TENSILE TESTING AND METALLOGRAPHIC EXAMINATION ON IRRADIATED CANDU PRESSURE TUBE SPECIMENS

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INTRODUCTION

Post-irradiation destructive examination of pressure tubes is done in order to detect alterations of the characteristics and damages occurred during irradiation. The purpose of these investigations is to get information used to increase the lifetime of the nuclear plant.

Pressure tubes see the most demanding service of any components in the heat transport system. As a result of operating conditions, the properties of pressure tubes change and these changes determine an operating life after which they must be removed and replaced. The life is usually expressed in terms of Equivalent Full Power Years (EFPY's), which is a product of the service life in years and the capacity factor. For the initial CANDU 6 reactors the expected life is 24 EFPY's, indicating that the units will run for 30 years at 80% capacity. [1, 2, 3]

The technological chain of examination of the removed pressure tubes assumes the following steps: picking of tube section, transportation, transfer and acceptance inside hot cells, post-irradiation examination, handling / conditioning of radioactive waste and data processing.

The post-irradiation examination takes place inside Post Irradiation Examination Laboratory (PIEL) hot cells from SCN Piteşti and consist of: surface visual examination of the tube with a periscope, preparation of samples, performing of tensile tests for the measurement of the mechanical characteristics, performing of metallographic analyses for the measurement of the oxide thickness, material hydriding and for the study of material structure.

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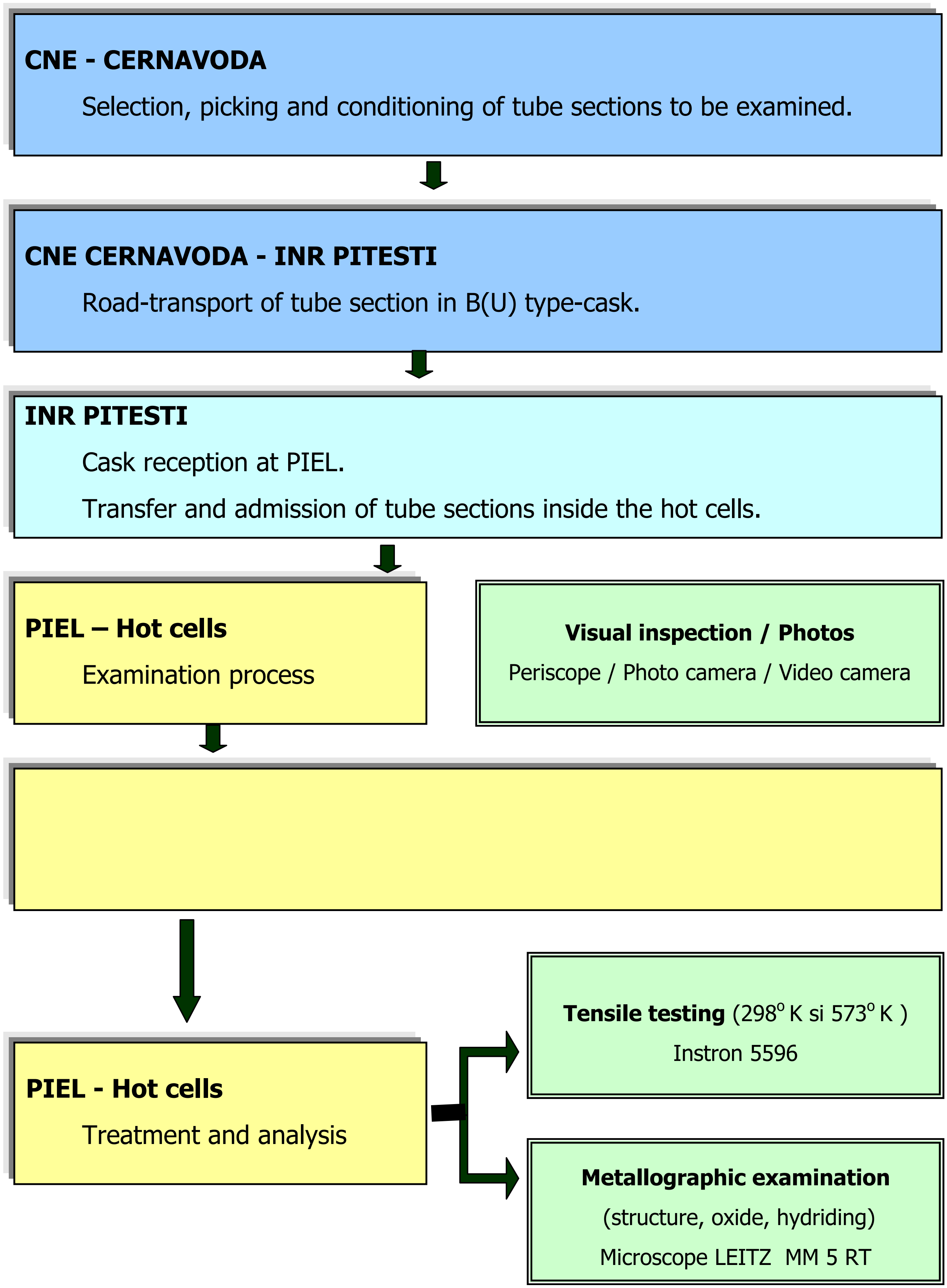

