DE LA RECHERCHE À L'INDUSTRIE

Innovative and safe supply of fuels for reactors

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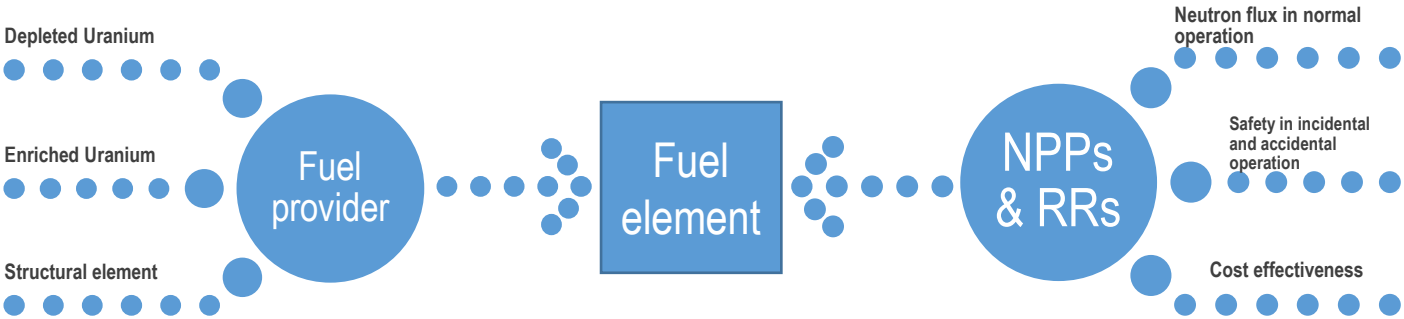
- **R**esearch **R**eactors (**RR**s) and **N**uclear **P**ower **P**lants (**NPP**s) are essential parts of a working ecosystem for nuclear power usage ;

- Interest for EU society:
  - Decarbonated supply of electricity;
  - Production of medical radio-isotopes;
  - High level science.

(1) FUEL SUPPLY CHAIN FOR NUCLEAR REACTORS



- Key challenges:
  - Diversifying the suppliers;
  - Innovate to reach non-proliferation goals.

- Fuel supplier diversification:
  - Historic fuel manufacturer;
  - RRs with original soviet design;
  - NPPs of VVER technology.
- Issues linked to a unique fuel provider:
  - What happens if the provider default?
  - No incentive for continuous improvement;
  - Cost effectiveness?
- Targeted reactors in europe:
  - NPPs (VVER440): Czech Republic, Finland, Hungary, Slovakia, Ukraine;
  - RRs: Czech Republic, Hungary, Poland(converted LEU), Ukraine.

- Challenges for fuel supplier diversification:
  - Analyzing the key functions ie. reverse engineering;
  - Reproducing the normal operation behavior;
  - Preserving and improving the key safety features;
  - Propose a cost effective solution.

- Key points to reach the goals:
  - Collaborative approach including manufacturers, research experts, reactors operators;
  - Improve safety and operational features of the fuel element;
  - Include the preparation of the licencing steps as soon as possible.

- Low enriched uranium RR fuel:
  - Enrichment larger than 20% ^{235}U;
  - Global Threat Reduction Initiative;
  - Conversion for medium performance research reactor technically feasible and ongoing;

