The RIAR DOVITA-1/2 P&T Program – Current Results of the 15-year R&D activities

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Experience in Closed Fuel Cycle including pyrochemical processes

Research Institute on Atomic reactors – RIAR (Dimitrovgrad) is most Russian R&D center of non-aqueous methods development:

- Pyrochemical investigation - from early 1960-s
- Demonstration of fluoride volatility reprocessing technology – 1970s
- Demonstration facility for pyrochemical MOX-fuel production for fast reactor – from late 1970-s
- Pyroelectrochemical reprocessing experience – 1990-2003
- Preparation for industrial application – from 1990-s
- Study on transmutation cycle, nitride fuel and other applications – from 1990s

Since 1992 RIAR has been performing own R&D DOVITA Program

- **D**ry technologies for MA fuel reprocessing and preparation
- **O**xide fuel application as the most widely studied one
- **V**ibropacking automated technology of the fuel pin production
- **I**ntegrated disposition of fuel reprocessing and fuel element refabrication facilities on the same site with the reactor
- **TA** The whole complex of approaches will permit a creation of the compact plant for Transmutation of Actinides

Experience in adding of minor actinides

in fuel compositions and results of irradiation

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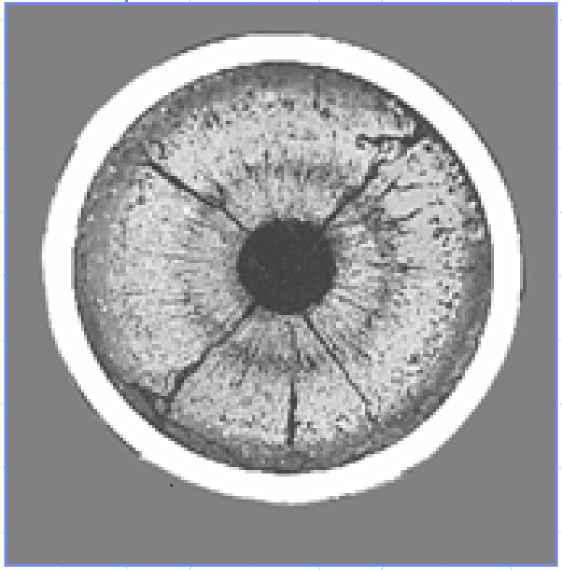
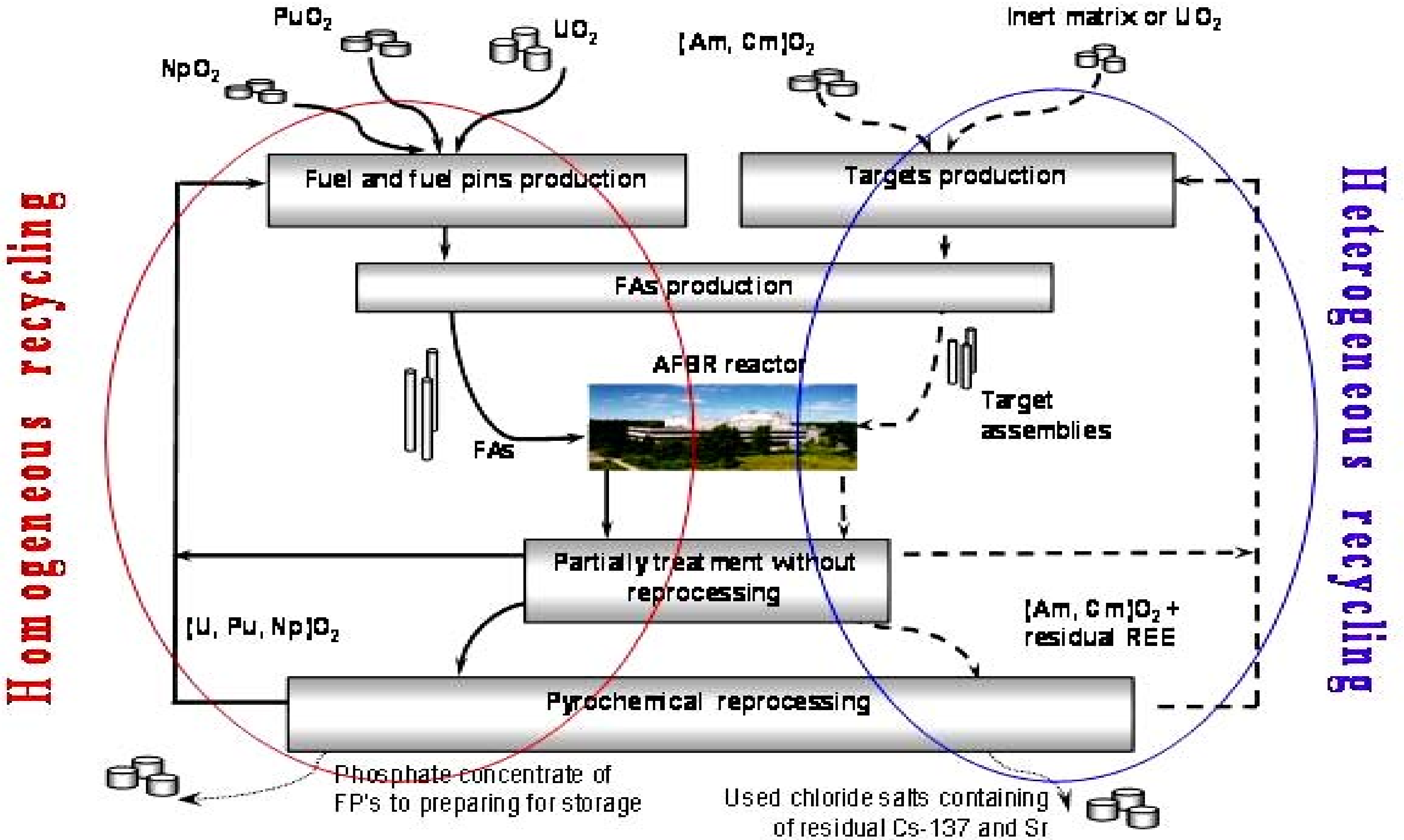


