PERFORMANCE OF CANDU-6 FUEL BUNDLES MANUFACTURED IN ROMANIA NUCLEAR FUEL PLANT

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ABSTRACT

The purpose of this article is to present the performance of nuclear fuel produced by Nuclear Fuel Plant (N.F.P.) - Pitesti during 1995 - 2012 and irradiated in units U1 and U2 from Nuclear Power Plant (N.P.P.) Cernavoda and also present the Nuclear Fuel Plant (N.F.P.) - Pitesti concern for providing technology to prevent the failure causes of fuel bundles in the reactor. This article presents Nuclear Fuel Plant (N.F.P.) - Pitesti experience on tracking performance of nuclear fuel in reactor and strategy investigation of fuel bundles notified as suspicious and / or defectives both as fuel element and fuel bundle, it analyzes the possible defects that can occur at fuel bundle or fuel element and can lead to their failure in the reactor. Implementation of modern technologies has enabled optimization of manufacturing processes and hence better quality stability of achieving components (end caps, chamfered sheath), better verification of end cap - sheath welding. These technologies were qualified by Nuclear Fuel Plant (N.F.P.) - Pitesti on automatic and Computer Numerical Control (C.N.C.) programming machines. A post-irradiation conclusive analysis which will take place later this year (2013) in Institute for Nuclear Research Pitesti (the action was initiated earlier this year by bringing a fuel bundle which has been reported defective by pool visual inspection) will provide additional information concerning potential damage causes of fuel bundles due to manufacturing processes.

Key words: (CANDU-6, Zircalloy-4, fuel bundle, UO_2 pellet)

I. Introduction

N.F.P.-.Pitesti processes sintered UO_2 powders make by Feldioara - Brasov from uranium ore. After complex manufacturing operations CANDU-6 fuel bundles are obtained. This fuel bundles are sent as raw material in nuclear reactors to Cernavoda. The Unit 1 and Unit 2 nuclear reactors transform nuclear energy produced by fission into electrical energy.

I.2. N.F.P. - Pitesti brief history

Nuclear Fuel Plant is located near the town Mioveni - Arges about 25 km from Pitesti.
Production of CANDU nuclear fuel began in 1980, with commissioning of the pilot station of nuclear fuel station at the Institute for Nuclear Research (ICN) Pitesti. Separation of Nuclear Fuel Plant as a distinct entity was made in 1992.

In 1994, the Nuclear Fuel Plant (FCN) was authorized by AECL and Zircatec Precision Industries Inc. (Canada) as producer for CANDU 6 nuclear fuel.

In the period 2004-2006, with low investment, NFP Pitesti doubled production capacity to provide nuclear fuel to the operation of two nuclear reactors units at Cernavoda NPP.

In 2007, NFP - Pitesti obtained TUV ISO 14001:2004 certificate for environmental management system. In 2012, NFP - Pitesti produced 10,080 nuclear fuel bundles. Nuclear Fuel Factory – Pitesti made on 04/03/2013 the fuel bundle with the number 120,000, which represents an important moment in the history of NFP - Pitesti as qualified manufacturer of CANDU- 6 nuclear fuel.

II. General production and inspecting of CANDU-6 fuel elements and bundles

CANDU reactor system uses natural uranium as fuel. The fuel bundle, shown in Figure 1, consists of 37 closely spaced elements each of which contains high density natural UO_2 in thin Zircaloy-4 sheath. The elements are held together by plates welded to the ends and are separated by spacers brazed to the sheaths. The bundle is 495mm long and 103mm in diameter and contains approximately 19.8 kg of U and 3.0 kg of Zircaloy-4. Inside the sheath the UO_2 pellets have densities over $10.5 g/cm^3$

CANDU-6 fuel bundle is assembled on the production line of six main components: UO_2 pellets and five metal parts made of Zy-4: end caps, end plate, spacers, bearing pads and fuel sheaths is show in **Figure 1**.

