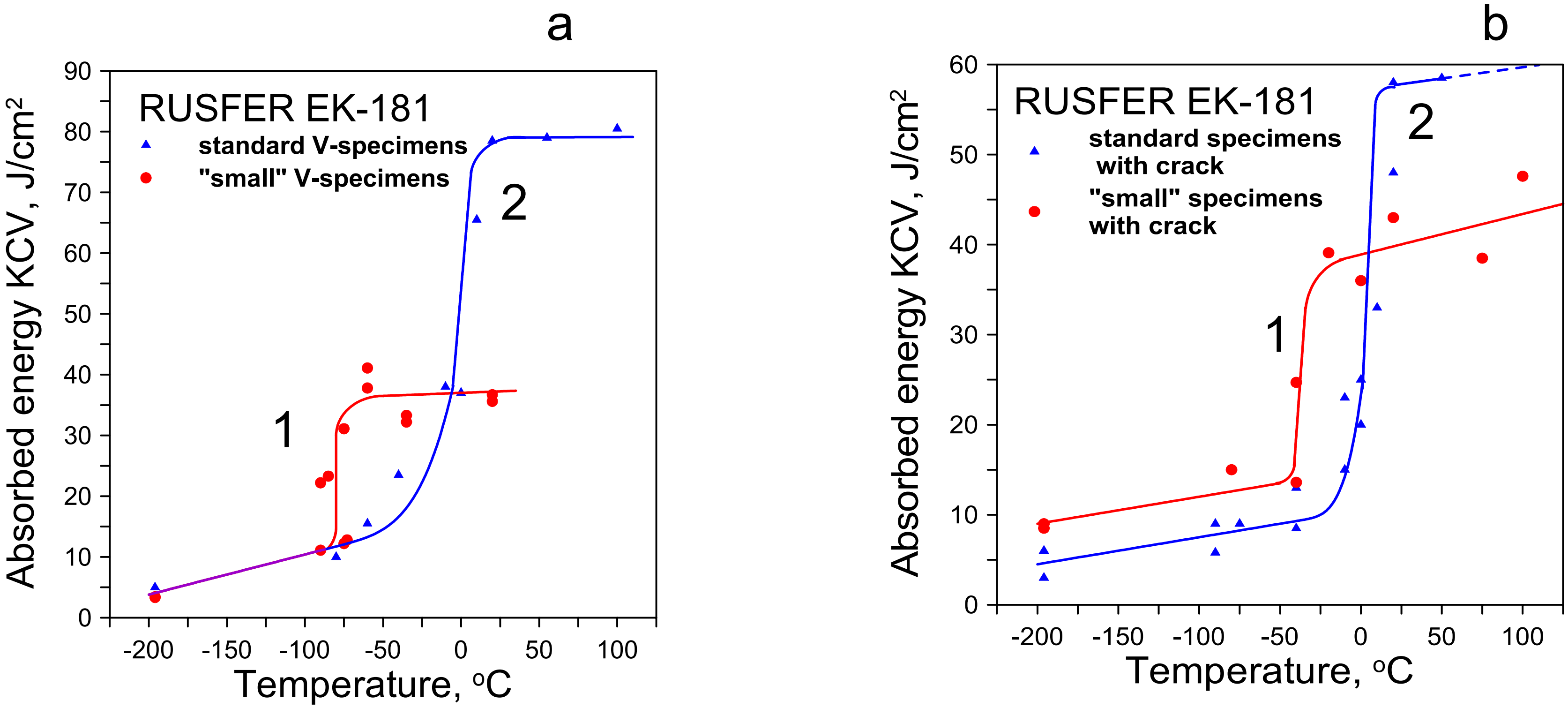


Mechanical properties of the specimens vs. temperature curves:
(a) elastic module (E, GPa), (b) yield point ($\sigma_{0.2}$, MPa) and ultimate stress (σ_u, MPa), (c) ultimate elongation (%).



(a) Stress and Time of the creep-rapture time (hours) and (b) creep rate (%/hour) as a function of stress (MPa) at 650 ^{0}C and 700 ^{0}C.

RAFMS RUSFER-EK-181 - Low Temperature Embrittlement (LTE)

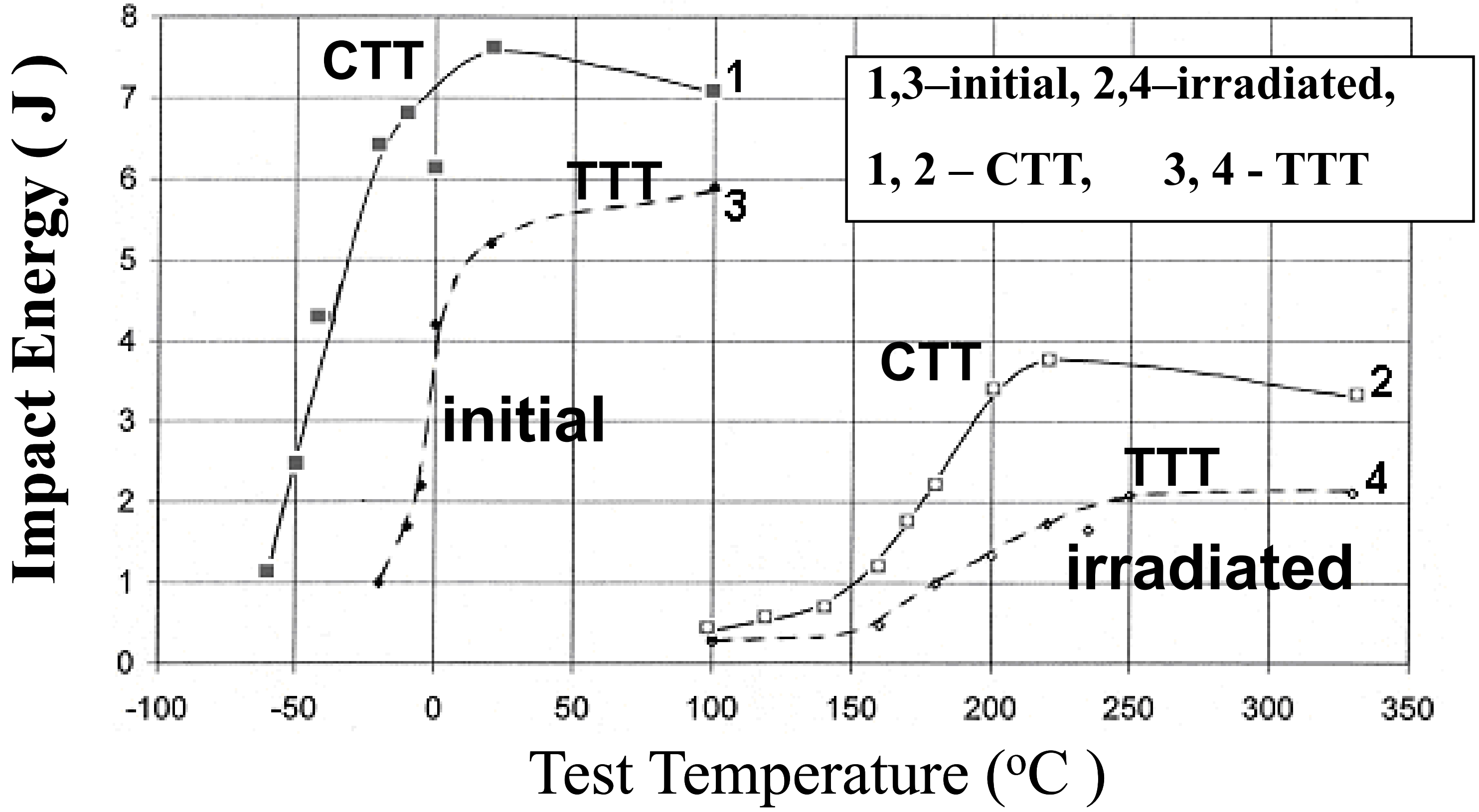


Charpy impact energy vs. test temperature curves for small (1) and standard (2) specimens without (a) and with (b) crack.

