

MATERIAL & METALLURGICAL RESEARCH, Ltd.,  
Ostrava, Czech Republic  
Faculty of Metallurgy and Materials Engineering  
Technical University Ostrava, Ostrava, Czech Rep.  
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1<sup>st</sup> International Conference  
SSTT (Small Sample Test Techniques)

DETERMINATION OF MECHANICAL  
PROPERTIES OF MATERIALS BY  
SMALL PUNCH AND OTHER MINIATURE  
TESTING TECHNIQUES

August 31 to September 2, 2010,  
Ostrava, Czech Republic

# Evaluation of the reactor pressure vessel material properties degradation due to the irradiation by SPTmethod

[Ludovít Kupča](#)

Martin Březina - Jana Petzová

Miloš Bařák

[kupca@vuje.sk](mailto:kupca@vuje.sk)

# INTRODUCTION

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- ❑ The results of standard tests are used for the structural integrity assessment of nuclear power plant (NPP) components.**
- ❑ The standard tests need relatively high amount of original RPV material and after irradiation the samples must be tested in the special hot laboratories due to its very high activity.**
- ❑ Due to these facts there have been a number of research activities on the evaluation of base mechanical properties using the Small Punch Test (SPT) method.**

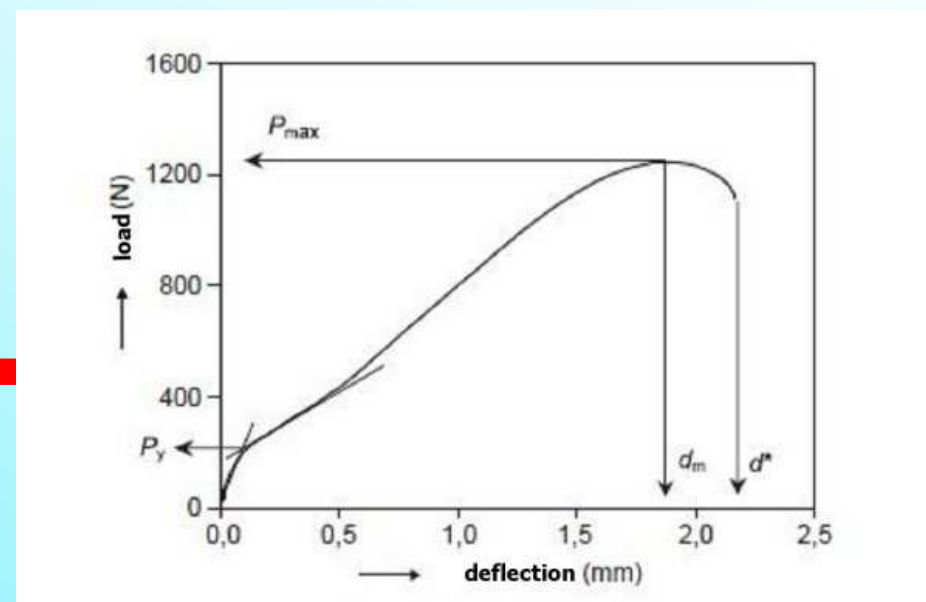
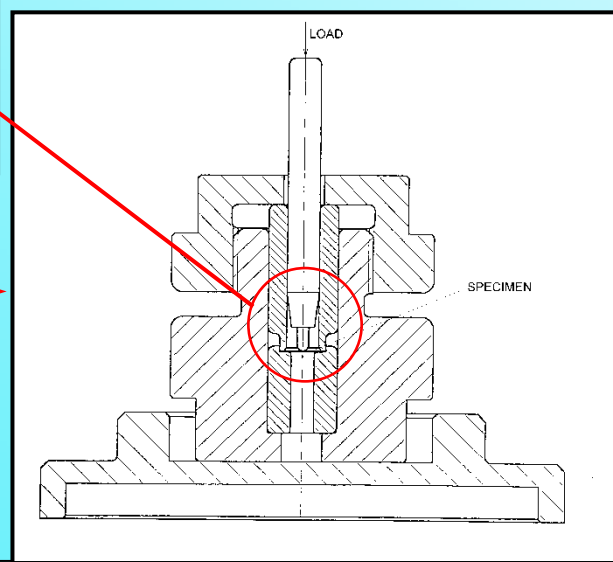
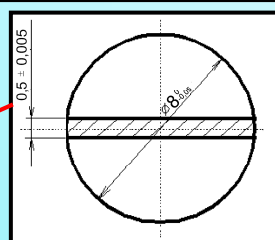
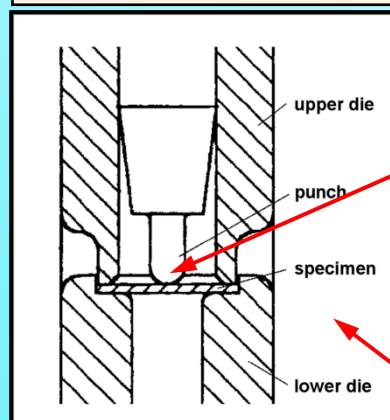
# INTRODUCTION

