Modelling Long Term Performance of Minor Actinide Fuel Targets in the Experimental ADS MYRRHA

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1.1. Introduction

- Subcritical ADS can provide effective and safe solution for MA transmutation and Pu burning.
- The Belgian nuclear research Centre SCK·CEN, in collaboration with other countries, works on design of an experimental ADS to study MA transmutation in innovative dedicated fuels.
- A new fuel performance code MACROS-II devoted to modelling of the behaviour of the dedicated fuels in ADS is under development and testing.

1.2. Introduction:

ADS MYRRHA

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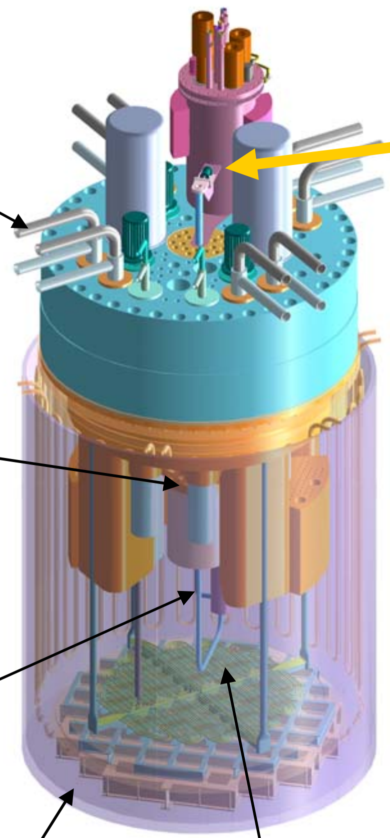
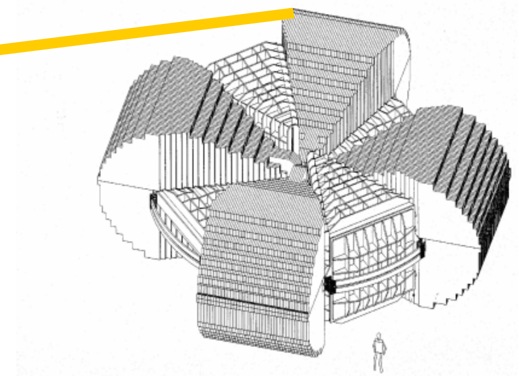
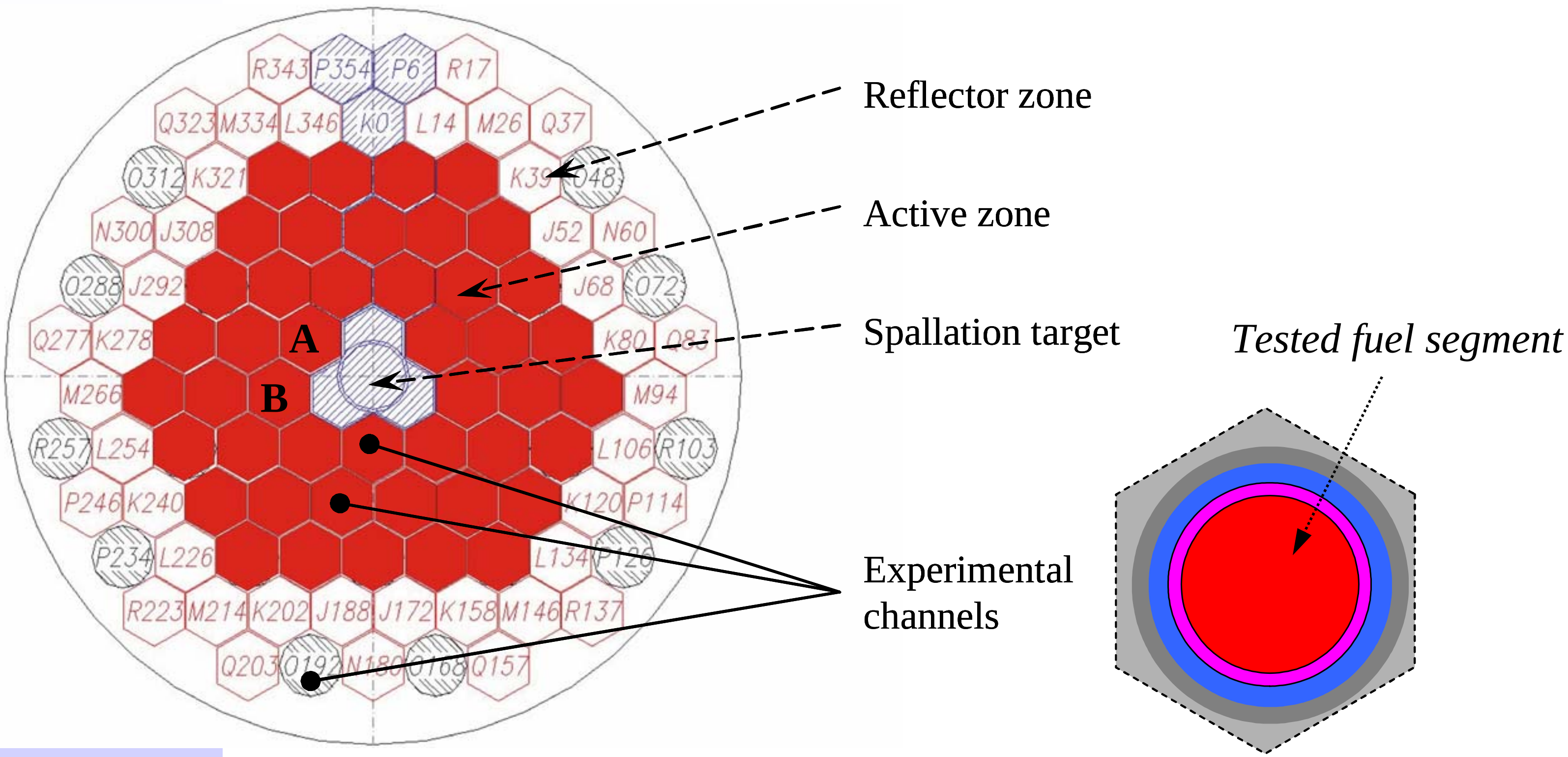




