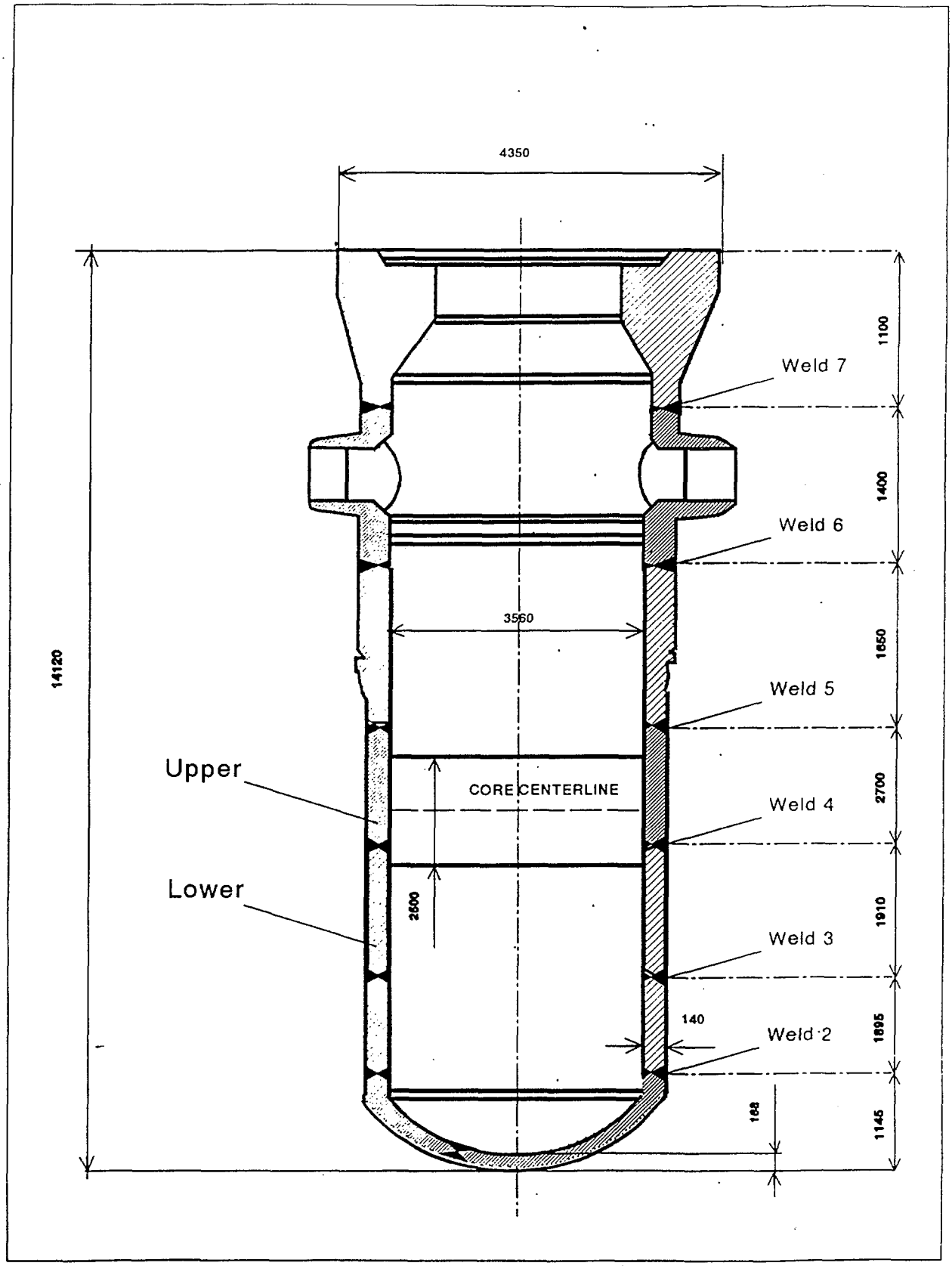
SPECIALISTS MEETING ON IRRADIATION EFFECTS AND MITIGATION