Irradiated $(U,Np)O_2$ fuel, 19% burn-up

- Pyrochemical technology of adding Np into oxide fuel (5-20%) has been developed
- Performance of vi-pack fuel with $(U,Np)O_2$ fuel has been validated experimentally to ~20% burnup in BOR-60
- No evidence of significant difference in performance of fuel rods with $(U,Np)O_2$ fuel compared with UO_2 or MOX fuel rods has been noticed
- Pyrochemical process of codeposition of Am with MOX fuel (2-4%) has been developed
- Methods of Am/REE separation in melts has been tested
- Special vi-pack targets containing Am oxide with UO2 or inert matrix have been developed
- Transmutation of Np, Am, Cm is being studied in BOR-60

DOVITA fuel cycle



New times consideration:

DOVITA → DOVITA-2

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1992

- **D**ry technologies
- **O**xide fuel with MA
- **V**i-pack
- **I**ntegrated disposition same site with the reactor
- **TA** Transmutation of Actinides

2006-2008

- **D**ry technologies
- **O**n-site reprocessing
- **V**arious type of fuel with MA
- **I**ntegration of MA recycling into FR Closed Fuel Cycle
- **TA** - Transmutation of Actinides

DOVITA-2

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Fuel type/ Stages	Oxide vi-pack	Oxide pellet	Nitride pellet/ vi-pack	Metal	Molten salt
Concept Studies	+	+	+	+/-	+
R&D	+	-/+	+/-	-	+
Fuel Production	+	-	-	-	-
Irradiation Testing	+	-	-	-	-
PIE	+	-	-	-	----
Reprocessing	-/+	-	-/+	-	+/-

DOVITA-1

Research area of pyrochemical and non-aqueous MA/FP partitioning in frame DOVITA-2 Program

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Melts/ media	Electrochemical methods				Oxides Precipi-tation	Metalli-zation
	Liquid cathodes	Solid cathodes	Anodic dissol-n	E/Chem. oxide titration		
Chlorides	Cd, Bi, Ga, Al	Al	+	+	+	+
Fluorides	Bi, Ga, Al, Pb	-	+	+	+	-
Cl^- / F^-	Cd, Bi, Ga, Al, Pb	Al	+	+	+	-
Molibdates	-	+	-	-	+	-
RTIL	Ga	Zn, Cu, Ni, Al, …	+	-	-	-