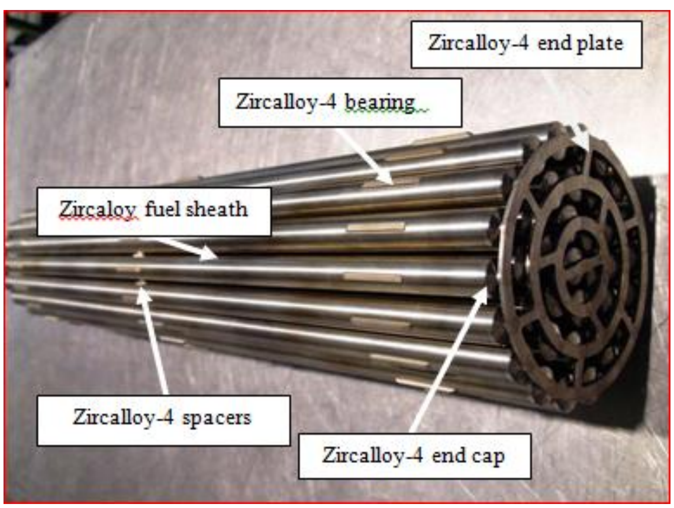


Figure 1 *CANDU-6 Fuel bundle assembled from five metallic components*

II.1.1. UO_2 pellets

The UO_2 powder is compacted on a rotary hydraulic press. The material is pressed, at “green" pellets to pre-determined weight, diameter and height.
A statistical sampling plan is used to confirm that the process is producing "green" pellets that conform to the specification.
The "green" pellets are placed in boats which are continuously stoked through a sintering furnace. The atmosphere in this furnace is hydrogen and the peak temperature is about 1700°C. Samples of the sintered pellets are checked for diameter, height, density and physical defects. Sample pellets are also checked for chemical analysis and a metallographic examination is carried out. The sintered pellets are ground to the required diameter on a center less grinder, are washed to remove the grinding coolant and sludge, are dried, and are inspected dimensionally and for surface imperfections

II.1.2.End caps

The end caps are then machined on a C.N.C. turning lathe. A visual and dimensional inspection is then carried out after which the end caps are ultrasonic degreased, rinsed and dried. The end caps are now ready for use at the closure welding (**Figure 2**).

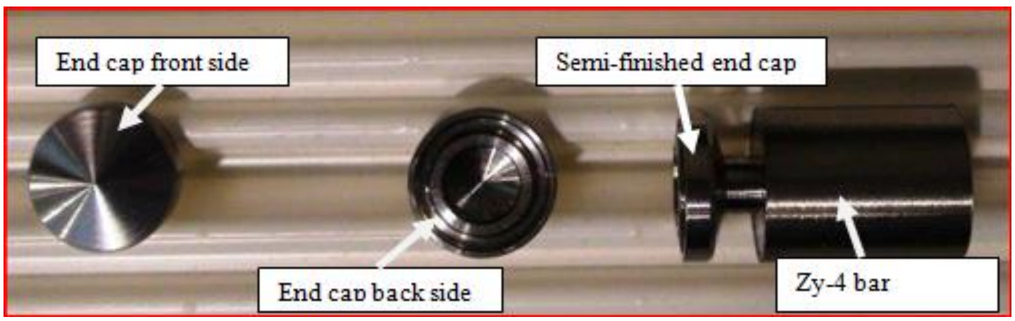


Figure 2 *End cap manufacturing*

II.1.3. End supports

The strip for end supports is inspected visually and dimensionally and the mill certificate provided by the vendor is checked for compliance with the specification. The end supports are blanked from the strip. A dimensional and visual inspection is carried out. Tumbling, deburring and ultrasonic degreasing and rinsing operations are carried out. Different parts during end plate fabrication are show in **Figure 3**.

