Nuclear Safety Research at JRC

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МИНИСТЕРСТВО
НА ОБРАЗОВАНИЕТО
И НАУКАТА

Nuclear Safety Research at JRC

Institute for Energy

*The Institute for Energy provides scientific and technical support for the conception, development, implementation and monitoring of community policies related to energy. **Special emphasis** is given to the security of energy supply and **to sustainable and safe energy production**.*

Institute for Transuranium Elements

*in **the nuclear fuel and fuel cycle research** to contribute to European efforts:*

- ***to increase the** useful life and **safety of nuclear fuel in commercial power stations and in advanced reactor systems***
- *to improve the spent fuel behavior under intermediate and final storage conditions*
- *to reduce the amount and the toxicity of radioactive waste (P&T)*

Nuclear Safety Research at JRC

Institute for Energy

AMA – Analysis and Management of Nuclear Accidents

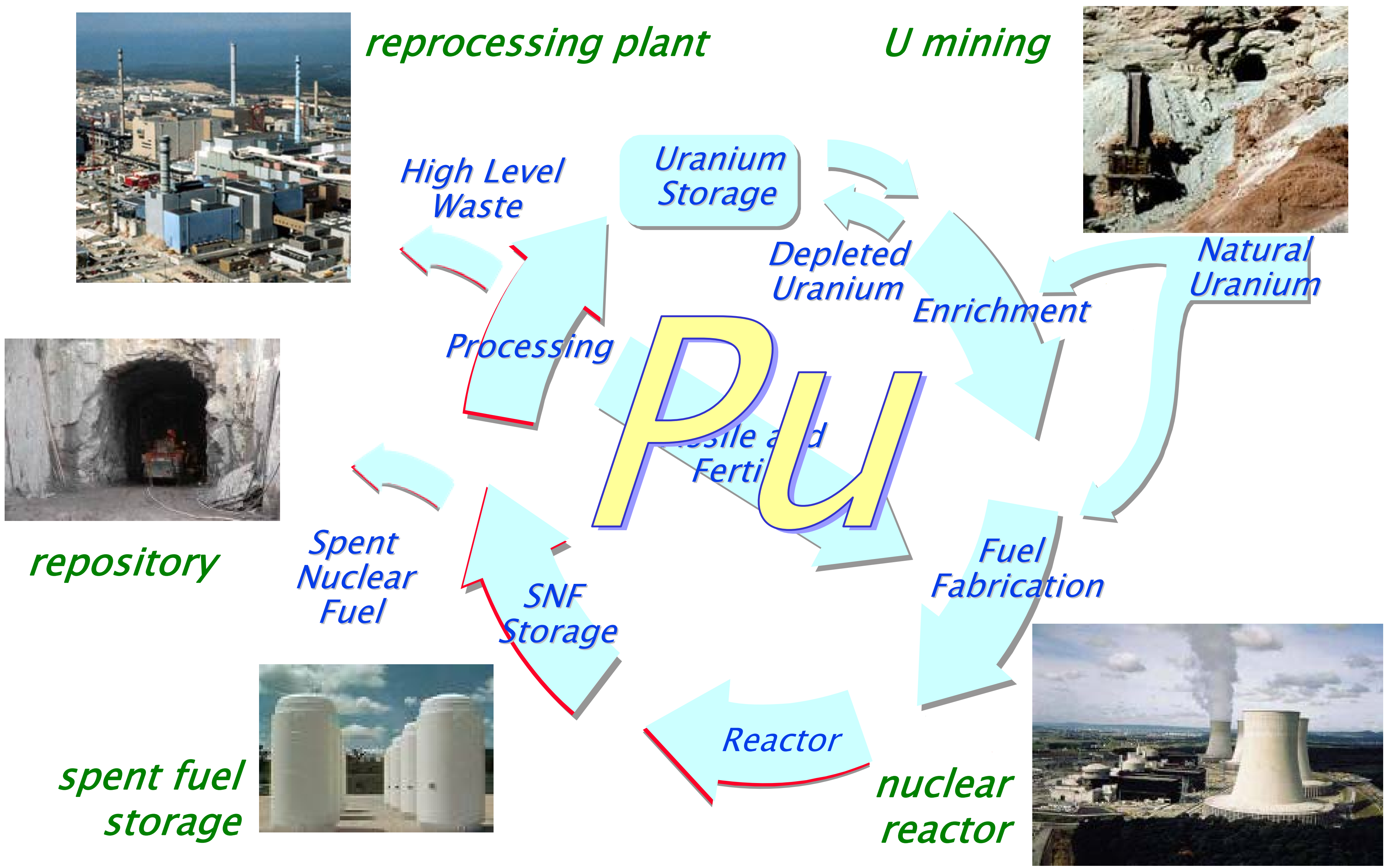
SAFELIFE – Safety of Ageing Components in Nuclear Power Plants

SONIS – Safe Operation of Nuclear Installations

NUSAC – Nuclear Safety Clearinghouse

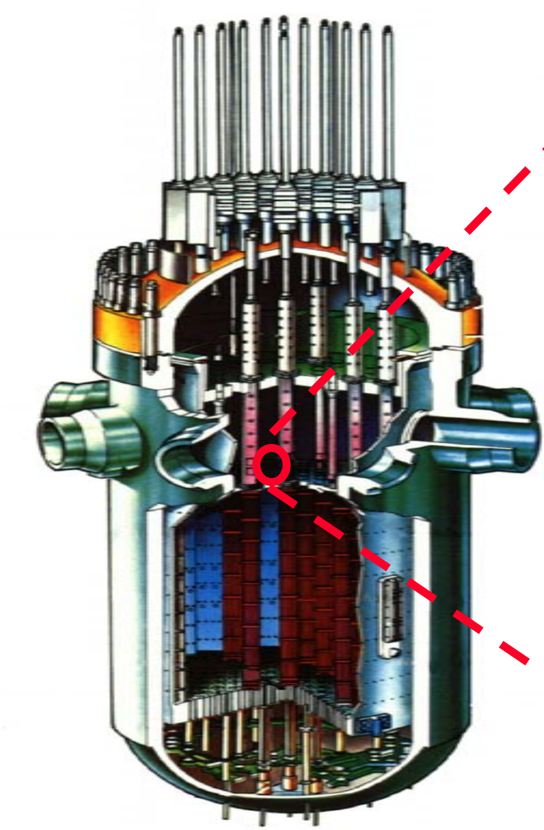
SAFETY-INNO – Safety of Innovative Reactor Design

The Nuclear Fuel Cycle

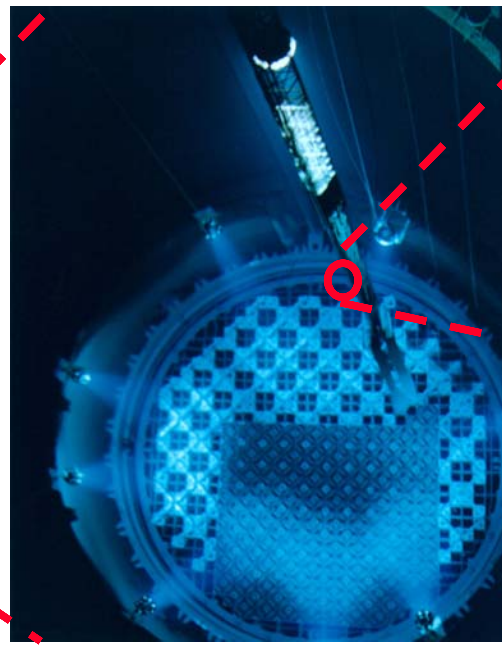


Safety of Nuclear Fuel

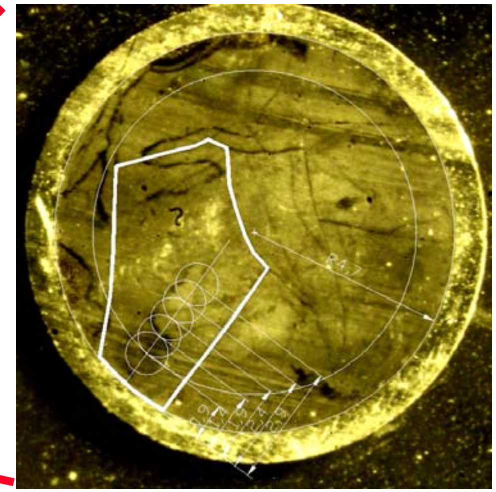
- *analysis of the thermal and mechanical behaviour of fuel rods in nuclear reactors*