Small V-Charpy: Sizes 3.3x3.3x27 mm, 0.8 mm V-noch depth,
0.1 mm noch radius, 45^0 noch angle

Standard V-Charpy: Sizes 5x10x55 mm, 2 mm V-noch depth,
0.25 mm noch radius, 45^0 noch angle

RUSFER-EK-181: IRRADIATION EMBRITTLEMENT.
Fast reactor BOR-60, T_{irr}=340 ^{0}C, dose = 15 dpa.
Different Thermal Treatments (TTT&CTT):

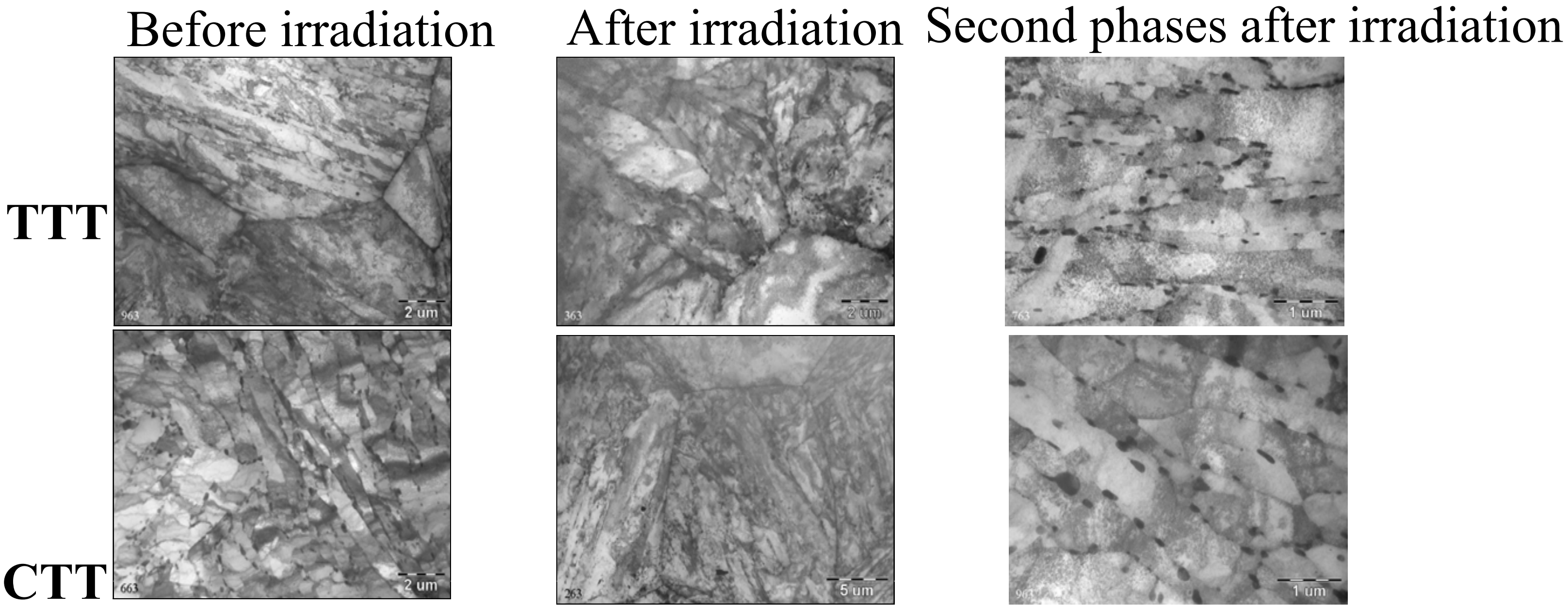


Temperature dependencies of impact energy of small specimens (small V-Charpy) with different thermal treatments

1-2 – CTT: Cyclic Thermal Treatment near critical point $\boldsymbol{A_{c1}}$*,*

3-4 – TTT: Traditional Thermal Treatment

RAFMS RUSFER-EK-181: structure before and after irradiation (BOR-60, 325 °C, 6 dpa)



- General character of the structural-phase state of the steel do not change under irradiation.
- No significant differences in distribution, size and concentration of secondary phases compared to the initial state was found independently of initial thermal treatment.
- Disperse particles **VC** and **(VTa)C** of size up to 3–5 nm remain after irradiation independently of initial thermal treatment.

TTT – Traditional Thermal Treatment.

CTT – Combined Thermal Treatment:
1-3 cycles around critical point $\mathbf{A_{c1}}$

The RF Low Activation V-4Ti-4Cr Alloys

V-(5-4)Ti-(5-4)Cr: Heats 50-100 kg. Any goods.
Today's recommendation (300)350-750(800) ^{0}C

+ Low Activation, Now swelling, High heat resistance, Ductile, Non-Ferromagnetic, Potentiality for large-scale fabrication.

- No high dose tests (> 100 dpa).

Applications: TBM DEMO in ITER, DEMO-FPP (Li, He).
FBRs (advanced core SM): BN-K (Na), HTGR (He).
Cosmic Power Reactors (Li).

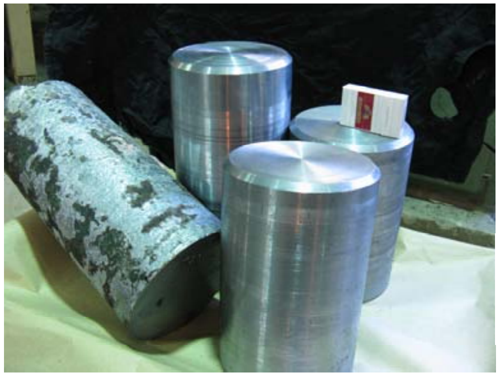
2009-2015: V-(8-4)Ti-(5-4)Cr(Me):
The R&D:

- To prepare the precipitation hardening (nanostructuring) industrial alloys.
- To Improve Homogeneity, Thermal Stability of Solid Solutions and Strengthening Precipitations and Phases.
- To Improve Radiation and Heat resistant Properties (100-200 dpa, Tmax: 850-900 ^{0}C).
- To Reduce Effect of the LTRE (Tmin: 300 ^{0}C).
- To manufacture new large heats (300 kg) with good rolling, welding and tubing.