Vladimir, Russia, 15-19 September, 1997

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

- **Higer 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

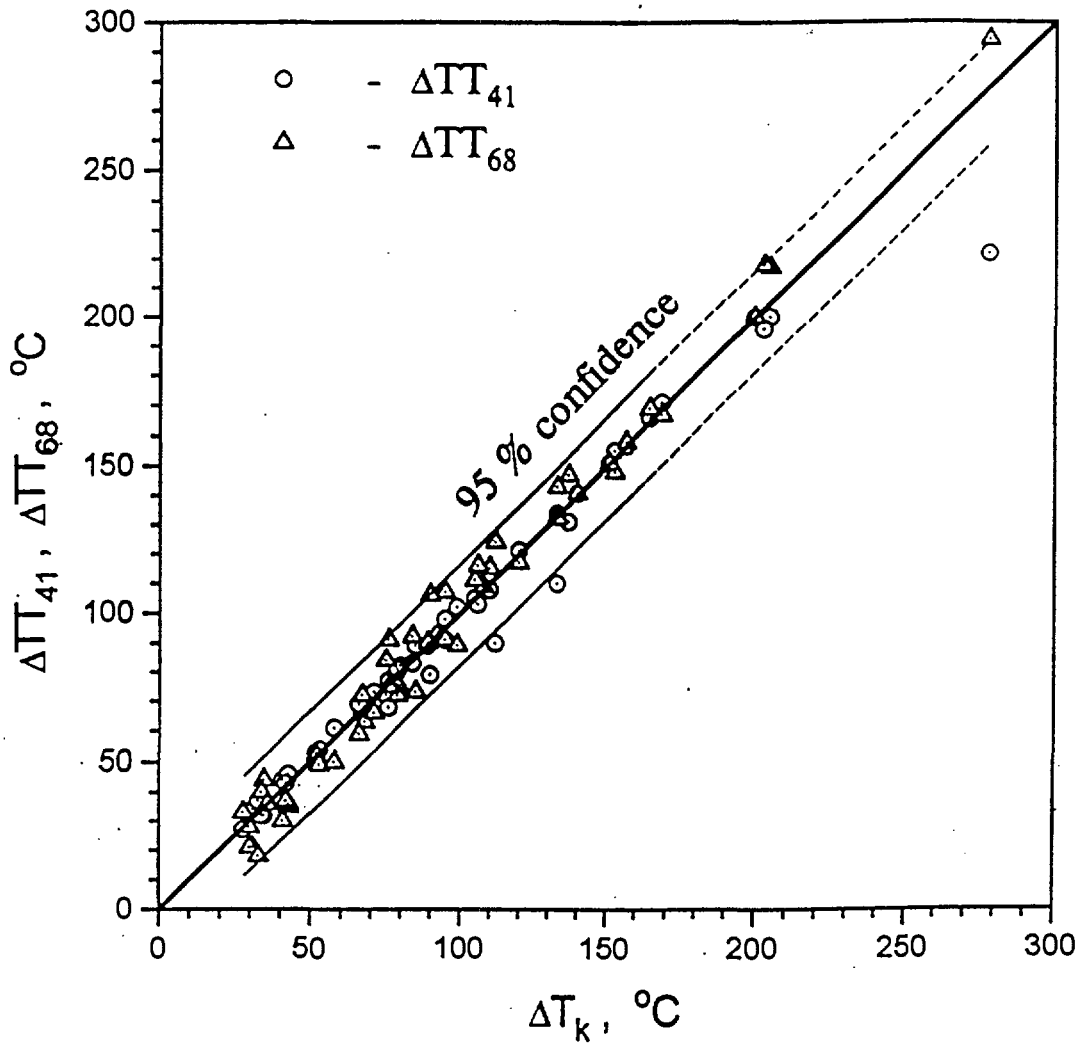
- **Validation of Empirical Relationships between Irradiation Embrittlement (DBTT shift) and Chemical Composition as well as Irradiation Conditions (Temperature, Fluence, Flux)**

- **Annealing Regime Validation**

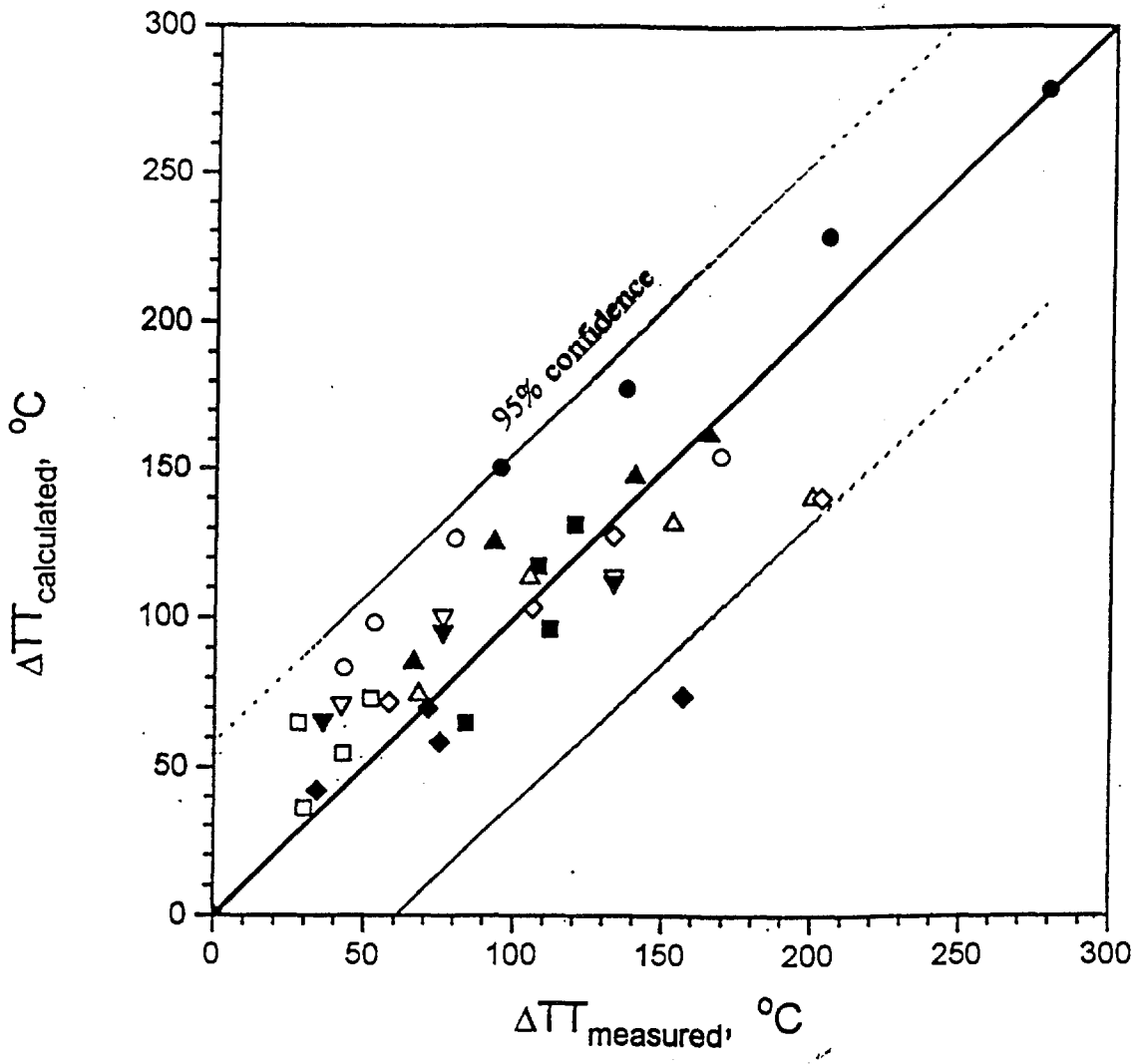
- **Re-Embrittlement after Annealing Behaviour Investigation**

