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"KOZLODUY" NPP WWER - 440/230 REACTOR PRESSURE VESSEL RADIATION LIFE TIME

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The designed life time of Kozloduy nuclear units WWER440/230 is 30 years. The world practice shows that as a result of fast neutron bombardment in the reactor pressure vessel (RPV) metal a process of embrittlement is running. As result the radiation life time gets less than the designed life time. For the moment there are relatively accurate empirical methods for predicting the range of neutron irradiation embrittlement (NIE) of the RPV metal while the embrittlement rate law of neutron re-irradiation embrittlement (NRE) after annealing is not definitely established. In spite of different procedures and reconstruction for neutron embrittlement effect mitigation the extension of life time for RPV with high P and Cu content in the weld metal is under safety limit. The possibility for solving of this problem is the determination of re-embrittlement rate law. In this moment the conservative re-embrittlement law is accepted in the world standards for assessment of RPV integrity. Now there are new data supporting the model for "lateral (horizontal) shift" of the critical transition temperature curve after neutron re-irradiation [1,2,3]. This model gives priority over conservative law as the re-embrittlement rate decrease gives extension of radiation life time. Those data are not statistically well grounded and a future confirmation of their validity is necessary.

The aim of this work is to compare the RPV WWER440 NPP "Kozloduy" radiation life time, calculated by means of the different re-embrittlement rate laws after annealing using updated parameters describing neutron irradiation embrittlement and standard method for RPV integrity assessment.

1. Activities for mitigation of the neutron embrittlement of RPV metal

In order to increase the life time of RPV some activities for mitigating the rate of NIE, restoring the mechanical properties and restricting the possibility for thermochocks are performed in NPP Kosloduy. The most important of them are:

- Decreasing the neutron loading on RPV metal by means of installation of 36 dummy elements in the periphery of the core zone. The years of dummy element loading are given in table 1:

Table 1

	Unit 1	Unit 2	Unit 3	Unit 4
Year	1987	1988	1987	low leakage

- Heating the water in tank for emergency core cooling up to 55°C.
- The recovery annealing is conducted according Russian methods : 475°C/150 h, heating rate <20°C and cooling rate <30°C as follows:

Table 2

	Unit 1	Unit 2	Unit 3
Year	1989	1992	1989

- Actualisation of the operation instruction for pressure decreasing in the case of compensated primary leak running at high pressure in RPV.
- ISI before and after annealing

- Actualisation of the P-T start and shut down diagrammes after annealing and of the permissible temperatures for hydrotests.

- Starting in 1992 a programme for installation of fast acting valves in main steam piping.

2. RPV metal embrittlement criteria parameters

For calculation of critical temperature of embrittlement (Tkf) a number of parameters, describing the metal properties, the irradiation conditions and the neutron field are necessary. Unfortunately in the early years of nuclear power production the process of NIE has not been investigated well enough and the values of some parameters haven't been measured and registrated during manufacture.

According Russian standards [4] the critical temperature of ductile to brittle transition (Tkf) for weld metal is given by:

$$Tkf = Tko + Af\ (F/Fo)^{0.33} = Tko + 800(P + 0.07Cu)\ (F/Fo)^{0.33} \quad (1)$$

where:

Tko- critical temperature of ductile to brittle transition for non irradiated metal, Af - chemical coefitient of embrittlement, F - fluence, $Fo=10^{18}$ n/cm^2.

2.1 Chemical composition

With respect to neutron induced embrittlement of RPV WWER440/230 metal only the P and Cu content in weld 4 is decisive. The P and Cu concentrations are shown in table 3. The Unit 3 and 4 values are factory data. The data for Unit 2 are received lately by means of optical emission spectroscopy and wet chemical analysis of templet material taken out from RPV [5] and for Unit 1 - by scraps chemical analysis . While the P an Cu contents in weld 4 -Unit 2 coincide with the predicted ones, those for Unit 1 are quite different: the Cu content is lower and P content - extremely higher.

Table 3

	Unit 1	Unit 2	Unit 3	Unit 4
P , %wt.	0.05	0.037	0.036	0.021
Cu, %wt.	0.11	0.18	0.20	0.04
A_f	48.3	40.1	40.0	19.0

2.2 Initial critical temperature of embrittlement (Tko)

Similarly to the impurity content, the Tko values have been determinated in factory only for Unit 3 and 4 (table 4). For Unit 2 Tko has been determinated by means of high temperature annealing (T=560°C/ 2h) of subsize specimens manufactured from templets material and for Unit 1 recalculated with the new P content . The increasing of P content up to 0.051% increase the Tko value from 52°C to 65°C [6]. There is an uncertainty in the last value due to the inaccuracy of formulae used for calculation.