**Application of SP testing has several advantages:**

- **reduction the high consumption of original RPV materials,**
- **better placing of SP samples in the limited space available for irradiation in nuclear power reactors,**
- **the determination of material properties, which are highly dependent on the local microstructure like the HAZ material,**
- **using the same geometry of samples for several types of testing.**

# Principle of SPT method

The principle of SPT testing procedure is penetration of a disk specimen by a hemispheric rod and recording of loads and deflections during the test



Typical SPT load-deflection curve

# SPT – testing equipments



Testing holder - depends on the testing temperature and others demands:

- Low-temperature tests - thermal insulated chamber
- Testing at elevated temperatures – special furnace
- Testing with direct observation of the specimen surface → fracture toughness



## Experimental procedure

**By SPT testing we can obtain the following data:**

- **The yield stress and ultimate tensile strength, which are well correlated with the parameters  $P_y$  and  $P_{max}$ , respectively**
- **Ductile-brittle transition temperature (DBTT) can be estimated from the results of temperature dependence of small punch energy determined from the area under the load – deflection curve**

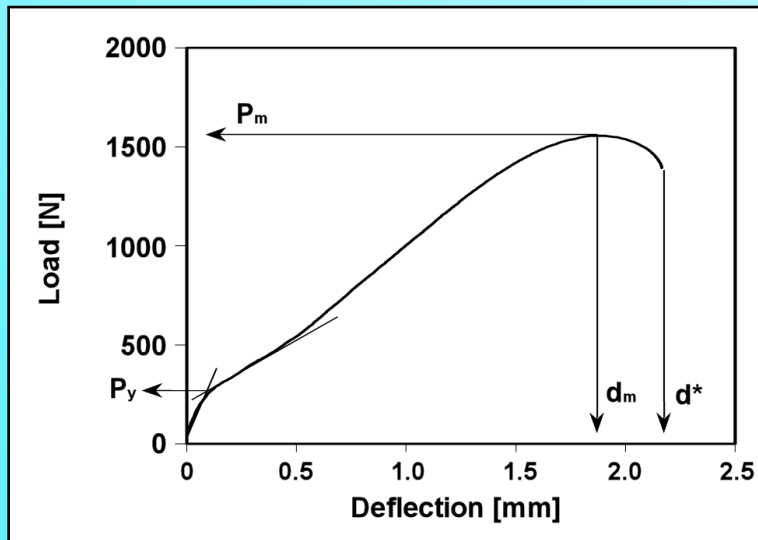
# Estimation of tensile properties

Following characteristics of load - deflection curve of tested specimen are used for tensile properties estimation:

$P_y$  [N] – load characterizing the transition from linearity to the stage associated with the spread of the yield zone through the specimen thickness (plastic bending stage)