PWR/VVER

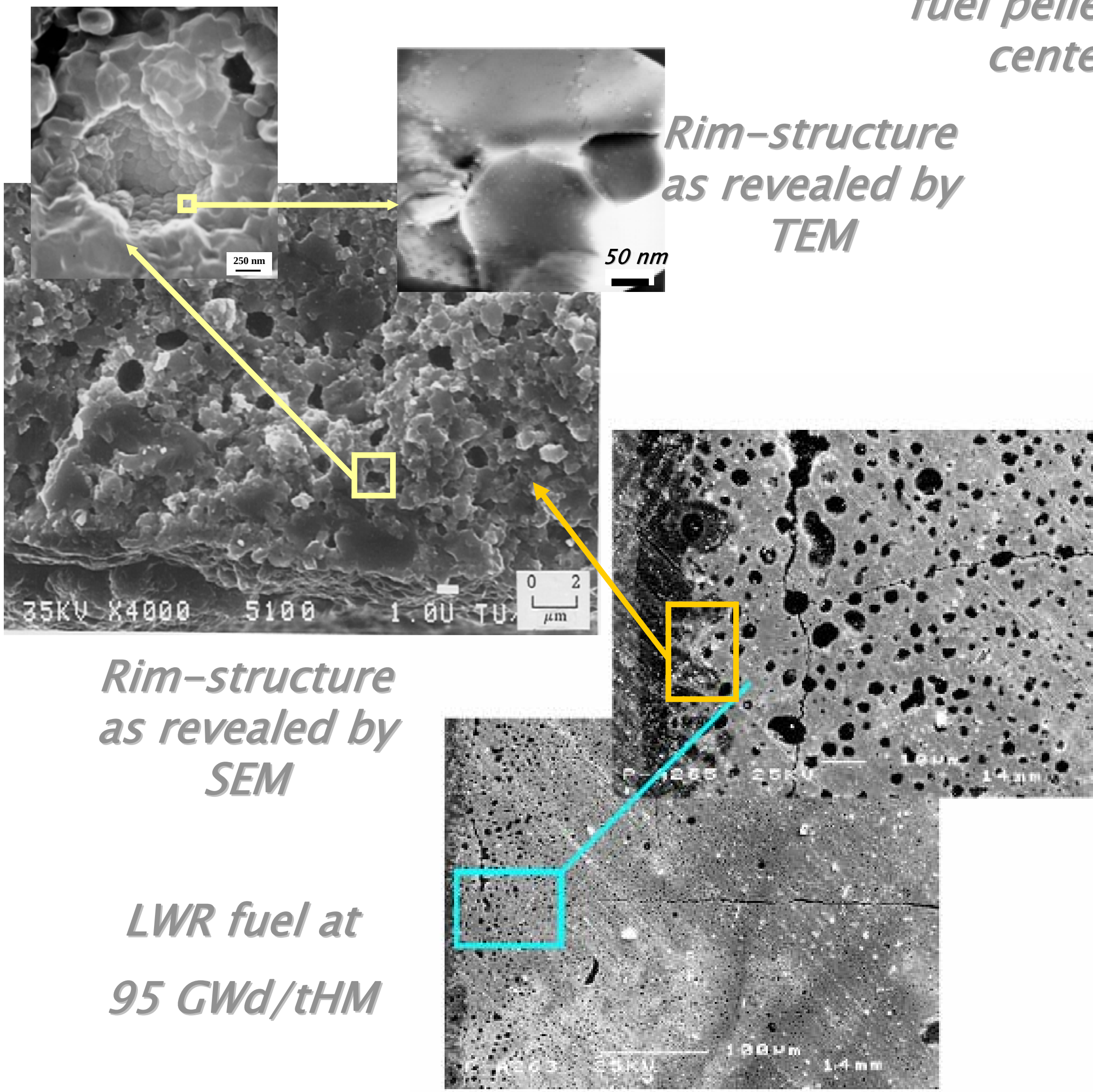


fuel element/pin



fuel pellets

Safety of Nuclear Fuel: in-pile behaviour



Rim-structure as revealed by TEM

Rim-structure as revealed by SEM

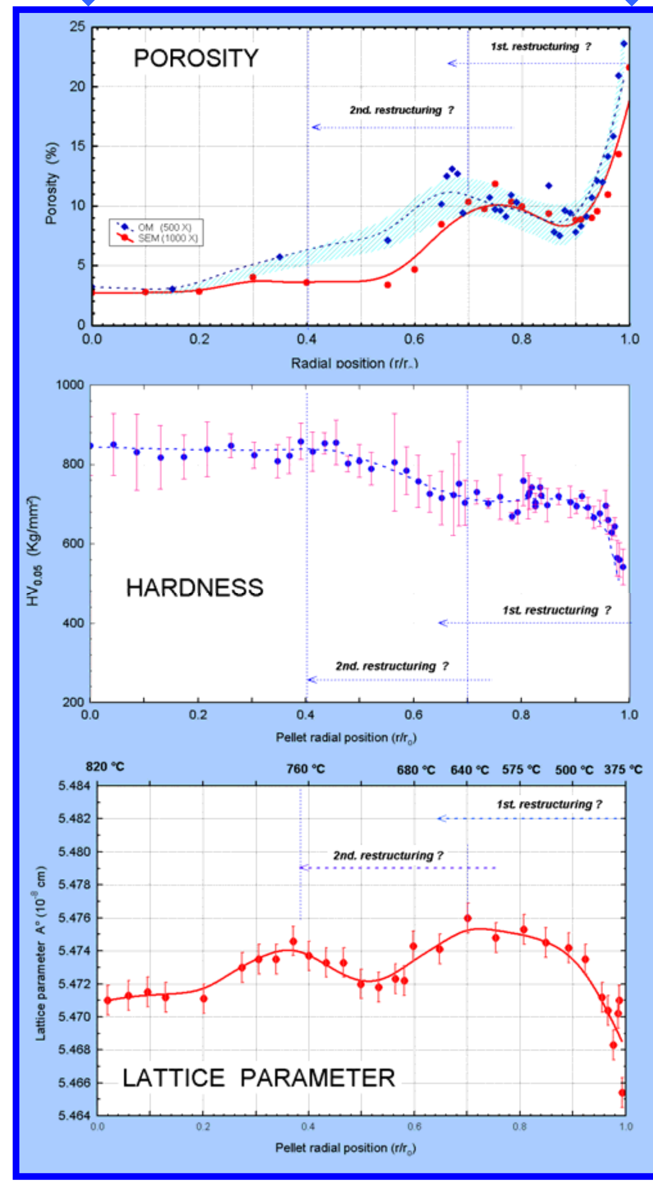
LWR fuel at

95 GWd/tHM

fuel pellet center

~ 5 mm

rim



“POLARIS”

POwer Laser Apparatus for Reactor Irradiated Samples

A flexible group of facilities for thermo-mechanical simulation of the behaviour of irradiated fuel based on heating using a multi-kW continuous wave laser.

Application fields

Local variation of the thermal diffusivity, integral thermal conductivity, fuel-cladding contact conductance, fission gas release, fuel/cladding interaction and melting behaviour.