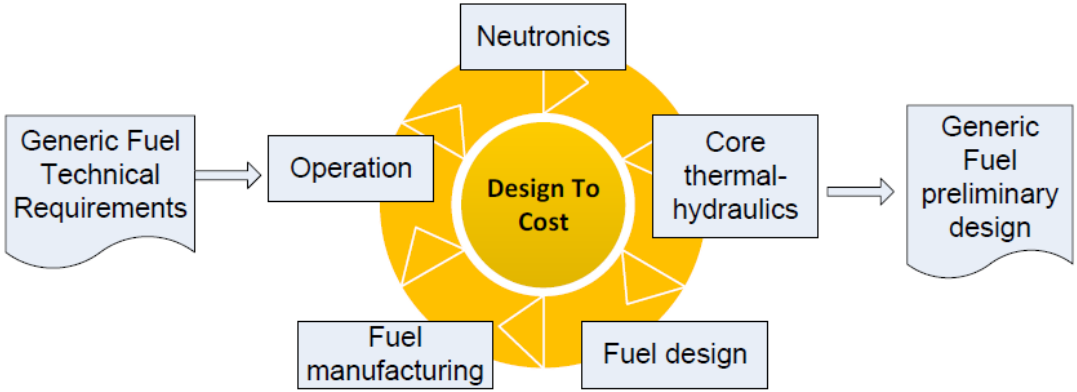
- Challenges for european high performance reactors:
  - Use fuel below the 20% enrichment;
  - Conserve the reactor performance;
  - Prove and improve reactor safety usage.

(1) FUEL SUPPLY CHAIN FOR NUCLEAR REACTORS

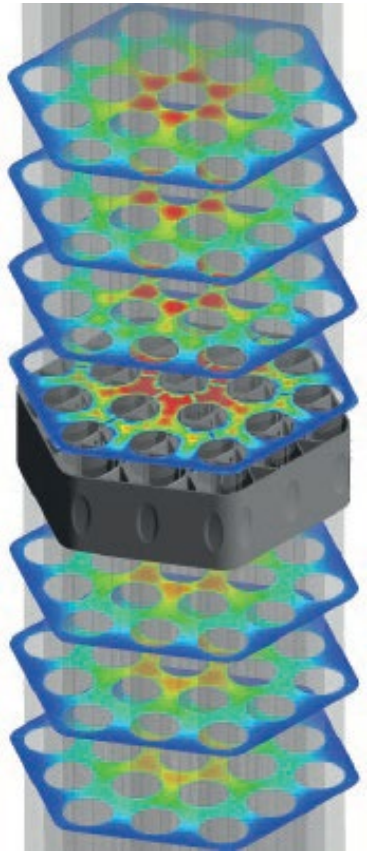
ESSANUF	LEU-FOREvER	HERACLES-CP
European Supply of SAfe NUclear Fuel	Low Enriched Uranium – Fuels fOr ResEarch Reactors	HERACLES-Comprehension Phase
Diversify sources of fuel supply for VVER type NPPs and RRs		
	Develop non-proliferant fuel for high performance RRs	
NFRP-16-2015	NFRP-11	NFRP-08-2015
2015-2017	2017-2021	2015-2019
http://www.essanuf.eu/	https://heracles-consortium.eu/forever.php	https://heracles-consortium.eu/cp.php
Westinghouse, Vuje AS, UJV REZ, Lappeenranta University of Technology, National Nuclear Laboratory Limited, NucleoCon SRO, National Science Center Kharkov Institute of Physics and Technology, Enusa Industrias Avanzadas SA, Joint Research Center	CERCA, CEA, CVR REZ, ILL, LGI, NCBJ, SCK.CEN, TechnicAtome, TUM/FRMII	CERCA, CEA, ILL, SCK.CEN, TUM/FRMII

(2) APPROACH: FUEL SUPPLY DIVERSIFICATION

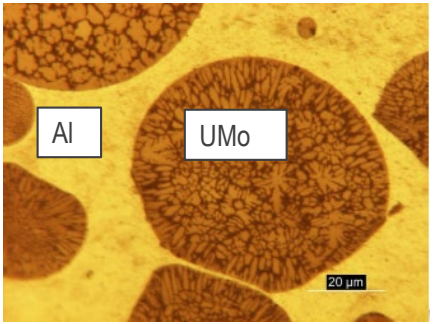
- Main hypothesis to be cost effective
  - Core and experimental load performances: at least, at the same level;
  - Safety methodologies: no change of the current one;
  - Main interfaces: Neither change of the control and shutdown systems components nor of the cooling systems, nor of the experimental devices, nor of the I&C, nor the core grid.
- Key drivers
  - A good data gathering and synthesis;
  - An innovative approach of the new fuel design based on U_3Si_2 proven technology.