$P_m$  [N] - maximum load recorded during punch test

$d_m$  [mm] - displacement corresponding to  $P_m$



$R_e$  - yield stress

$R_m$  - ultimate tensile strength

are well correlated with parameters

$P_y$  and  $P_m$

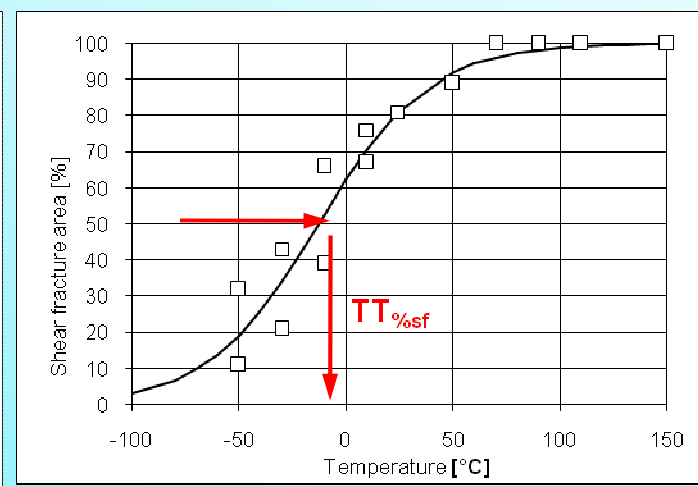
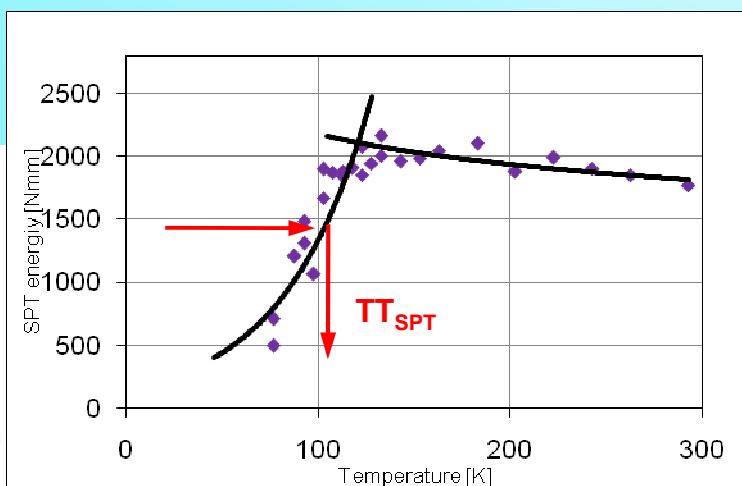
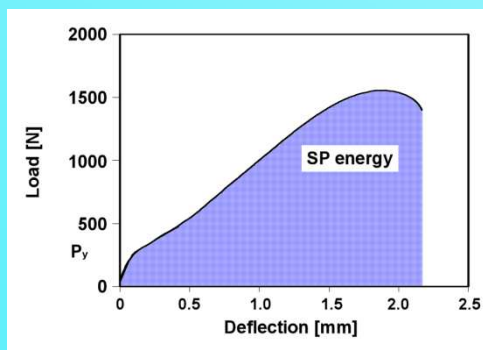
# DBTT estimation

**Ductile to brittle transition behaviour of dependence SPT fracture energy on temperature.**

**SPT fracture energy E [J] - energy obtained from the area under the load - deflection curve up to the fracture load or displacement corresponding to the specimen fracture.**

$$TT_{SPT} = \alpha \cdot TT_{\%sf}$$

$\alpha$  – correlation coefficient ( $\alpha \approx 0,40$ )



# Experimental materials

- **The experimental material used in the project New Surveillance Specimen Program for Jaslovské Bohunice V-1 NPP was base material of the RPV steel 15Ch2MFA, weld metal and heated affected zone.**
- **It is a reference material from original producer of RPVs NPP V-1 Izhora plant Russia**
- **From this type of material we prepared specimens which have been irradiated in power reactor in Jaslovské Bohunice V-2 NPP unit 3**

Type of material	Element content [mass. %]										
	C	Mn	Si	P	S	Cr	Ni	Mo	V	Cu	Ti
BM	0,132	0,39	0,30	0,0130	0,0133	2,69	0,119	0,59	0,201	0,072	0,014
WM	0,044	1,02	0,49	0,0275	0,0137	1,575	0,128	0,462	0,221	0,127	0,014

## Chemical composition of the used experimental materials

**The SPT samples were prepared from all material types of the RPV:**

- **base material (BM),**
- **heat affected zone (HAZ),**
- **and weld metal (WM).**