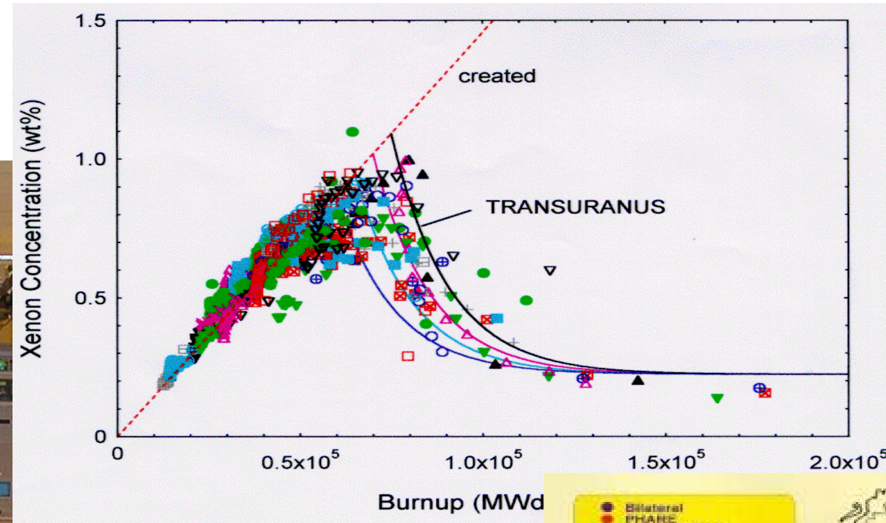
Measurement of the fuel performance under severe **transients**, corresponding to power ramps simulating **accident conditions** up to the limit of core disassembly.

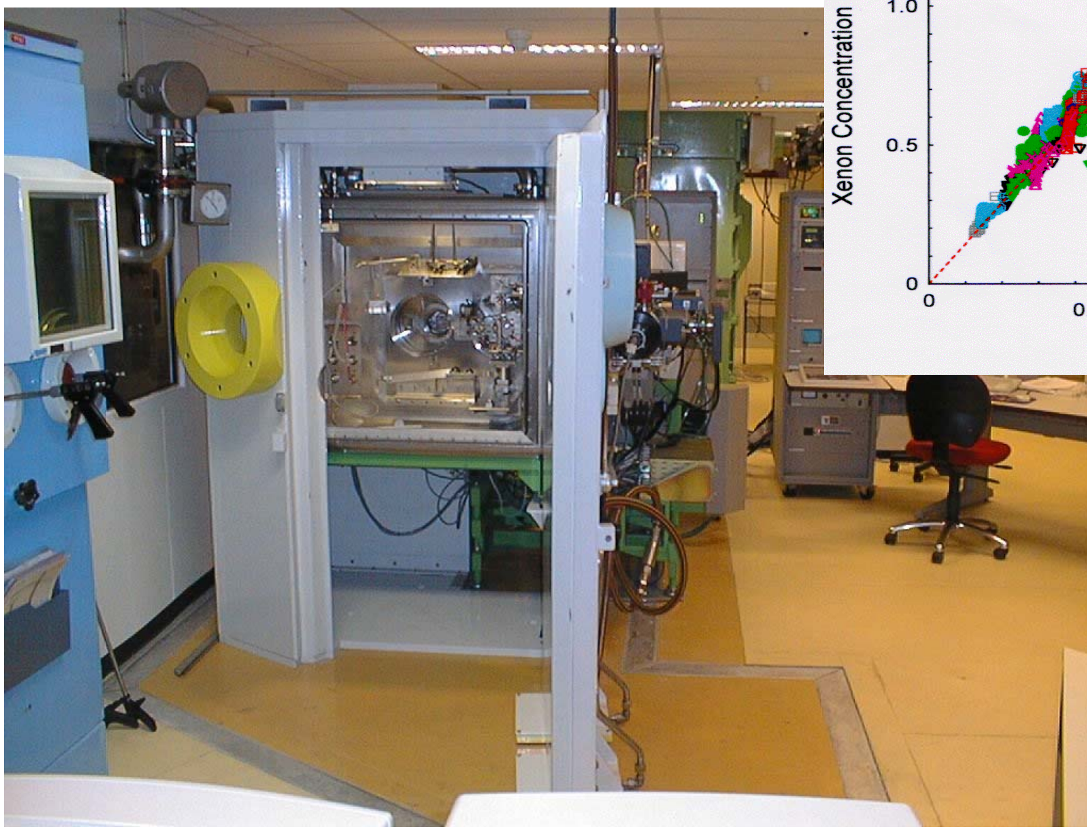
The **detailed information** obtainable by ***POLARIS*** will **improve interpretation of in-pile measurements, hence calibration of fuel performance codes**.

POLARIS constitutes an evolution of the ITU thermophysical measurement tools. It will provide an improvement in the quality and insight of experimental data.