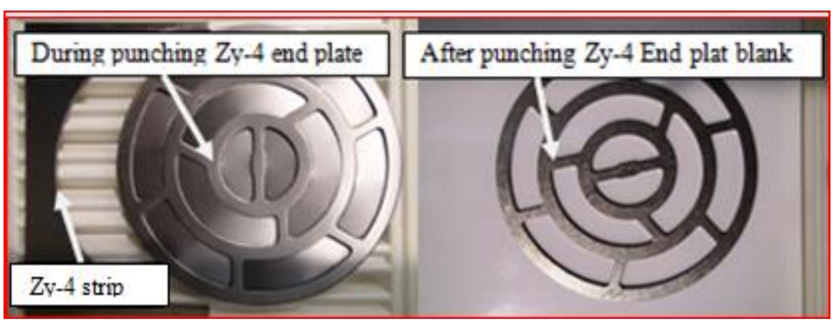


Figure 3 *End plate parts during fabrication*

II.1.4. Spacers and bearing pads

The spacers and the baring pads are blanked from the zircalloy strip and loading into the beryllium coating machine where a thin layer of beryllium is deposited on one side.
The coating process is "vacuum deposition" (**Figure 4**).

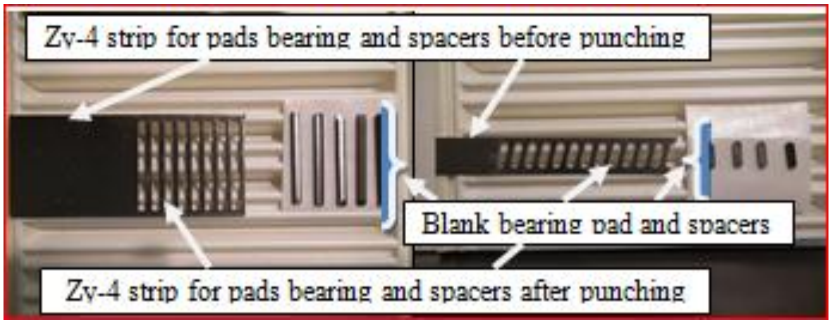


Figure 4 *Blank bearing pads and spacers during fabrication*

II.1.5. Element and bundle

The Zircalloy sheaths for the fuel are inspected on a statistical basis both visually and dimensionally including straightness and the mill certificate from the vendor is checked against the specification.

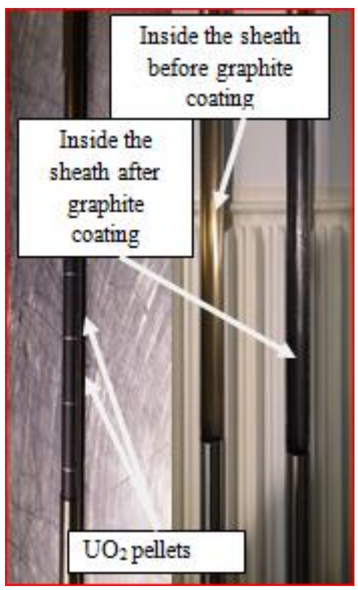


Figure 5 *For inside sheath CANDU-6 elements*

The bearing pads and spacers are tack welded to the sheaths, after which the brazing operation is performed. Heating for brazing is done by induction in a vacuum chamber. After the brazing operation another visual and dimensional inspection is performed and a metallurgical examination for completeness of brazes and amount of eutectic. The sheaths are graphite coating and chamfering is performed (**Figure 5**).

The closure welder operation (by resistance welder), the remove of the weld flash on the face of the end cap and the joint integrity of these welds by eddy current is performed on the new automatic welding machines. The elements are leak test performed.

The next operation is the assembly of the elements into bundles in the configuration shown in **Figure 1**. A spot welder is used to weld each element to the end supports. After assembly the bundles are inspected visually and dimensionally and are packed for shipment.

II.1.6. Control and inspection

Special control and inspection procedures exist for every operation in the production line fuel bundle manufacturing.