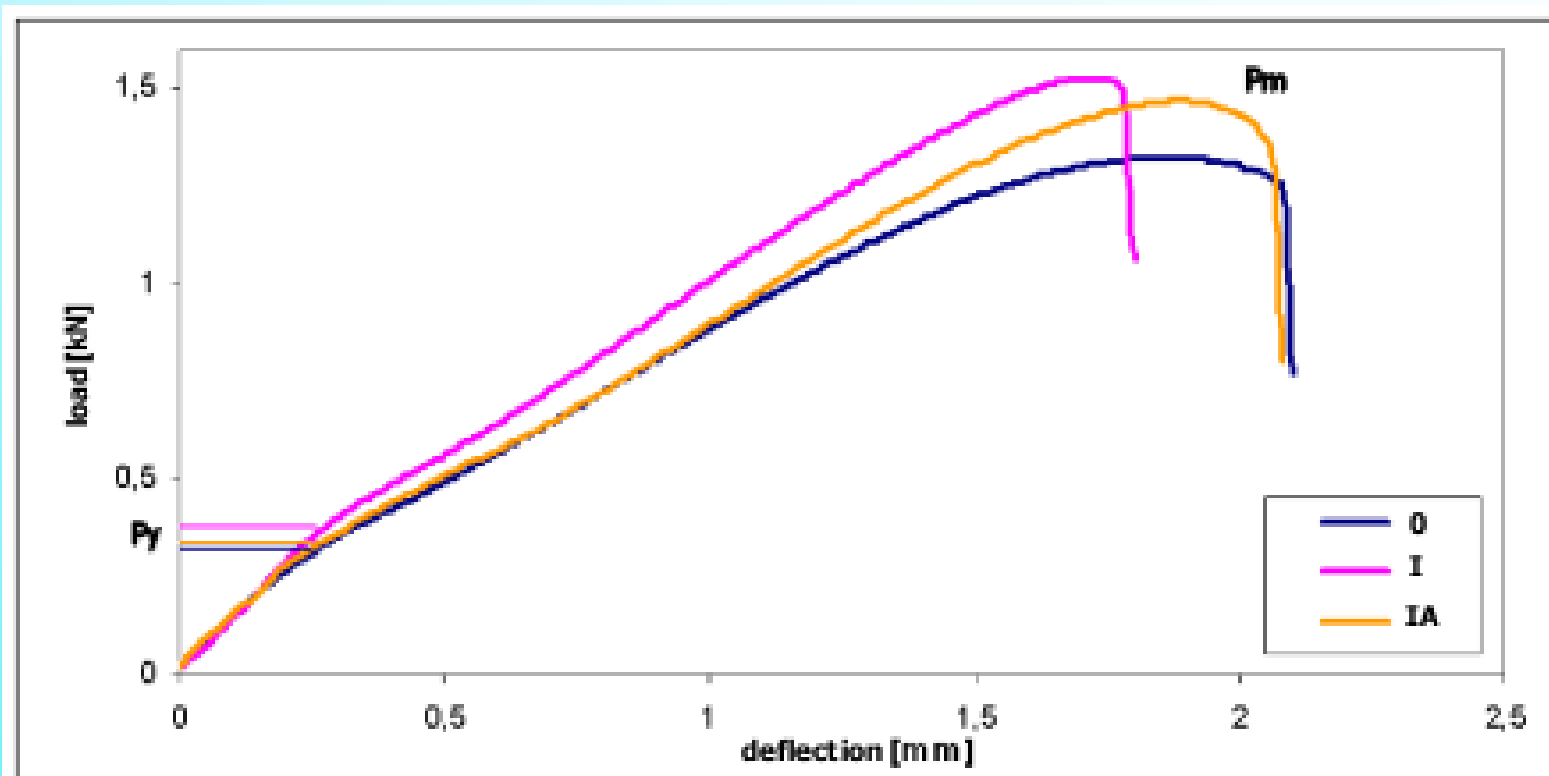
**Degradation of the materials properties is evaluated on the several sets of small samples:**

- **in initial condition (0),**
- **after one year of irradiation (I),**
- **after irradiation and annealing (IA),**
- **after reirradiation (IAI),**
- **double irradiation and annealing (IAIA)**
- **and after third cycle of irradiation (IAIAI).**

