THE STATE OF THE ART OF WWER TYPE RPV:
radiation embrittlement and mitigation

A.Kryukov

RRC “Kurchatov Institute”
The schematic of weld seam locations on the WWER-440 Reactor Pressure Vessel.
PROBLEMS

- Higher IE of the Weld with High Levels of P and Cu
- Lack of Surveillance Program
- Lack of Archive Metal
- Lack of Precise Data for P and Cu Content
- Relatively High Levels of Fluence and Flux
- Out of the 16 Vessels 9 are not Cladded
MAIN ACTIVITIES

- Validation of Empirical Relationships between Irradiation Embrittlement (DBTT shift) and Chemical Composition as well as Irradiation Conditions (Temperature, Fluence, Flux)

- Annealing Regime Validation

- Re-Embrittlement after Annealing Behaviour Investigation

- Initial Mechanical Properties ($T_k$) Determination

- Evaluation of Actual Materials Properties of Pressure Vessels of Operating WWER-440/230 NPP
Correlation between the values of radiation response measured in accordance with Russian Guide ($\Delta T_k$) and those of $\Delta T T_{41}$ and $\Delta T T_{68}$
Comparison between measured and calculated values of the radiation-induced DBTT shift.

- □ - R-1 / BM
- ■ - R-1 / WM
- △ - R-2 / BM
- ▲ - R-2 / WM
- ○ - R-3 / BM
- ● - R-3 / WM
- ◇ - R-4 / BM
- ■ - R-4 / WM
- ▽ - R-5 / BM
- ▼ - R-5 / WM
Fig. 3 Phosphorus distribution near grain boundary in the irradiated 15KhMFA steel (1 - F=1.2x10^{20} n/cm^2, 2 - unirradiated steel)
Dependence of the residual DBTT shift on nickel content.
Transition temperature as a function of lifetime for weld metal 4 NVNPP-4.
Transition temperature as a function of neutron fluence for "Kozloduy-1" weld metal 4.
Comparison of calculated and measured values of re-irradiation response
The dependence of P and Cu variation though the wall thickness of RPV weld metal 4 NVNPP-2.
Evaluation of irradiation embrittlement and also efficiency of NVNPP-2 weld annealing.
CONCLUSIONS

On the Base of Preliminary Results of TACIS '91 and Former Research Programme the Following Conclusion Can Be Drawn:

- There is a correlation between subsize specimens and standard Charpy specimens

- The actual properties of RPV can be evaluated by subsize impact and tensile specimens fabricated out of samples taken from the RPV inner surface

- There is an agreement between predicted and measured Tk shift values caused by primary irradiation

- The uninitial transition temperature Tko, calculated from chemical composition is not conservative

- Annealing is the effective method to recover Tk

- The prediction of the transition temperature shift under re-irradiation after annealing by the "lateral shift" model, by the results available up to now, to be conservative
Fig. 6 Transition temperature shift observed for melt with different levels of copper and phosphorus content.

\[
F = 1 \times 10^{20} \text{ cm}^{-2} \quad (E > 0.5 \text{ MeV})
\]

\[
\text{Tirr} = 270 \degree C
\]

Cu = 0.05\%

P = 0.010\%
Effect of nickel content on radiation stability of weld metal.
CURRENT CONCERN TASKS for WWER-440
LIFE MANAGEMENT

( 230 and 231 models )

- to elaborate RE assessment method taking into account neutron fluence, flux and spectrum

- to relate the surveillance results to embrittlement trends for RPV

- to elaborate new Codes on the modern database

- to justify the model for re-embrittlement (after annealing) prediction

- to create International Data Base on Aging Management and Life Extension (IAEA)
CURRENT CONCERN TASKS for WWER-1000 
LIFE MANAGEMENT

- most of WWER-1000 RPV do have high Ni contents from 1.5 up to 1.9% in welds - higher rate of IE is expected

- only two materials, one from a shell beltline course, one from a beltline weld are included in surveillance programme

- surveillance capsules are located above core in the position with high fluence gradient. Mean flux level is approximately the same as on RPV wall while the energy spectrum is different

- surveillance results for vessel embrittlement assessment may give non-conservative results