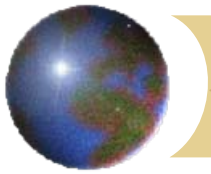


***MATINE-Study of Minor Actinide Transmutation in
Nitrides: Modeling and Measurements of Out-of-pile
Properties***

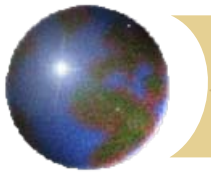
L.Zabudko (*IPPE*), *Obninsk, Russia*
Progress report on ISTC Project #2680

*Meeting of Contact Expert Group on ISTC Transmutation related Projects.
Brussels, January 30-31, 2006.*



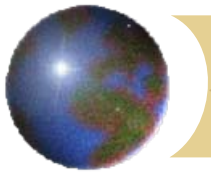
Introduction

- **On May, 1 2004 the Project has started . The duration of the Project is 29 months.**
- **Objective - to identify the optimum fuel pin design that would perform well under irradiation in ADS fast neutron spectrum
Fuel (Pu,Am,Cm,Zr)N (with ZrN=50-65%,
Pu/Am/Cm=40/50/10)**
- **Three Institutes –IPPE, VNIINM, RIAR-are participations.
CEA (France) and KTH (Sweden) are collaborators.**



MATINE Scope of activity

- Task 1:** compilation of literature data on nitride fuels and on MA containing fuels. The objective of this task is to perform input data for the codes calculation
- Task 2:** Experimental study of out-of-pile PuZrN properties: high temperature stability, thermal conductivity, high temperature creep, linear expansion
- Task 3:** Modeling of (Pu,Am,Cm, Zr)N behavior under irradiation up to 35at% in ADS (pellet for helium, sodium and lead-bismuth bonded fuel pin, vibro for helium-bonded pins only). Parameters to be investigated and determined: optimum range of power density; allowable cladding temperature, burn-up value.
- Task 4:** Technical – economical assessments of fabrication feasibility of (PuAmCmZr)N with (60 ± 10) at% ZrN and with 10 at% Cm at RIAR site.

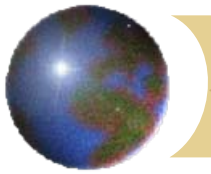


***Task 1*- completed. The report is handed to ISTC and collaborators (CEA, KTH)**

Review of literature data on UN, UPuN, UN+ZrN, PuN+ZrN properties as well as, on fuel compositions with MA is done. Today most proved relationships on basic properties of (Pu, Am, Cm, Zr) N are proposed: **thermal expansion coefficient, Young module, Poisson module, creep rate, thermal conductivity, gas release, maximum allowable temperature, fission gas release.**

No experimental swelling data for ZrN fuel. At stress-strain state calculation of pins with ZrN fuel the model of “spherical cells” developed for dispersion type inert matrices fuels is adopted for swelling estimation. The model requires matrix creep data that are absent. In Task 2 some additional measurements of ZrN creep are planning to be done that have to specify the parametric calculations.

Big uncertainty with He release from fuel matrix. Additional analysis of NIMPHE , BORA-BORA experiments will be done .



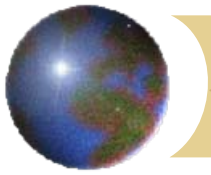
Task 2 (VNIINM, Moscow)

PuZrN fabrication technology is finalized with ZrN as a dummy. Relations between density of sintered PuZrN samples and density of compressed samples (compression pressure), sintering time and temperature have been studied.

(Pu,Zr)N samples with ZrN=60mol% of 85%th , 93%th density, met to the specifications, have been fabricated using direct nitridation of metals. Nitride powders were mixed using a patented electro-vortex blending method (rotating ferro-magnetic needles) - solid solution received.

Creep and thermal conductivity of (Pu,Zr)N samples are measured.

(Pu,Zr)N creep rate about one order lower than UPuN, recommended for modeling, thermal conductivity – good agreement with CEA data.



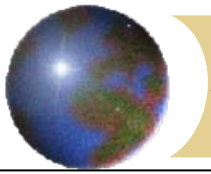
Task 3 –IPPE, Obninsk.

CARE code : calculations of max burn-up, He production, fission gas production are done.

FACIC code (Fuel Assembly Channel Isobar Calculation) for ADS core thermo-hydraulic calculation is developed. Optimization of FA design in order to get allowable values of Pb-Bi coolant rate, inlet coolant temperature, max clad temperature – is done.

DRAKON-3D code – is developed for temperature and stress-strain state calculation. Model of spherical cells (MSC) is developed for fuel swelling. The model will be verify using BORA-BORA PIE data (PuZrN irradiation in BOR-60).