+ Methods of Volatility of Fluorides and /or Chlorides

Recent RIAR activities in frame of DOVITA-2 Program

ISTC Project # 3261 (2006-2008)

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Study of Cm thermodynamics in molten chlorides

Objectives

Reactions of formation for oxygen Cm compounds

- equilibrium constants for reactions of Cm oxygen compounds formation versus temperature;
- equilibrium constants for reactions of Cm oxygen compounds formation versus the inverse effective radius of solvent cathion

1st Year is completed

Reactions of formation for oxygen-free Cm compounds

- standard potential for redox pair versus temperature;
- standard potential for redox pair versus the inverse effective radius of solvent cathion

Simulation of Cm behavior in molten chlorides

Pourbaix diagrams

Collaborators – ITU, CIEMAT, CEA, KTH

ISTC project #3261. Current Results

Potentiometric titration of $CmCl_3$

ISTC project #3261. Current Results

Potentiometric titration of $CmCl_3$

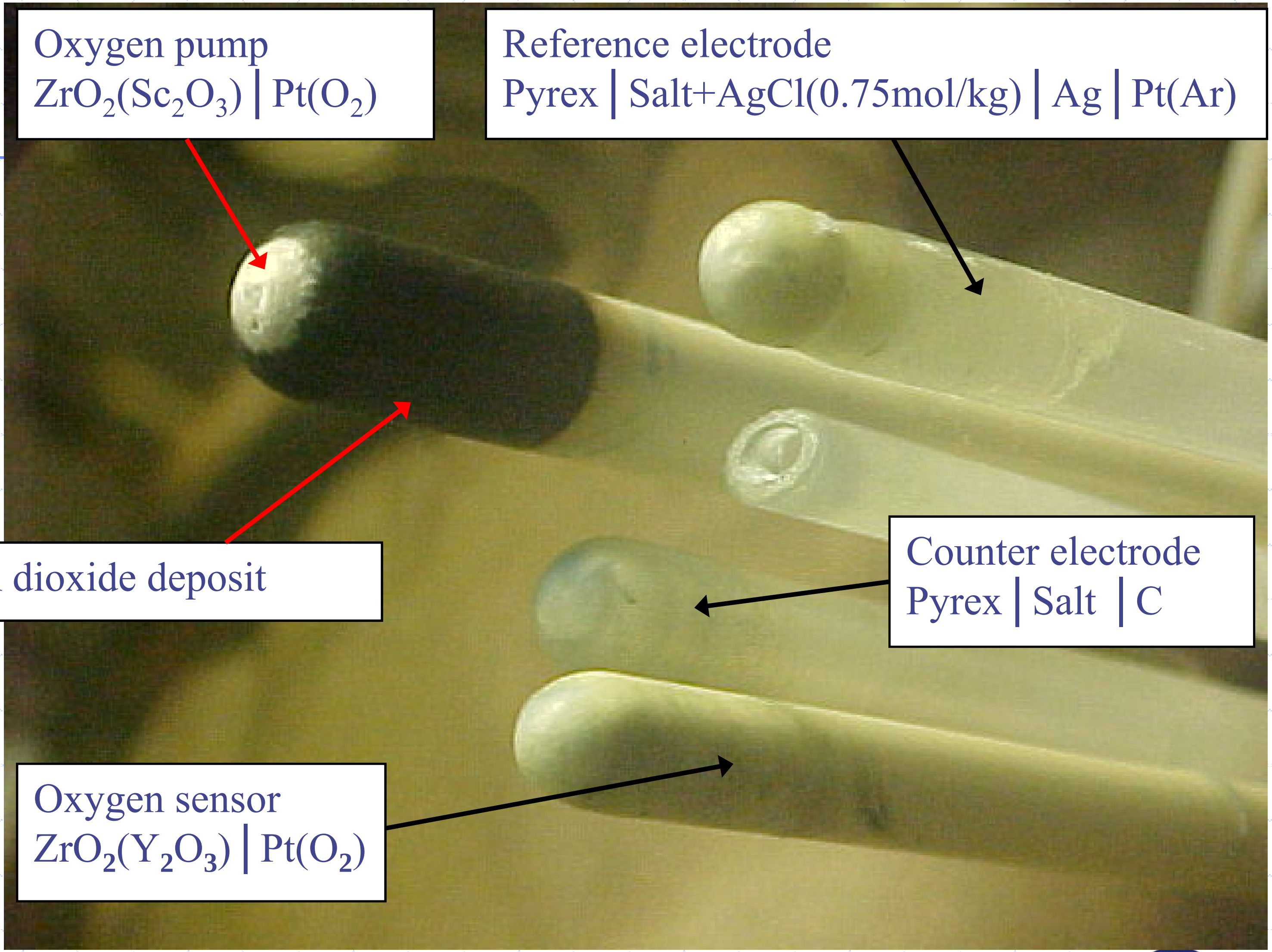
Applied methods:

- main - titration by BaO

- combined - in case of absence of Section on preliminary experimental curve for CmO^+ formation :

titration by current through the electric circuit "oxygen pump" – "counter electrode" and then by BaO

ISTC project #3261. Current Results



Oxygen pump after experiment

ISTC project #3261. Current Results

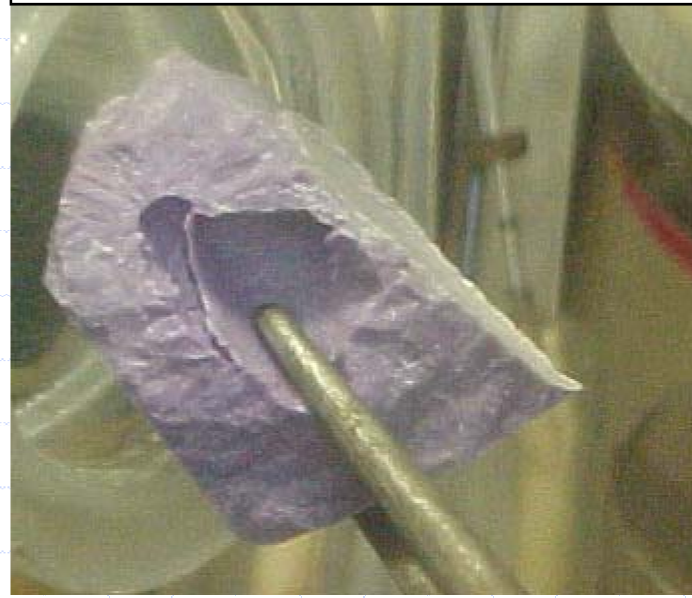
Conditions of experiments

Salt	Amount of Runs	Temperature range,°C	Range of Cm content in melt, mole/kg
NaCl-2CsCl	11	550-750	$(1.1\text{-}14)\cdot10^{-3}$
3LiCl-2KCl	7	450-650	$(1.9\text{-}7.9)\cdot10^{-3}$
NaCl-KCl	3	750-850	$(5.0\text{-}6.9)\cdot10^{-3}$

ISTC project #3261. Current Results

NaCl-2CsCl+$CmCl_3$($1.4 \cdot 10^{-2}$mole/kg)

LiCl-KCl+$CmCl_3$($5.5 \cdot 10^{-3}$mole/kg)



NaCl-KCl + $CmCl_3$($5.0 \cdot 10^{-3}$mole/kg)

