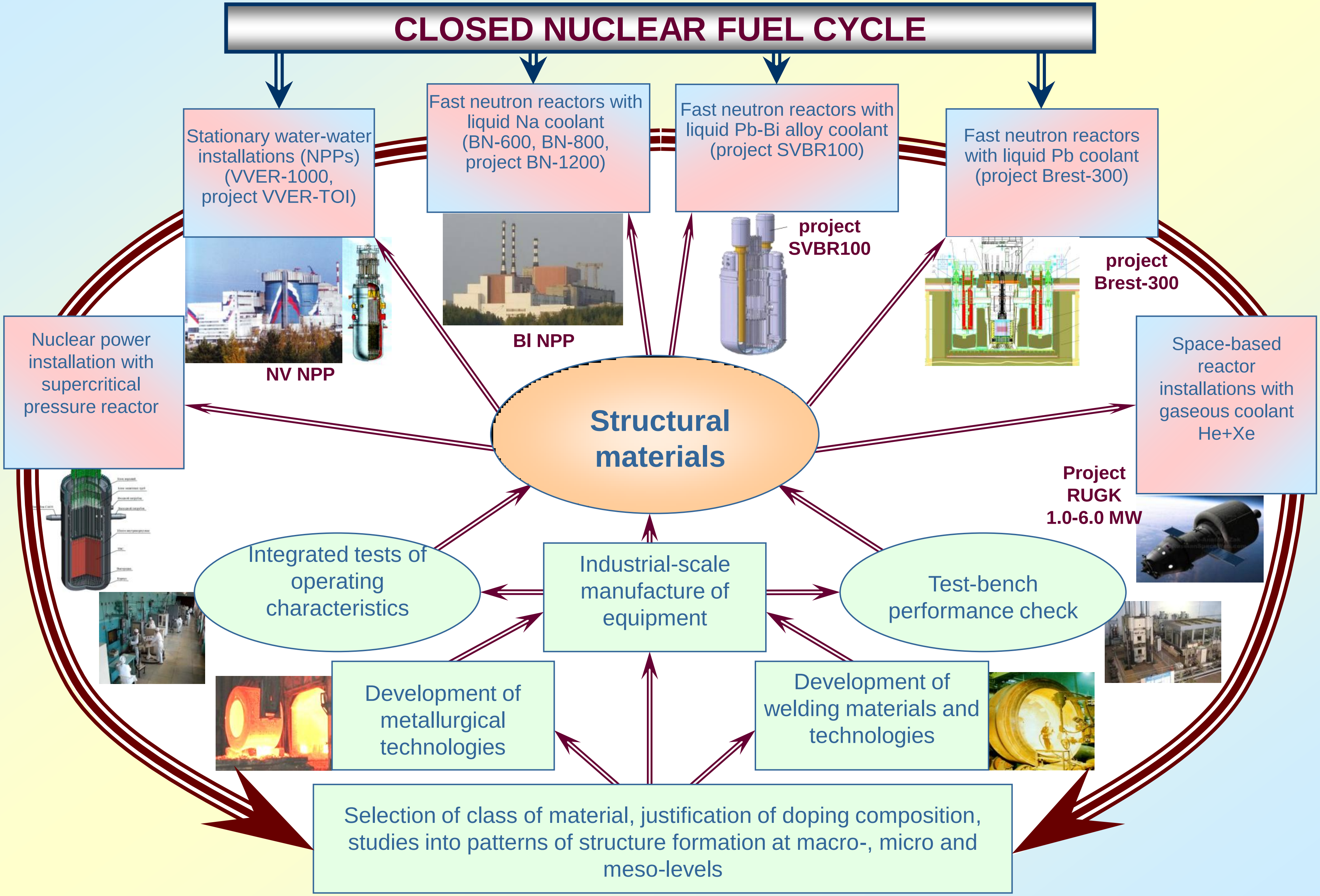
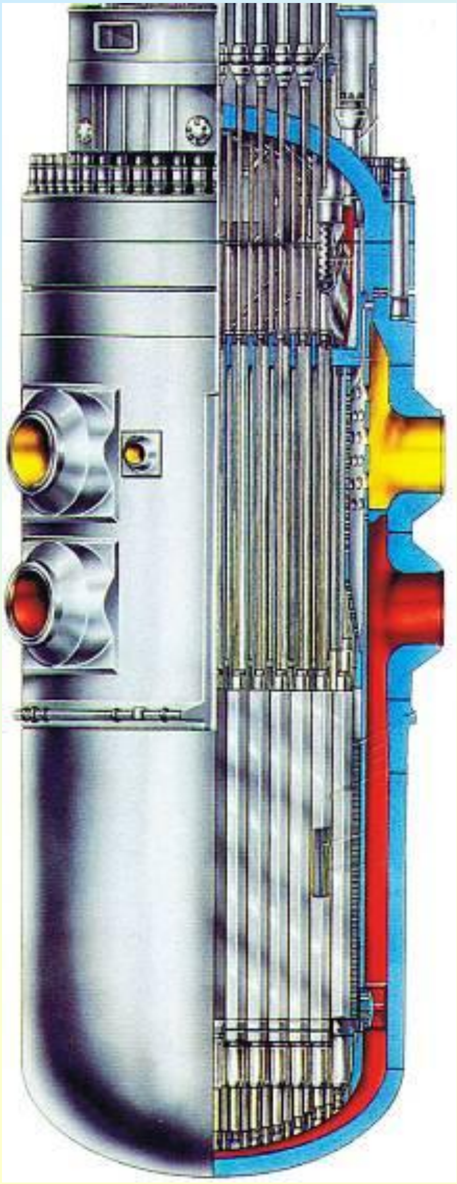
Federal State Unitary Enterprise
CENTRAL RESEARCH INSTITUTE OF STRUCTURAL MATERIALS "PROMETEY"

DEVELOPMENT OF NEW STRUCTURAL MATERIALS TO IMPROVE EFFICIENCY AND RELIABILITY OF NPP EQUIPMENT

G.P. Karzov, Deputy Director General

MATERIALS FOR NUCLEAR POWER



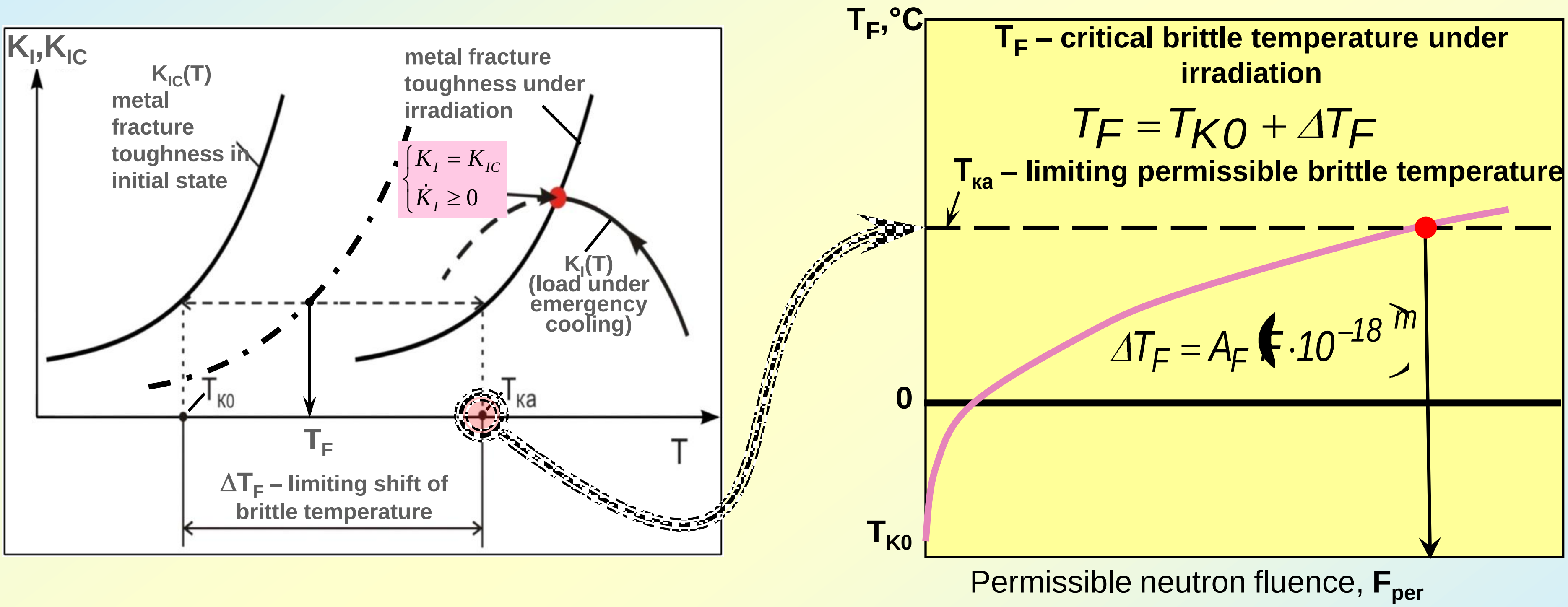


WATER-WATER NUCLEAR POWER REACTORS OF VVER TYPE

DETERMINATION OF TOLERABLE REACTOR PRESSURE VESSEL SERVICE LIFE

Determination of tolerable RPV conditions

Determination of tolerable neutron fluence



$T_{ка}$ – limiting critical temperature of RPV metal

F – neutron fluence

A_F – metal radiation embrittlement ratio

Limiting fluence:

$$F = \left(\frac{T_{ка} - T_{ко}}{A_F} \right)^n$$

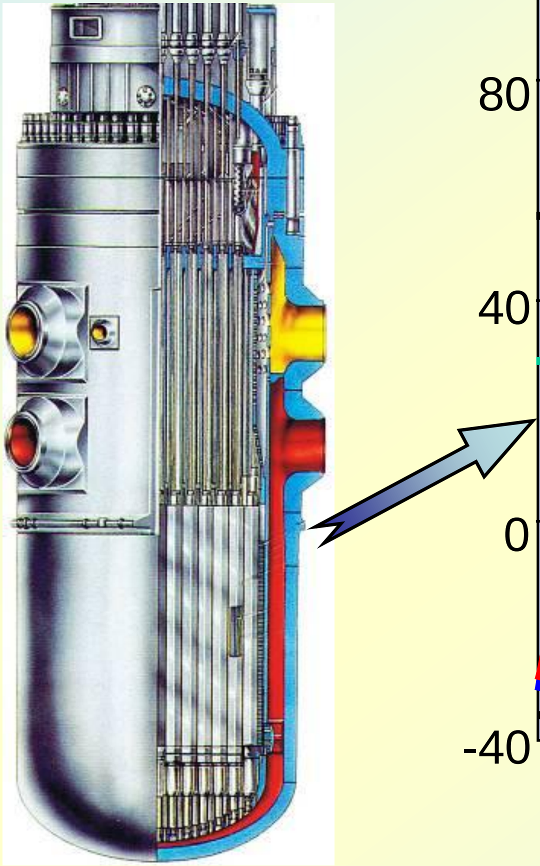
Resource: $t = \frac{F}{\Phi}$

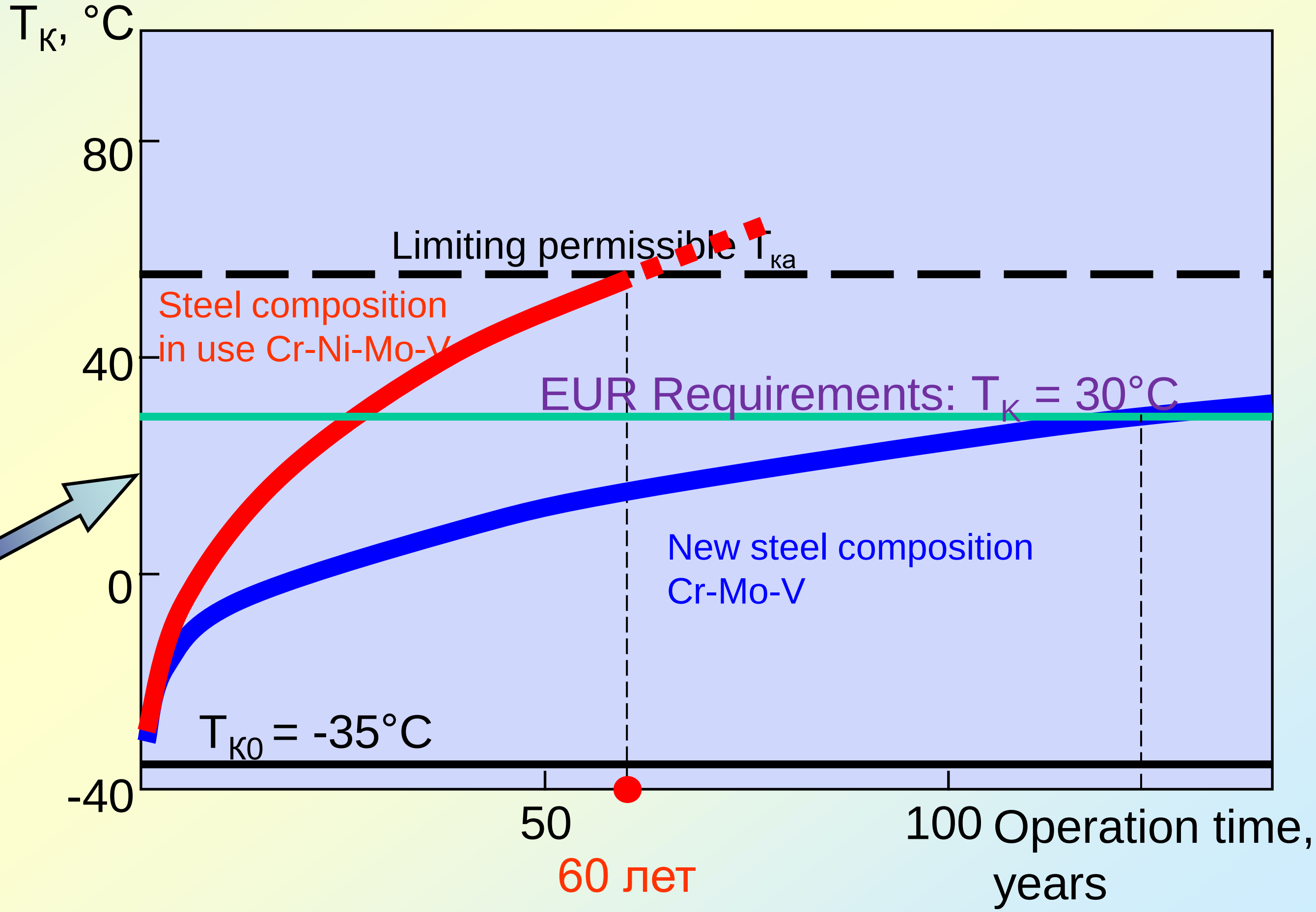
Φ – neutron flux

REQUIREMENTS FOR RPV MATERIAL

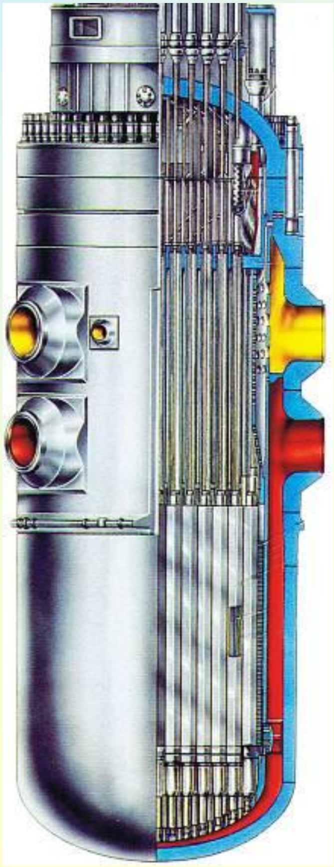
STEEL of Cr-Mo-V COMPOSITION

- **ensures high properties of steel: пstrength, ductility and viscosity over the entire thickness range required for nuclear RPVs (150÷550 mm);**
- **ensures unprecedented high radiation stability of steel that exceeds foreign analogs by 4÷5 times.**





INTERNALS OF NUCLEAR POWER REACTORS VVERs



Internals

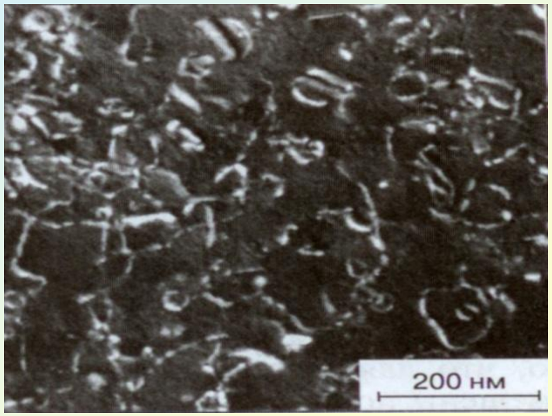
Types of operational impacts
1. Neutron irradiation
2. Cstatic and vibration loads
3. Corrosiveness of the primary circuit activated by water radiolysis products

Damage mechanisms
1. Radiation embrittlement
2. Radiation swelling
3. Radiation creep
4. Stress corrosion