The RF V-4Ti-4Cr Ingots.
ALL GOODS FOR THE TBM DEMO in ITER

2000.
Ingots:
45-50 kg

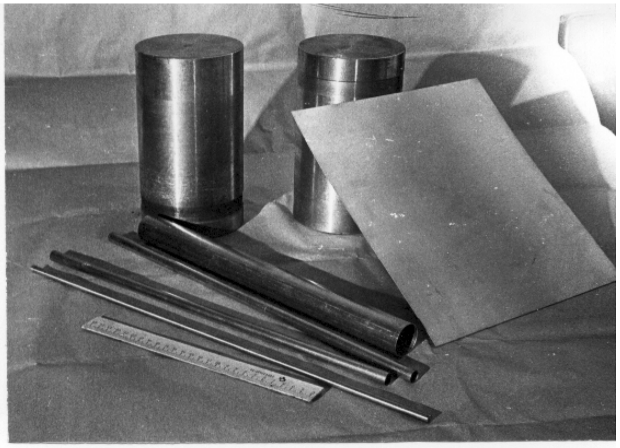
October 2008.
Ingots: 50-55 kg



March 2009.
Ingots: 100-110 kg

2012.
Ingots: 300 kg

The 50 kg ingot:
- tubes 75×5 ÷ 20×1 mm,
- profiles 120×20×5mm;
- sheets 1930x367x5 mm;
- other items.

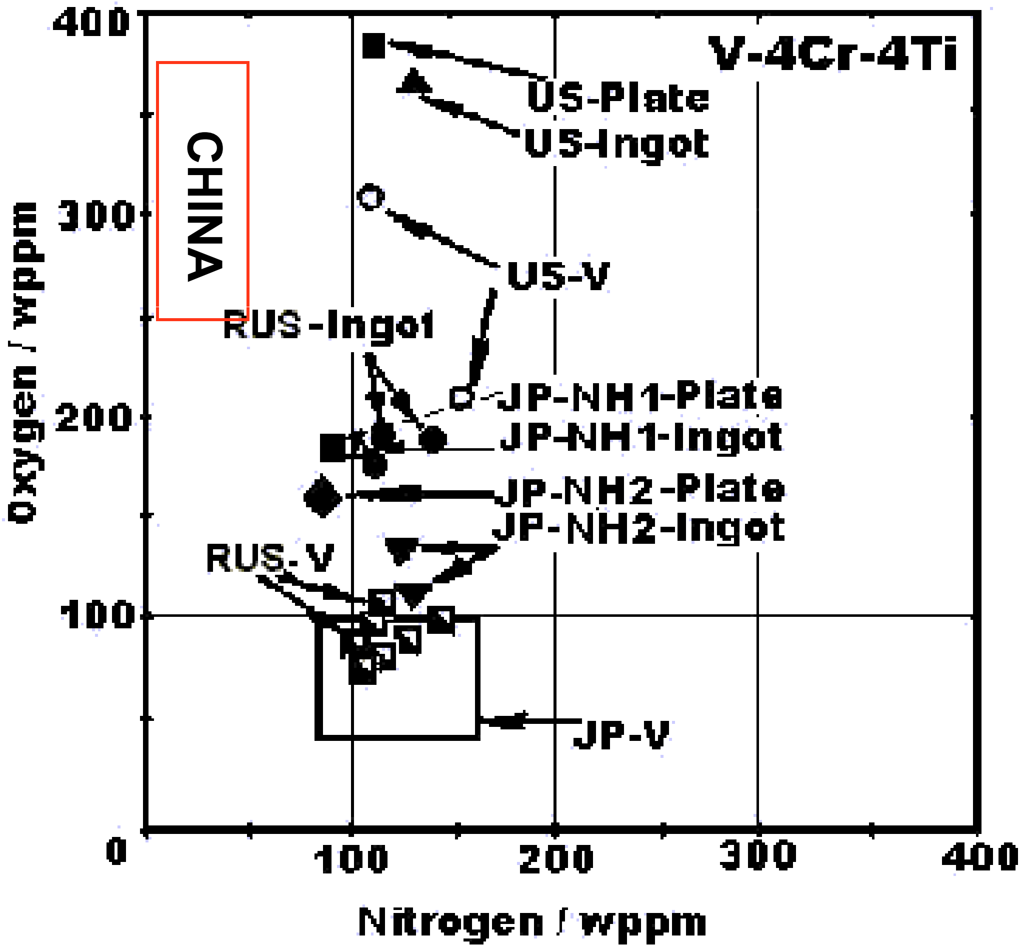


- sheets 1930x367x15 mm;
- plates 1500x257x80 mm,
- tubes.

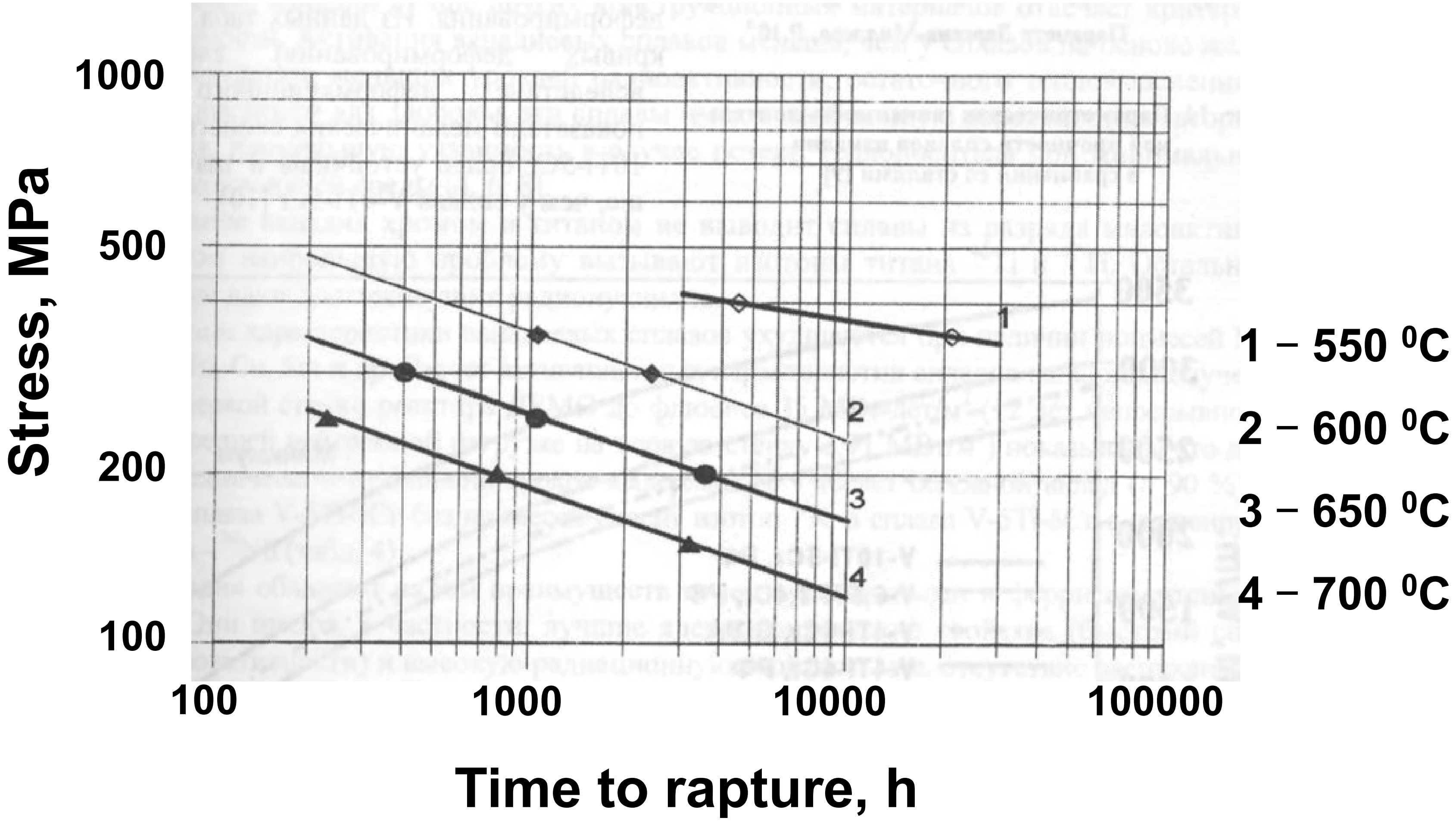
The chemical compositions of the manufactured V-4Ti-4Cr alloys (USA, Japan and RF).