II.1.7. Bundle assembly weld

As a control procedure, a percentage of bundles are autoclaved to confirm that the surface of the bundle has not been contaminated with some foreign material. In addition a percentage of bundles are monitored for radio-activity to confirm that the surfaces of the bundles are free of such contamination.

II.1.8. Pelletizing operation

In the Pelletizing Operation high density pellets which meet tight tolerances on diameter, length, end squareness, land width, and dish depth. This high level of quality is attained with a minimum of scrap**.**

II.1.9. Taking and brazing

The tacking and brazing operations are controlled so that the sheaths are not deformed and so that the metallurgical and physical properties are still satisfactory after the sheaths have been exposed to the high brazing temperatures. In addition the requirements for completeness of braze and maximum amount of free beryllium are met.

II.1.10. Diametric clearance

The diametric clearance between pellets and element sheath must be closely controlled and the stack length must also be closely controlled. These items require a system of control which ensures that the diameter of pellets which are loaded into the fuel sheaths is that which gives the designed diametric clearance and that the stack length leaves the required amount of space in the element.

II.1.11. Closure welding

A statistical sample of welds is made during which the machine parameters are checks for a normal production run. All of the welds in this sample are examined to determine if they meet the specification from the viewpoints of integrity and geometry (**Figure 6**).

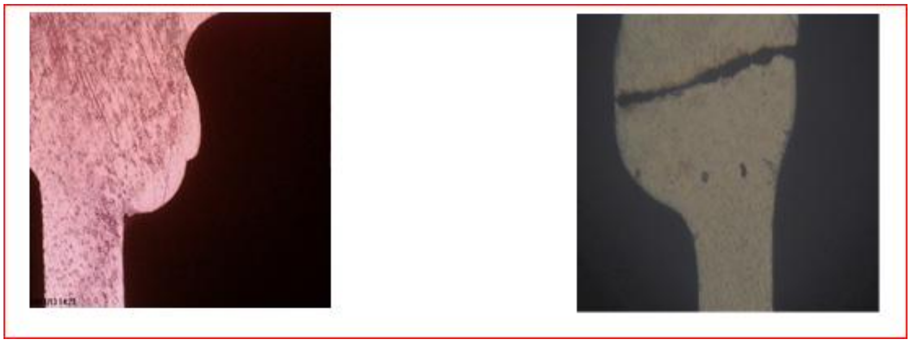


Figure 6 *End plug weld metallographic structure. Left - healthy weld, right - heavy contaminated weld*

Control parameters have been developed to indicate when the welding process is beginning to deteriorate so that equipment maintenance can be carried out before poor welds are made [1].

II.1.12. Bundle assembly

Each fuel bundle must be assembled so it meets the specification with respect to squareness of the end supports, diameter, minimum spacing of elements, radial distance from the outer surface of the outer element to the end support, location of spacers and overall size (**Figure 7**). This last check is performed on a "GO-NO-GO" gauge which represents the smallest opening that a bundle has to pass through in entering and leaving a fuel channel in the reactor.

Figure 7 *Fuel bundle general view*

III. Common types of manufacturing defects

- Incomplete end cap welds,
- Circumferential cracking of the end cap welds,
- Porous end caps,
- Excess hydrogen gas inside the fuel element**.**

In the Cernavoda U2 from de start of commercial operation (2007) until February 2008 visual examination confirmed 55 defective bundles. The investigation conclude that roots cause defects was overriding defect mechanism due to debris fretting and incomplete closure weld. [2].

III. 1. 1. Incomplet end cap welds

Generally, incomplete end caps welds it is the result of weld contamination by graphite, UO_2, defective handling of sheaths or end caps, superficial cleaning of components, damaged electrodes or out of range parameters of the welding equipment.

In N.F.P -Pitesti - these defects were removed by: careful handling zircalloy components, washing and degreasing by ultrasound waves, by preventive maintenance of welding equipment, welding verification by inspection with eddy current settings and using a proper plan and metallographic analysis of welds.