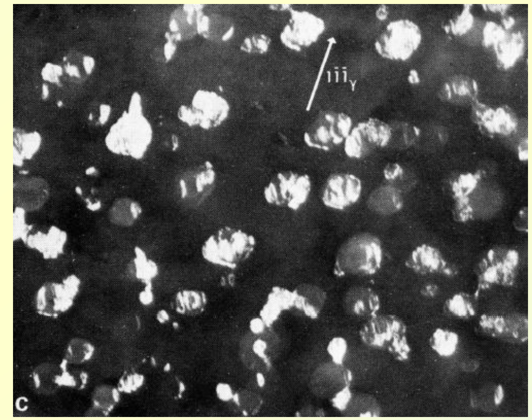
Potential damage
1. Initiation and development of corrosion fatigue cracks
2. Low energy ductile fracture in swelling zones

SWELLING IMPACT ON PHASE TRANSFORMATIONS IN STEEL. $\gamma \rightarrow \alpha$ – TRANSFORMATION

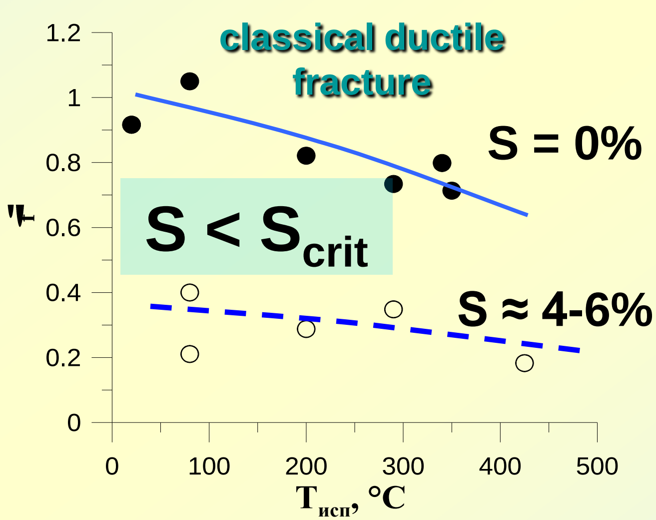
Swelling S



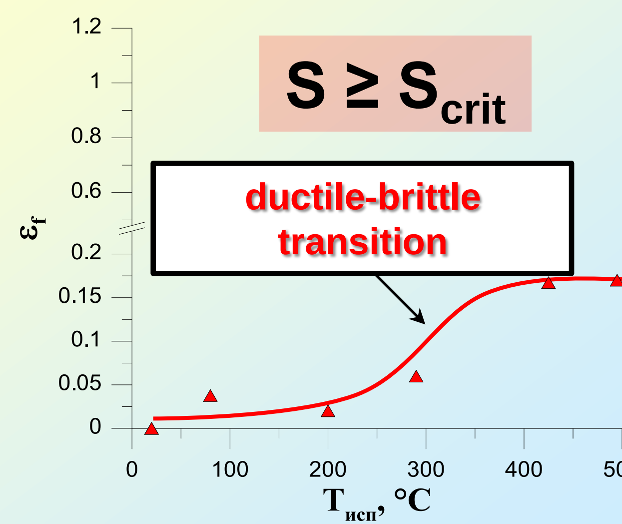
Dislocation structure of irradiated steel.
No vacancy pores.



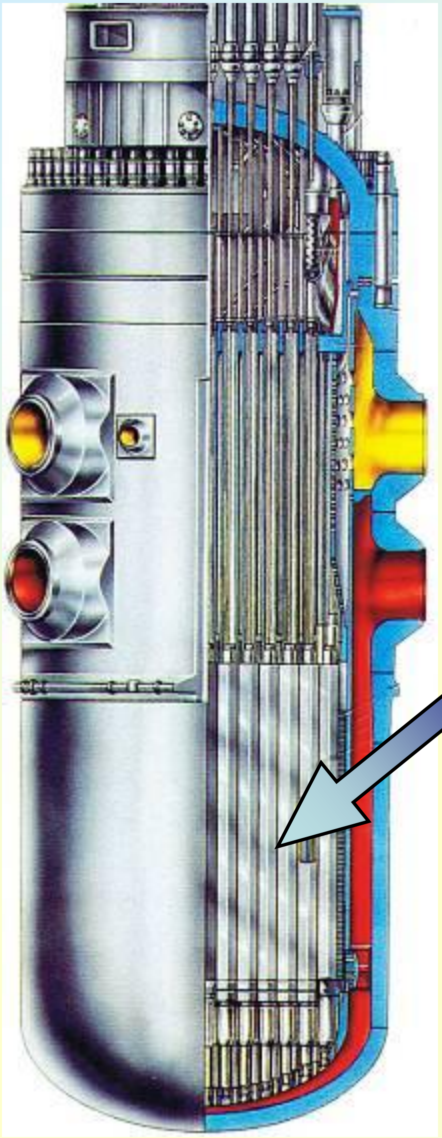
α-phase shells around irradiated steel pores.
Dark-field image (111-γ reflex).

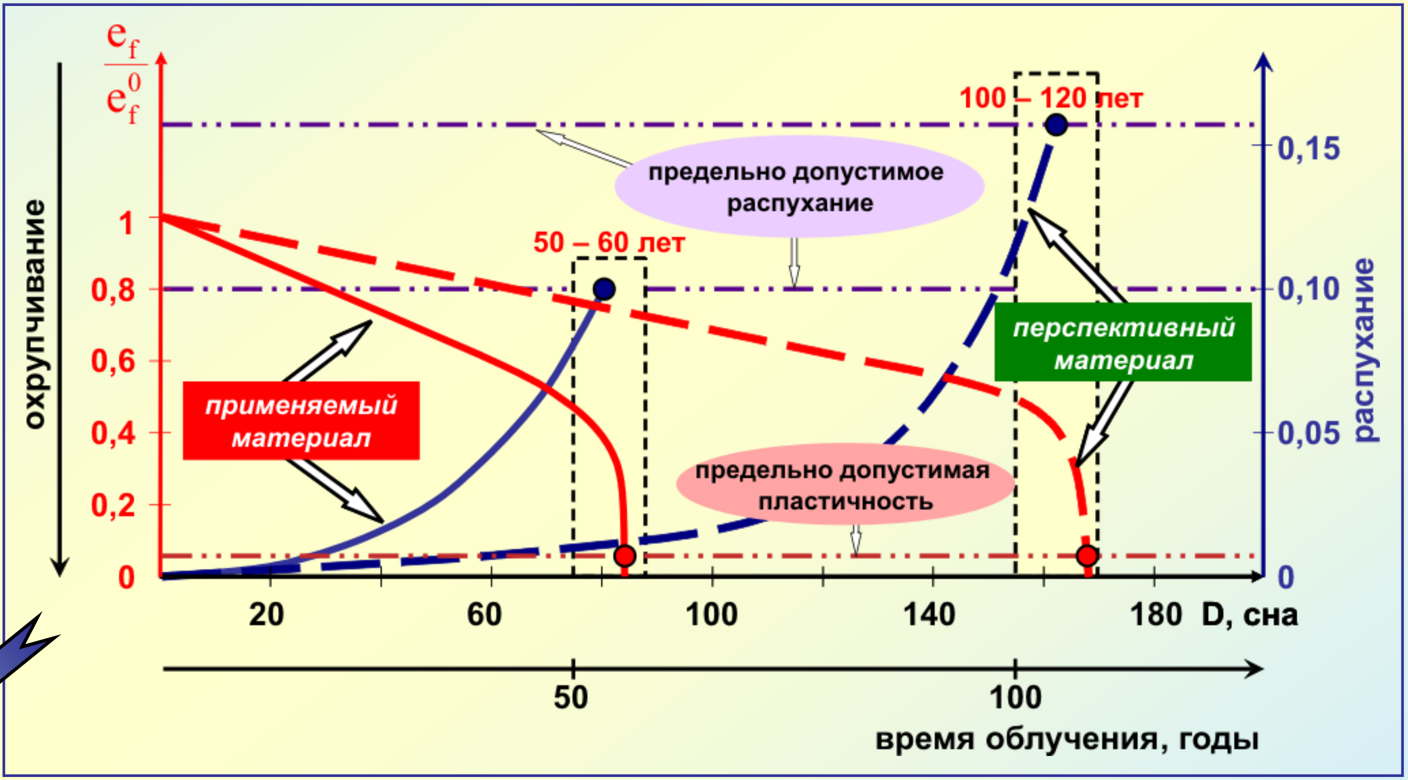


$S_{crit} \approx 7\%$



VVER REACTOR INTERNALS MATERIALS

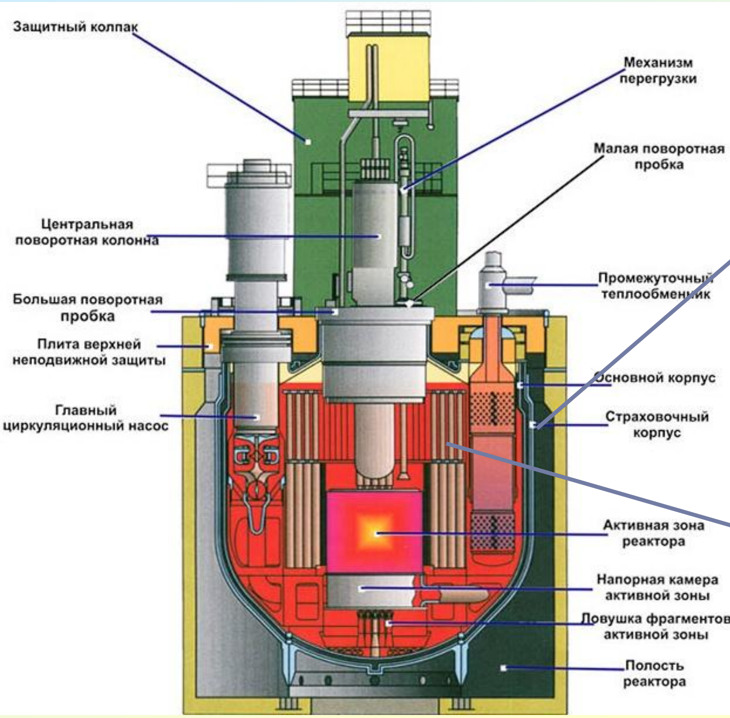




material in use — steelX18H10T

promising material — steel with an increased nickel content and nanostructure of short-range order domen