**Annealing parameters were following:**

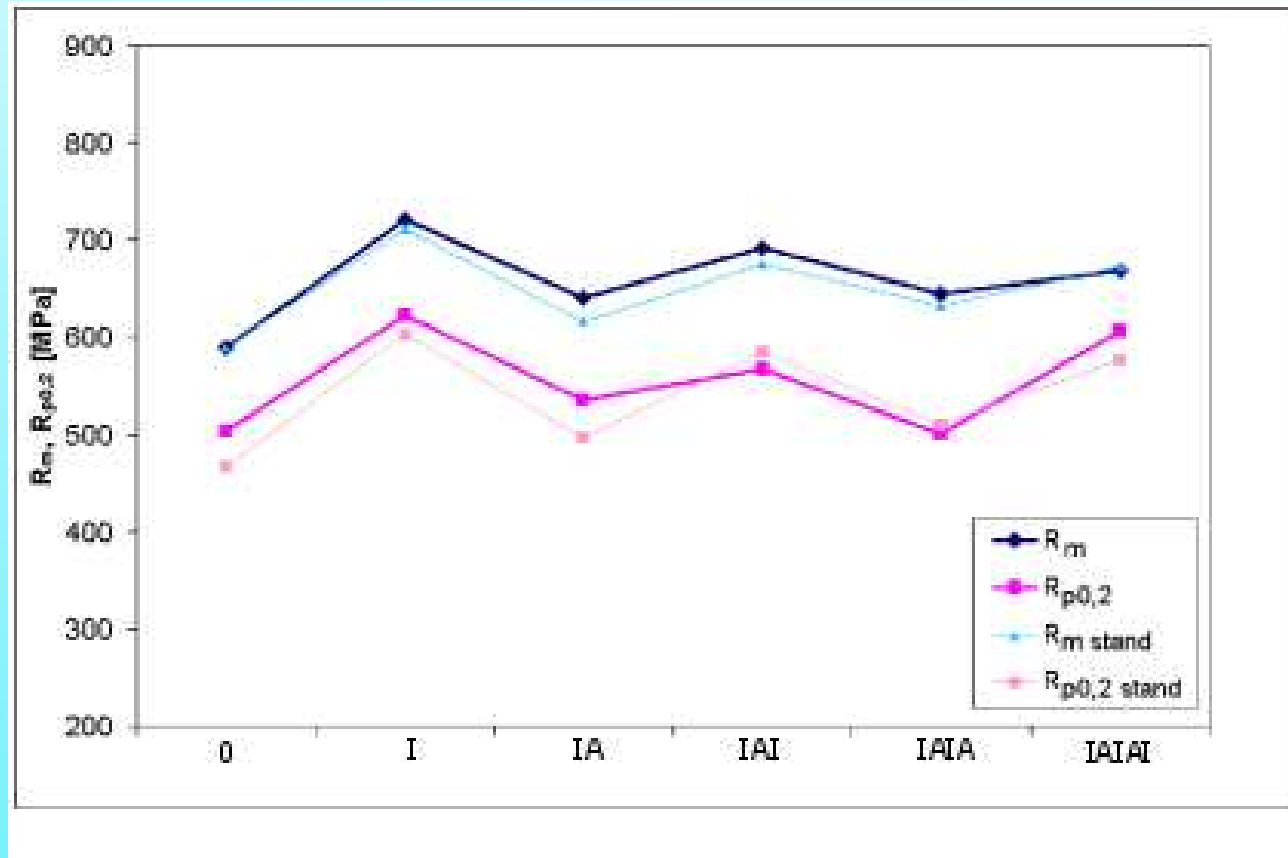
**temperature  $T = 475^{\circ}\text{C} \pm 10^{\circ}\text{C}$ ,**  
**holding time on the temperature  $t = 100$  hour.**

# Results of tensile properties



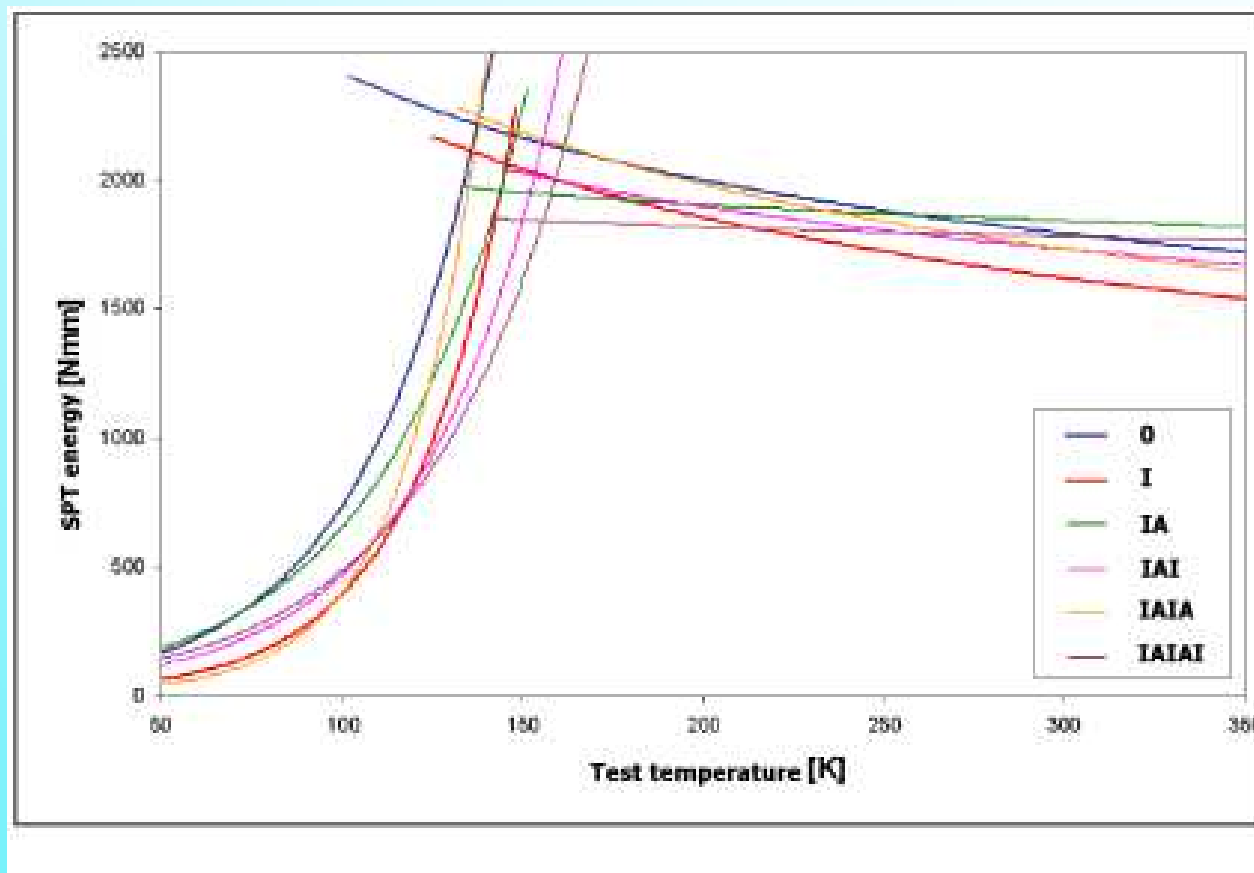
**Shift of the SPT curve due to irradiation and annealing**

