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ScienceDirect

Energy Procedia 127 (2017) 3–10

Energy Procedia

www.elsevier.com/locate/procedia

International Youth Nuclear Congress 2016, IYNC2016, 24-30 July 2016, Hangzhou, China

# Applying method of electrophysical diagnostics testing of uranium nitride under irradiation

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**Abstract**

The paper studies deformation of nitride fuel at an early irradiation stage with a functional electrophysical non-destructive diagnostic method. For this purpose, we measured relative thermoelectric voltage and voltage drops on the fuel surface under irradiation. Uranium nitride tests started at the self-heating temperature, which was gradually raised to 1,500$^0$C. Load was growing stepwise, from zero to 30 MPa. Signal structures were analyzed with discrete Fourier and wavelet transform algorithms. We build a deformation curve based on time dependence of thermoelectric voltage. The curve shows granular influence of changes in temperature and load. Accumulation of plastic strain increases internal stress until it reaches a critical point and relaxes, accompanied by spontaneous signal spikes.


Peer-review under responsibility of the organizing committee of IYNC2016

*Keywords:* dense nuclear fuel, NDT, electrophysical diagnostics

## 1. Introduction

Russia's principal plan for innovative nuclear power envisions full recycling of fuel and a combination of thermal and fast reactors. Russia in 2013 resumed research into nitride fuel as the main candidate for fourth-generation reactors, as part of Project Breakthrough ("Proyekt Proryv"). Nitride fuel, despite its immense potential, (higher density and thermal conductivity than those of conventional fuel [1]) is still not widely used. Understandably, fuel for a fast reactor should be dense to ensure large reproduction coefficient. One of the main technical problems in using nitride fuel is the lack of a reliable foundation for work with high levels of burnup [2]. The estimated burnup levels for a fast reactor that uses nitride are small compared with those for a water-cooled reactor that uses

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Peer-review under responsibility of the organizing committee of IYNC2016
10.1016/j.egypro.2017.08.085

traditional fuel. The main problem (dimensional instability) with nitride start at 8-9 percent burnup. Research into an experimental fuel element using uranium-plutonium nitride, being conducted in a multi-purpose research reactor on fast neutrons in Institute of Atomic Reactors, Dimitrovgrad, the BOR-60 reactor, should be finished by 2015. Then the behavior of such fuel at average burnup levels will possibly become known. Existing results of nitride fuel trials are few and limited, and were generally found with a diversity of apparatus [3].

Another serious problem is the insufficient knowledge of nitride fuel's behavior in transient and extreme situations. A comprehensive study of dense fuel's properties under irradiation is needed to develop appropriate usage techniques as well as universalized equipment able to ensure acquisition of necessary information throughout a wide range of changing external factors, especially temperature and physical stress.

To raise the effectiveness of inner-reactor studies, in our opinion, it is desirable to apply methods of technical diagnostics and nondestructive testing. *ElphysLAB*, a research facility at the National Research Nuclear University and Moscow Engineering Physics Institute, has built up experience in functional electrophysical diagnostics and nondestructive testing under irradiation. The high sensitivity of such methods has enabled clarification of many important issues connected with the internal processes that occur in uranium nitride [4-7]. During our experiment, thermoelectric voltage E was measured against a tungsten-rhenium alloy (W-20Re). The voltage drop on the pellet surface (proportionate to electric resistance) $\Delta U$ was measured with a 4-contact potentiometric method.

In particular we have received encouraging results during studying nitride fuel's resistance to radiation dimensional instability by applying functional electrophysical diagnostics and nondestructive testing under irradiation [8,9]. While developing the tests, we took into account several requirements for maintaining control conditions, especially regarding high temperatures (up to 2,000K) and simultaneous interaction of neutron flux (fluence of up to $10^{24}$ $m^{-2}$).

Over the course of experimentation (*in situ*), we developed a method of radiation temperature-power processing to trigger deformational alteration of uranium nitride.

## 2. Radiation Temperature-Power Processing

Samples of nitride fuel with varying grain size (8-15μm) and porosity (8-11 percent) were prepared by using powder metallurgy techniques [1,2]. Cylindrical samples with a height of 10-13 mm and a diameter of 5-7 mm were deformed through compression via a previously developed method [4]: radiation temperature-power processing (a method of low-cycle fatigue tests under irradiation).

The experiment included choosing such an interval and sequence of changes of external factors (temperature and physical stress) to cause maximum form-alteration of the core tablets. By conducting isothermal exposure of the sample in various cycles with various loads and test durations, it is possible to achieve changes in diagnostic parameters ($E$, $\Delta U$) within a rather wide range. Shading denotes the range of parameter changes of radiation temperature-power processing in the Ashby-Frost deformation mechanism diagram (Fig.1). Where $\sigma$ is applied compressive stress, $E$ is the elastic modulus, $T$ is test temperature and $Tm$ is the melting point. The scope of changes to processing parameters is shown in the Ashby-Frost deformation mechanism diagram (Fig.1).

For example, a prolonged incremental increasing of temperature by 100-150K with a heating rate of $50K\cdot s^{-1}$ from the self-heating temperature to 750K over the course of 30 hours under a constant load (σ=5 MPa) causes substantial form-alteration of carbonitride uranium tablets where the value of the control parameter may rise to 3 percent or more with a fluence of $8.4\cdot 10^{21}$ $m^{-2}$ [4]. We were observed at test temperature of about 2,100K after four hours of annealing at a temperature of about 0.3 $T_m$ an even greater (up to 30 percent) with this fluence.

Studies have revealed a pattern of extreme changes in diagnostic parameters prior to a high degree of deformation. Accumulation of plastic deformation leads to an increase of internal pressure up to a certain critical value above which a relaxation occurs, accompanied by irregular signals of a spontaneous character.

Using functional electrophysical diagnostics and nondestructive testing (in this case, a thermoelectric method) enables us to obtain information about the state of the core within the reactor and, in particular, quantify the amount of irreversible deformation under irradiation.