Salt ingot with $CmCl_3$

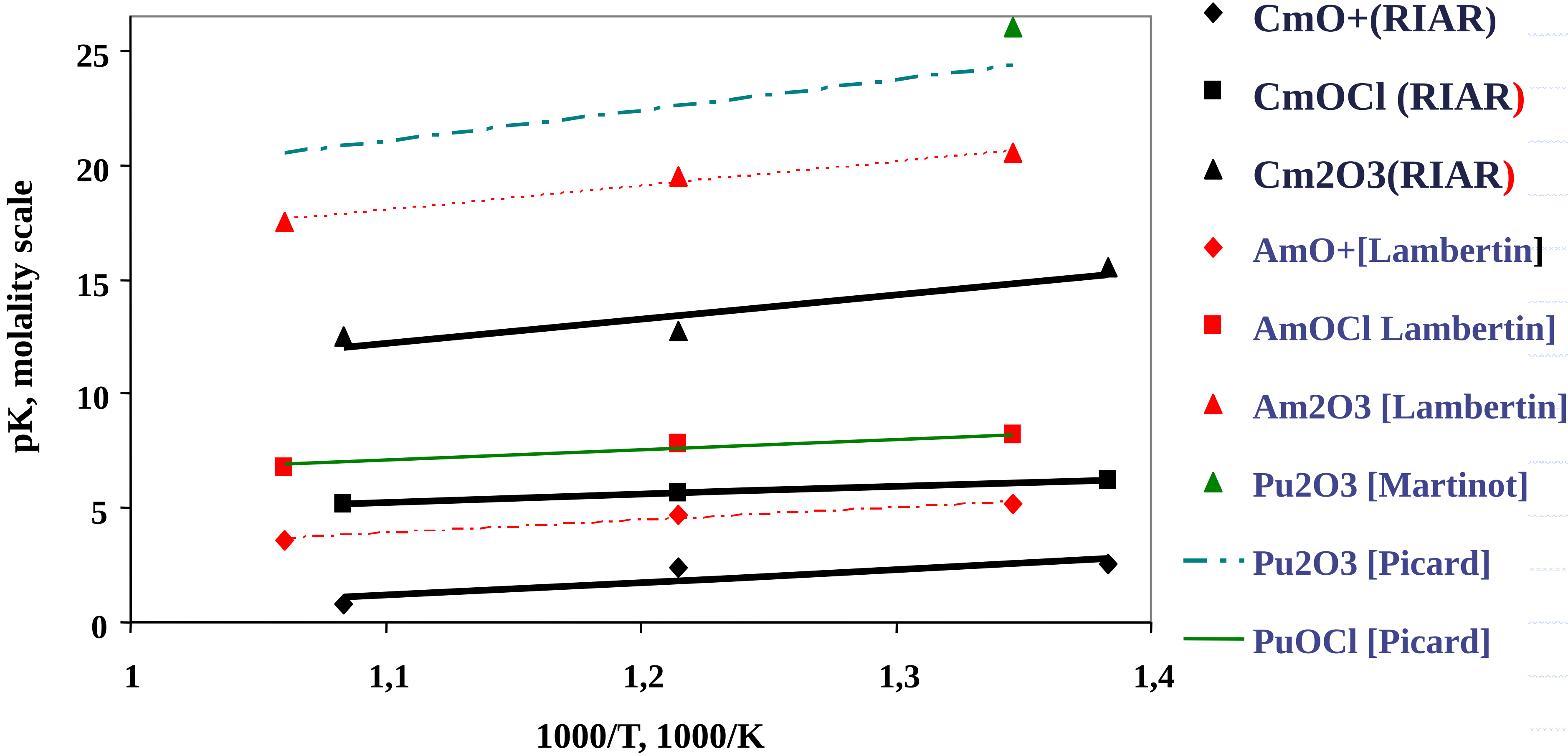
ISTC project #3261. Current Results

Experimental constants of CmO^+, CmOCl and Cm_2O_3 dissociation in molten chlorides at different temperatures, molality scale

Melt	T, °C	pK(CmO^+)	pK(CmOCl)	pK(Cm_2O_3)
NaCl-2CsCl	556	4.2±0.2	7.9±0.2	20.1±0.3
	650	3.4±0.2	7.5±0.2	18.5±0.3
	750	3.7±0.2	6.7±0.2	16.8±0.3
3LiCl-2KCl	450	2.5±0.2	6.2±0.2	15.5±0.5
	550	2.4±0.2	5.7±0.2	12.7±0.5
	650	0.83±0.1	5.2±0.2	12.5±0.5
NaCl-KCl	750	2.6±0.2	5.9±0.2	12.9±0.4
	800	2.4±0.2	5.8±0.2	12.6±0.4
	850	1.3±0.1	5.6±0.2	12.1±0.4

ISTC project #3261. Current Results

Comparison with literature data on other actinides.
Dependence of dissociation constant for actinides upon temperature in LiCl-KCl



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Recent RIAR activities in frame of DOVITA-2 Program