- **Initial Mechanical Properties (T_{k0}) 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 (ΔT_k) and those of ΔTT_{41} and ΔTT_{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

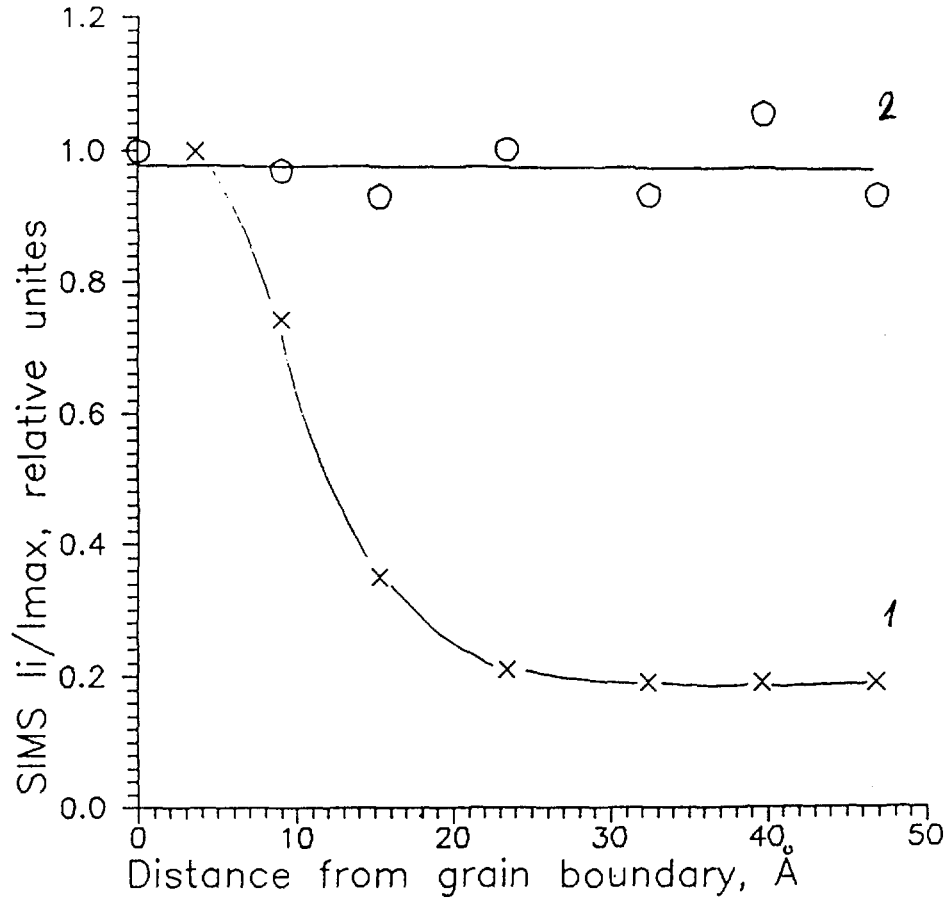
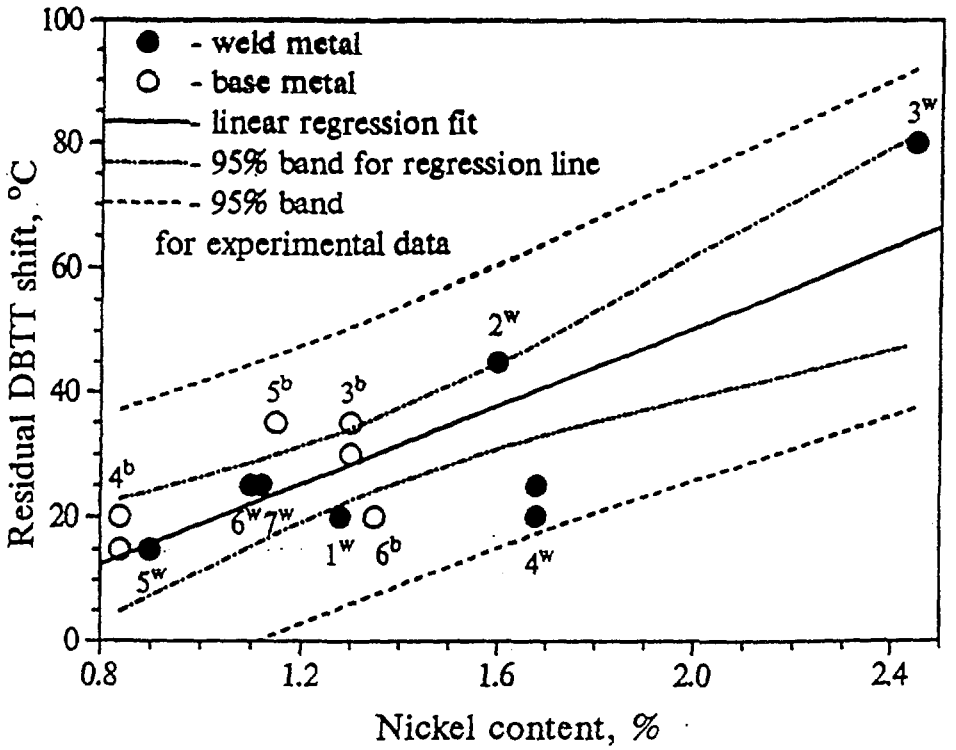
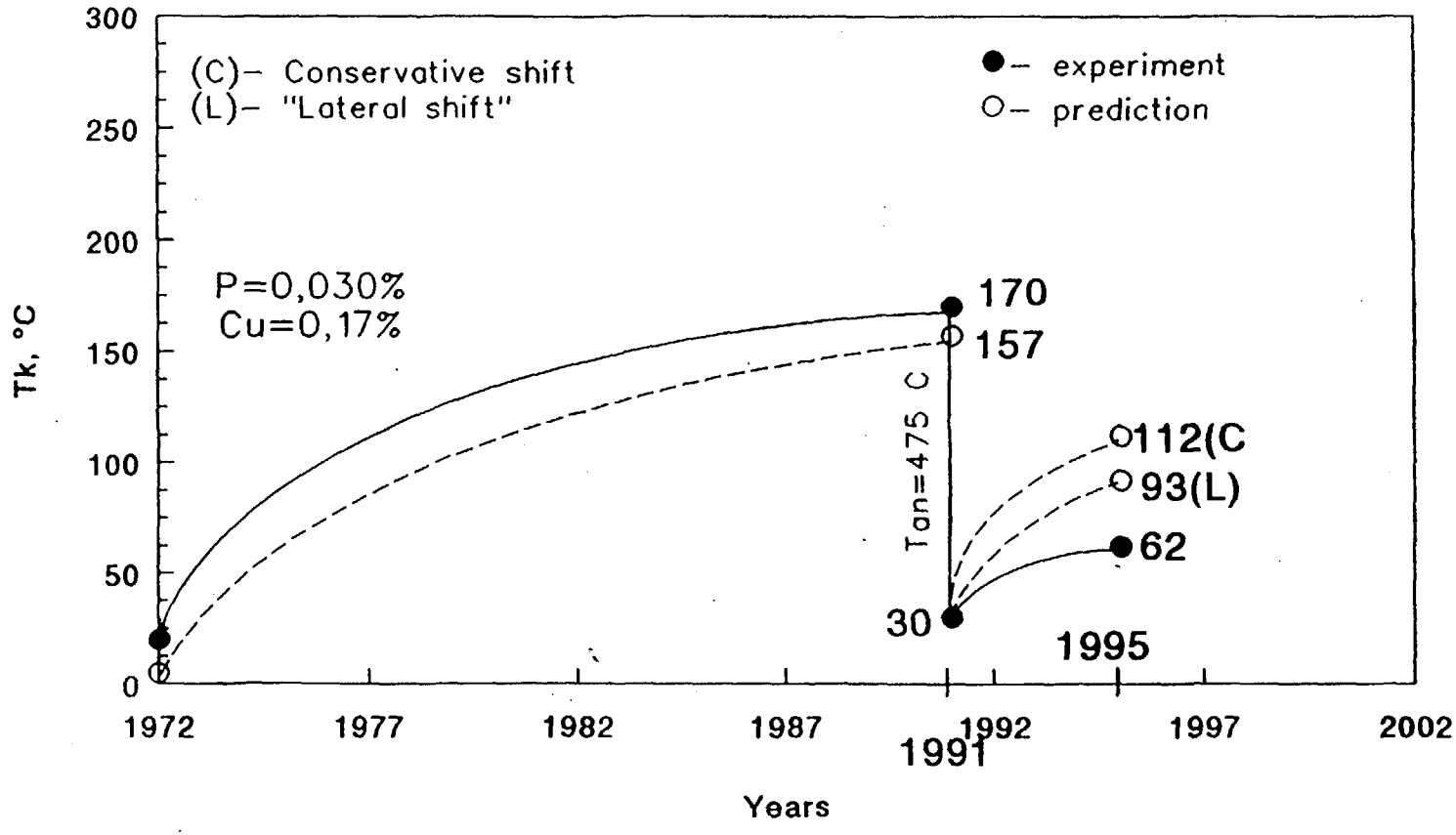