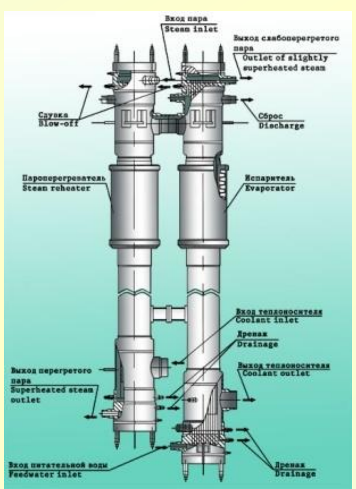
MAIN CHALLENGES OF SELECTING STRUCTURAL MATERIALS FOR BN REACTORS



Challenges

RPV — Stability to heat-induced aging

Intls — High resistance to creep under intensive neutron irradiation

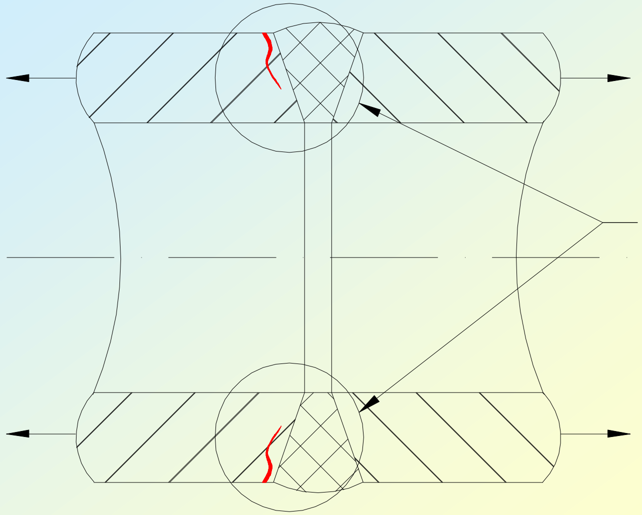


Steam generator — High corrosion resistance and heat resistance.

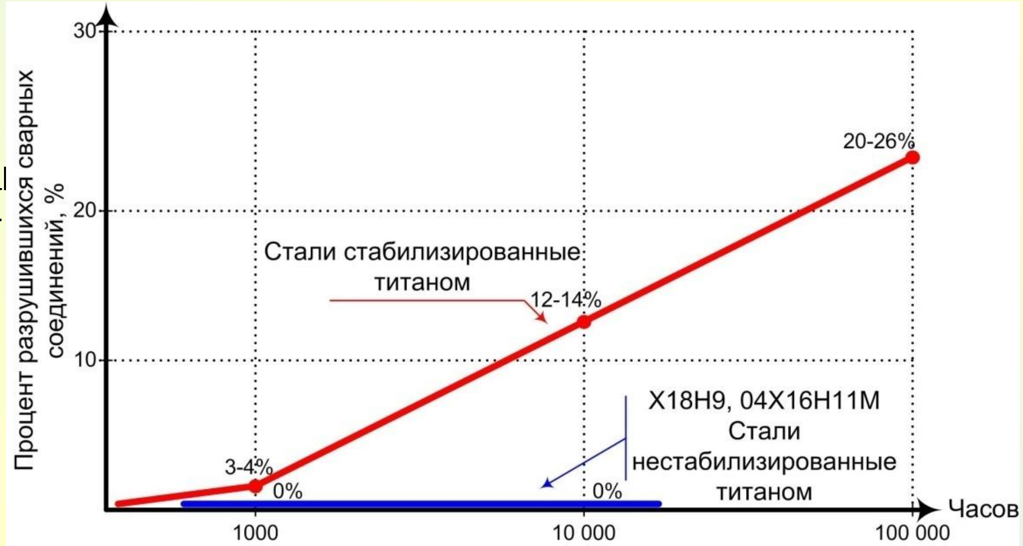
Corrosion resistance during installation under atmospheric corrosion

SELECTION OF STEEL GRADES FOR BN REACTOR INSTALLATIONS

Component of supercritical pressure piping

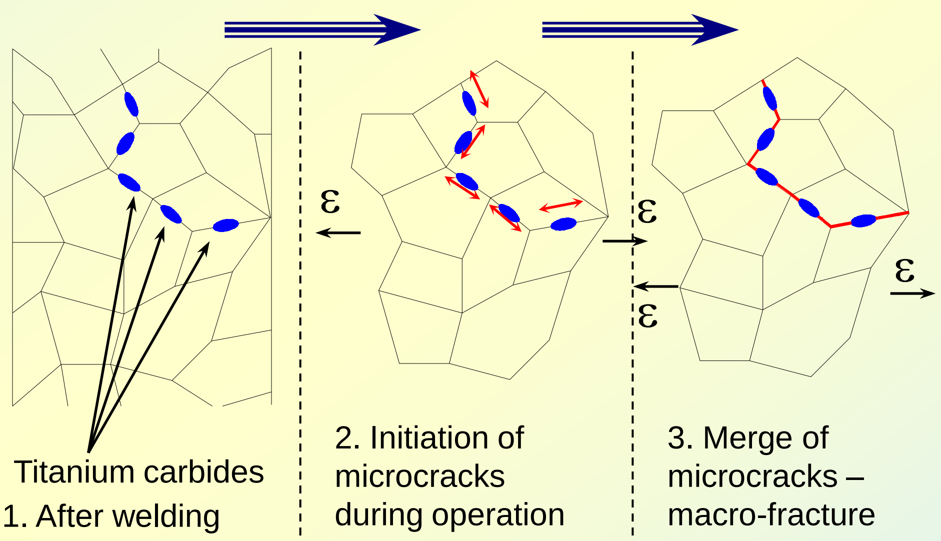


T-570-620 C P=25-27 MPa
Steel: 06X17H11M3T
07X16H11M3ФT



Results of pilot operation at Chernigov DTPP

Initiation of fracture in heat-affected zone



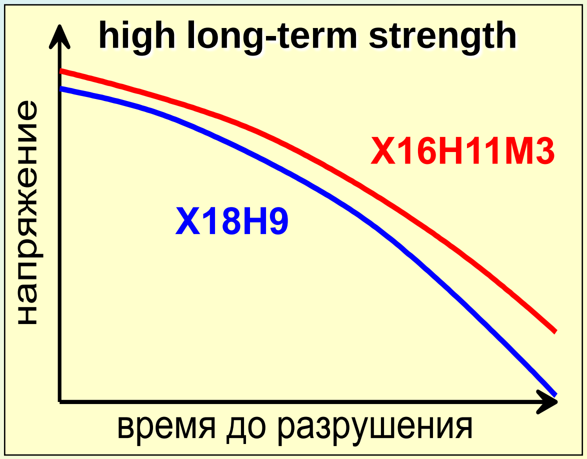
Titanium unstabilized steel is recommended for manufacture of BN reactors that operate at a temperature of 560 C

NEW MATERIALS FOR BN REACTORS (Stage I)

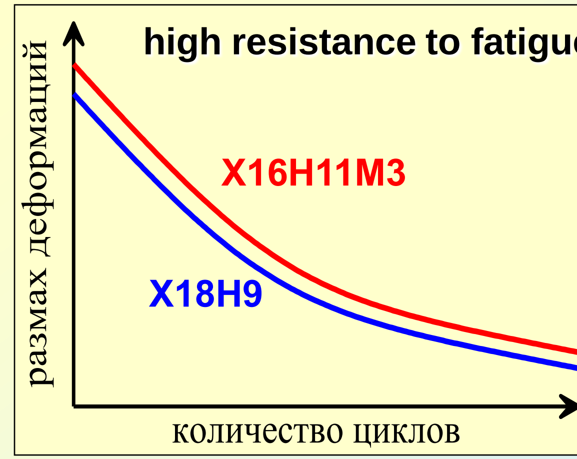
APPLICATION OF STEEL X16H11M3 TO MANUFACTURE MOST LOADED COMPONENTS OF RI BN-800 AND BN-1200 INSTEAD OF STEEL X18H9