# Results of tensile properties



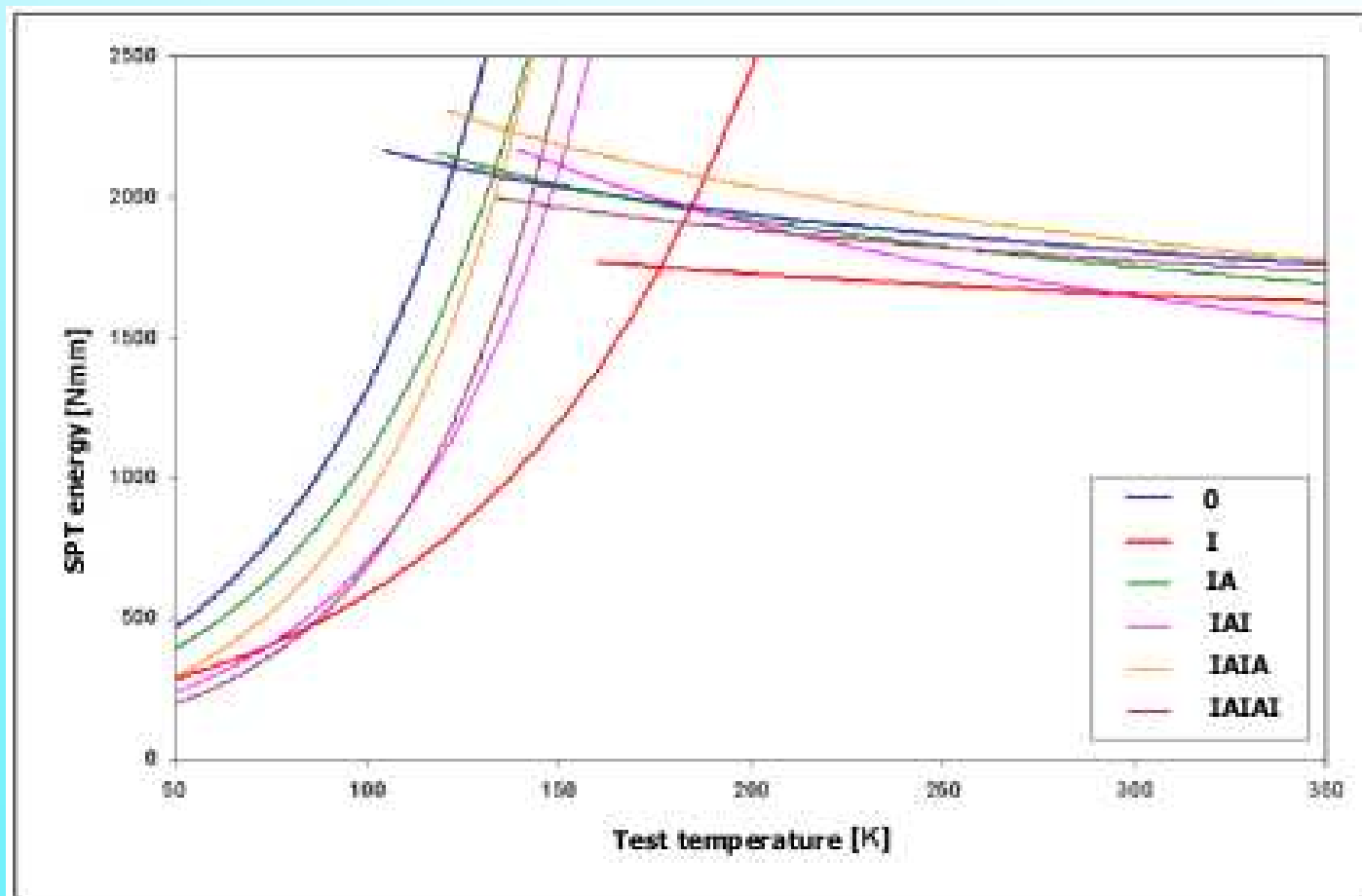
## Comparison of the tensile properties changes for WM