III.1.2. Porous end cap

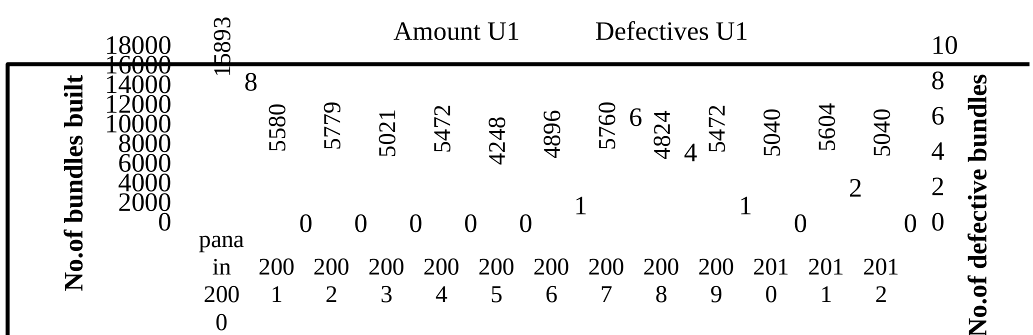
This type of failure is not detectable on the production line. The bar stock material for fabricating end caps is performed 100% ultrasonic testing by supplier.

III.1.3. Excess hydrogen gas inside the fuel element

The possible presence of H_2 in fuel beam element may be due to: deep roughness of UO_2 pellets in conjunction with a labor high humidity atmosphere, defective graphitization. In FCN these possible causes are removed by careful control of surface roughness of pellets, atmosphere monitoring of loading pellets in the sheaths, well planned technology of drying and deposition of graphite inside the sheath, statistical quality control of the degree of adhesion graphite layer.

IV. Performance of CANDU-6 fuel bundles, manufactured by N.F.P. Pitesti and delivered to Cernavoda N.P.P.

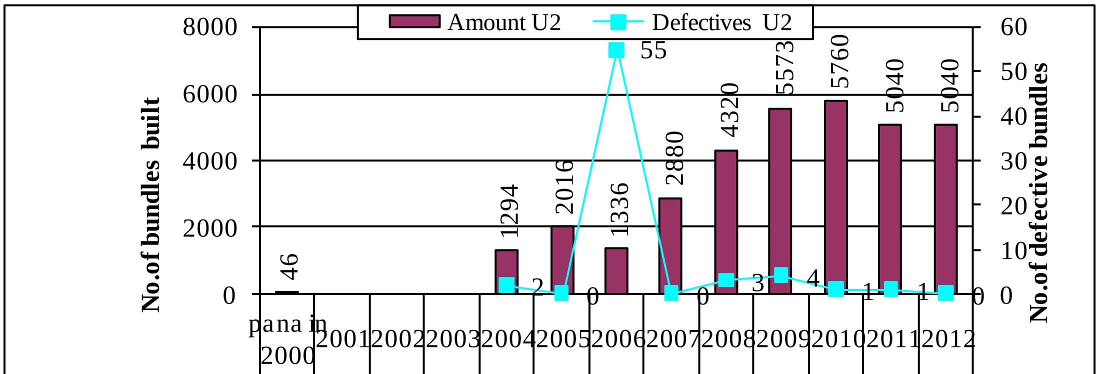
Since the commissioning of the two reactors of Cernavoda they were unloaded fuel bundles defects as follows: 28 Fuel bundles of U1 and 66 Fuel bundles of U2;
Of the 26 fuel bundles downloaded from U1, 6 bundles are first shipment , delivered by ZPI, Canada, and the remaining 22 fuel bundles are manufactured and supplied by FCN Pitesti during 1994-2011, the last were unloaded defects on the 24.08.2012, 17.10.2012 respectively (Figure 8) .