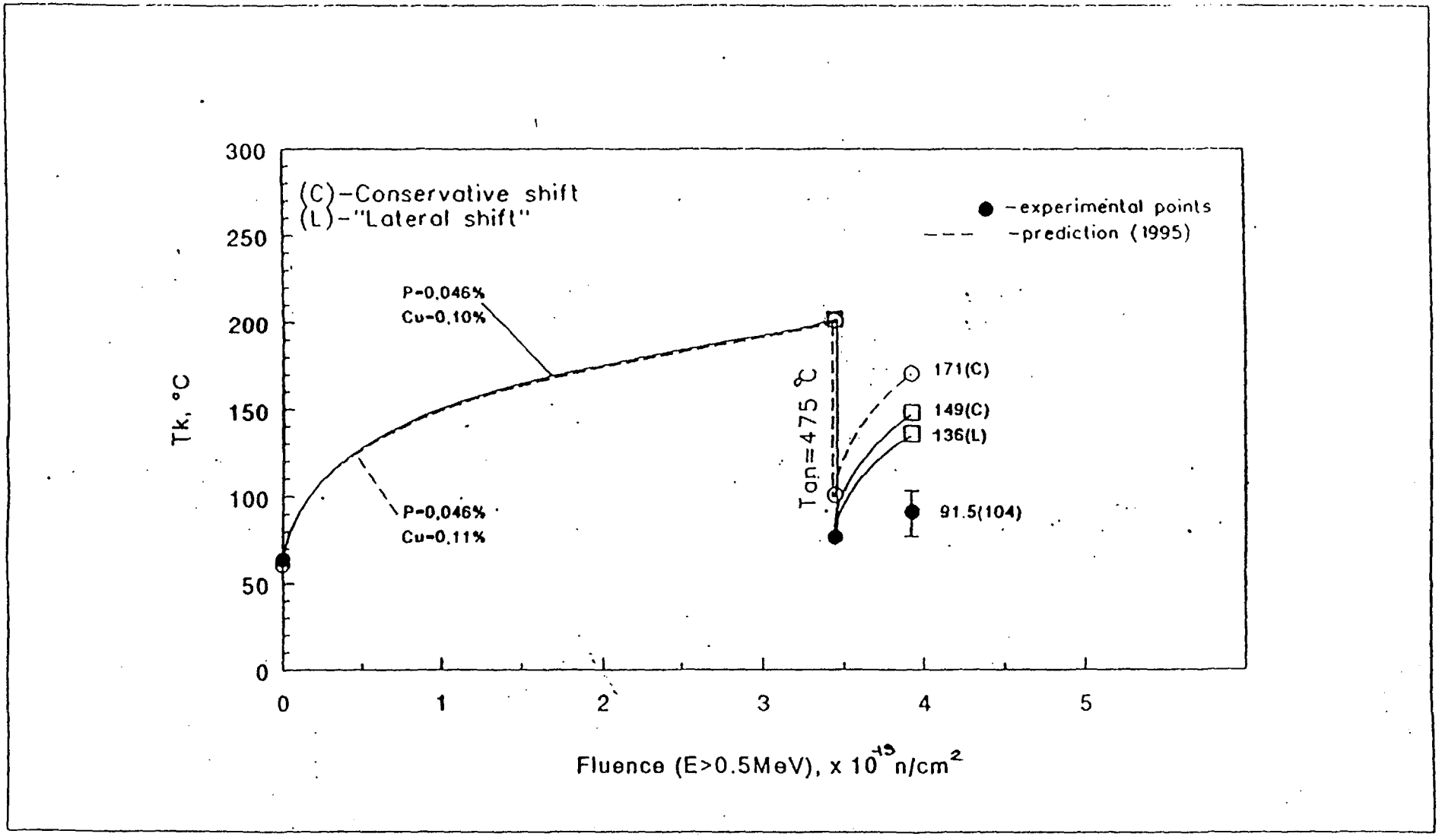
Fig. 3 Phosphorus distribution near grain boundary in the irradiated 15KhMFA steel (1 – $F=1.2\times10^{20}$ n/cm^2
2 – unirradiated steel)