Figure 1. The technological chain of examination of the removed pressure tubes

2. PIEL tests

Tensile testing machine is INSTRON Model 5569. The machine uses the Merlin software to process the data obtained from the mechanical tensile tests. The tests were performed according to the procedure and standards [4, 5].

The tests have been made to establish the following mechanical characteristics:

- Strain-stress diagrams and load extension (numeric and plotted);
- Young modulus;
- Yield strengths (offset method at 0.2%);
- Elastic limit;
- Ultimate tensile strengths;

First, an initial test on un-irradiated irradiated samples was performed in order to obtain the tensile test machine stiffness. Test was made with the machine furnace to assess the correlation between the required temperature and real probe temperature measured by a thermocouple.

In the Post Irradiation Examination Laboratory (PIEL) the tensile tests was performed according to ASTM procedures using the INSTRON 5569 testing machine [4, 5].

From the PIEL tensile tests performed on the Zr-2.5%Nb samples it was obtained the following mechanical characteristics:

- Tensile yield diagrams
- Yield strength (2% offset method)
- Ultimate tensile strength (UTS)
- Fracture elongations.

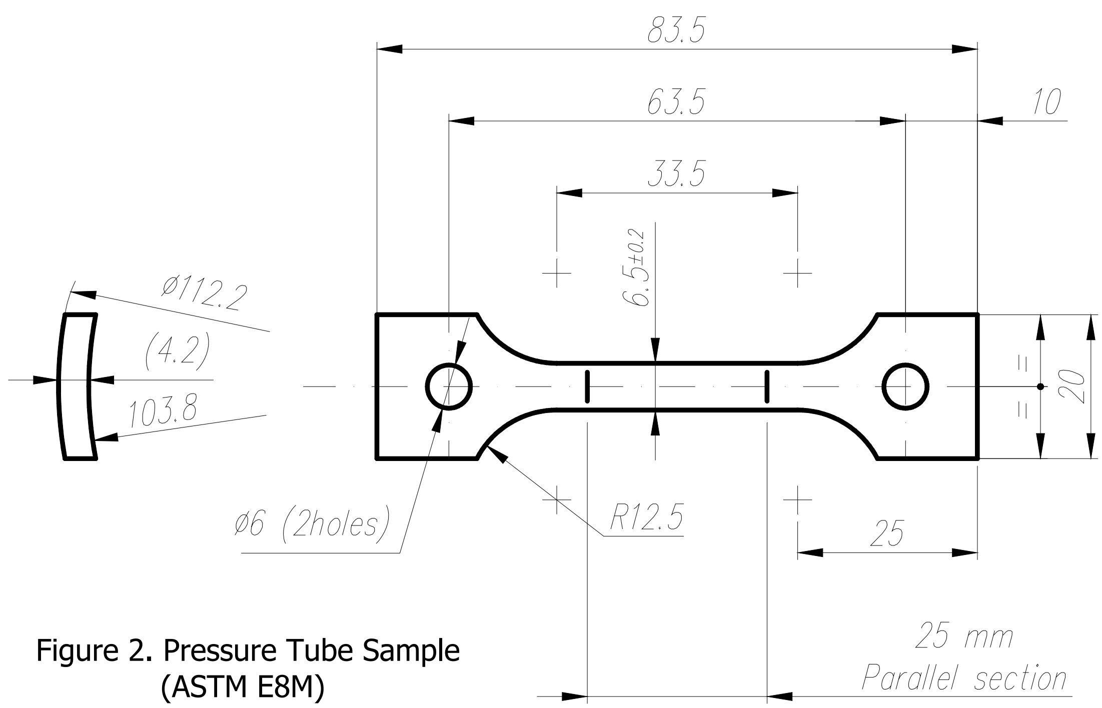

Figure 2. Pressure Tube Sample (ASTM E8M)