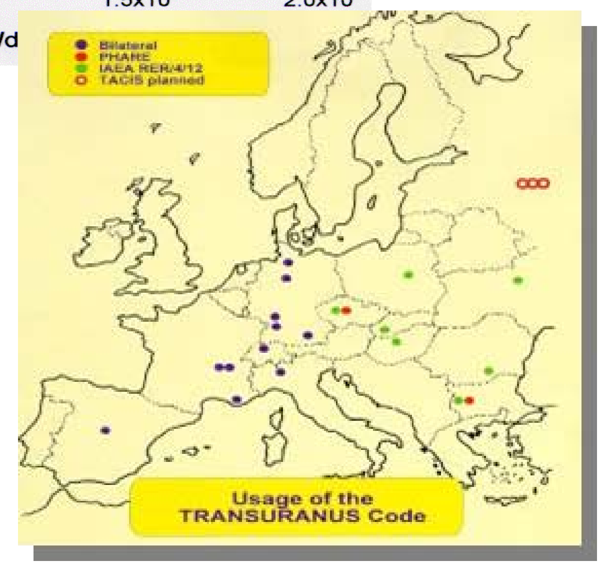
Modeling of experimental data

Xe distribution in the outer region of high burn-up UO_2 pellets



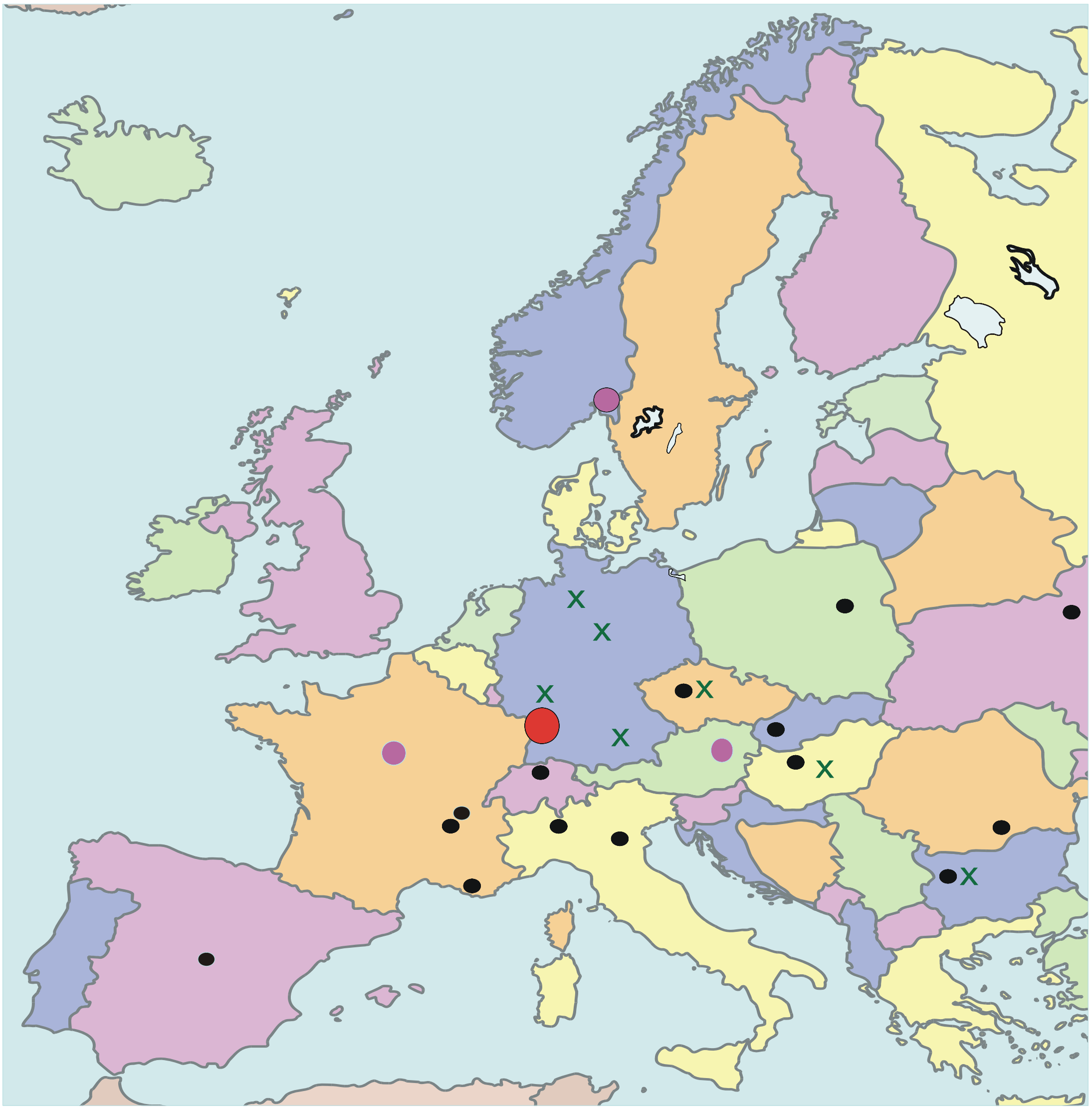


shielded SIMS



TRANSURANUS modeling

network – application in Europe



- ● International Organisations
- x Licensing Authorities
- ● Research and Industry

One tool for different applications

Fuel type: Western-type and Russian type

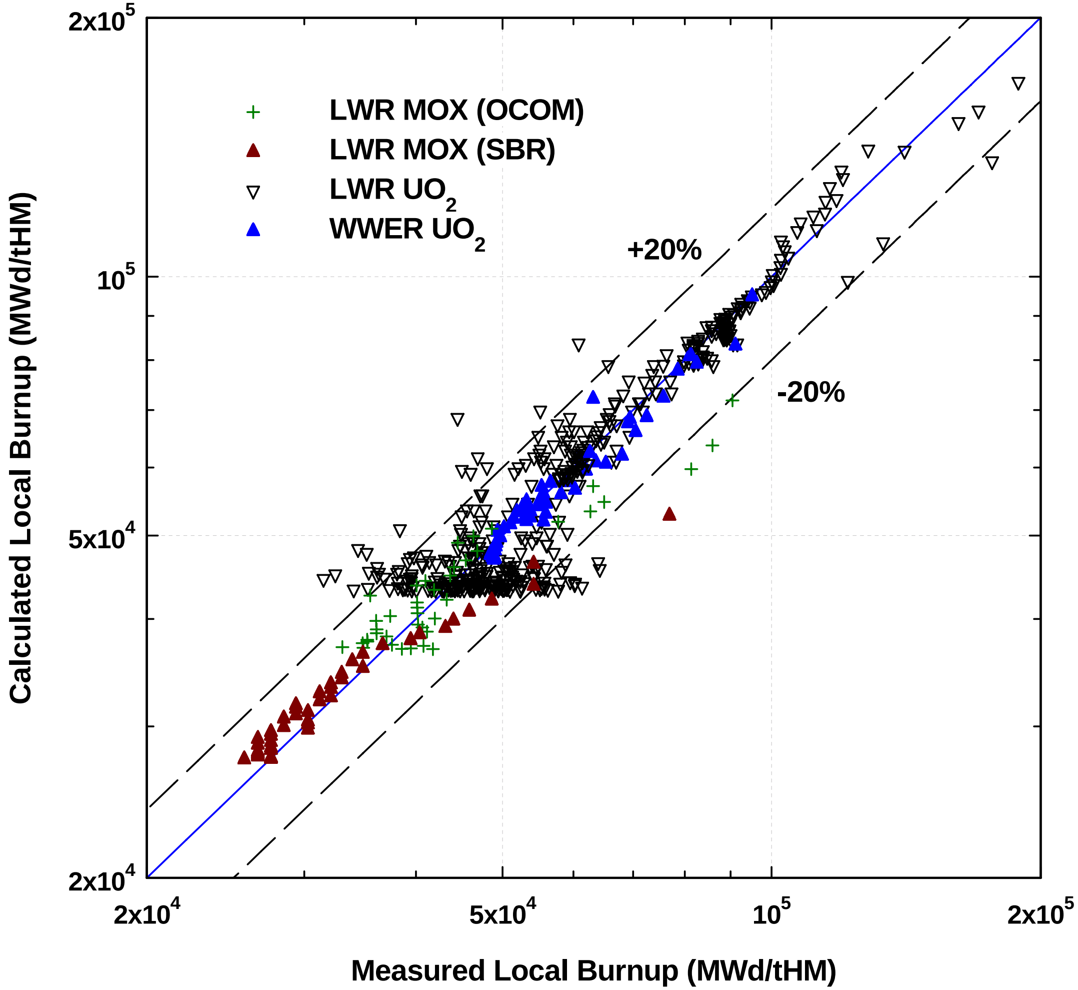
Operating conditions: steady-state and transient (off-normal)

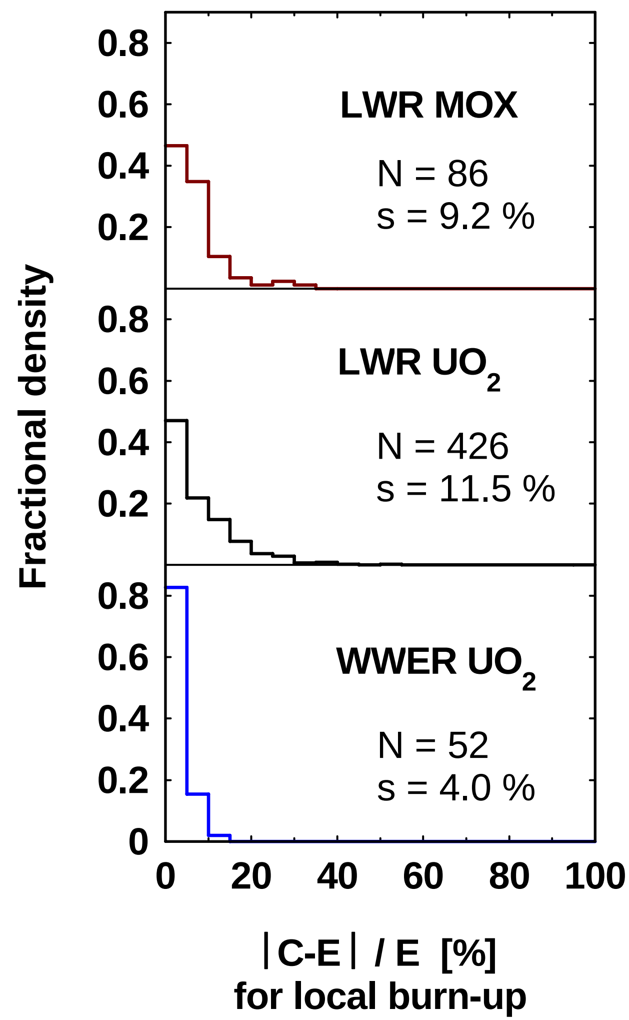
Suitable for independent verification of fuel suppliers declarations