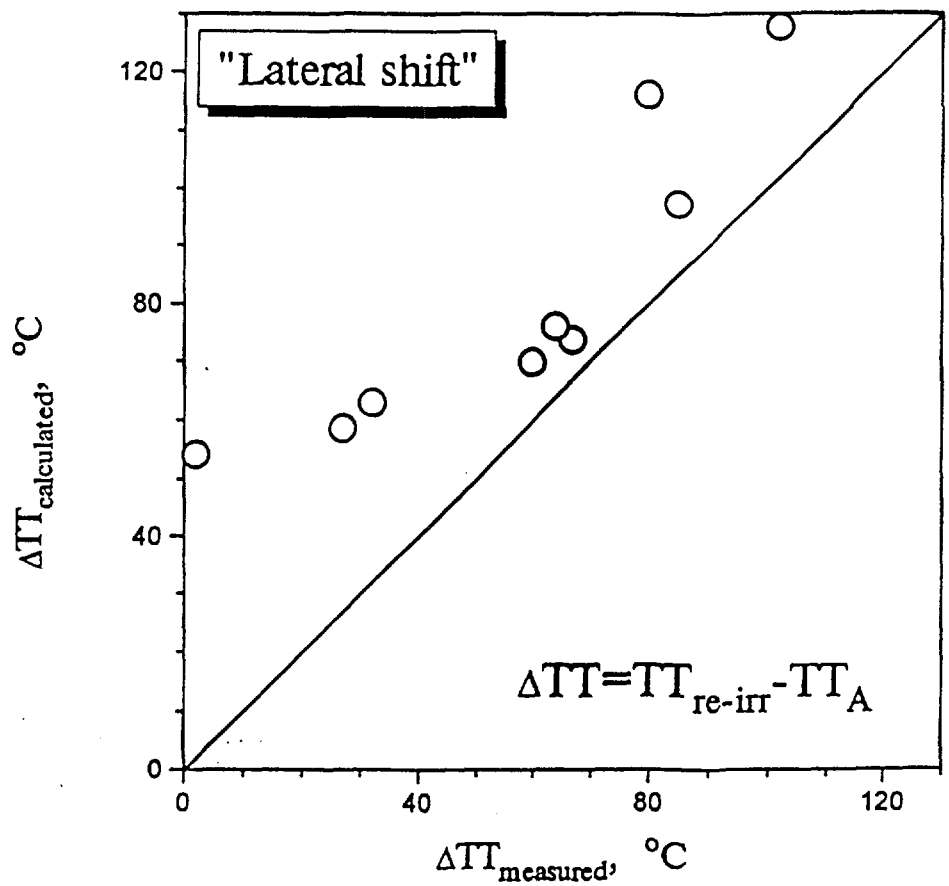
Dependence of the residual DBTT shift on nickel content.