Parametric comparative calculations of He-bonded pin performance for different pellet fuel creep laws (from literature review and from VNIINM Task 2 measurements) are completed; possible problem due to FCMI are revealed.



Example of DRAKON calculations

Fig.1. Clad hoop and axial stresses axial distribution at EOL (33.5at%)

Fig.2. Clad hoop and axial stresses per time at axial section 50% of core height

Fig.1

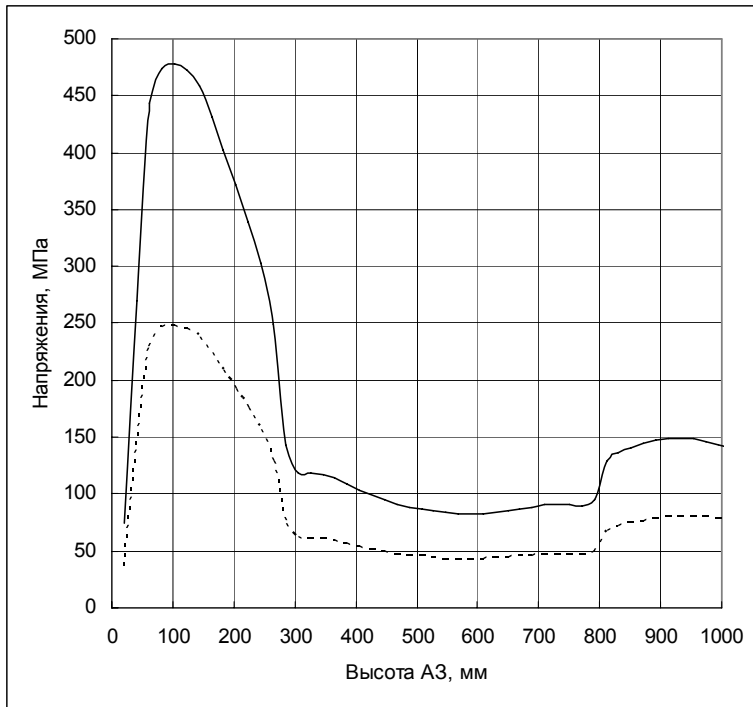
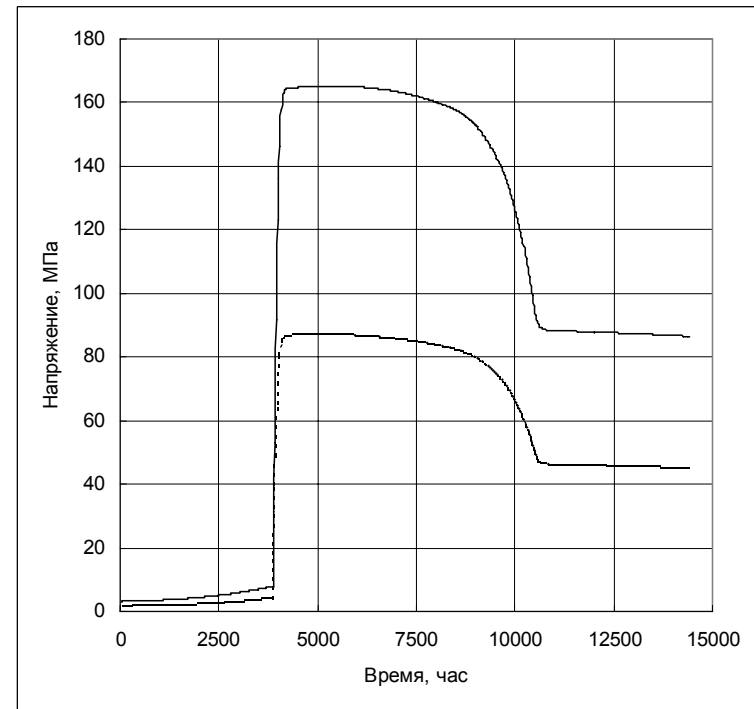
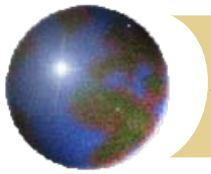


Fig.2



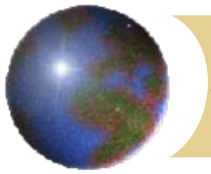


Task 4 –completed (RIAR, Dimitrovgrad). The report is handed to ISTC and collaborators (CEA, KTH)

The possibility is considered of fabrication on RIAR site of (Pu, Am, Cm, Zr)N fuel, (60±10)at% ZrN and 10at% Cm sufficient for manufacturing of 2 BOR-60 fuel pins- ~0.6 kg . Fuel pins manufacturing comprises the following main stages:

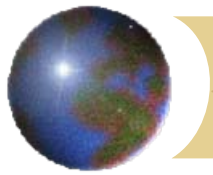
- chlorination of the initial components;
- production of MA nitrides;
- nitride fuel production;
- manufacturing of fuel pins.