Element	**Recom. USA, 1997**	**USA US832665**	**Japan NIFS-2**	**RF VVC-2**
B	<0.0015	0.00037	0.0004	0.002
C	<0.0220	0.0170	0,0052	0.013
N	<0.0240	0.0100	0.0110	0.011
O	<0.0400	0.0330	0.0129	0.020
Al	<0.0200	0.0355	0.0050	0.0027
Si	0.05±0.04	0.785	0.0024	0.019
Ca	<0.0010	0.0004	0.0011	0.001
Ti	**4.0±0.5**	**4.05**	**3.75**	**4.36**
V	**Balance**	**Balance**	**Balance**	**Balance**
Cr	**4.0±0.5**	**3.25**	**3.46**	**4.21**
Fe	<0.0250	0.0205	0.0042	0.0163
Ni	<0.0020	0.00096	0.0005	0.00127
Cu	<0.0020	8E-5	<0.0001	0.00085
Nb	<0.0010	0.0060	<0.0009	0.00072
Mo	<0.0010	0.0315	0.0023	0.0025

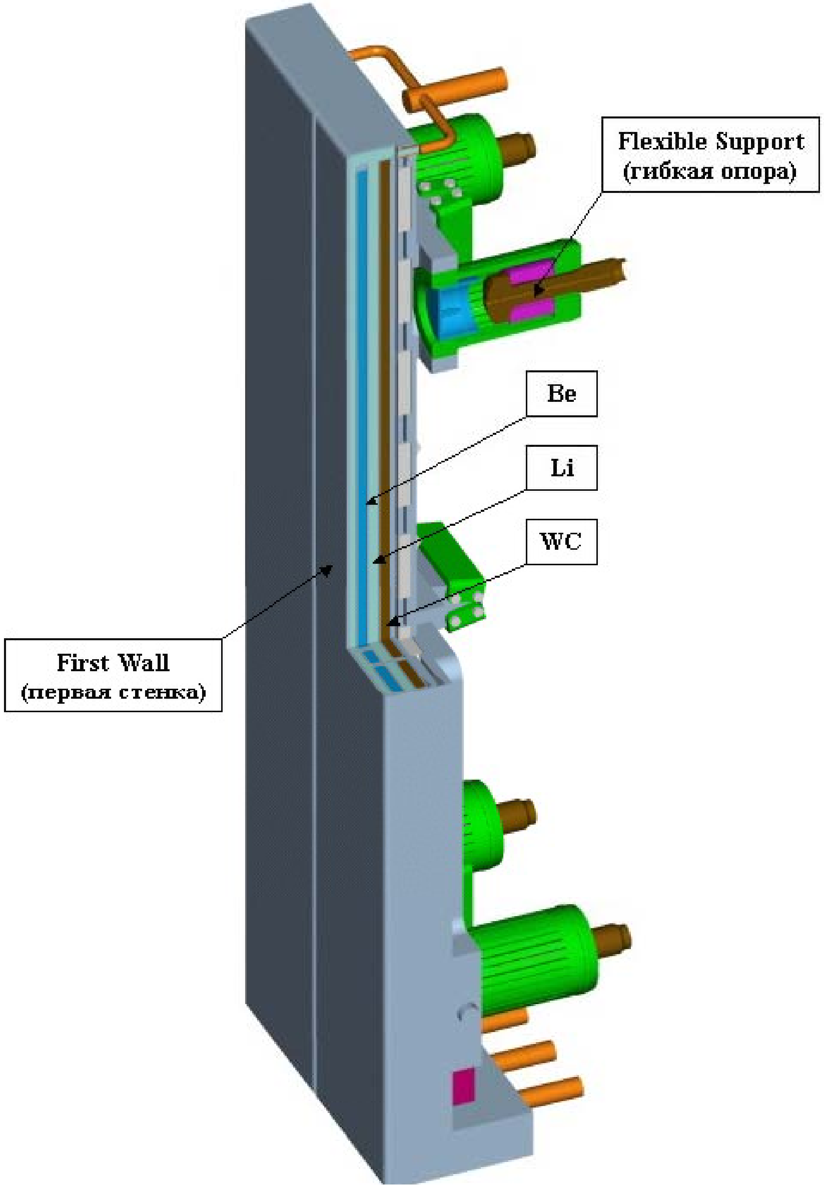
V-4Ti-4Cr: The impurity contents (O, N) in the ingots and plates (USA, Japan, Russia and China)



V-4Ti-4Cr alloy: Time and Stress to rupture as a function of stress at different temperatures (S.N.Votinov et al. In “The RF atomic electric stations”, Ed. A.M.Lokshin, Moscow, 2007)



The RF V-Li Test Breeding Module (TBM) DEMO in ITER



Efremov Inst. (ROSATOM) , project

The RF (Efremov Inst., Bochvar Inst., Industry) is capable to product the necessary V-4Ti-4Cr ingots and goods for the full scale TBM DEMO in ITER (2012).

V-4Ti-4Cr goods for the TBM : 315 kg.

FEATURES OF VANADIUM ALLOYS WHICH ARE OF GREAT IMPORTANCE FOR THE FORMATION OF ALLOY MICROSTRUCTURE AND SERVICE PERFORMANCE

1. High chemical activity to interstitial impurities (C, N, O) resulting in saturation of alloys with these impurities during the production of ingots and the subsequent thermomechanical treatments (TMT).
2. Low solubility of carbon.
3. Low activation energy of the diffusion of carbon and, as a consequence, high rate of formation of vanadium carbides.

As a result, even a rather low carbon concentration transforms vanadium alloys to the category of dispersion (precipitation)-hardening alloys with a complex sequence of phase transformations, whose degree of dispersion and secondary phase distribution are highly sensitive to the parameters of the technological TMT cycle.

Minor variations in these parameters may strongly affect:

- the thermal stability of the microstructure of the alloys;
- the grain size;
- the phase composition of grain boundaries;
- the level of high-temperature strength of the alloys;
- their propensity to low-temperature radiation embrittlement;
- other structure-sensitive properties of the material.