# Results of DBTT properties



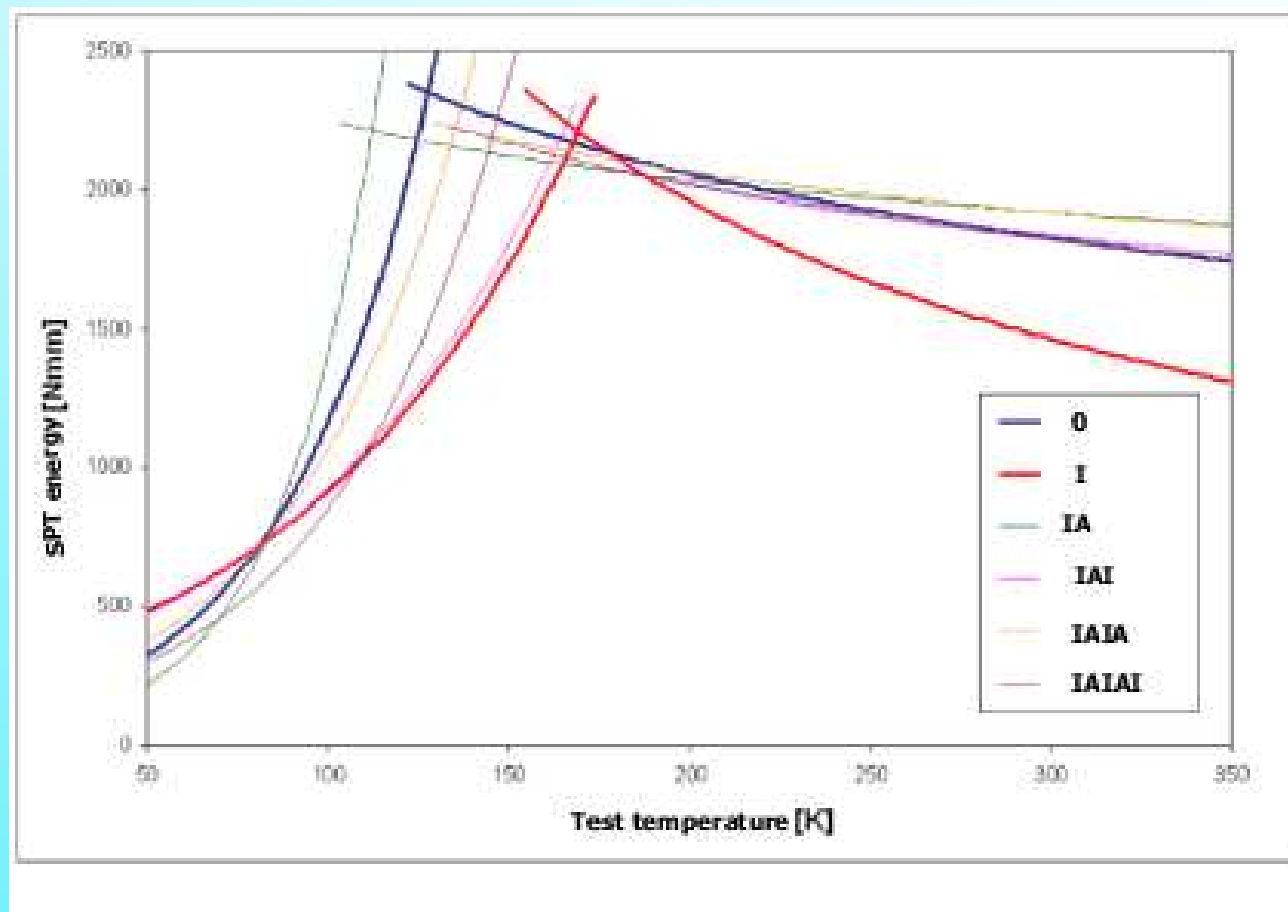
**Temperature dependences of SPT energy and its shift for RPV base material**