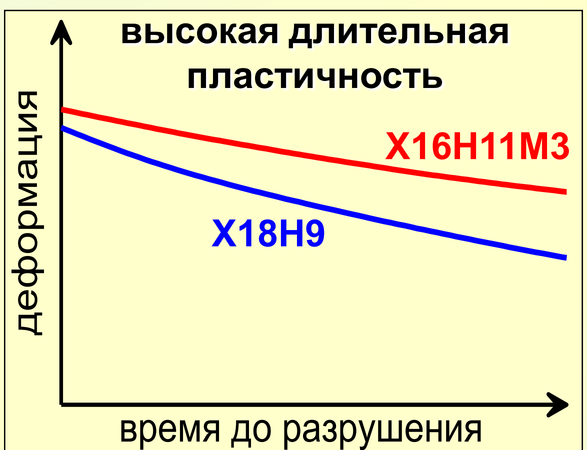
Stress factors:
- temperature
- irradiation
- swelling

Failure mechanisms:
- fatigue
- creep
- form change

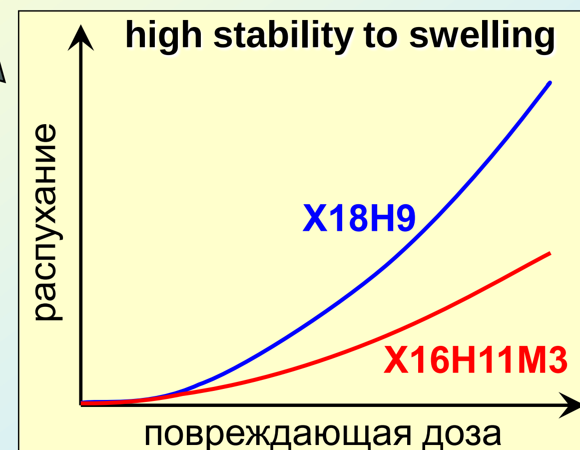


Advantages of steel X16H11M3





No necessity in post-welding heat treatment



NEW MATERIALS FOR BN REACTORS (Stage II)

DEVELOPMENT OF MATERIALS FOR A SERIES BN-1200 FAST NEUTRON REACTOR

Installation

Atmospheric corrosion

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Higher resistance to pitting corrosion

Modification of structural materials

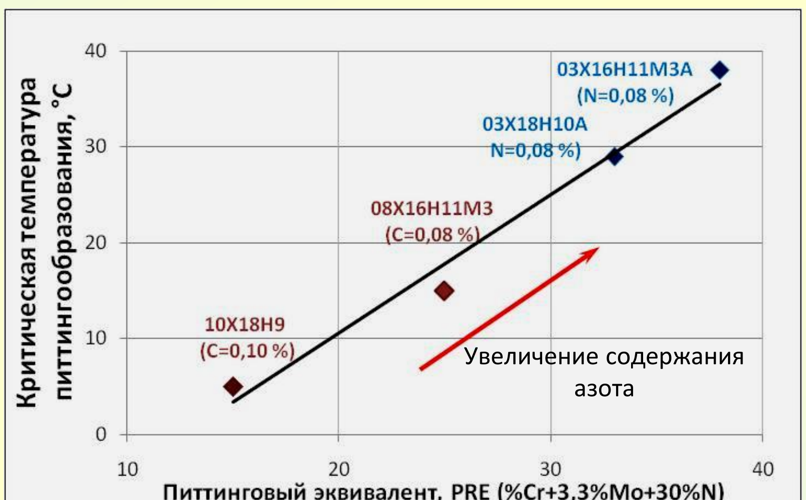
Lower content of carbon and nitrogen doping of steel grades 08X18H9 and 08X16H11M3

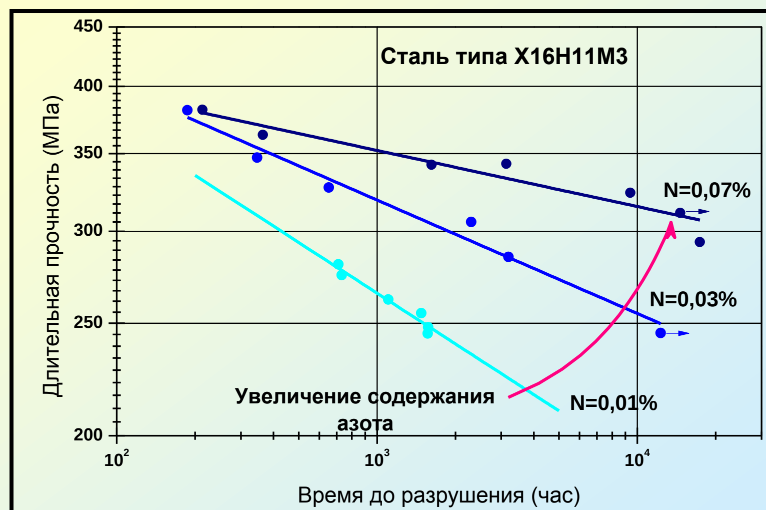
Operation

Operation under creep conditions

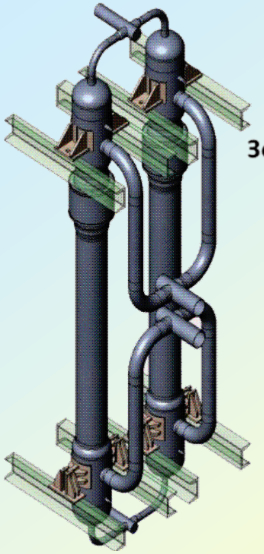
↓

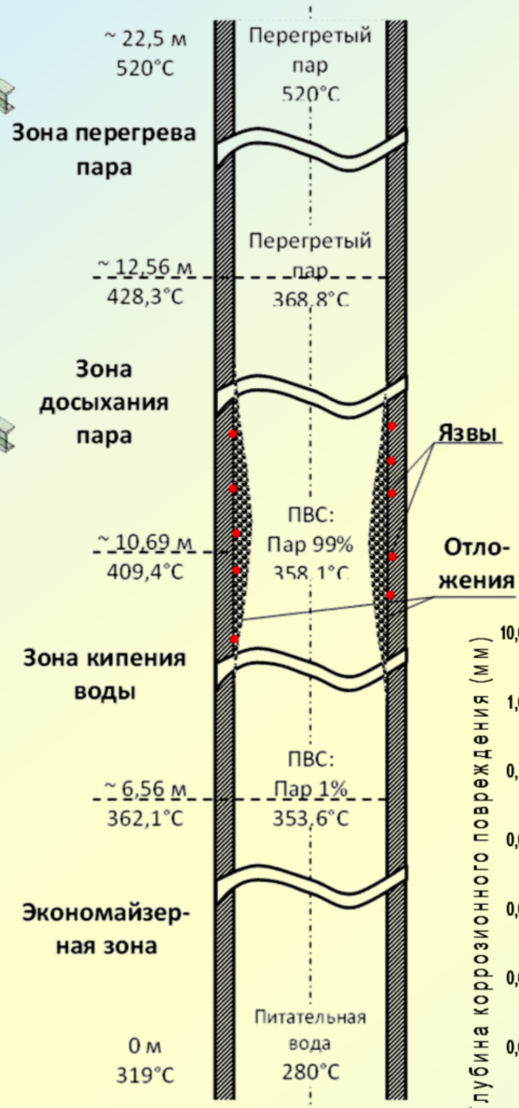
Higher resistance to heat-induced aging





DEVELOPMENT OF MATERIALS FOR STEAM GENERATOR OF BN-1200 FAST NEUTRON REACTOR





Corrosion damage

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Higher resistance to pitting corrosion