For EU member states

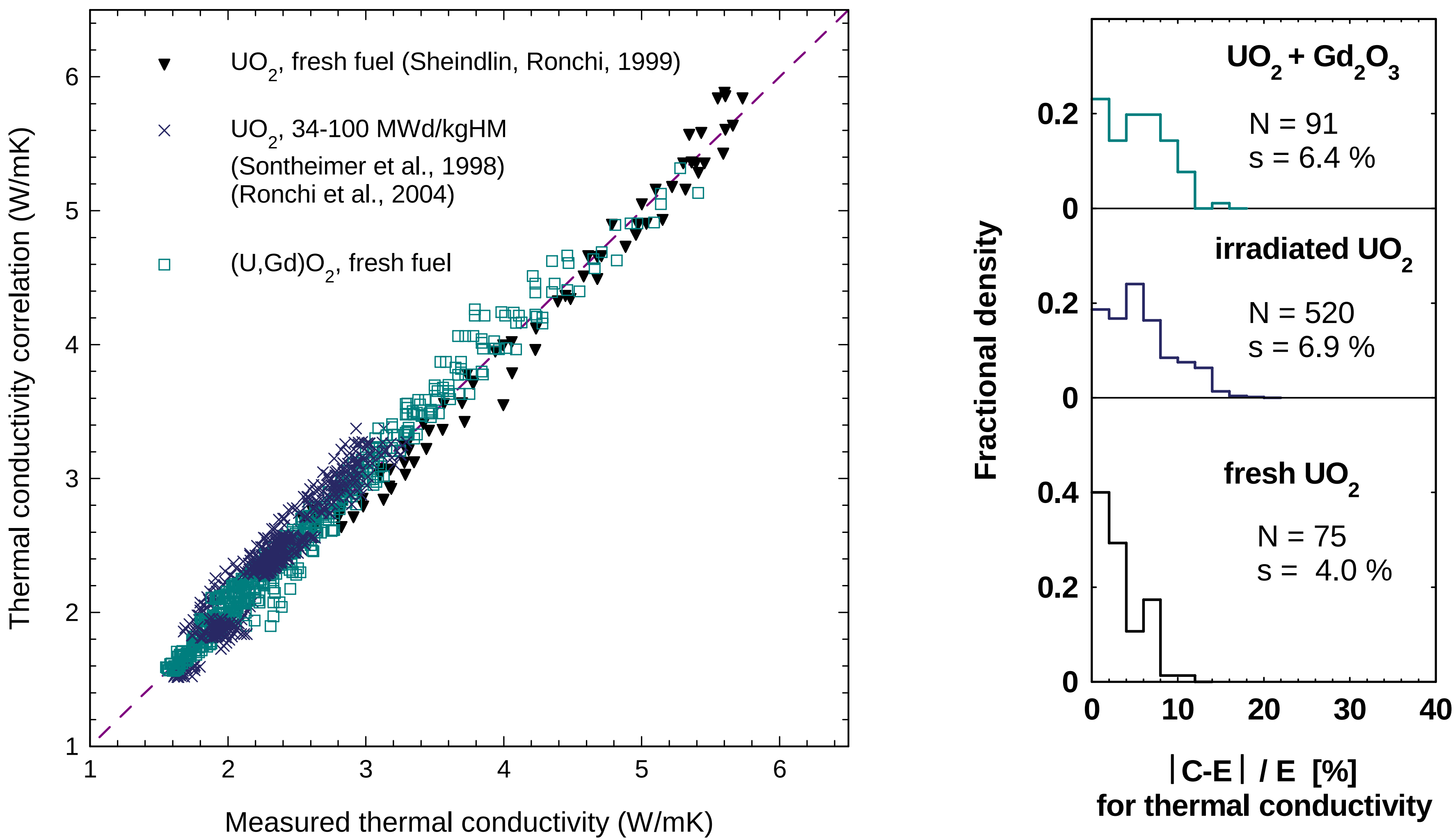
- → *Development and verification (Exp. vs. Theory)*
- → *Strengthen the network across Europe*
- → *Harmonizing safety standards (criteria)*
- → *Dissemination of knowledge*
- → *Education and training*

Verification of TUBRNP: good predictions of TUBRNP for UO2 in PWR, WWER as well as for MOX