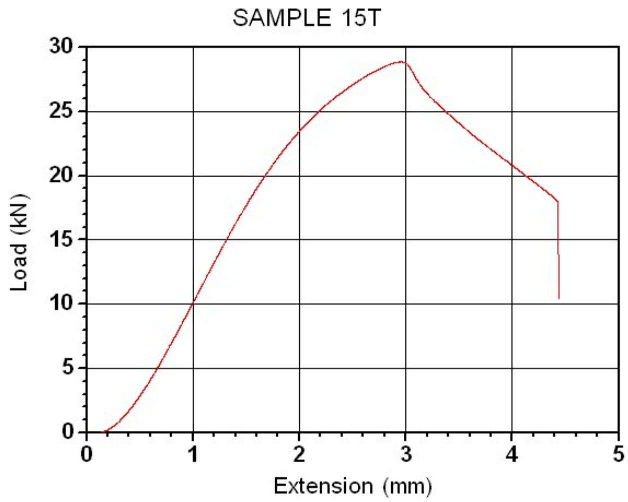

Figure 3.

Load extension curve for irradiated sample 15T

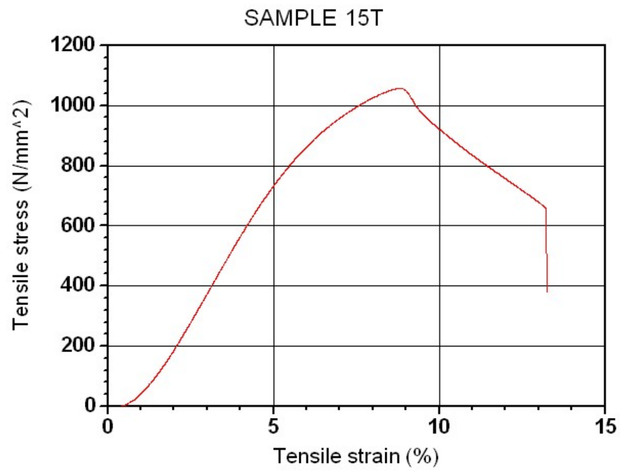

Figure 4.

Strain–stress curve for irradiated sample 15T

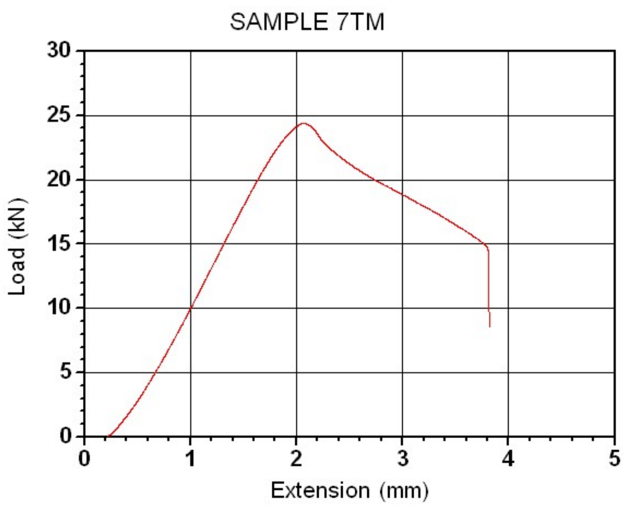

Figure 5.