Operation inder creep conditions

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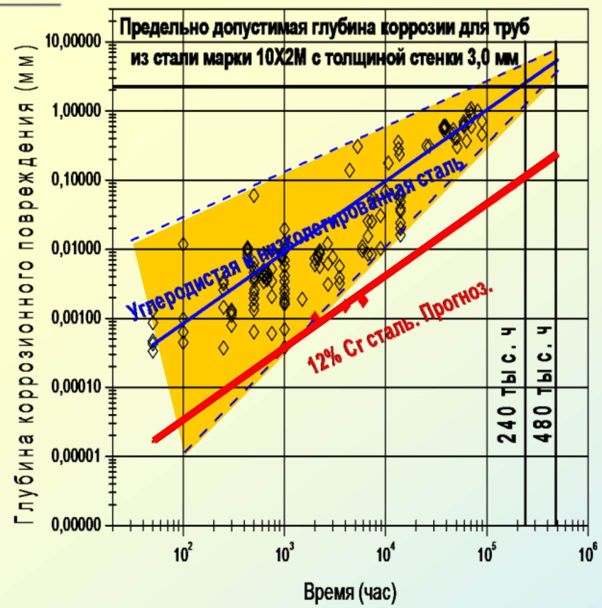
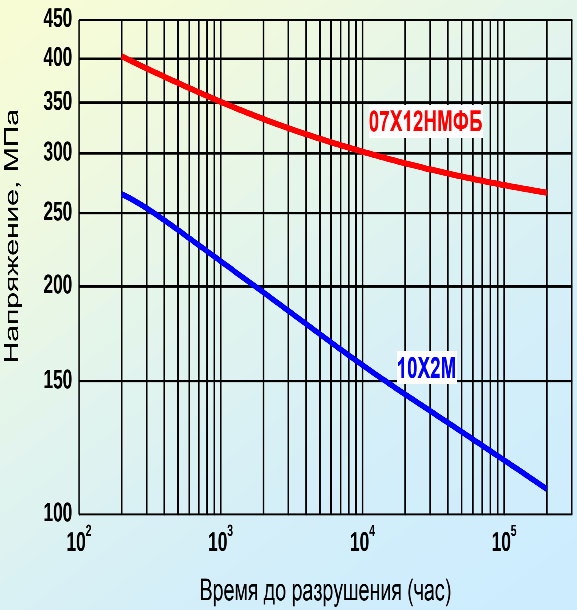
Higher heat resistance

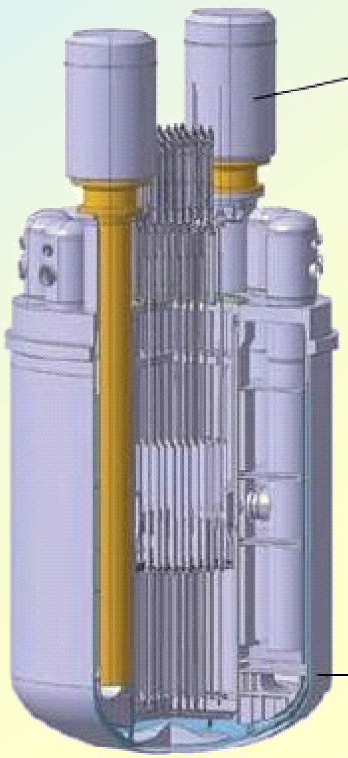
Material
Development of new heat-resisting steel
12% Cr 07Х12НМФБ





CHALLENGES TO ENSURE STRENGTH AND DURABILITY OF RPV AND EQUIPMENT OF RI WITH Pb and Pb-Bi COOLANTS

Pb-Bi



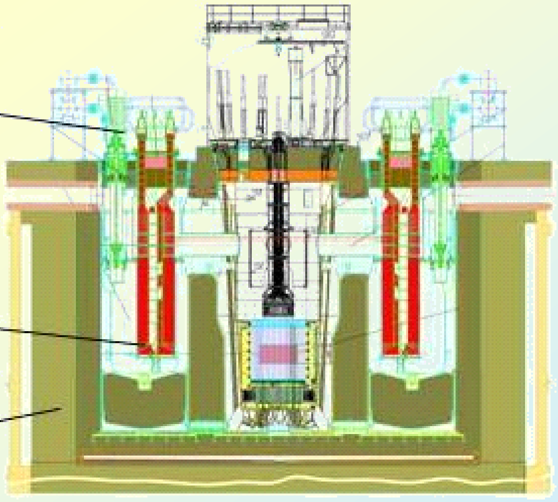
Парогенератор

- Коррозионная стойкость в пароводяной среде при ресурсе до 400 тыс. час.
- Коррозионная стойкость в жидком Pb и Pb-Bi.

Корпус + ВКУ

- Коррозионная стойкость в жидком Pb и Pb-Bi.
- Радиационная стойкость при повреждающих дозах до 20-30 сна.

Pb



SVBR-100

Brest - 300

DEVELOPMENT OF MATERIALS FOR REACTORS WITH Pb and Pb-Bi COOLANTS

N-subs Pr. 705

-Development of structural materials: austenitic silicon steel 10Х15Н9С3Б1 (EP 302), low-alloyed silicon steel grades 15Х1СМФБ, 10Х1С2М
Testing of coolant technology
-Pre-oxidizing of coolant piping in gas and liquid metal media;
-Periodic treatment of Pb-Bi alloy with hydrogen and subsequent addition of oxygen

Pb-Bi, T_{max} = 465°C

BREST-300

Application of steel: austenitic silicon steel 10Х15Н9С3Б1 (EP 302), 16Х12ВМСФ5Р (internals),
9%-chromium steel with silicon 10Х9НСМФБ, austenitic silicon steel Х18Н13С2АМВФ5Р (steam generator tubes)
Maintaining concentration of O_2 in Pb at 10^{-6} %

Pb, T_{max} = 550°C

SVBR-100

Application of steel
-10Х15Н9С3Б1 (EP 302) (internals)
-bimetal tubes in steam generator 10Х15Н9С3Б+ 03Х21Н32М3Б (EP 302 + CS-33)
Maintaining concentration of O_2 in Pb-Bi at 10^{-6} %

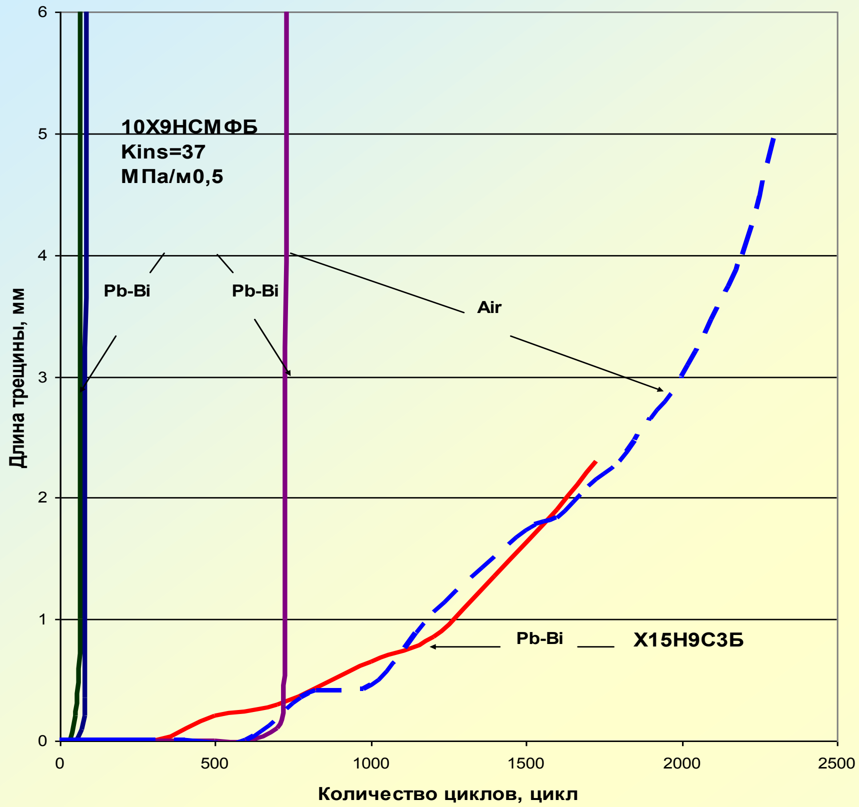
Pb-Bi, T_{max} = 490°C

BREST-1200

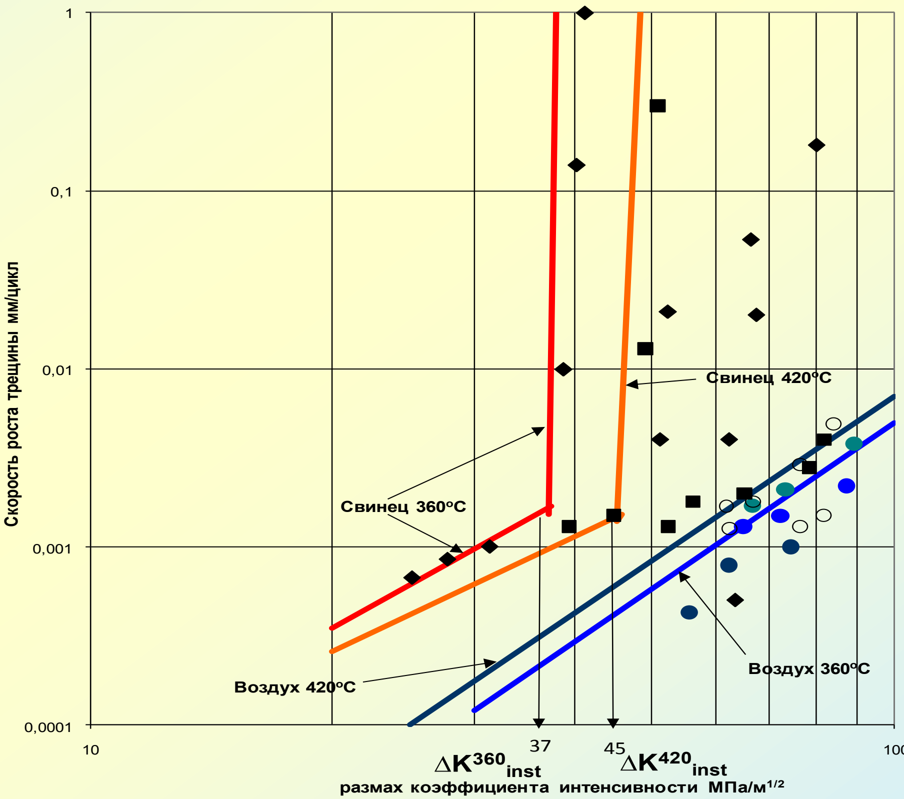
Development of structural materials: austenitic silicon steel 04Х15Н11С3МТ (internals)
9%-chromium steel with silicon 10Х9НСМФ
austenitic silicon steel Х18Н13С2АМВФ5Р (steam generator tubes).
Maintaining concentration of O_2 in Pb at 10^{-6} %