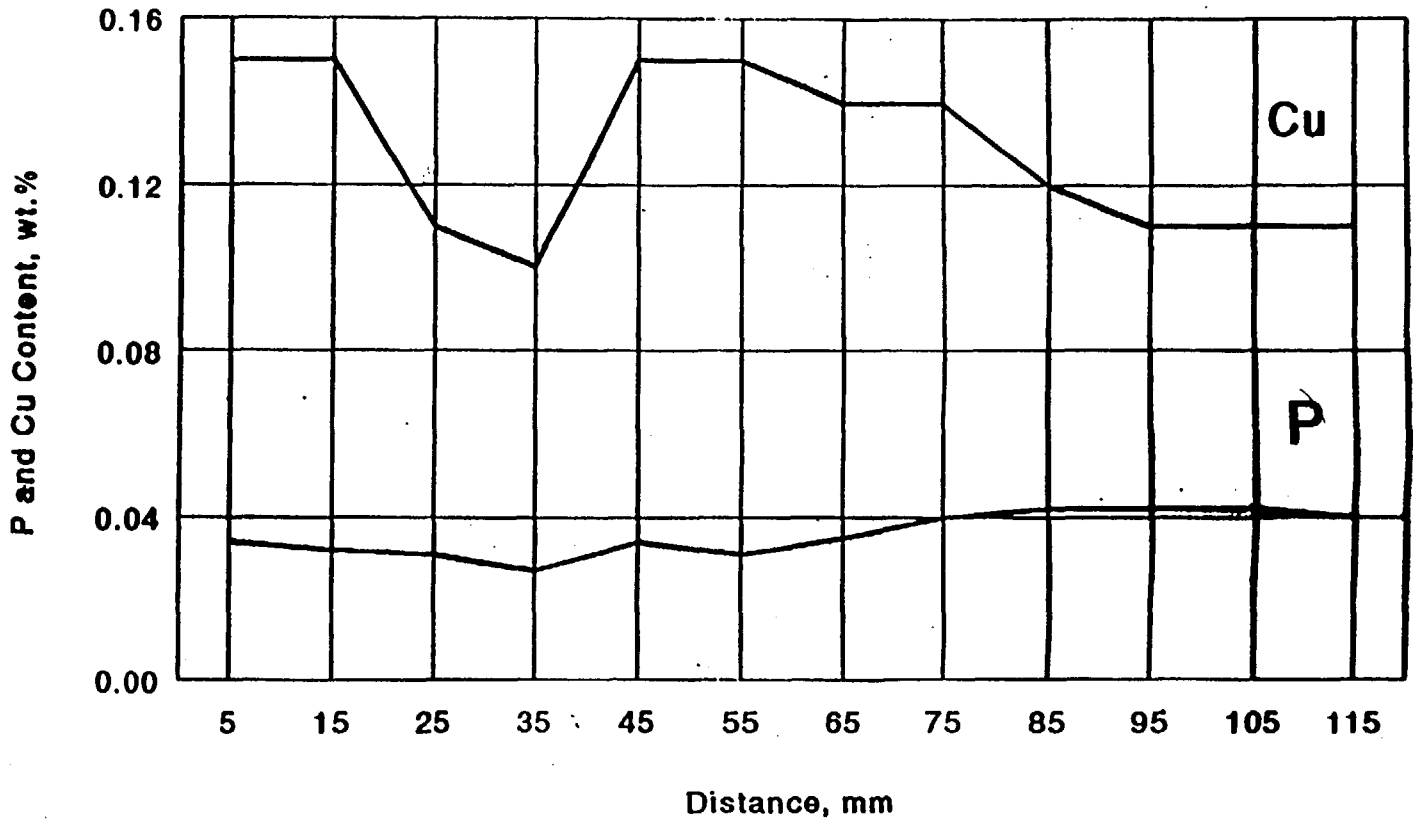
Transition temperature as a function of lifetime for weld metal 4 NVNPP-4.



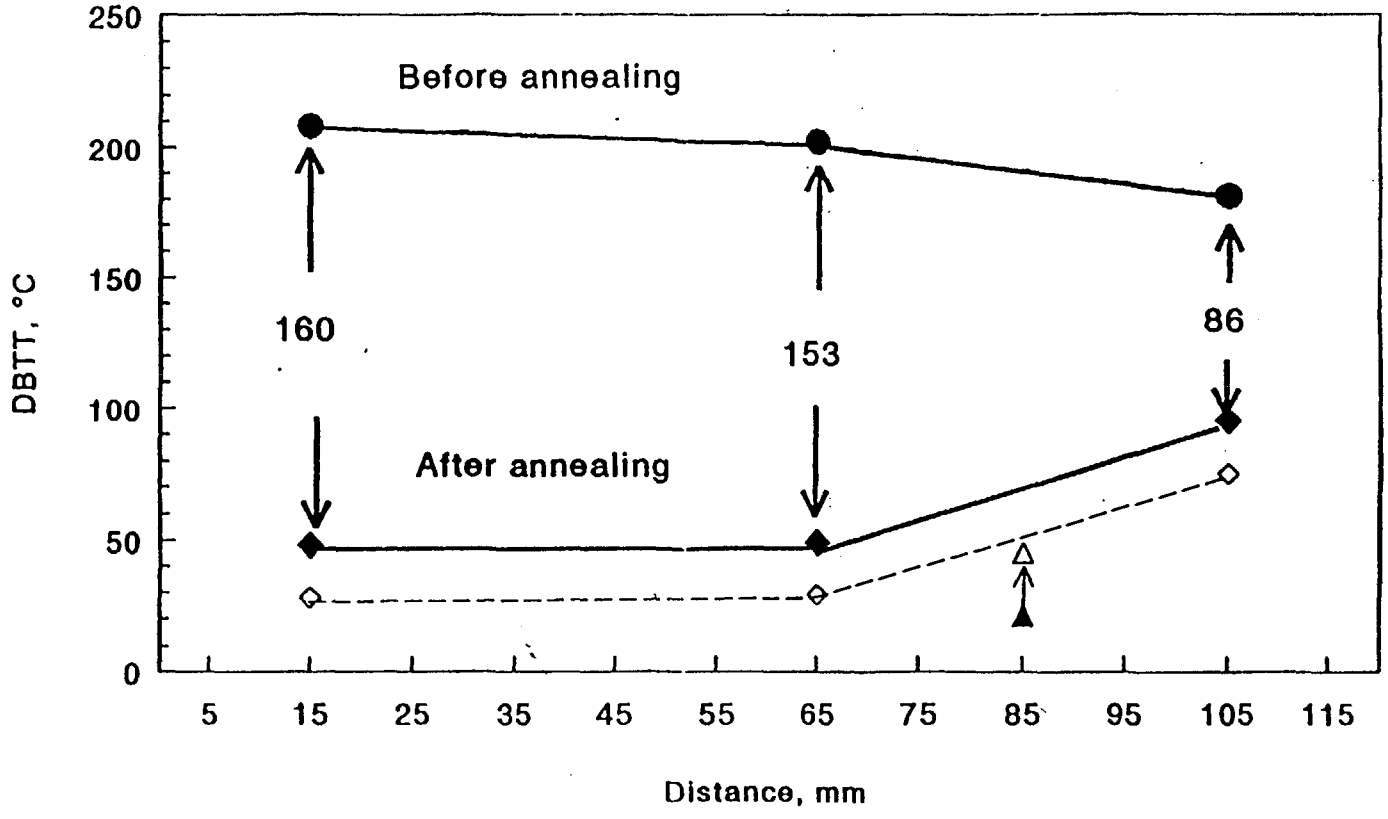
Transition temperature as a function of neutron fluence for "Kozloduy-1" weld metal 4.