Load extension curve for irradiated sample 7TM

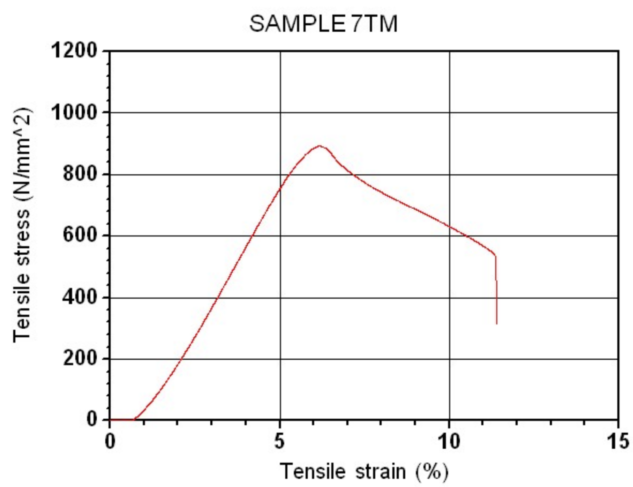

Figure 6.

Strain–stress curve for irradiated sample 7TM

The metallographic examination after the tensile tests was made to analyze the irradiated samples surface macroscopic status and characteristics of the fractured area [6].

The primary data of the tensile tests were used to infer Ramberg-Osgood relationship parameters. The Merlin software was used to process the tensile experimental diagrams.

Two fixtures were specially designed for tensile specimens. Tension tests were carried in an INSTRON testing machine – Model 5596.

Load – extension and strain - stress curves and the metallographic aspect of the crack front propagation for irradiated transversal sample 15T and 7TM are presented.

The metallographic examination was carried out in the hot cell using metallographic microscope – Leitz MM 5RT.

The macrographies and micrographies were obtained by using Olympus – Micro Image software.

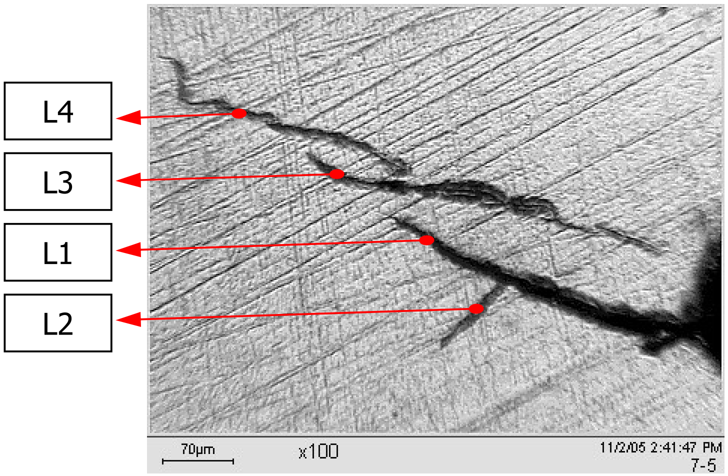

Figure 7. Microscope irradiated sample crack aspect for sample 7 TM (x 100)
L1 = 333 μm;
L2 = 86 μm;
L3 = 365 μm;
L4 = 275 μm;

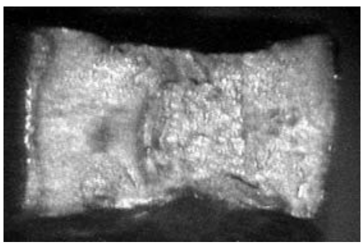

Figure 8. Macrography for sample 15 T (x 10)

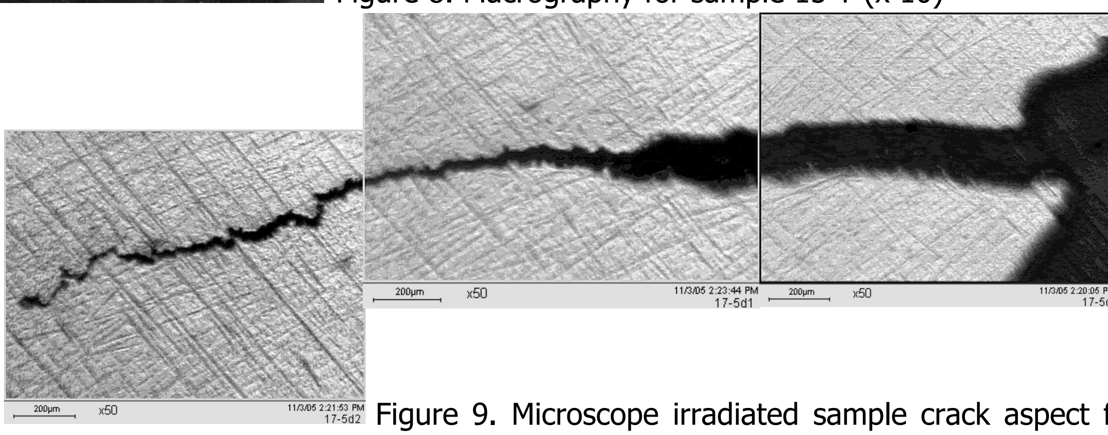

Figure 9. Microscope irradiated sample crack aspect for sample 15 T (x 50)