Pb, T_{max} = 550°C

ADSORPTION EFFECTS BY LIQUID METAL COOLANT ON STRUCTURAL MATERIALS

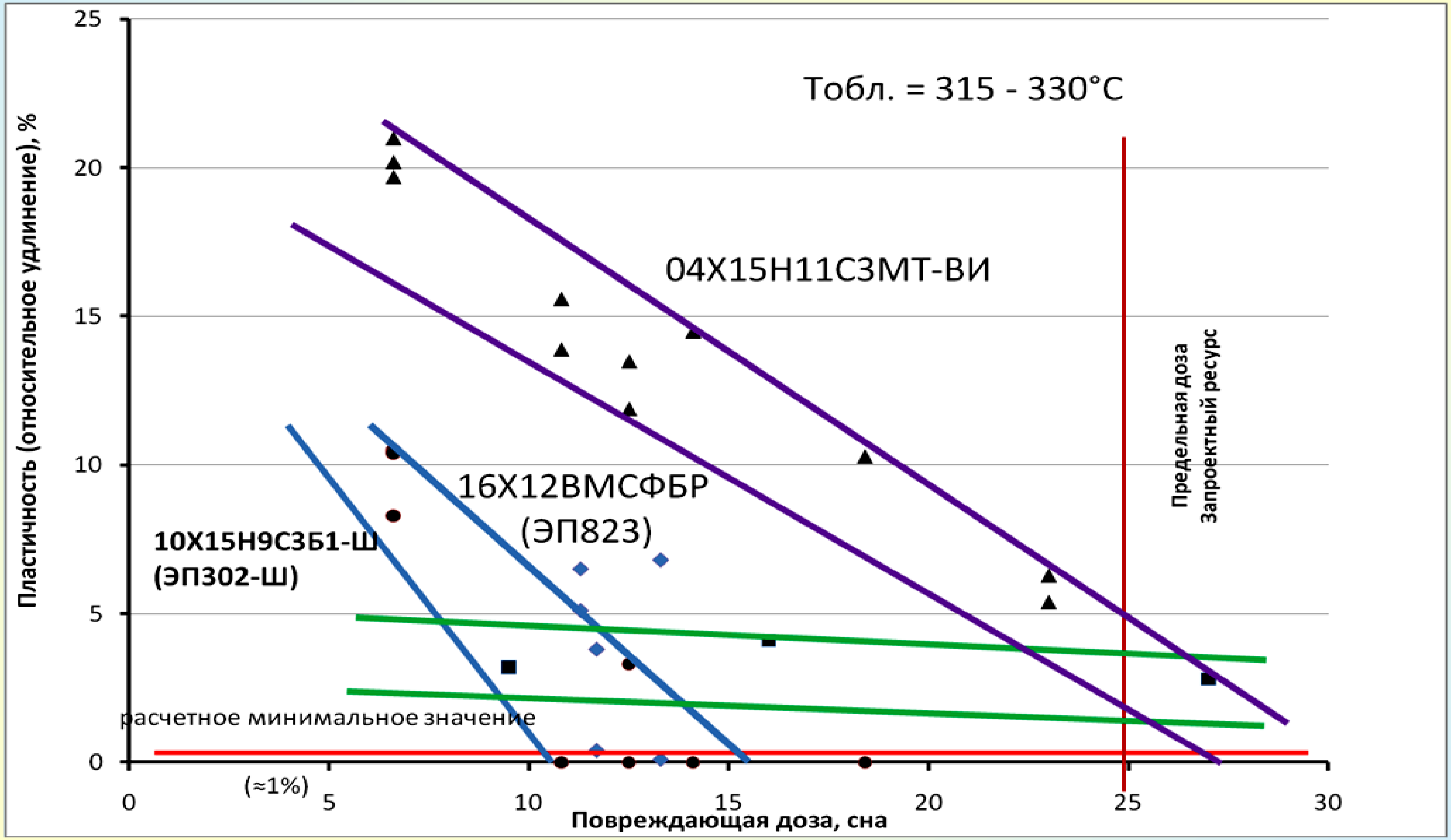


Crack kinetics at 360 C for chromium steel 10Х9НСМФБ and austenitic steel 10Х15Н9С3Б (EP 302) in liquid metal coolant and air



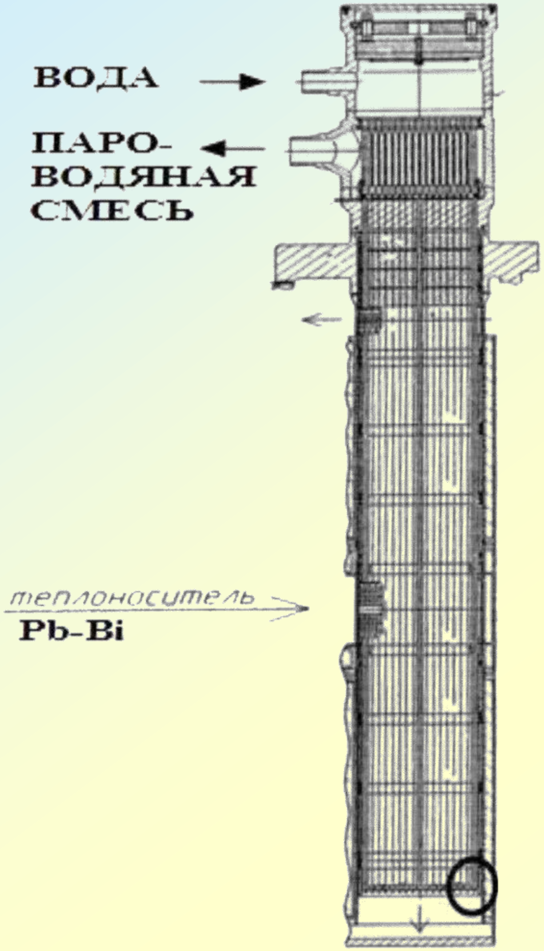
Generic dependence of growth of fatigue cracks in steel 10Х9НСМФБ(ά) in lead and air at different temperatures.
(– lead 420 C, - lead 360 C,
o - air 420 C, - air 360 C.)

RADIATION RESISTANCE OF STRUCTURAL MATERIALS OF REACTOR INTERNALS OF RIs WITH HEAVY COOLANTS

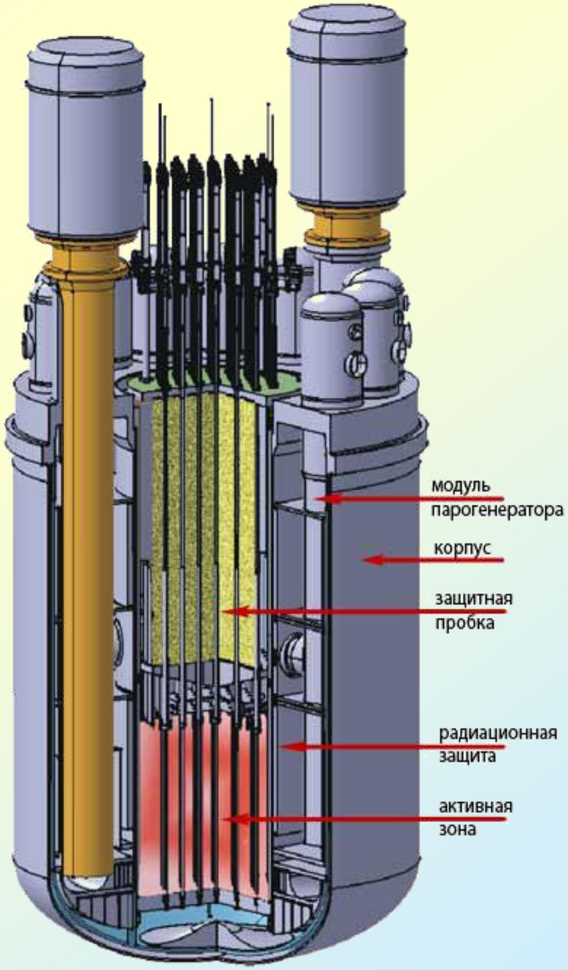


Steel plasticity depending on damaging dose (dpa)