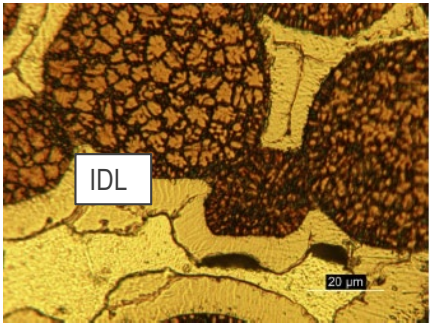
- Design input organised around workshops:
  - Fault analysis (LOCA & RIA) ;
  - Fuel rod design ;
  - Thermal-hydraulic design;
  - Nuclear criticality safety.
- Use of scientific calculations:
  - Code coupling between Transuranus, dyn3D, ATHLET, RELAP, SERPENT, APROS ;
  - CFD models used for new fuel design assembly.



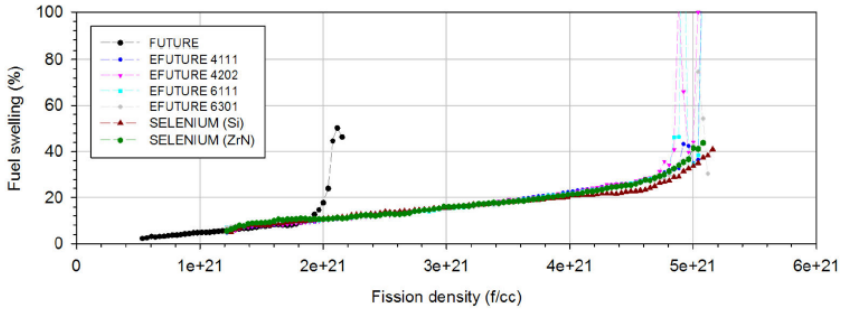
FUTURE, BOL



FUTURE, EOL

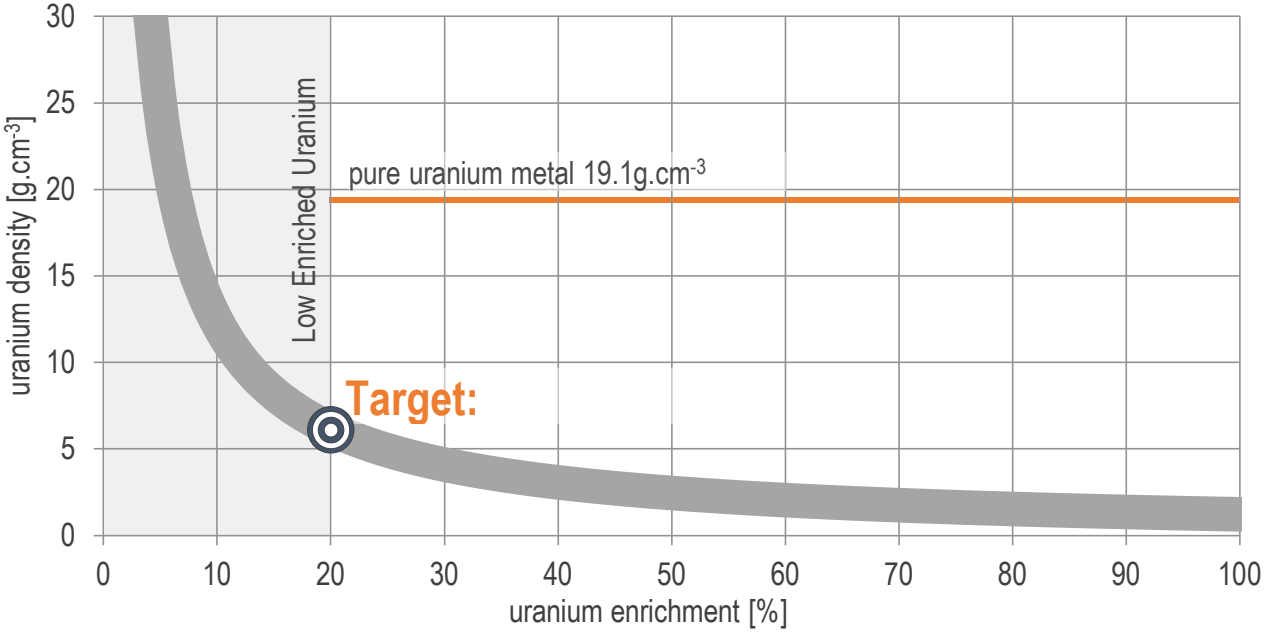


- UMo fuel types:
  - U 7% wght. Mo dispersion;
  - U 10% wght. Mo monolithic.
- UMo dispersion behavior:
  - no barrier (FUTURE) **I**nter-**D**iffusion **L**ayer (IDL) formation -> breakaway swelling;



(2) APPROACH: LEU CONVERSION

- LEU:
  - Prevent proliferation;
  - Enrichment below 20%.
  - Increase uranium density;
  - Use of UMo or U_3Si_2 compounds.
- How:



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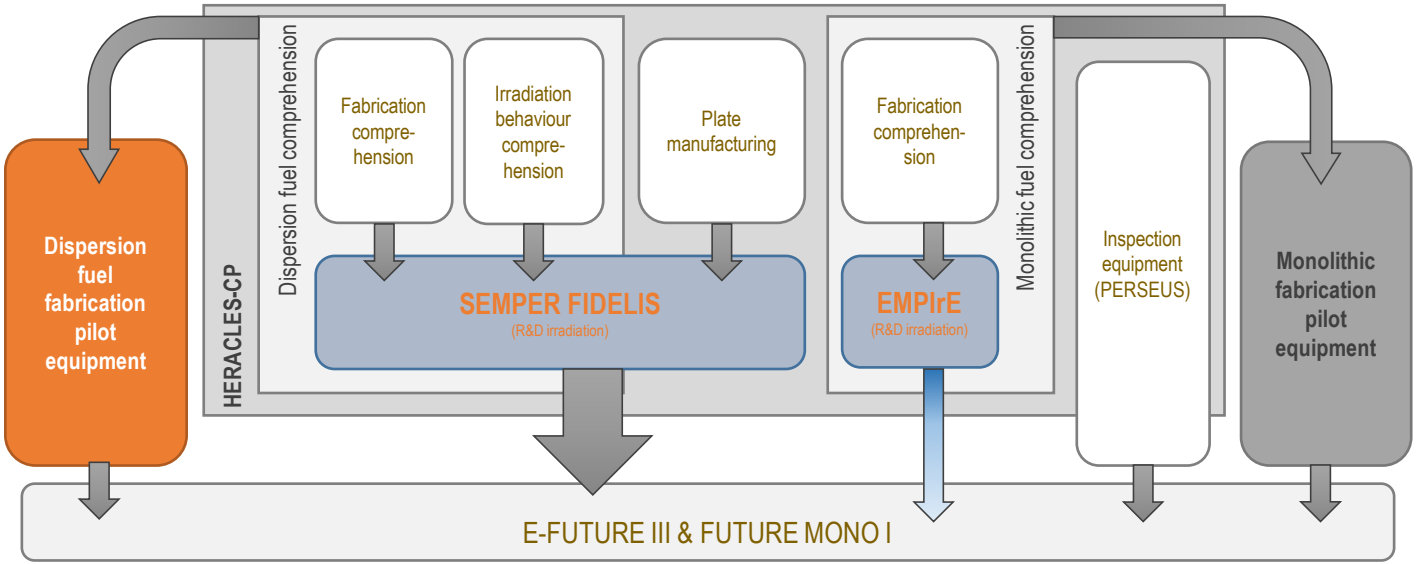


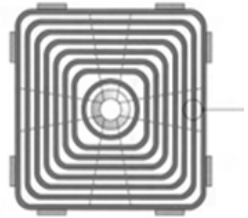
- Examinations on UMo
  - X. Iltis et al., poster A0084;
  - F. Vanni et al., poster A0121.
- Irradiations
  - Stepnik et al., presentation A0120;
  - Glagolenko et al., presentation A011.