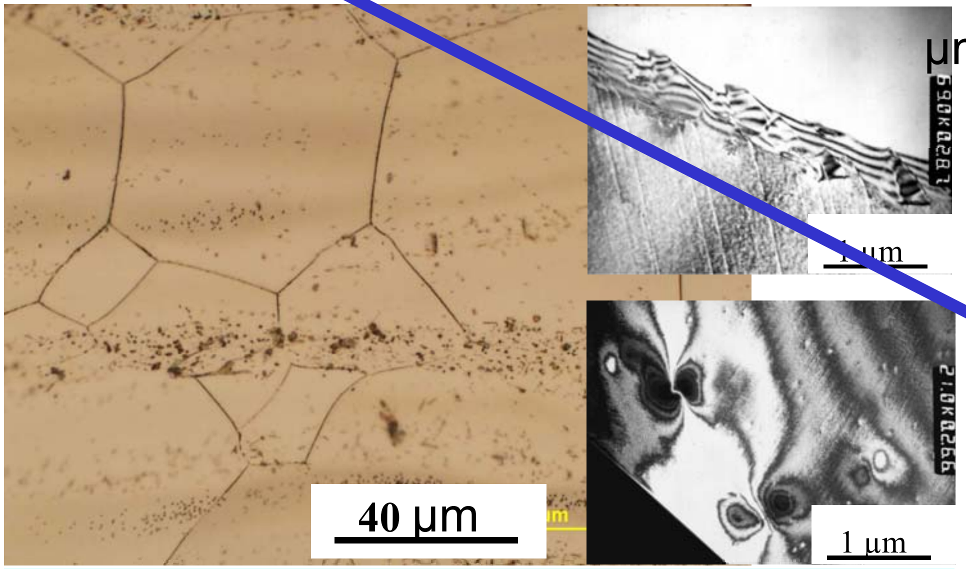
The Thermal and Mechanical Treatment (TMT) to improve the Mechanical Properties of the vanadium alloys

1. **The TMT allows one to produce phase-structure states with the multiphase and defect substructures showing high degree of dispersion (precipitation) and thermal stability, to elevate the recrystallization temperature by (100–200) °C, and to improve the low-temperature and high-temperature strength characteristics of alloys with their high plasticity preserved.**
2. **A promising way for developing radiation-proof vanadium alloys and improving their high-temperature strength is *controllable interstitial alloying (C,N,O) followed by the TMT to produce structural states with highly homogeneous high-dispersion nonmetallic phases and thermally stable multiphase and defect substructures (PRECIPITATION HARDENING ALLOYS).***

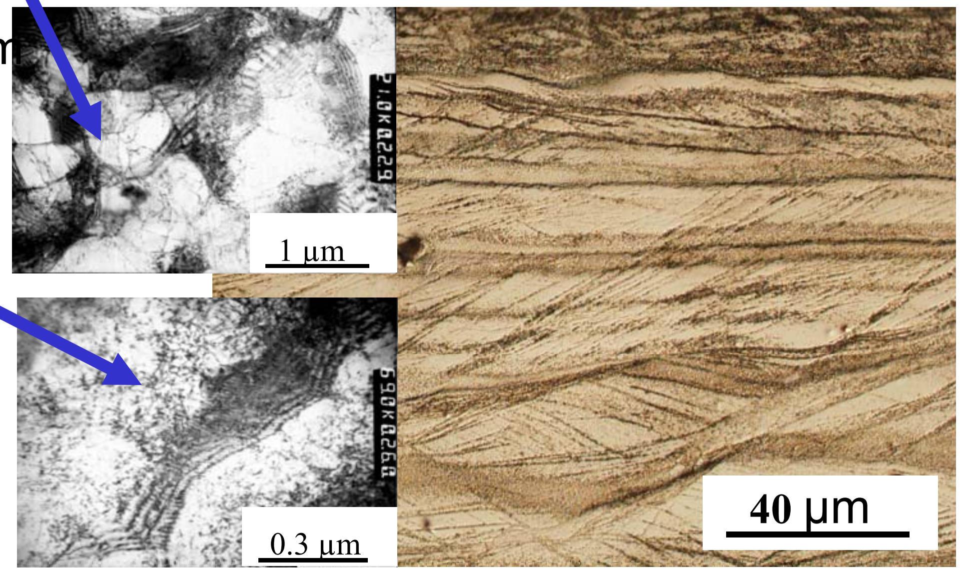
THE TMT OF V-Ti-Cr ALLOYS: Fine particles of the second phase can show rather high thermal stability and, fixing the elements of the defect substructure, **increase the recrystallization temperature of the alloys.**

The recrystallization temperature of an alloy can be over the temperature of the final stabilizing annealings $T = 1000–1100°C$.

After these annealings, either polygonization of the alloy or the formation of structural states with high (about 10^{10} cm^{-2}) density of chaotically distributed dislocations fixed by second phase particles is observed.



TMT by a conventional mode
+ annealing at 1000°C for 1 h.



TMT by a new mode
+ annealing at 1000 °C for 1 h.

TMT OF V-4Ti-4Cr: The efficiency of the method developed is determined by the degree of dispersion and volumetric content of the second phases, and by the content of interstitial impurities in the alloy.

The high-temperature strength of the V-4Ti-4Cr alloys can be substantially increased by TMT combined with oxygen diffusion alloying.

TMT modes	20^0 C		800^0 C	
	$\sigma_{0.2}$, МПа	δ, %	$\sigma_{0.2}$, МПа	δ, %
V-4Ti-4Cr				
TMT I	340-360	22-24	190-210	12-14
TMT II	360-370	19-20	250-260	11-14
TMT III	360-380	17-19	290-300	11-12

TMT I - conventional TMT mode.

TMT II - new TMT mode.

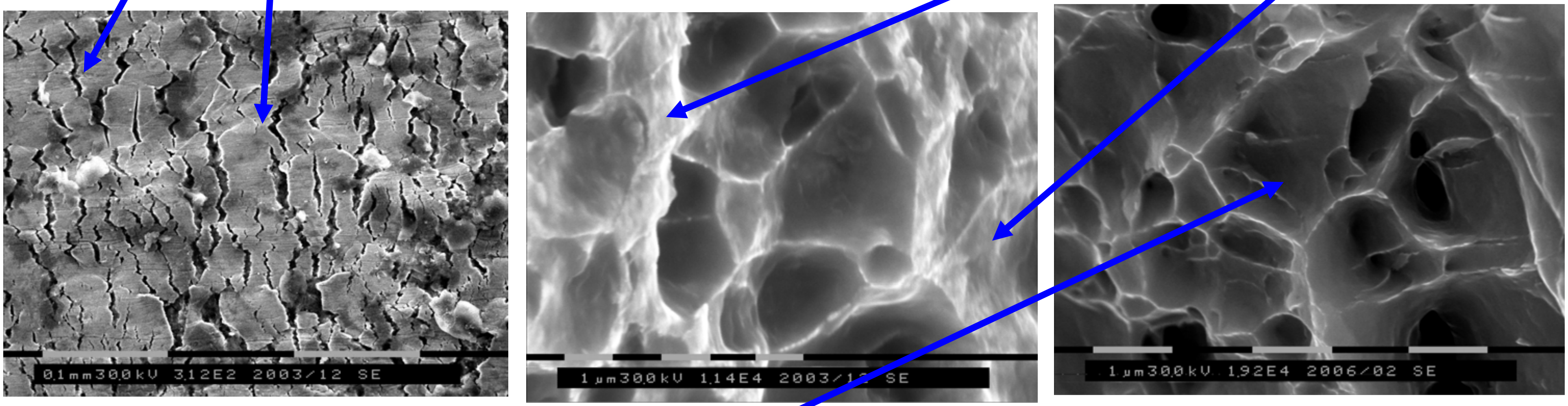
TMT III - new TMT combined with oxygen diffusion alloying.