IMPORTANT CONCLUSION:



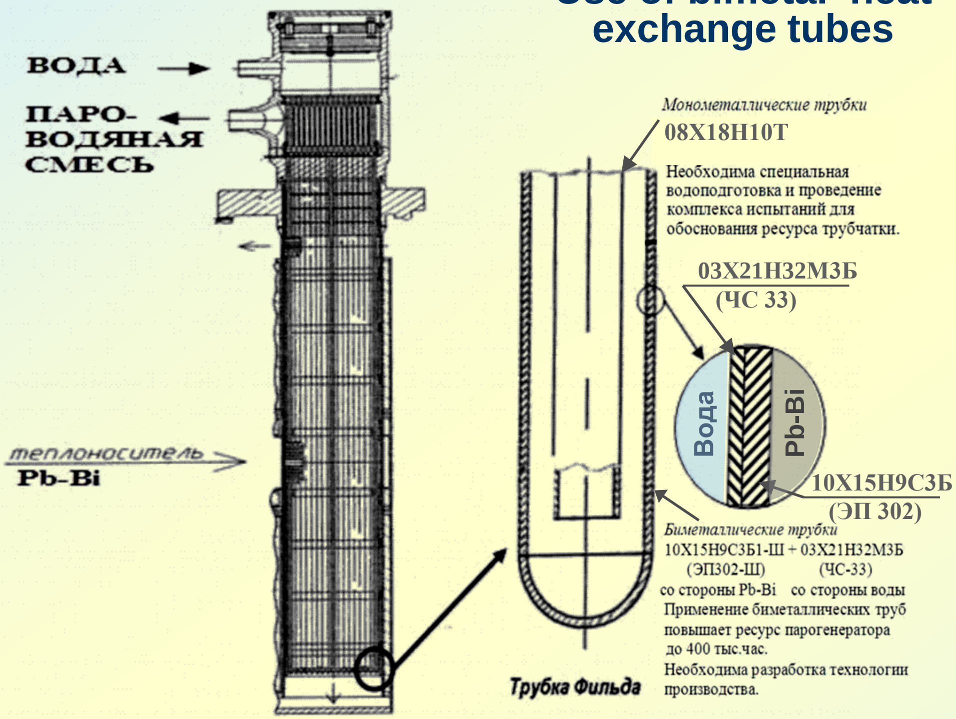
To ensure safe operation of fast neutron reactors with lead and lead-bismuth coolants, ferritic steel grades contacting with liquid metals should not be applied

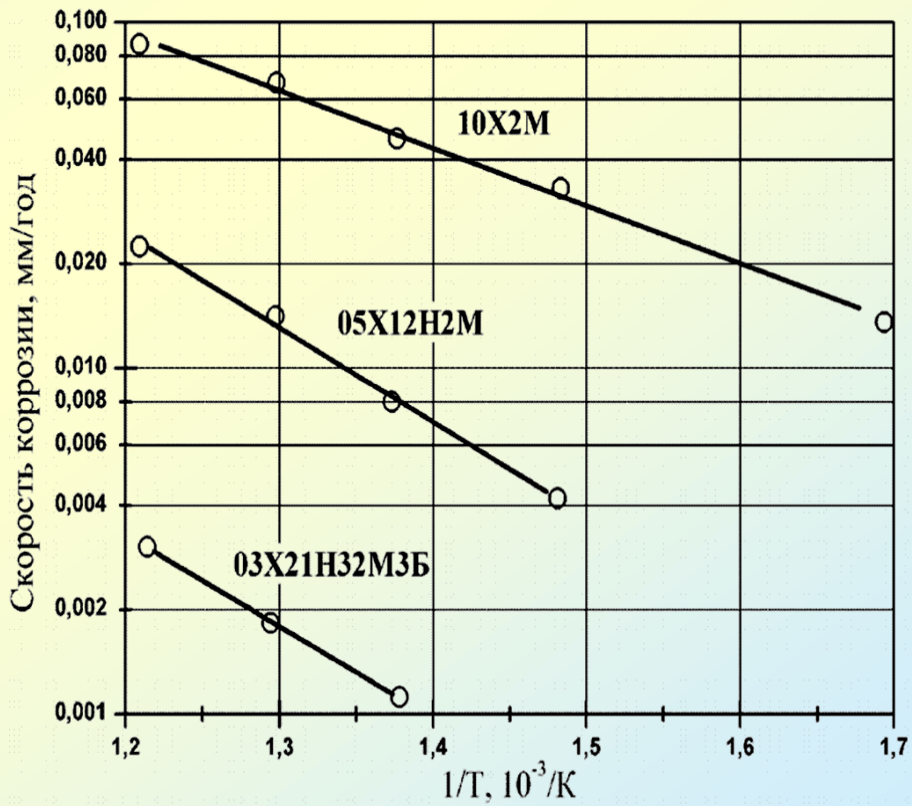


SELECTION OF STRUCTURAL MATERIALS FOR HEAT EXCHANGE TUBES OF STEAM GENERATORS OF REACTOR INSTALLATIONS WITH HEAVY COOLANTS

Особенности: одновременное воздействие жидкого металла и пароводяной среды.

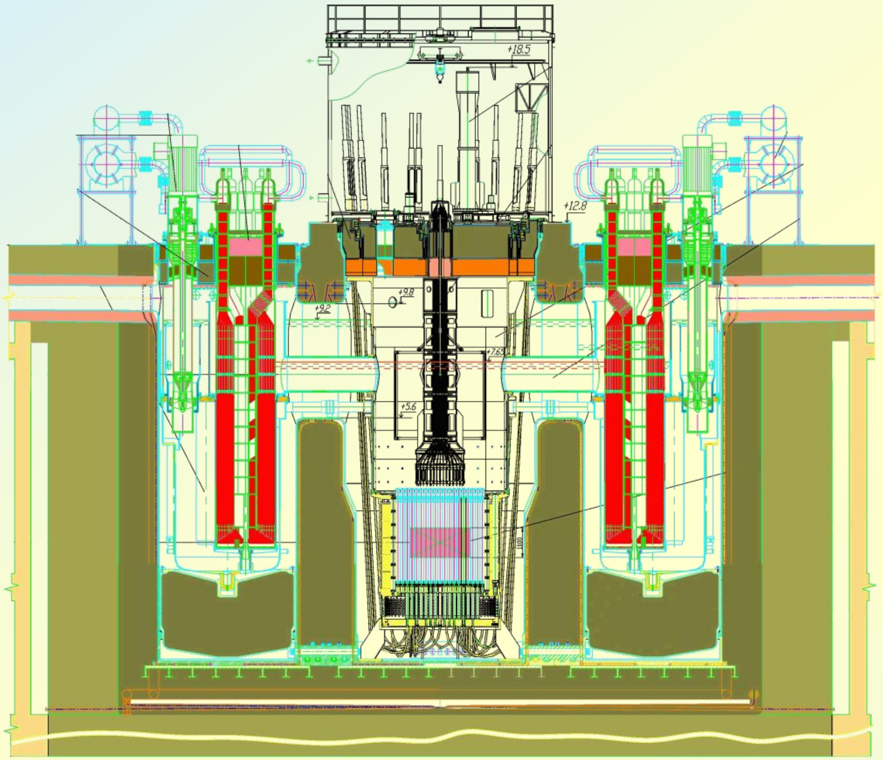
Use of bimetal heat exchange tubes





Total corrosion in steam-water medium of main structural materials of steam generator heat exchange tubes

REACTOR INSTALLATIONS WITH LEAD COOLANT BREST-OD-300, BREST-1200



General view of BREST-OD-300 installation

Operational impact on structural materials of reactor installations with lead and lead-bismuth coolants is similar.
This opens up an opportunity to use the same materials for reactor installations of designs SVBR-100, BREST-OD-300 and BREST-1200.
However, with this, higher operating temperature of installations with lead coolant should be taken into account: 550°C instead of 475°C.

CONCLUSION

1. At the modern stage of the nuclear power advancement the process of development and performance justification of new structural materials determines to a great extent the success of development and implementation of entirely new engineering solutions.
2. The development of structural materials for nuclear power installations equipment is a complex and long-term process which envisages:
   - stage-by-stage improvement of a material chemical composition;
   - stage-by-stage improvement of its fabrication technology;
   - integrated tests of its service characteristics;
   - generalization of operating experience.
3. The process of development and advancement of structural materials and their fabrication technologies is an intrinsic part of safety ensuring during operation of the nuclear power equipment.

THANK YOU FOR ATTENTION!