- New VVER440 fuel design:
  - Optimized Zirlo cladding;
  - Fuel rod dimensions optimization with 3D neutronic calculations;
  - Design enabling inspection and repair;
- Assessment of manufacturing capabilities
  - Time frame of 24 months to establish the full productionchain;
  - 24 months to licence necessary fuel transport containers.

Westinghouse new conceptual VVER-440 fuel design

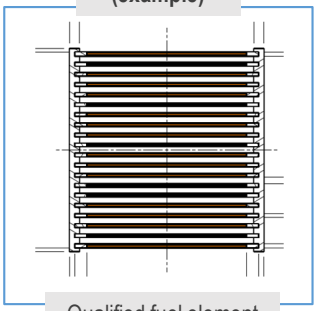
(3) RESULTS: FUEL SUPPLY DIVERSIFICATION

Current Qualified FA (IRT-4M)



(UO_2 – Al)

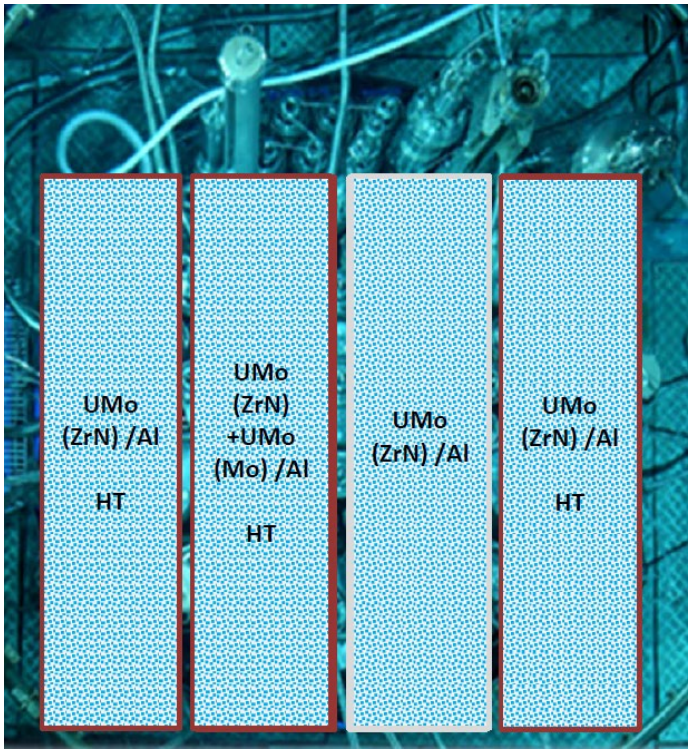
Alternative FA (example)



Qualified fuel element (U_3Si_2 Al) – 4.8 $g_u . cm^{-3}$

- A path toward fuel supply diversification:
  - Workshop organized for specific needs determination;
  - Preliminary design proposed;
  - Communications RRFM 2019: Boyard et al, Koubbi et al, Duperray et al.

- Semper-Fidelis irradiation campaign
  - 11 plates irradiated over 4 cycles ;
  - 1 plate with 4 cycles without failure signs;
  - First analysis results encouraging;
- LEU-FOREvER:
  - DU plates for high loaded U_3Si_2 manufactured;
  - Proven feasability of gradient monolithic UMo on surrogate material.



(3) RESULTS: COMMUNICATIONS

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Objectives

- Secure the supply chain of nuclear fuels;
- Reduce the proliferation threat;

Achievements

- Design of a replacement element for VVER-440 thus opening the market for fuel supplier diversification;
- Test of reliable conversion fuels for high performance RR;
- Design of a conversion element for medium power RRS.

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