Table 4

	Unit 1	Unit 2	Unit 3	Unit 4
Tko, °C	65	50	50	5

2.3 Residual part of Tkf shift (Δ Tres) and re-embrittlement law

After annealing the Tkf increase can by determinated by standard conservative method :

$$Tkf = Tko + \Delta Tres + Af.\ (F/Fo)^{0.33} \quad (2)$$

As we mentioned above there are new data supporting the *model for "lateral (horizontal) shift"* of the critical transition temperature curve after neutron re-irradiation [1, 2, 3]. According to this model the re-embrittlement rate significantly decreases in comparison to the conservative law:

$$Tkf = Tko + (\Delta Tres^3 + AF^3 . (F/Fo))^{0.33} \qquad (3)$$

According Russian standard for weld metal with P content up to 0.04% an Δ **Tres** = 20°C is accepted. This value is correct for annealed Unit 2 and Unit 3, but for Unit 1 the P content is significantly higher. For this case a value of 40°C is proposed in [3]. The Δ Tres values are shone in table 5.

Table 5

	Unit 1	Unit 2	Unit 3	Unit 4
Δ Tres, °C	40	20	20	-

3. RPV radiation life time assessment

The contemporary values of P and Cu concentrations, Tko and Δ Tres are used for prediction of the neutron embrittlement of the weld metal. The trend curves are calculated using designed fluence (G) and the calculated mean values (CAL)[6,7] at 1/4 wall thickness (D). The results obtained by "conservative" (CON) and " horizontal" (LAT) re-embrittlement calculation model for Tkf are compered on figures 1,2 and 3.

The designed maximal allowed Tka values are used for RPV radiation life time prediction.

The life time extension of RPV metal for Unit 1,2,3 and 4, determinated by different methods are compared in table 6. The new method for RPV life time determination by maximal allowed flaw is proposed by Gidropress. This method is applied now on Unit 1 and designed life time (30 years) is proved in the case of validity of conservative re-embrittlement law.

Table 6

EOL		Unit 1			Unit 2			Unit 3			Unit 4
[years]											
	CON		LAT		CON	LAT	CON		LAT		
F	G	CAL	G	CAL	G	G	G	CAL	G	CAL	G
[1/4 D]											
Tka											
[°C]											
163	1992	1993	1997	1999	2002	2009	1999	2003	2006	2011	2119
193	1996	1998	2004	2009	2014	2021	-	-	-	-	-
210	-	-	-	-	--	-	2019	2032	2021	2035	228

4. Conclusions

- In the case of validity of the lateral re-embrittlement law for P content up to 0.05% all RPV reach or exceed their designed life time;
- The installation of MSIV is obligatory for each of the first three Units;
- After MSIV installation Unit 2 and 3 reach their designed life time;
- For Unit 4 (low impurity content and low Tko) no problems connected with neutron embrittlement of RPV are expected;
- The use of the real fluence values in Tkf calculation results in a radiation life time extension;

- A new verification of the chemical composition of RPV Unit 1 weld 4 metal is recommended;
- A standardisation of new Gidropress life time determination by maximal allowed flaw and determination of the ultra sonic inspection limit flaw resolution are necessary;
- The fracture mechanics methods and thermo-shock hydraulic conditions should be re-assessed and developed, so that more accurate determination of the maximal permissible critical temperature (Tka) could be achieved. Only in this case it could be possible to obtain an exact prediction of the residual life time.

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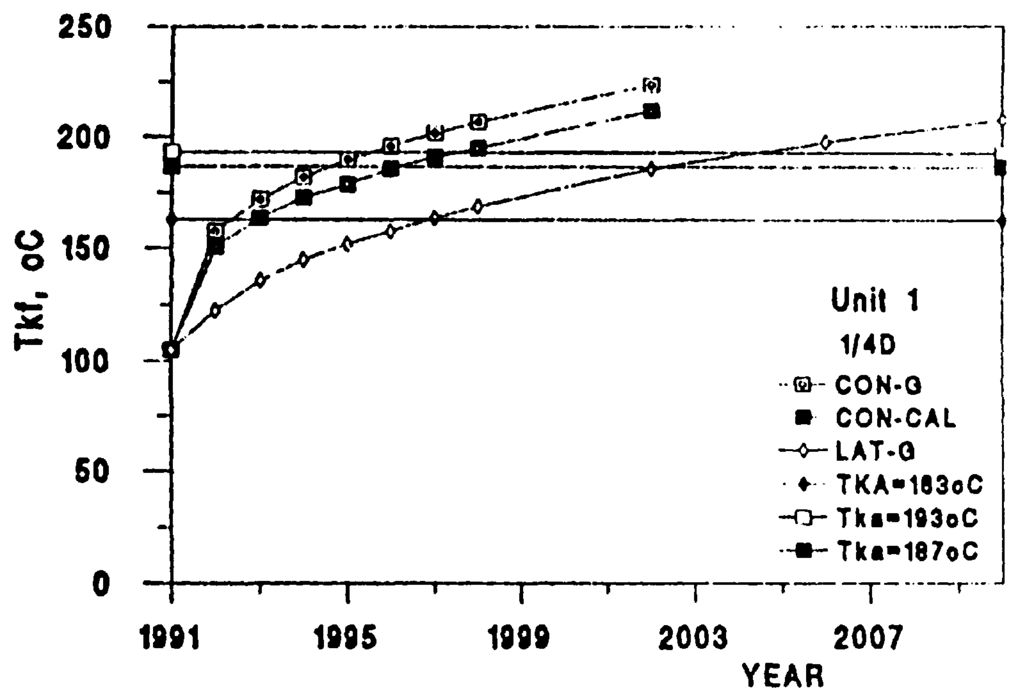