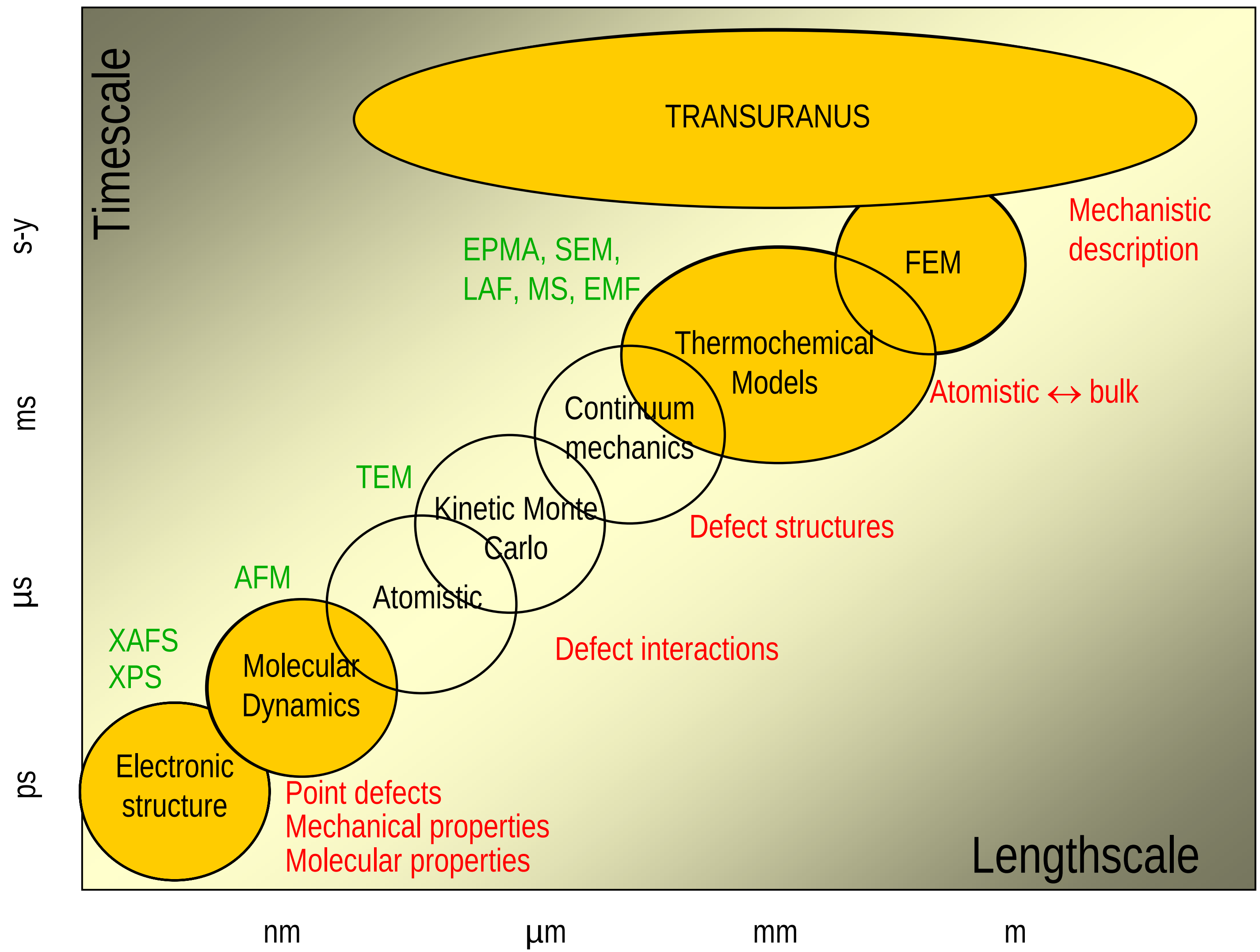


Verification of thermal conductivity for UO_2



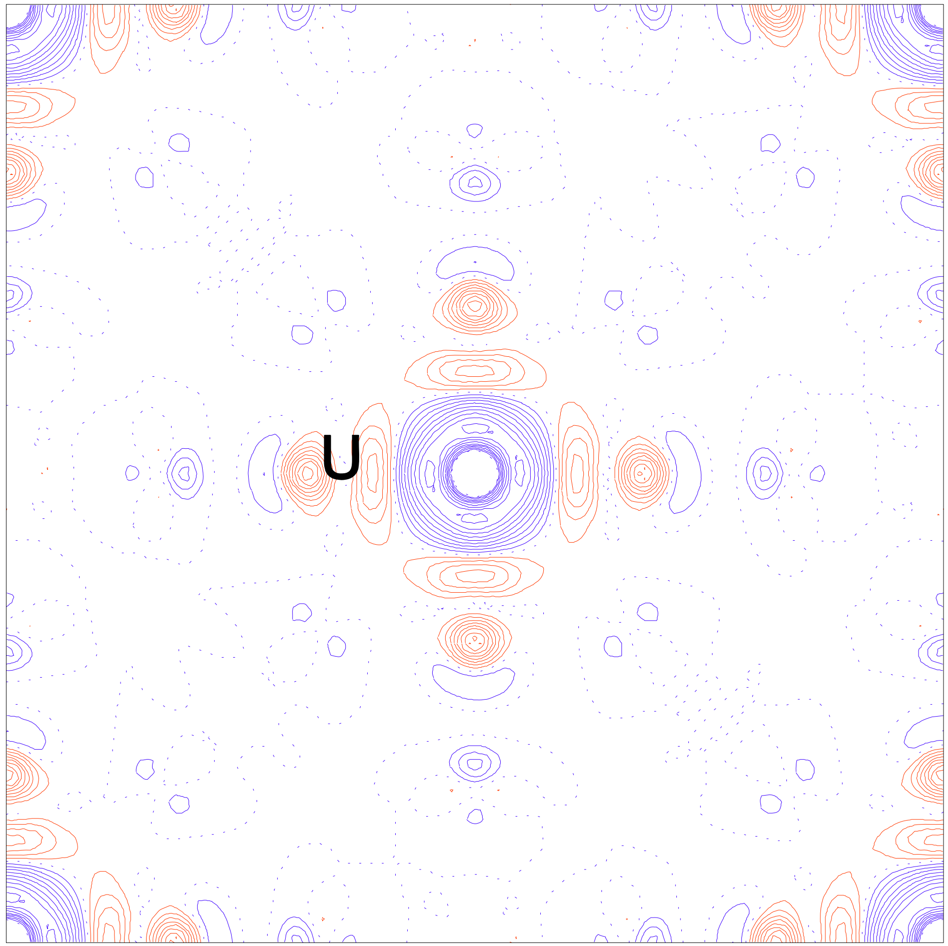
Modeling tools

The diagram of time and scale



Ab-initio calculations

Ab-initio calculations of defects in UN



The difference electron density around the N vacancy.
The electron density of a missing N atom (blue on-line, in the center) is transferred towards the six nearest U atoms (red on-line).

Co-operation projects with Bulgarian partners

Previous:

- *PHARE: "Fuel Rod Modelling and Performance (FERONIA)" (1995-1998)*

  Development of VVER version of TRANSURANUS

- *JRC-PECO: "Validation of the TRANSURANUS-VVER version" (2000-2002)*

Review given at JRC Information Day (INRNE Sofia, February 2003):

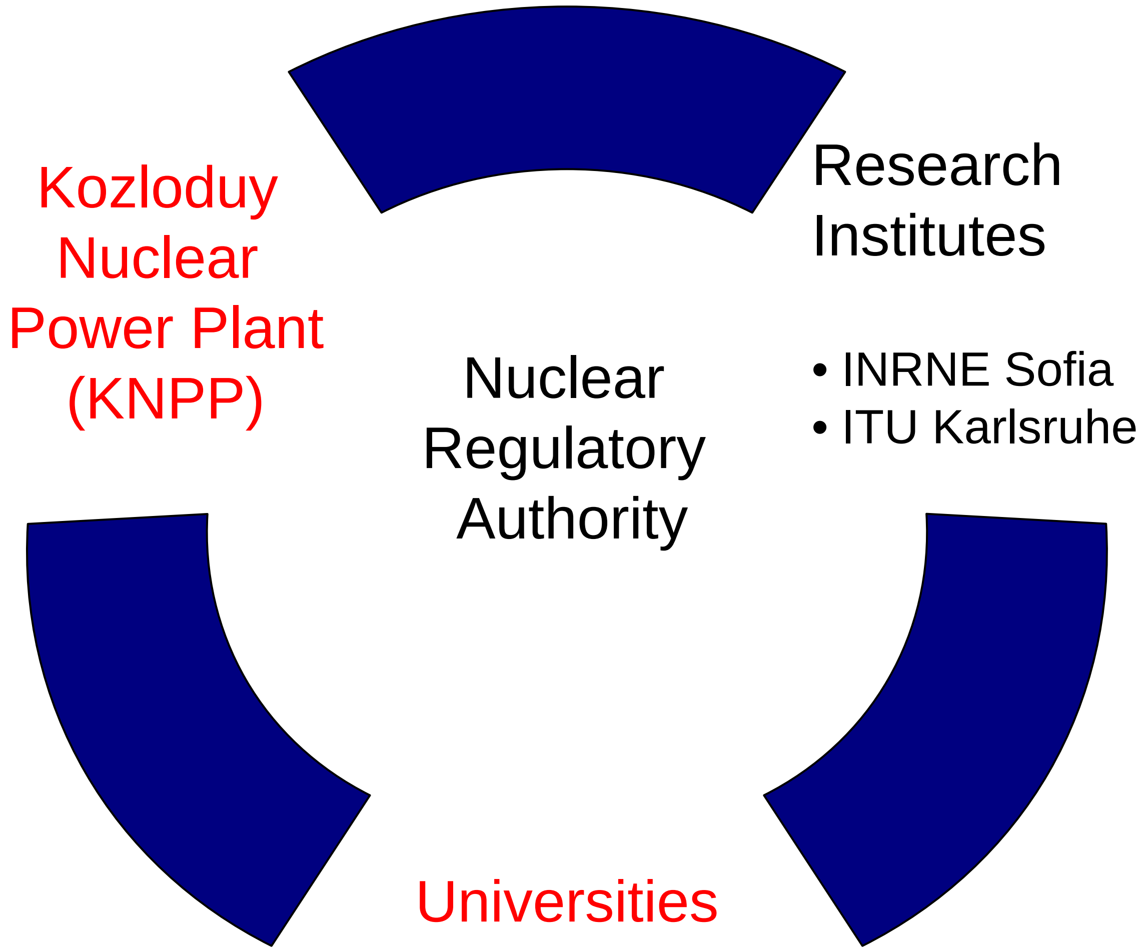
K. Lassmann: "Safety Aspects of Fuel Rods and Licensing"

After the enlargement:

- *JRC-Enlargement: "Application of fuel rod modelling in licensing" (2004-2006) Harmonisation in licensing of nuclear fuel*

  VVER fuel, independent verification of fuel supplier declarations

Co-operation projects with Bulgarian partners



Work-packages

1. Coordination and Management
2. Code Verification
   - Dedicated database at the OECD/NEA, supported by IAEA
   - OECD Halden Reactor Project
3. Code Application at Kozloduy Nuclear Power Plant (KNPP)
4. Education and Training
   - KNPP
   - Technical University of Sofia
5. Research and Development: spent fuel
   - Reloading of spent fuel at KNPP
   - Develop tools for analysis of spent fuel storage facility

Application of fuel rod modelling for licensing

Bulgarian Academy of Sciences

Institute of Nuclear Research and Nuclear Energy

Final Report

Study on the verification of the TRANSURANUS code for nuclear fuel used in Bulgaria