	pana in 2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
Amount U1	15893	5580	5779	5021	5472	4248	4896	5760	4824	5472	5040	5604	5040
Defectives U1	8	0	0	0	0	0	1	6	4	1	0	2	0

Figure 8 *CANDU-6 Performance for Cernavoda U1*

In accordance with agreed procedures and practices, during January to December 2012, were sent notifications to Cernavoda "identifying suspect bundles U2 Cernavoda NPP Unit”. Last fuel bundles defect in Unit 2 was download in on the 14.08 .2012 (**Figure 9**). The 66 fuel bundles downloaded from U2 are manufactured by FCN Pitesti delivered from 2004-2011 and from 2006-2011

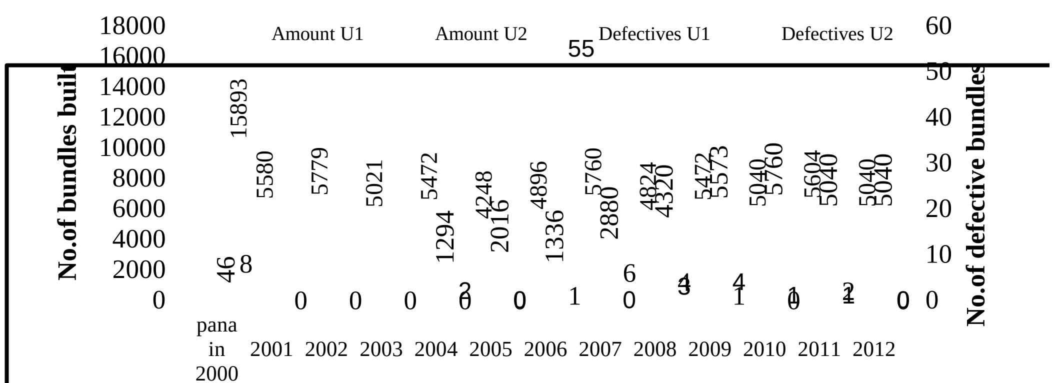


	pana in 2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
Amount U2	46				1294	2016	1336	2880	4320	5573	5760	5040	5040
Defectives U2					2	0	55	0	3	4	1	1	0

Figure 9 *CANDU-6 Performance for Cernavoda U2*

In 2012 were notified 3 pairs of fuel bundles as suspect or damaged, 1(one) in U1and 2 (two) in U2. N.F.P. - Pitesti received from N.P.P. Cernavoda, failure rate from commissioning until 31.12.2012.

- U1, 0.034% total defects fuel bundles 28 of a total of 83,090 fuel bundles irradiated (downloadable);
- U2, 0.251% total defects fuel bundles 66 of a total of 26,340 fuel bundles irradiated (downloadable).



	pana in 2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
Amount U1	15893	5580	5779	5021	5472	4248	4896	5760	4824	5472	5040	5604	5040
Amount U2	46				1294	2016	1336	2880	4320	5573	5760	5040	5040
Defectives U1	8	0	0	0	0	0	1	6	4	1	0	2	0
Defectives U2					2	0	55	0	3	4	1	1	0

Figure 10 *CANDU-6 defective (notified as defective) fuel bundles for Cernavoda U1 and U2*

Until the present article was carried out, N.F.P. Pitesti was not notified for any defective fuel bundles or suspect fuel bundles manufactured and delivered in 2012 (**Figure 10**).

IV. Conclusions

Application of new technologies to detect welding defects by eddy current, checks of chamfered ends, end plugs close to nominal due by automatic and Computer Numerical Control programming machines, the application of technology by the ultrasound waves to wash and degreasing components zircaloy-4, led N.F.P. – Pitesti made on 04/03/2013 the fuel bundle with the number 120,000, which represents an important moment in the history of N.F.P. - Pitesti as qualified manufacturer of CANDU- 6 nuclear fuel.

V. Acknowledgements

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VI. References

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