TMT OF V-4Ti-4Cr ALLOYS: Effect of the TMT mode on the features of plastic deformation and fracture at $T \geq 700°C$.

An important consequence of the suppression of recrystallization after TMT by the new modes is prevention of grain-boundary mechanisms of deformation and fracture at elevated temperatures ($T \geq 700°C$).

Numerous microcracks are observed **at grain boundaries** on the surface of samples ***treated by a conventional mode*** and subjected to tensile deformation at $T = 700°C$. In this case, facets are detected on the fracture surface which can be treated as **facets of viscous intergrain fracture**.

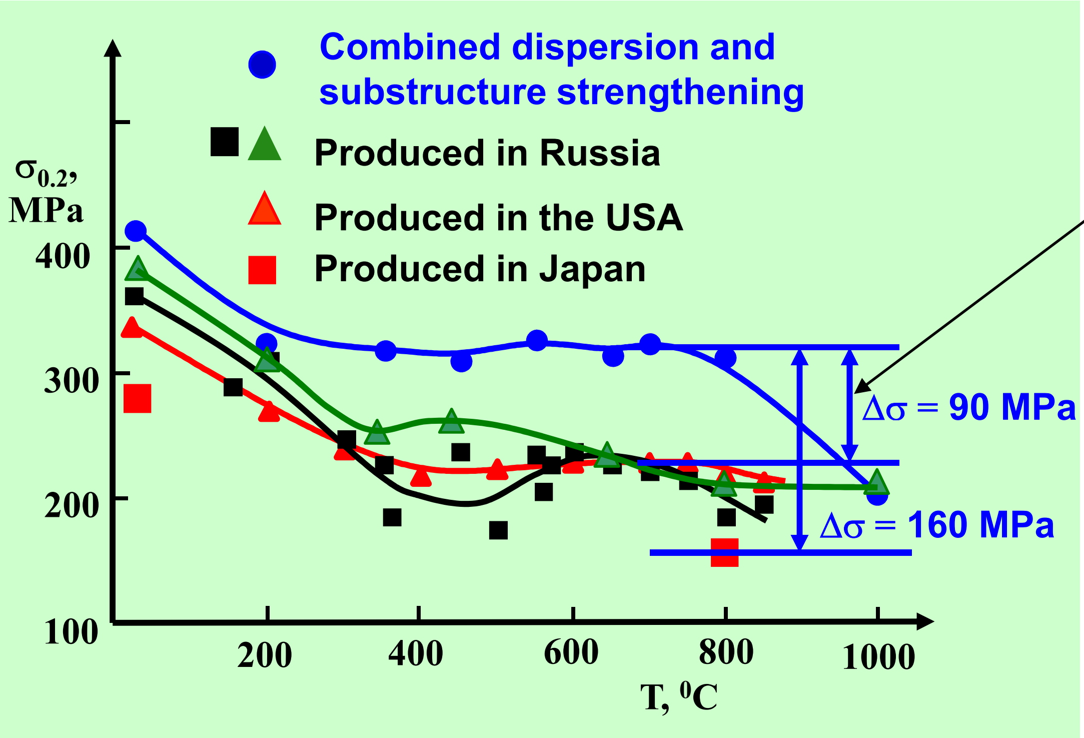
This testifies to a significant effect of grain boundaries on the pattern of plastic deformation and fracture of the alloy at $T = 700°C$.

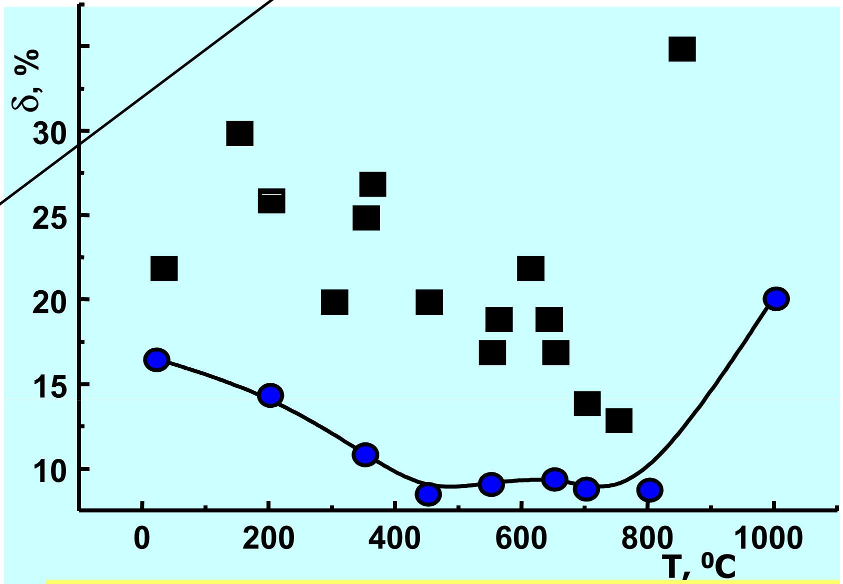


After TMT by a new mode, the above features were not revealed. It is observed that the strain relief of the side surface of samples deformed at $T = 700–800°C$ is much more uniform, and the fracture surface shows **viscous pitted fracture**.

TMT OF V-4Ti-4Cr ALLOYS: An increase of volumetric content of finely dispersed (nano-) phases and suppression of recrystallization substantially increase the yield strength at *T* = 20–1000°C.

The maximum hardening is achieved in the temperature range, *T* = 600–800°C, the gain in yield point after new TMT reaches values of about Δσ ≈ 90 MPa.





The temperature dependence of the relative elongation of V–4Ti–4Cr alloy samples treated with the use of a conventional (■) and a new (●) TMT mode.

A substantial increase in strength is achieved with a high margin of plasticity preserved.

NEUTRON SOURCES: KEY NEED TODAY AND FUTURE

Different Neutron Sources are necessary to combine design, materials and technologies R&Ds (3-4 iterations of irradiation followed by materials modifications) with the goal to propose the concepts of innovation reactors and the way

Via the FBRs (BOR-60, BN-600, BN-800) and IFMIF

as advance the materials science and technology base towards to **BN-K (2020), DEMO (2035) and Fusion Power Plant (2050).**

2008-2015: BN-600 Tests: RUSFER-EK-181 / V-4Ti-4Cr.

Neutron flux 6.5 x 10^{15} n/cm^2/s (E>0), passive irradiation of the specimens. Irradiation Time 560 x 2 = 1120 days. Doses 40-80-160 dpa. **Irradiation Temperature Stability: ±(15-25) ° C.**

RUSFER-EK-181: Fe-12Cr-2W-V-Ta-B:

Project BN-600-Fe1(2): Tirr: 375-700 ^{0}C.
Environment – flowing sodium or static argon.
Total number of samples of various types is 290 (SSTT).

V-4Ti-4Cr:

Project BN-600-V1(2): Tirr: 400-800 ^{0}C.
Environment – static ^{7}Li, Na, Ar.
Total number of samples of various types is 300 (SSTT).