Study Contract **no. 207793-2007-05 F1ED KAR BG**

24 April 2007 – 23 April 2008

extension of the studies done during the last ten years of collaboration

the verification database of TRANSURANUS, to cover a larger range of fuel subtypes and irradiation conditions

Application of fuel rod modelling for licensing

Task 1: The GAIN program, compiled in the IFPE, i.e. 4 (UO2+Gd2O3) rods, covers:

- ✓ *changes of fuel rod length and diameter;*
- ✓ *pin pressure and fission gas release.*

Task 2: One WWER-1000 fuel assembly irradiated in Novovoronezh NPP selection of the most representative fuel rods (up to 15) that cover the max. range of burn-up available from this assembly, including analysis of rod geometry (elongation,diameter changes, evolution of the gap) of the selected rods;

Task 3: Analysis of ramp tests of WWER-440 fuel in the MIR reactor (9 rods pre-irradiated in KOLA-3 WWER unit up to 60 MWd/kgU), namely:

- ✓ *fuel temperature;*
- ✓ *pin pressure;*
- ✓ *FGR, derived indirectly from the pressure data.*

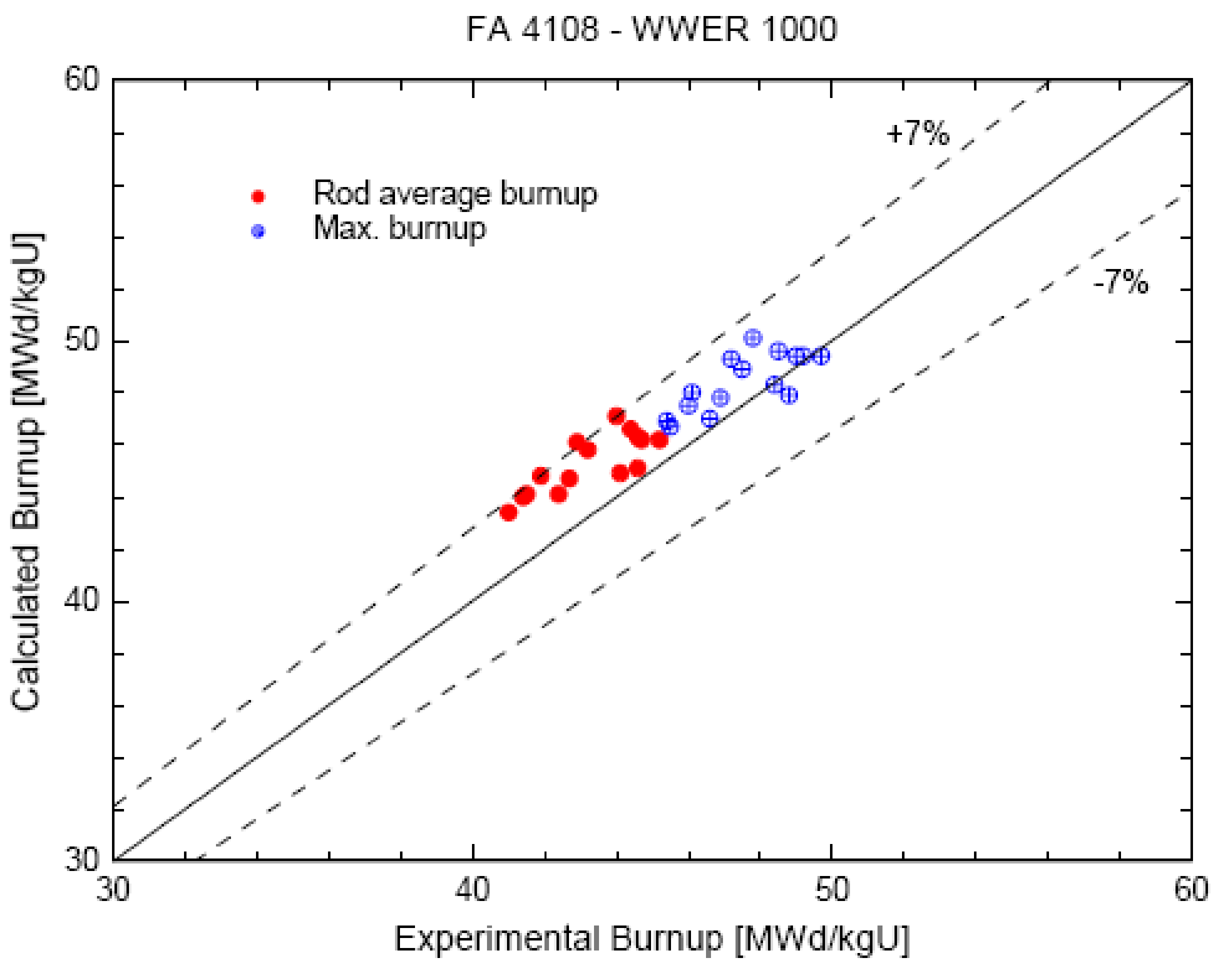


Fig. 3.2. Calculated versus measured burnup of the 15 selected rods from the FA4108, irradiated 3 cycles in the Novovoronezh NPP.

Outlook & Conclusions

- ✓ renewal of the user license agreement for all our Bulgarian partners
- ✓ to collaborate mostly in the frame of the next fuel performance code benchmark (FUMEX-III) organised by the IAEA
- ✓ INRNE will simulate the VVER rods involved in the FUMEX-III exercise, such as the simulation of VVER fuel in the MIR reactor workshop in September 2009 in Bulgaria together with colleagues from INRNE in the wake of the International conference on WWER fuel performance that is organised by INRNE with support of the IAEA

Safety of Nuclear Fuels

- Result of optimisation of whole nuclear power plant (design, operation, storage), fuel cycle, nuclear strategy
  Consequence: ongoing activity; man-power
- Tremendous contributions from industry (for instance increase of burn-up, nearly zero-failure fuel rods)
- Extensive irradiation experience from nuclear power plants and
- Detailed theoretical knowledge manifested in
  codes such as the TRANSURANUS code test reactors through
  Post Irradiation Examinations (PIE)

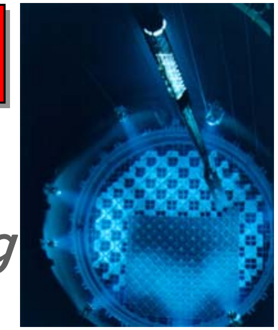
Generation IV & GNEP overall objectives

- *promote long-term availability of the systems and effective fuel utilization*
- *minimize and manage the nuclear waste produced (co-recycling of **all** actinides) and notably reduce the long term stewardship burden in the future, thereby improving protection for the public health and the environment.*
- *increase the assurance that systems are a very unattractive and least desirable route for diversion or theft of weapons-usable materials.*

Change of philosophy

dirty fuel-clean waste instead of clean fuel-dirty waste

Fuel Cycle Back-End



spent nuclear fuel

spent fuel interim storage → Industrial reprocessing

final retrievable/ non-retrievable

potential release

advanced aqueous

advanced pyro

separated radiotoxic elements

cancer therapy

conditioning

transmutation

Interaction with biosphere: water, soil, air, food

Human metabolism

Spent fuel corrosion under repository relevant conditions (presence of hydrogen)

Finnish and Swedish concepts for spent fuel disposal based on copper canisters with inner iron-cast

- *water intrusion causes corrosion of the iron insert*
- *equilibrium hydrogen pressure: several hundred atmospheres*

  could determine the redox conditions for several 10,000 years in the repository
- *laboratory experiments in ITU show that spent fuel corrosion rate is reduced by > 1000 times in the presence of hydrogen (U conc.: 10^{-12} M, Pu not detectable)*