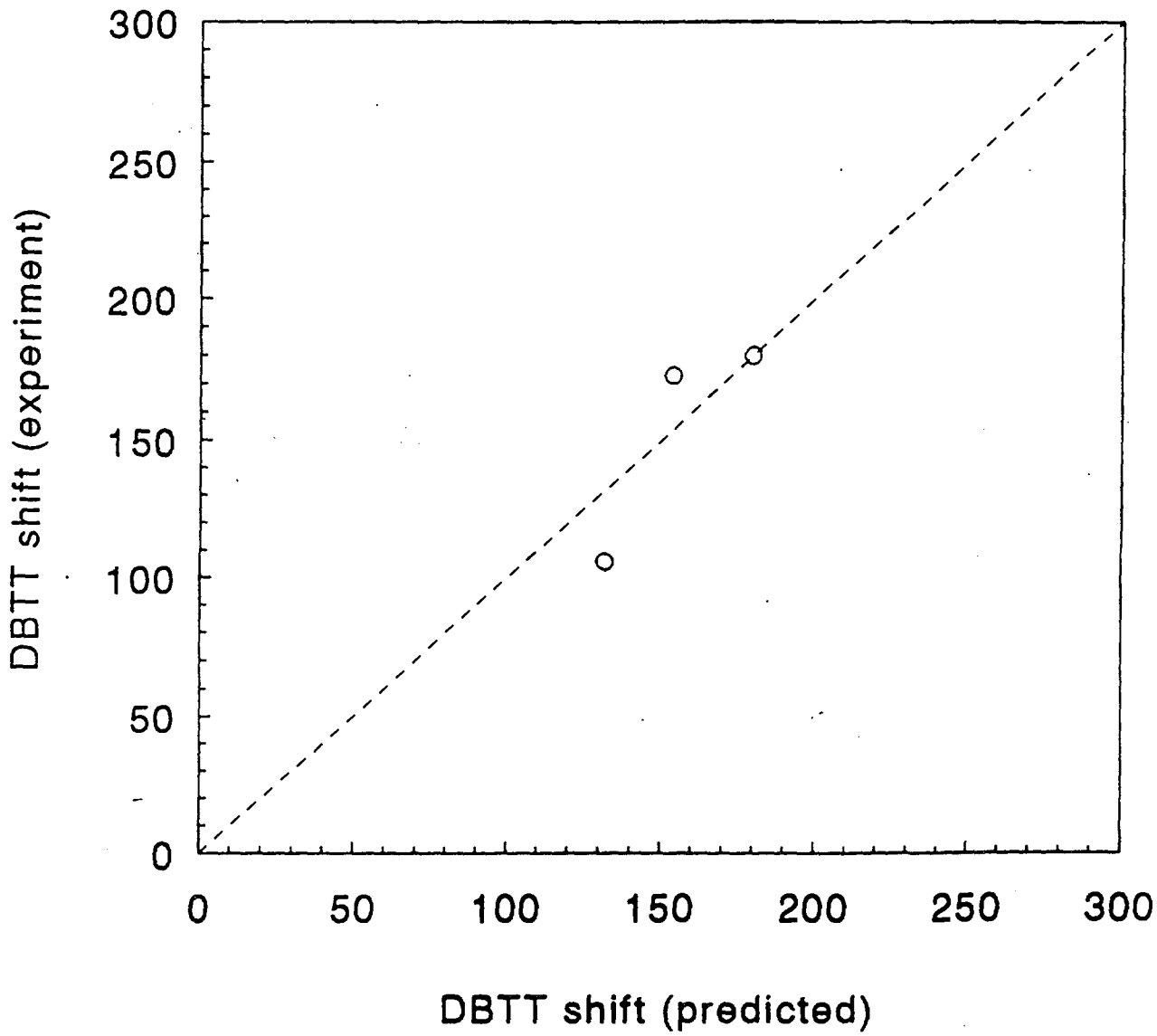
Comparison of calculated and measured values of re-irradiation response



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.


