# *Study on the Production of Cr-coated Zr-1%Nb tubes as an ATF evolutionary cladding candidate*

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## Abstract
After some accidents like TMI and Fukushima Daiichi, the belief that nuclear fuels can safely and reliably be used up to 65 MW.d/kgU was revised. Different short to long term concepts started to be assessed more seriously. Among these concepts, Cr-coated Zr cladding tubes were taken into consideration as a promising remedy for the short term perspectives. Various efforts to evaluate important aspects of such designs (including coating methodologies, full size coating of cladding tubes, performance analysis, licensing features and so on) have been implemented and some activities are yet under accomplishment. In this study, an optimized cathodic arc PVD coating condition, from the defect density point of view, for applying Cr and CrN coating layers up 10 microns on typical VVER-1000 cladding tubes (Zr-1%Nb alloy) have been obtained. SEM results approved improvements, and further modification has been postponed till the finalizing the performance examinations in normal operational and accidental conditions (specifically, LB LOCA condition). Additionally, the list of required test, from characterizations to mechanical and performance experiments, in order to qualify the applicability of such coated samples are suggested.
**Keywords: Advanced Technology and Accident Tolerant Fuel (ATF), Chromium coated cladding tubes, Physical Vaper Deposition (PVD), Chromium nitride, coating defects.**

## *Introduction*
Nuclear fuels have been under continuous enhancement during last decades and it was believed that they could be used safely and reliably up to 65 MW.d/kgU. However, after the occurrence of a sequence of events in the Three Mile Island and Fukushima Daiichi, the research of ATFs accelerated and various concepts started to be examined more seriously. Currently, different concepts from modifications and improvements of existing technologies to introduction of revolutionary materials have been taken into consideration [1]. Among different alternatives concerning increase of cladding accident tolerance, Cr-coated cladding is common to various fuel manufacturing companies as a short-term resolution [2]; The reason is that the kinetics for oxidation of Cr-coated samples is several orders of magnitude slower than that for Zr alloys at LOCA conditions [3]. Another concern from the coating perspective itself, is the coating methodogy. There are wide range of coating techniques such as chemical vapor deposition (CVD), laser coating, physical vapor deposition (PVD), and the cold spray (CS) techniques. However, PVD technique has been frequently used to produce Cr-coated cladding samples, and its applicability checked in different studies.

This article focuses on the production of Cr- and CrN-coated Zr-1%Nb cladding tubes as a near term solution to improve cladding performance during normal operational condition, as well as increase the cladding tolerance in design basis accidents (such as large break loss of coolant condition). The preliminary results concerning this production of such cladding tubes, and the planned/on-going tests, have been reviewed briefly in the next sections.

## *Experimental*
### *Preparation of the materials*
The coatings were applied using a semi-industrial PVD machine with four cathodic arc evaporators. The chromium targets used has the purity of 99.9%. Before deposition, samples were cleaned by Alkaline degreasing, as well as by Aston and Ethanol in ultrasonic bath for 15 min, and finally, rinsed with distilled water. After putting samples within the chamber, puls Argon Ion sputtering for 20 min with 700 bias Voltage was implemented. A schematic diagram of the PVD machine is shown in Fig. 4.

## *Results and discussion*

First coated samples were produced, and then characterized using SEM tests. Results are shown in Fig. 5. Detected non-homogeneities in the particle sizes convinced researchers to work on the coating condition. After performing modifications on the coating condition and introducing magnetic filters in the way of evaporated particles towards the coating tubes, samples illustrated in Fig. 6 were achieved.

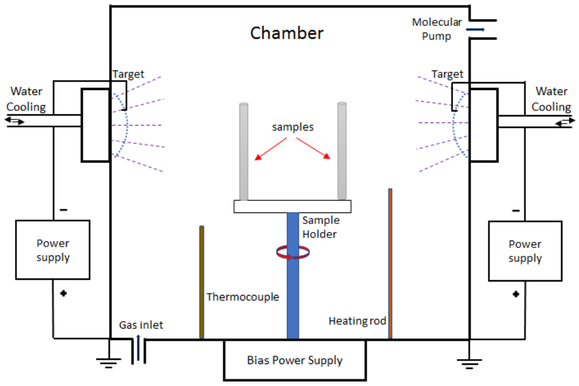


Figure 4. Schematic of the PVD machine for arc ion platting.

a)

b)

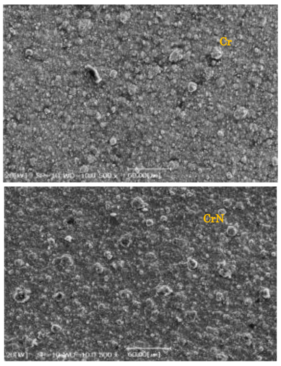


Figure 5. SEM photomicrograpgs from the top surface of the coated tubes (initial samples)

a)

b)

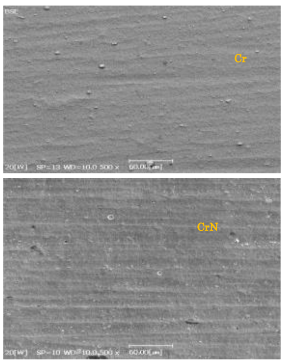


Figure 6. SEM photomicrograpgs from the top surface of the coated tubes (final samples)

As shown in Fig. 7, based on some manufacturing characteristics and results obtained from the quality control tests, different uncoated tubes were selected and coated in order to analyze a wide range of substrates with diverse manufacturing properties. Further results are not finalized yet and so that, they will be released in future publications.


Figure 7. coated samples divided into different categories base the manufacturing specifications

## *Conclusions*

Breakaway oxidation of Zr-base cladding tubes under high-temperature accidental conditions (typical to LOCA temperature ranges), and consequently, accelerated Hydrogen release, renewed interests for more tolerant nuclear fuel concepts. Among these concepts, coated claddings are approved as a short-term promising remedy and is being under preliminary, and in some cases, LTR (lead test rod) testings by different fuel manufacturing companies around the world.

NRF company, as the only fuel manufacturer organiztion in IRAN, planned to carry out wide variety of efforts from choosing and optimizing the efficient coating technique, to performing performance examinations. In this work, final results in production of Cr- and CrN-coated samples are presented. Initial results show acceptable coating characteristics and so that, produced samples are sent to test institutes and organiztions through an international collaboration in IAEA project dedicated to test and simulation of ATF concepts (known as CRP ATF-TS). Furthur achievements will be released in future publications.

## *References*

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