3. Results

The temperatures in the INSTRON 5569 furnace for all the irradiated samples are presented in the Table 1.
Merlin software processed the data obtained by INSTRON 5596 test machine and load – extension and strain - stress curves for irradiated transversal sample 15T and 7TM are presented in the Fig. 3, 5 respectively Fig. 4, 6. The metallographic aspect of the crack front propagation is presented in the figure 7, 9.
The tensile characteristics for the Zr-2.5%Nb irradiated samples the processed data are presented in the Table 2.

Table 1 Temperature for tensile test in PIEL

Temperature (^{0}C)	Irradiated samples number
70	11L, 15T, 1TM, 5TM
150	12L, 16T, 2TM, 6TM
250	13L, 17T, 3TM, 7TM
300	14L, 18T, 4TM, 8TM

Table 2. Obtained tensile characteristics for the Zr-2.5%Nb irradiated samples at $3.5x10^{24}$ n m^{-2}(E> 1MeV)

Irradiated sample no.	Strengths (MPa)						Obs.
	σ_o eng.[1]	$\sigma_{0.2}$ eng.[2]	UTS eng.[3]	σ_o real[4]	$\sigma_{0.2}$ real[5]	UTS real[6]	
11L			944			1114	failed
15T	657	800	1056	653	901	1138	done
1TM	800	942	1003	887	1044	1066	done
5TM	875	975	1017	892	1009	1078	done
12L	800	830	890	835	863	956	done
16T	725	833	933	808	867	983	done
2TM	800	900	927	842	944	978	done
6TM	753	833	868	820	932	924	done
13L	660	750	806	725	778	864	done
17T	717	817	832	760	835	871	done
3TM	800	867	884	853	918	928	done
7TM	800	887	892	833	929	939	done
14L	533	687	769	667	732	824	done
18T	653	750	784	700	803	820	done
4TM	740	833	835	800	874	874	done
8TM	760	780	773	800	808	808	done

Legend

1 σ_o eng – elastic limit, engineering values
2 $\sigma_{0.2}$ eng – yield strength, engineering values
3 UTS eng – ultimate tensile strength, engineering values
4 σ_o real – elastic limit, real values
5 $\sigma_{0.2}$ real – yield strength, real values
6 UTS real– ultimate tensile strength, real values

4. Conclusions

- The technological chain of examination of the replaced pressure tubes was presented.
- For the irradiated Zr-2.5%Nb pressure tube samples with a fluence up to 3.5x1024 n m-2 (E>1 MeV) were done tensile tests in PIEL for the temperature range 70ºC to 300ºC to obtain mechanical characteristics used for structural integrity assessment.
- The metallographic examination after the tensile tests was made to analyze the irradiated samples surface macroscopic status and characteristics of the fractured area
- The procedures for PIEL tensile tests and metallographic examination of the irradiated samples were followed.
- The obtained results will be used for FEA–Crack computer code models for materials properties.

5. References

[1] Annual Report 2002, Nuclearelectrica SA, 2002, Bucharest, Romania
[2] CAN/CSA-N285.4-94 "Periodic Inspection of CANDU Nuclear Power Plants Components", National Standard of CANADA, ISSN 0317-5669, 1994
[3] E.G.Price „Fuel Channel- Introduction and Review", "2004-Fuel Channel Seminar" Proceedings, November 15-16, 2004, Toronto, Canada
[4] ASTM E 8M – 96 "Standard Methods for Tension Testing of Metallic Materials [Metric]"
[5] ASTM E 21- 92 "Test Methods for Elevated Temperature Tension Tests of Metallic Materials"
[6] ASTM E 3-95 "Standard Practice for Preparation of Metallographic Specimens