Fig. 1

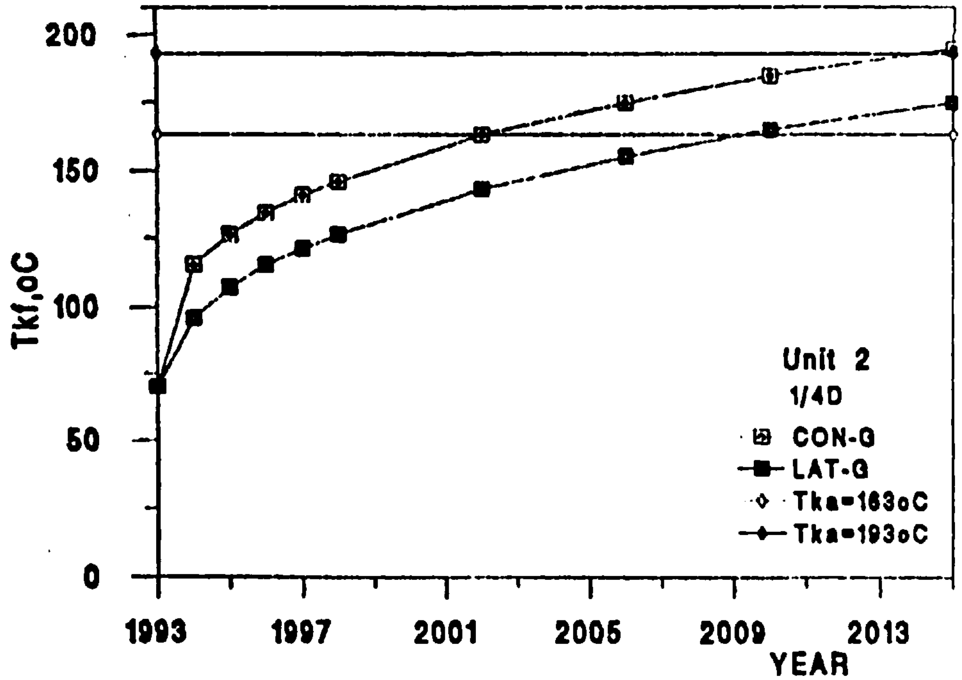

Fig. 2

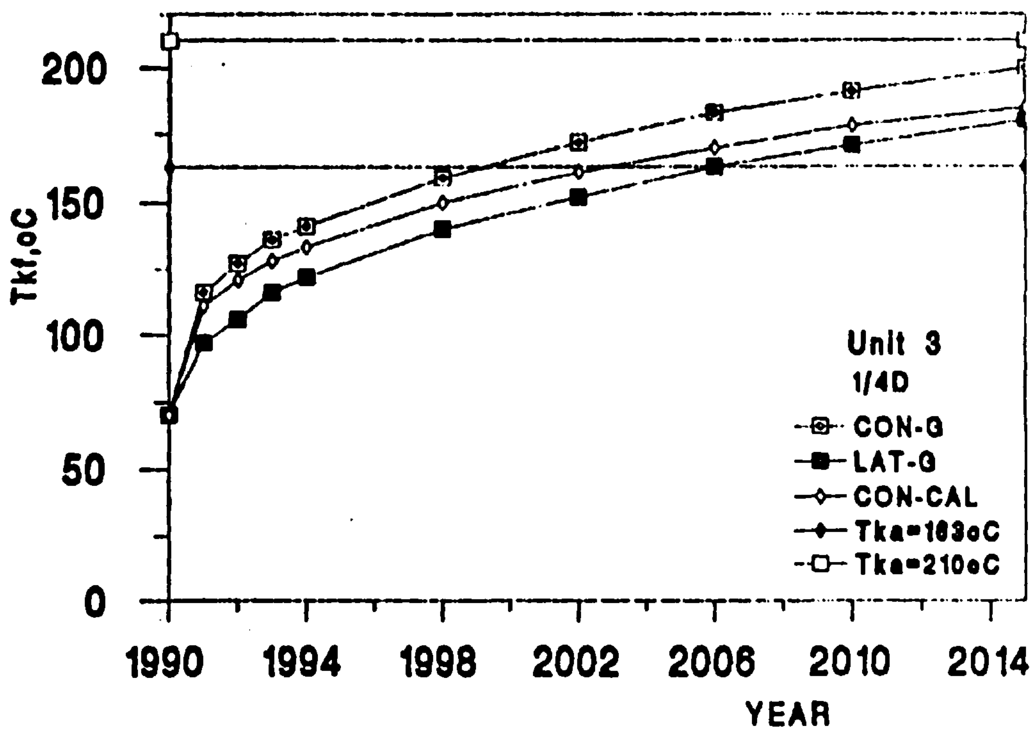

Fig. 3

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