300
250
200
150
100
50
0
0
50
100
150
200
250
300
DBTT shift (experiment)
DBTT shift (predicted)

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 unitial 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**

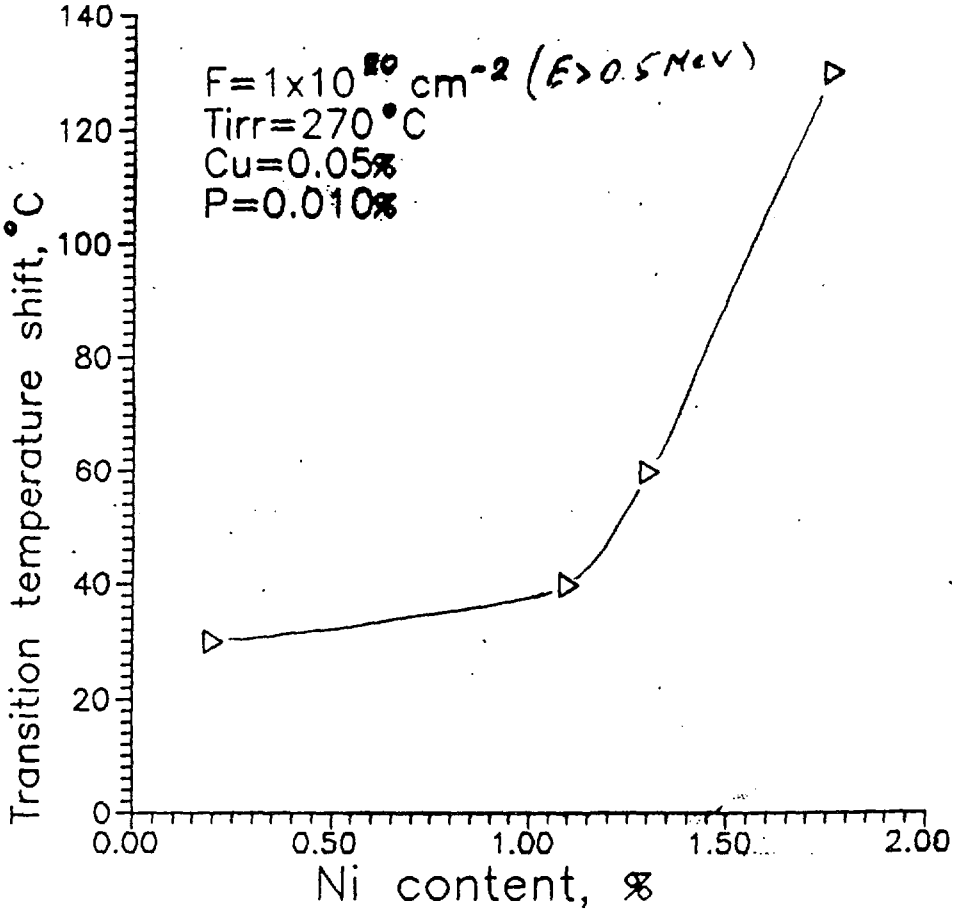
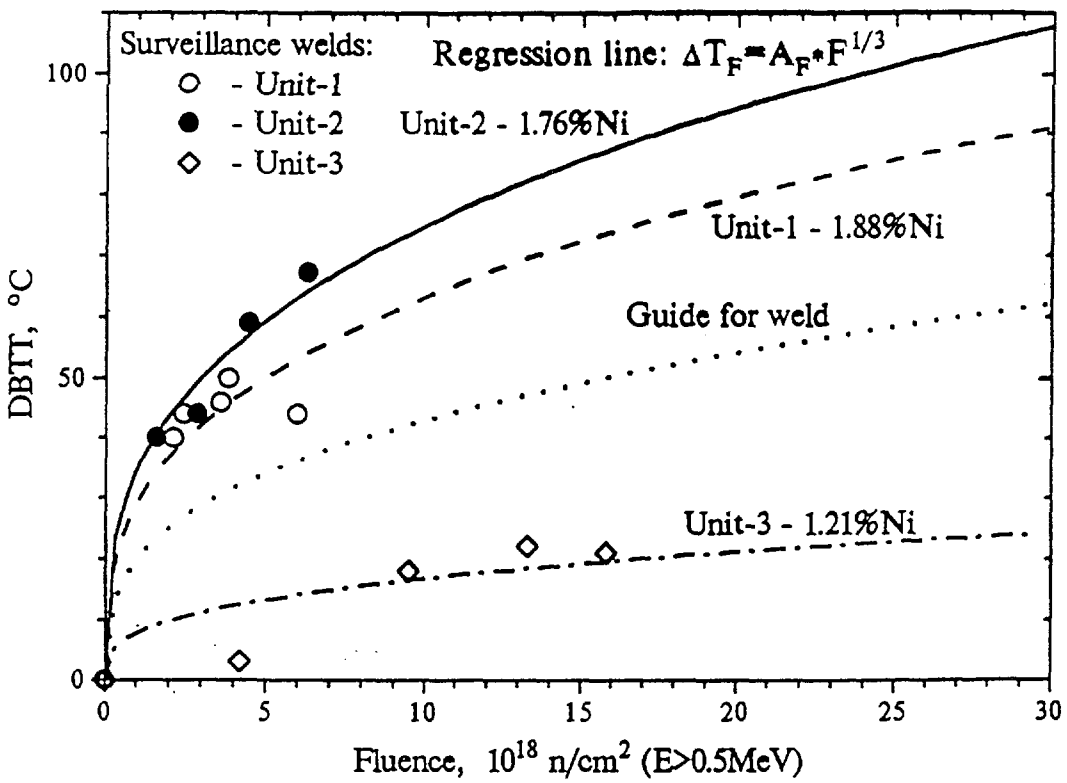


Fig.6 Transition temperature shift observed for melt with different levels of copper and phosphorus content



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