High cost of full-scale pin fabrication (885 000 euro) is completely determined by Cm cost. As the initial stage of the researches, the manufacturing of the micro fuel pin or the special irradiation device is possible with the purpose of the expenses decrease.



Conclusion

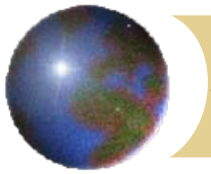
- 7 quarters work on ISTC MATINE- #2680- project is completed.
- PuZrN solid solution samples have been fabricated. PuZrN high temperature creep and thermal conductivity measurements are finalized. High temperature stability measurements are under completion. Thermal expansion coefficient will be measured additionally.
- Calculation modeling of (PuAmCmZr)N fuel in ADS core is under completion
 - DRAKON-3D code has been developed (stress-strain, temperature and clad damage calculations);
 - model for fuel swelling calculation is developed;
 - all necessary input data are prepared (properties relation for fuel and EP-823 cladding steel; He and fission gas production – CARE code calculation; axial temperature distribution of clad outer surface by FACIC code calculation);
 - comparative calculations of He-bonded pin performance are completed; possible problem due to FCMI are revealed;
 - calculations of Na- and Pb-Bi-bonded pins performance are under completion.
 - Modernization of VIKOND code: model of vibro fuel thermal conductivity, fuel restructuring, gap conductance. Vipac fuel performance estimations are done using fuel swelling rate 1%/1at% (accordingly, for fissile fraction of ADS three zones -0,35%, 0.4%, 0.5% per 1at%)



Proposal for new ISTC Project

"MATINE -2: Study of MA Transmutation in INert-matrices fuels: modelling and measurements of out-of-pile properties"

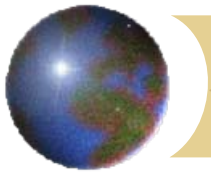
- Results of in-pile performance calculation made in MATINE have shown that liquid metal bonded fuels may perform well up to the target burn-up of 30%. He- bonded fuels however may exhibit problems at high-burn-ups in ADS core. The reason is fuel swelling rate under high linear ratings and low level of fuel creep that leads to the severe fuel-cladding mechanical interaction (FCMI). Since He bonding is preferable to remain compatible with aqueous reprocessing options, alternative fuel compositions are of interest.
- One of the possible options are the composite materials based on porous matrix made of refractory compounds, like Zr carbide or its solid solutions, with heavy nuclides incorporated into the pores. The fuel is developed in VNIINM, Moscow.



Proposal for new ISTC Project

"MATINE -2: Study of MA Transmutation in INert-matrices fuels: modelling and measurements of out-of-pile properties"

- Relative simple fabrication technique, including the absence of dust operations with high radioactive materials, since the last ones are introduced into matrix pores as liquid solutions. Thermal destruction process, mixed oxides formation as thin film on matrix pores surface.
- Porous Zr carbide matrix of required diameter and length is fabricated prior to the filling by actinides. All basic stages of technological route may be robotized. Matrix porosity 20-80%.
- Formation of mixed oxides even of those nuclides that don't form solid solution in melt (e.g., Np+Am). The possible solid solutions: Pu-Am-Np-Cm, U-Np-Am-Cm, Np-Am-Cm-Th, Pu-U, U-Th etc.
- Irradiated fuel reprocessing may be carried out using traditional routes of radiochemical facilities.



Project Proposal

"MATINE -2: Study of MA Transmutation in INErt-matrices fuels: modelling and measurements of out-of-pile properties"

- The objective of the Project - identification of uranium-free fuel types that would perform well under irradiation to high burn-up in ADS fast neutron spectrum . The possibility to use ZrC porous matrix impregnated by heavy nuclides oxides is proposed for investigation.
- The calculation modeling of neutronics and thermo-hydraulics will optimize ADS core parameters for effective actinides transmutation. The basic result – substantiation of PuAmCmO₂-ZrC fuel pins performance. **IPPE, Obninsk.**
- Fabrication and properties measurement of PuO₂-ZrC fuel : thermal conductivity, creep, linear thermal expansion, Young module – required input data for the calculation. **VNINM, Moscow.**
- On the base of MATINE-1 estimations the vipac PuAmZrN granulate samples and CmN powder will be fabricated. Thermal stability will be measured. **RIAR, Dimitrovgrad.**
- **Project duration – 2.5 years, cost US \$ 500 000.**