RADIATION PROPERTIES (Data Base):

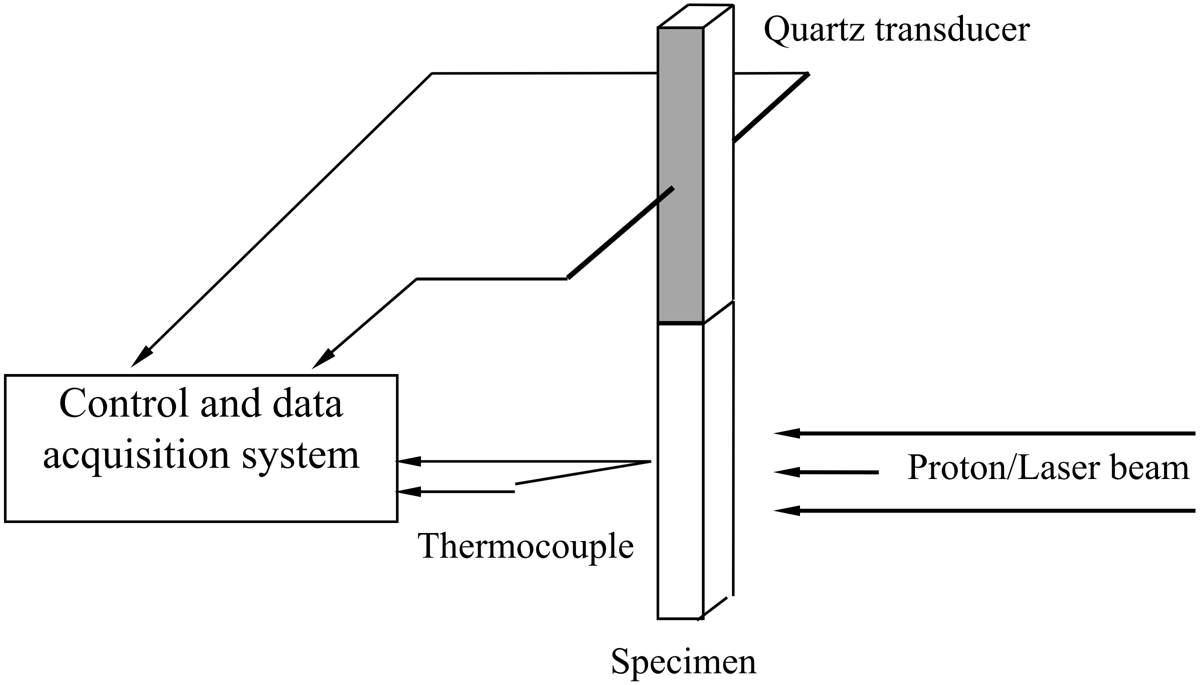
elastic and micro-plastic; mechanical; swelling; creep (pressure tubes); impact ductility; DBTT, crack-resistance; corrosion; structural and phase transformations.

Preparations for BN-800 and IFMIF Irradiations.

ACCELERATOR&LASER TESTS OF SMs DURING ION (damage&thermal) AND LASER (thermal) IRRADIATION:

Composite oscillator technique - Frequency 10^5 s^{-1}

(B.K.Kardashev, V.A.Stepanov, V.M.Chernov)

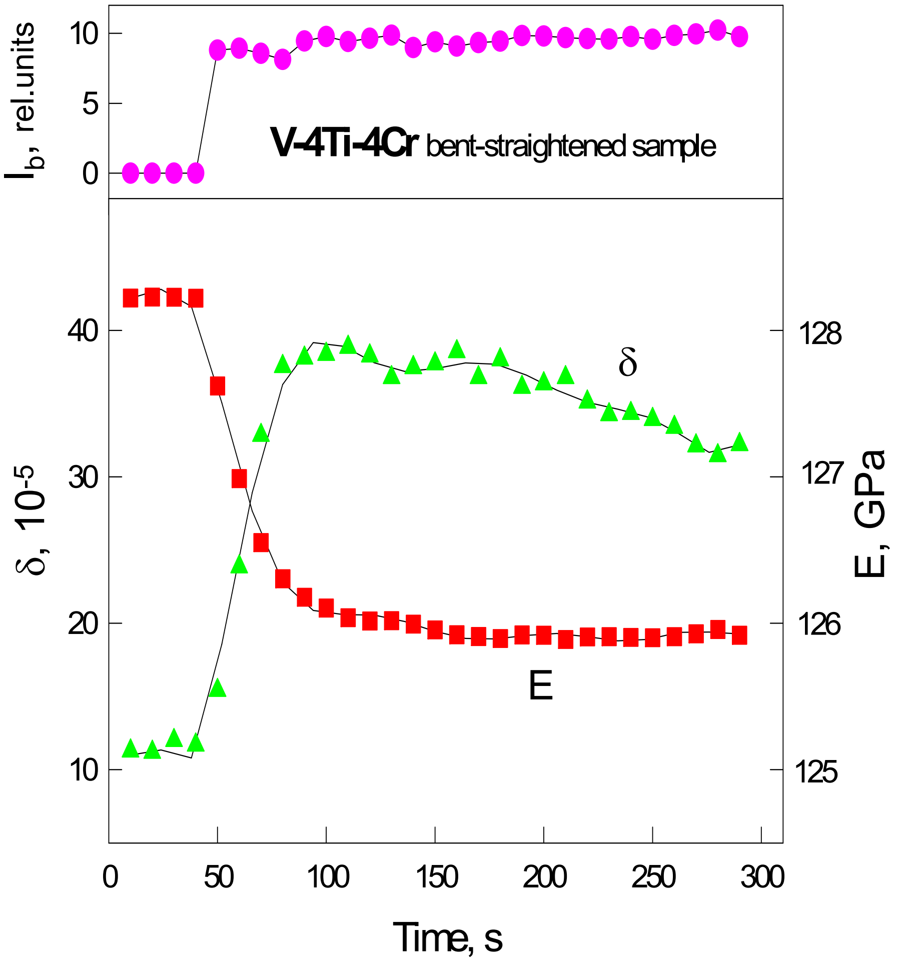


Measured parameters under irradiation:

E – Young's modulus

δ - logarithmic decrement

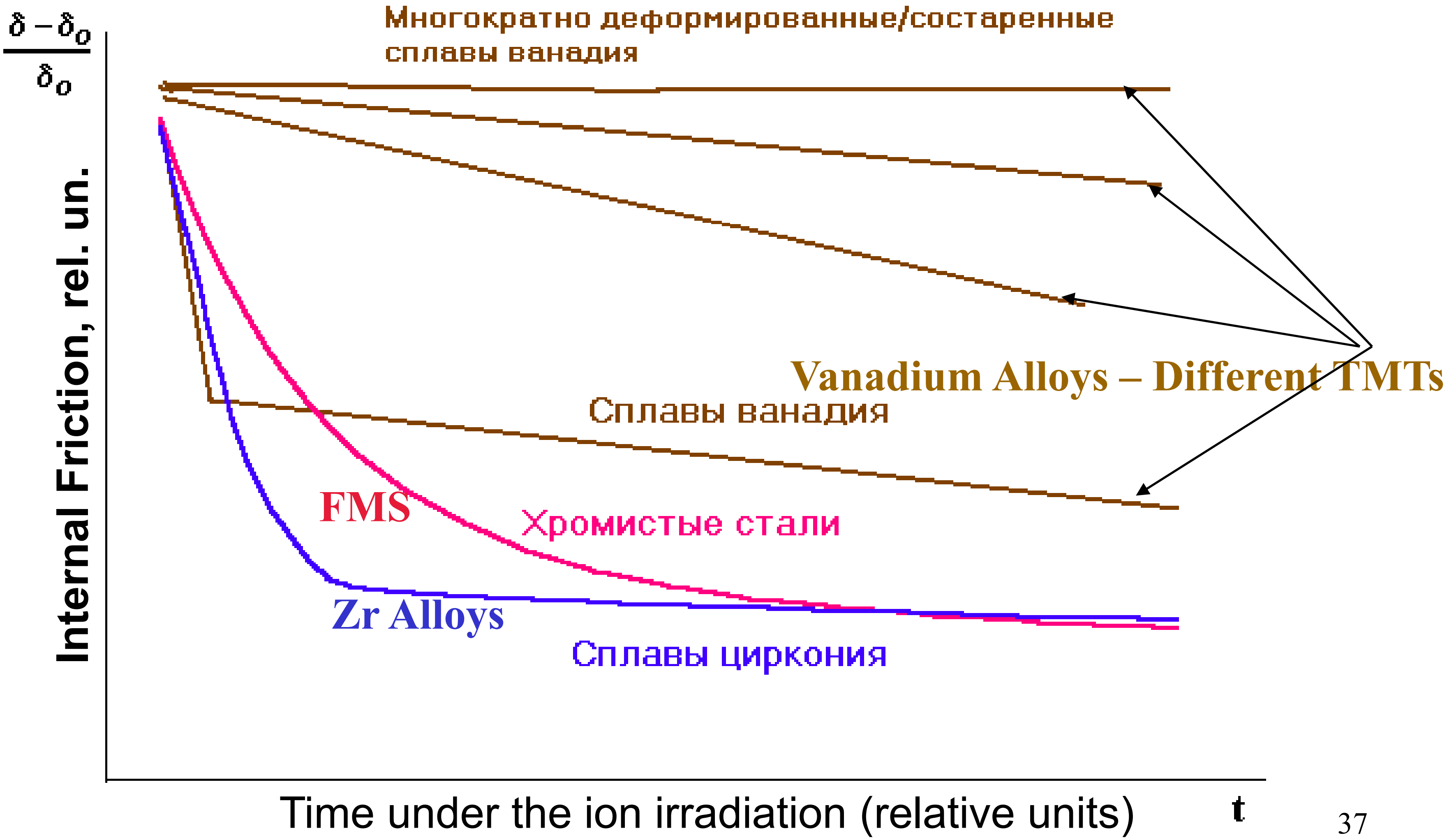
V-4Ti-4Cr: THE TESTS DURING ION IRRADIATION BY ACOUSTICS METHOD (8 - MeV protons)



Time dependences of the Young's modulus E and the decrement δ during ion irradiation with intensity I_b

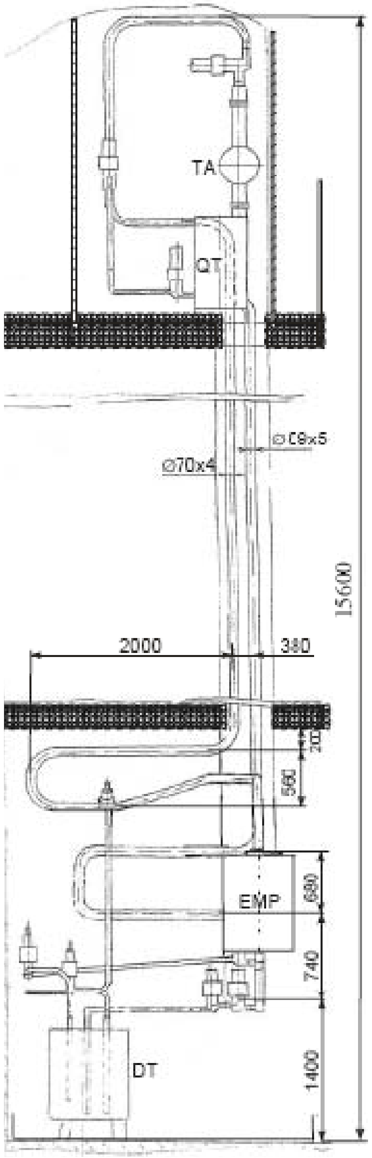
Accelerator Tests (8 MeV protons) of different Steels and Alloys.

Internal Friction during Ion Irradiation. The relaxation of microstructure and elastic properties of the SMs via acoustic method (frequency ≈ 10^5 s^{-1})



The RF Li Test facility (IPPE, Obninsk),

H=15,6 m, V=210 l, Flow rate = 50 m^3/h, Li velocity = 20 m/s (70 mm x 10 mm)



Model of IFMIF target

CONCLUSION (1)

THE RF NON(LOW)SWELLING Structural Materials FOR NUCLEAR APPLICATIONS (FBRs&DEMO-FPP).

THE SMs TEMPERATURE WINDOWS

Today recommendations:

- RAFMS RUSFER-EK-181 (Na, Pb, PbLi): **300 – 670(700) ^{0}C**,
- Vanadium alloys V-(5-4)Ti-(5-4)Cr (Li, Na, He): **300 – 750(800) ^{0}C**.

Advanced Dispersion/Precipitation Hardening (Nanostructuring) SMs:

- RAFMS type RUSFER-EK-181 (Na, Pb, PbLi): **300 – 700 ^{0}C,**
- Vanadium alloys type V-(8-4)Ti-(5-4)Cr(Me) (Li, Na, He): **300 – 850(900) ^{0}C.**

CONCLUSION (2):
What is to be done for the SMs towards BN-K & DEMO-FPP via FBRs (BN-600, BN-800) and IFMIF neutron sources

Our Knowledge Data Bases seem to be appropriate but further progress is anticipated for BN-K & DEMO-FPP conceptions and designs.

But We Need:

- New knowledge on the high Neutron Flux / Fluence damage of the SMs for different neutron spectra and temperatures **(dpa, H, He, H/dpa, He/dpa)**.

- High dose neutron irradiation data and more clear understanding of the effects of alloy composition and microstructure evolution on irradiation strength and creep over the temperature window (RT ≤ T ≤ 1000 ° C).

- New knowledge on the LTRE (Tmin) in correlation with Heat Resistance (Tmax) of the SMs to wide the temperature windows ∆Tmax = Tmax – Tmin.

- High neutron fluences (100-150-200 dpa) and wide temperature windows (300-800-1000 ^{0}C) of irradiations in BOR-60, BN-600 and BN-800 fast reactors and in the neutron source IFMIF to provide adequate the SMs databases for the designs of BN-K & DEMO-FPP in time.

We are certain – the RF will have the technologies and the industry to fabricate the advanced Structural Materials for Power Fast and Fusion Reactors in time.

“OUR NEAR FUTURE IS NUCLEAR FISSION & FUSION JOULE-POWER”

MY GRATITUDE TO THE IAEA & ICTP

Thanks for your Attention & Patience