# Results of DBTT properties



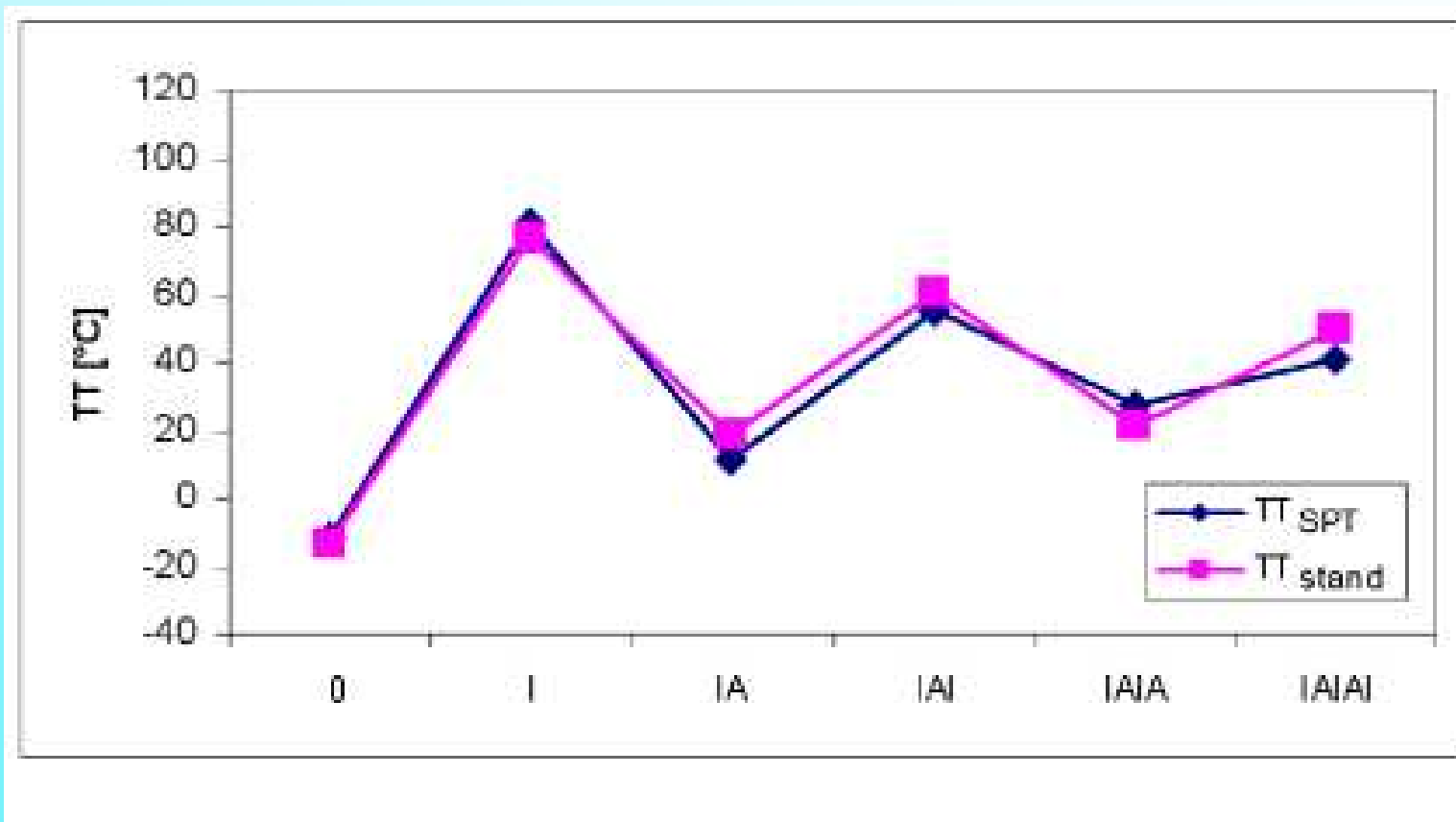
**Temperature dependences of SPT energy and its shift for RPV weld metal**

# Results of DBTT properties



**Temperature dependences of SPT energy and its shift for HAZ of RPV material**

# Results of DBTT properties



## Shift of the transition temperatures for WM

# Conclusions

## From the testing results follows:

- SPT methods are suitable for basic mechanical parameters measurement like tensile properties or evaluation of DBTT.
- The great advantage of SPT methods is in situation when is the lack of experimental material.
- For the testing of irradiated materials is **big advantage the small volume of specimen due to its low activity.**
- Small dimensions of specimen enable to use this method for irradiation in power reactors.
- Geometry of specimen is convenient for heat affected zone materials properties evaluation.
- **Results determined by SPT are in a good agreement with values obtained from standard tests.**

**Thank you for your attention**

**Ďakujem Vám za pozornosť**