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- R&D for production of vi-pack oxide Fuel with MA
  - Under continuation
- R&D for production of vi-pack nitride Fuel with MA
  - Under development
- R&D for production oxide pellet fuel with MA
  - Under development
- R&D for production metallic fuel with MA
  - Feasibility Stage
- Molten Salt chemistry of Am and Cm for fluorides
  - Under preparation
- Partitioning of MA/REE in molten chlorides/fluorides
  - liquid cathodes
  - reductive extraction
  - Oxide precipitation

Official Investment Frames for Russian Nuclear Renaissance

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- Federal Tasks Program "Development of Nuclear Power Complex of Russia on a period of 2007 - 2015 " - accepted in 2006

  - *NPP construction*

- Federal Tasks Program "Nuclear and Radiation Safety" (2008-2015) - accepted in 2007

  - *RAW Heritage*

- Federal Tasks Program "New Generation Nuclear Energy Technologies" (2010-2020) – on a final preparation Stage

  - *Innovations*

Federal Tasks Program
"New Generation Nuclear Energy Technologies"

RIAR planned participation

- **Multi-functional Fast Research Reactor (MFRR) - 2016**
- **Large Multi-Purpose Pyrochemical Reprocessing Complex - 2015**
  - ➢ **Molten salt Reprocessing Facility**
    - ✓ capacity – up to 2 500 kg of SNF per Year (fuel type: oxide, nitride, metallic, IMF)
  - ➢ **Fluoride volatility Reprocessing Facility,**
    - ✓ capacity – up to 500 kg of SNF per Year (mainly – LWR SNF)
- **New Lab for Experimental and Innovative Fuel Production – 2010-1012** (incl. Fuel and Targets with MA)
- **Demonstration of Closing Fuel Cycle based on Pyrochemical technologies -2016-2020-... on a levels:**
  - ➢ **Up to 50 spent FAs of BN-600/800**
  - ➢ **Full scale CFC for MFRR from initial fuel loading**
  - ➢ **Other experimental implementations**

New Russian Sodium Fast Research Reactor – Multi-functional Fast Research Reactor (MFRR)

Location – RIAR site

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Characteristic	Value
Maximum flux Φmax, n/cm2·sec	~ $6.0 \cdot 10^{15}$
Thermal power, MWth	~ 150
Electric power, MWe	~ 50
Number of independent experimental loops (~1 MWth, sodium, heavy metal and gas coolant + salt coolants)	3 (+1 behind reactor vessel)
Driven Fuel	Vi-pack MOX, (PuN+UN)
Core height, mm	400-500
Maximum heat rate, kW/l	1100
Fuel Cycle	Full Scale Closed FC based on Pyro Processes
Test Fuel	Innovative Fuels, MA Fuels and targets
Maximum fluence in one year, n/cm2	~ $1{,}2 \cdot 10^{23}$ (up to 55dpa)
Design lifetime	50 year
RR creation time (no more than, years)	9 (2008 – 2016)

Start of BN Closed fuel Cycle based on RIAR technologies

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- **2011 - start of vi-pack MOX-fuel production for BN-800**
- **2012 – start of BN-800 operation**
- **2016…2018 – demonstration of BN-800 closed fuel cycle technologies**

Key final official decisions:

- MOX-fuel production by pyroelectrochemistry and vibropacking
- Trend to closing of fuel cycle by compact dry technologies
- Development and testing of new fuel and new technologies

RIAR R&D International cooperation in the field of advanced FC

	Fuel production		Repro-cessing	P&T	Other	Cladding materials	Concept Studies	Funda-mental Studies
	MOX	other						
France	-	MA oxide	-	Am/Cm recovery	Pyro	+	FS	Cm
INPRO	-	-	-	-	-	-	CPP RUS-2	-
Japan	MOX vibro	-	MOX	MA/REE separ.	Fluorex/ MoO_4^{2-}	ODS	FS	MA
Korea	-	-	Metalliz. / vibro-DUPIC	MA/REE separ.	Pyro	-	-	-
US?	*TRU fuel ?*		*UREX+1 ?*	*TRU fuel?*	-	-	-	*Pu in RTIL's*
EU	-	MA nitride	-	-	MSR fuel	-	-	Cm

Red color – DOVITA-1/2 activities