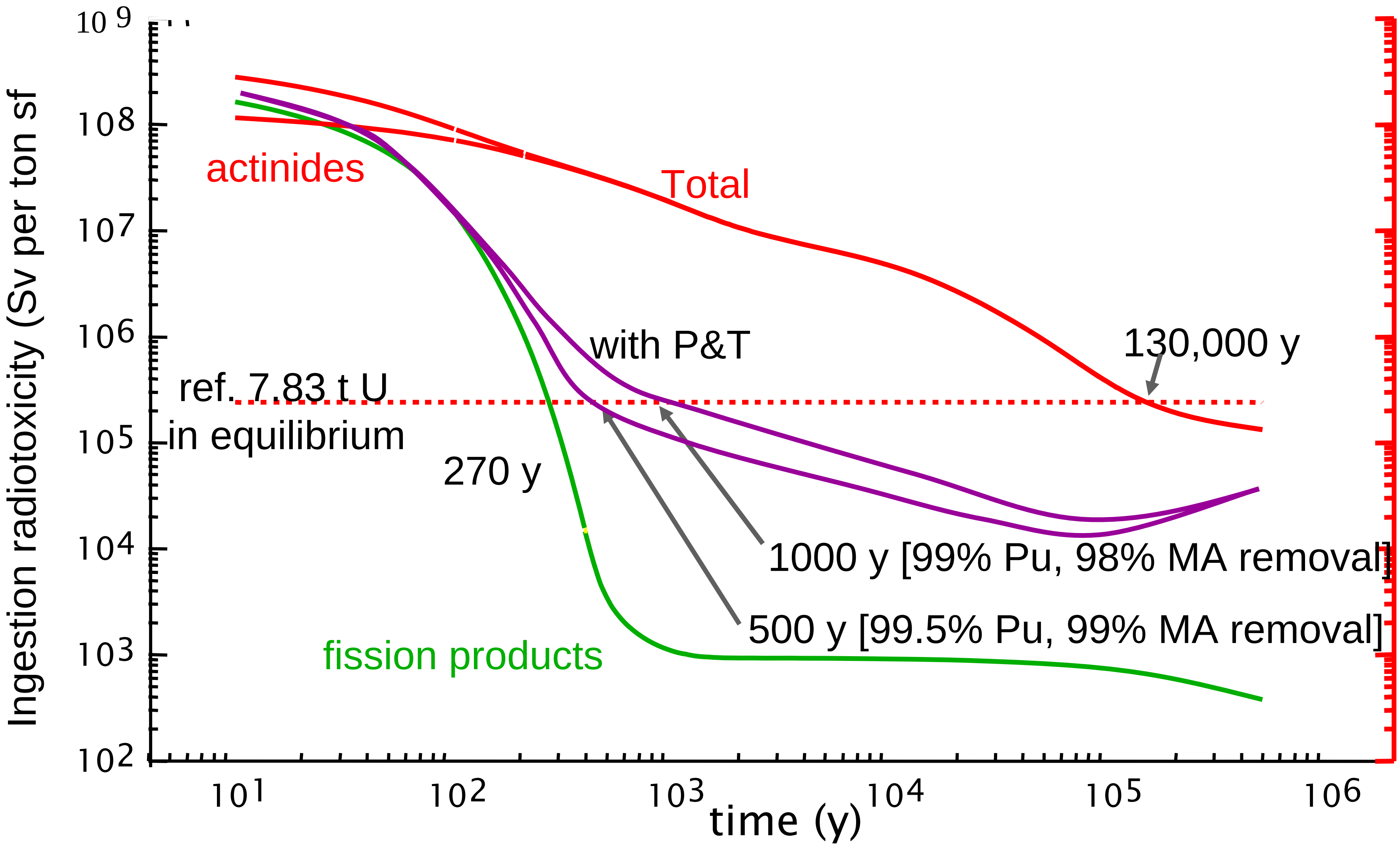
significant impact on Performance Assessment of European fuel repositories

Composition of irradiated fuels

FUEL TYPE		LWR-UOX			LWR-MOX
AVERAGE BURN-UP (GWd/t)		33	45	60	45
COMPOSITION	Pu (g/tU)	9.740	11.370	12.990	48.850
	Np (g/tU)	433	611	887	161
	Am (g/tU)	325	521	765	4.480
	Cm (g/tU)	23	92	213	810
	Zr (g/tU)	3.580	4.740	6.280	3.440
	Tc (g/tU)	814	1.085	1.403	977
	Ru (g/tU)	2.165	3.068	4.156	3.924

waste radiotoxicity

Evolution of radiotoxicity as a function of time



evaluation by CEA, FZK and ITU based on ICRP72

Nuclear Fuel Cycle Strategy
double strata concept

commercial reactor
EPR, Olkiluoto, Finland

spent fuel

fresh fuel (MOX)

reprocessing plant
La Hague, France

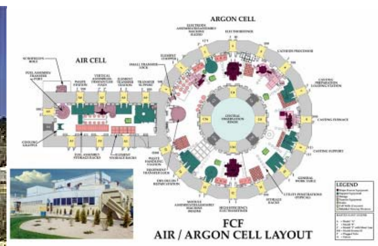
PUREX & advanced aqueous

long-lived MA, Tc, I

short lived fp

Integral fast reactor or ADS

Monju, Japan

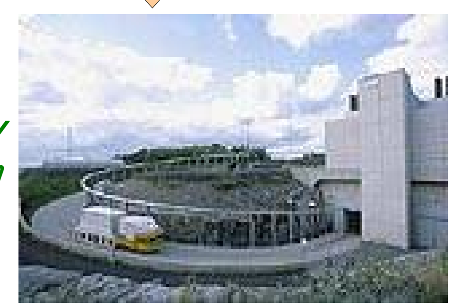


INL, US

pyro

short lived waste

waste repository
SFR, Forsmark, Sweden



reprocessing in the second strata fuel cycle
reasons for selecting pyro-reprocessing

compact process

Integrated Fast Reactor concept, ANL
lower costs, reduced number of transports

faster recycling

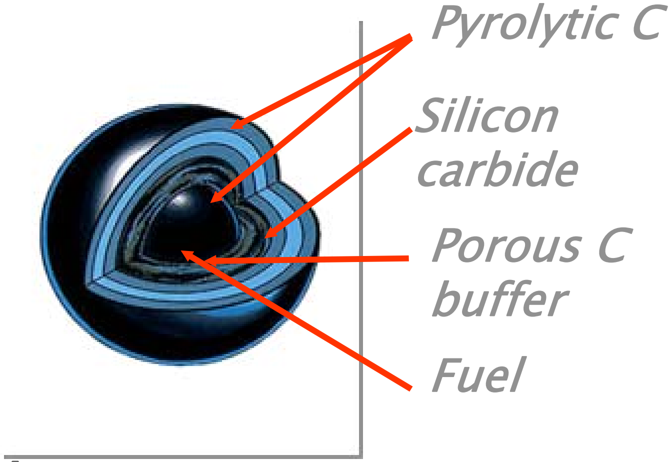
salt more radiation resistant => short fuel cooling-times

"impure" product fractions

more "proliferation-resistant" process

fuel composition

- Metallic fuels, CERMET
- Inert Matrix (MgO, ZrO_2) fuels
- Th – MOX
- Nitrides eventually carbides
- Coated HTR, kernels, various geometries



Summary

Pu (together with minor actinides) is a key element in a closed fuel cycle
This impact is increasing in advanced fuel cycles because:

- *considerable increase of transuranics formed*
- *recycling of all actinides to achieve sustainability (GENIV, GNEP)*

under storage conditions (open fuel cycle)

- *degradation of fuel under control*
- *beneficial H_2 effect on the fuel corrosion*

advanced reprocessing

- *co-recycling of all actinides demonstrated in pyroprocess (lab-scale)*
- *multiple recycling possible with low losses*
- *new types of fuel require significant R&D*
- *large safeguards R&D efforts needed especially in pyro-reprocessing*

The interaction with and the effect on biological matrices has to be understood