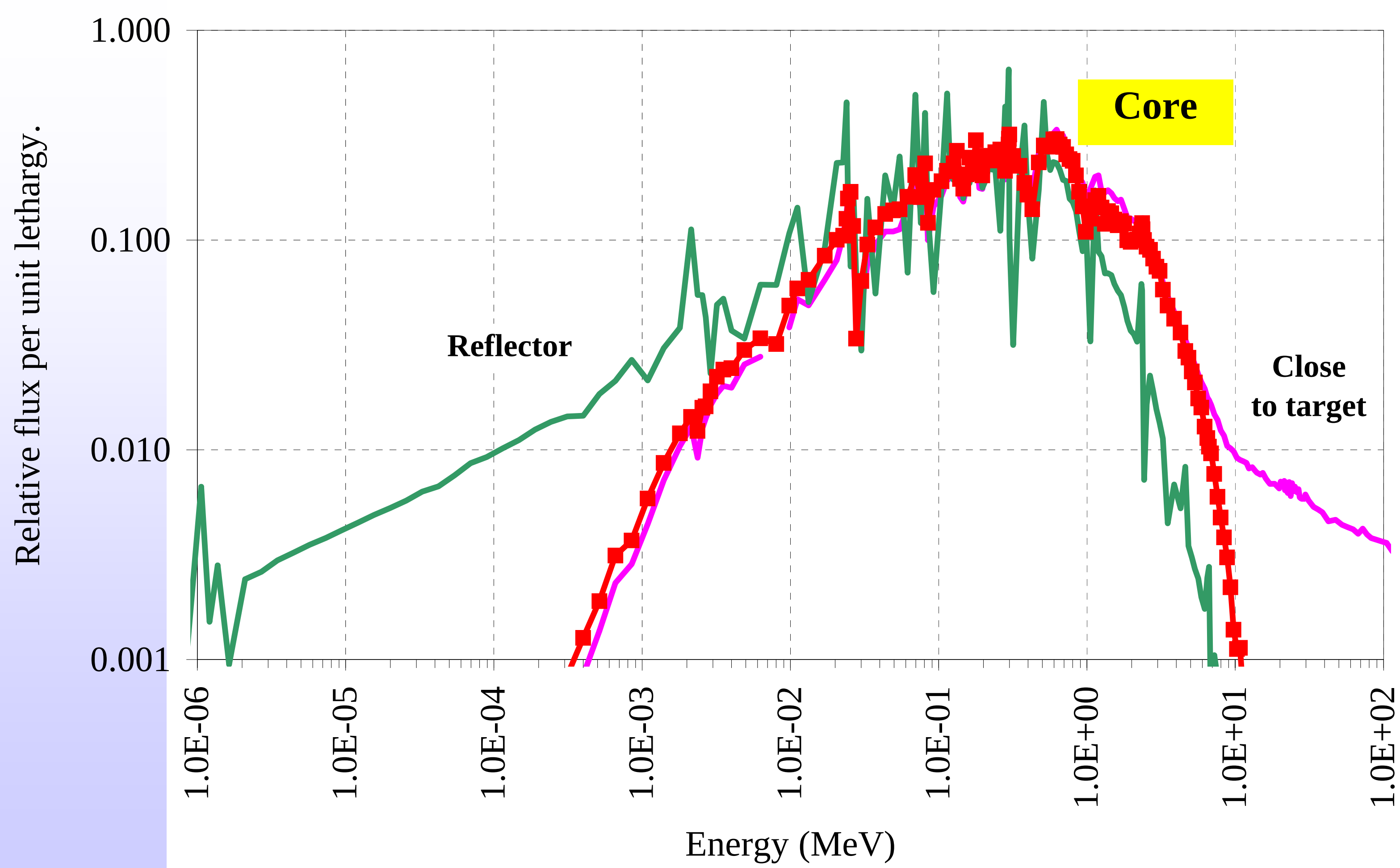
<u>Main performances</u>:

- Proton source: E_p~350 MeV, I_p~ 5 mA
- Liquid Pb-Bi spallation source and coolant
- Highly enriched MOX in the sub-critical core
- k_{eff} limited to ~ 0.95
- Total power ~ 50 MW(th)
- Fast neutron flux ~ 10^{15} n $cm^{-2}s^{-1}$

1.3. Introduction:
Option of the core



2.1. Irradiation conditions:
Neutron spectrum



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2.2. Irradiation conditions: A-assembly position

MYRRHA

Neutron spectrum :

• mean neutron flux	$3.17 \cdot 10^{15}$ neutron/(cm$^2 \cdot$s)
• thermal (En < 0.5 eV)	$6.0 \cdot 10^{-5}$ %
• epithermal + resonance (0.5 eV < En < 20 keV)	10.97 %
• fast (20 keV < En < 1 MeV)	74.24 %
• Very fast (En > 1 MeV)	14.79 %

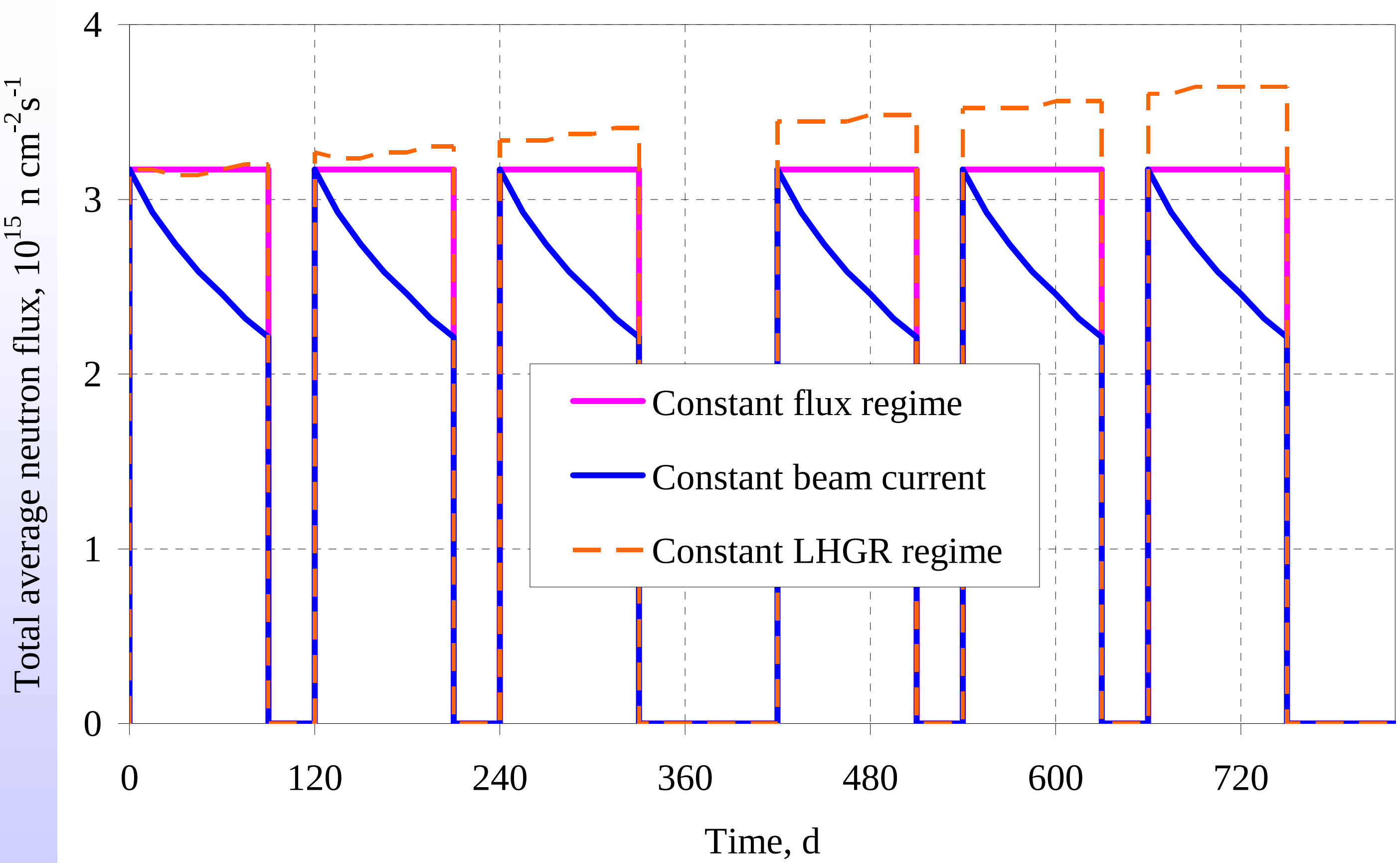
LM coolant: Pb-Bi eutectic

• max. velocity in sub-channel	2.0 m/s
• input temperature	200-250 °C

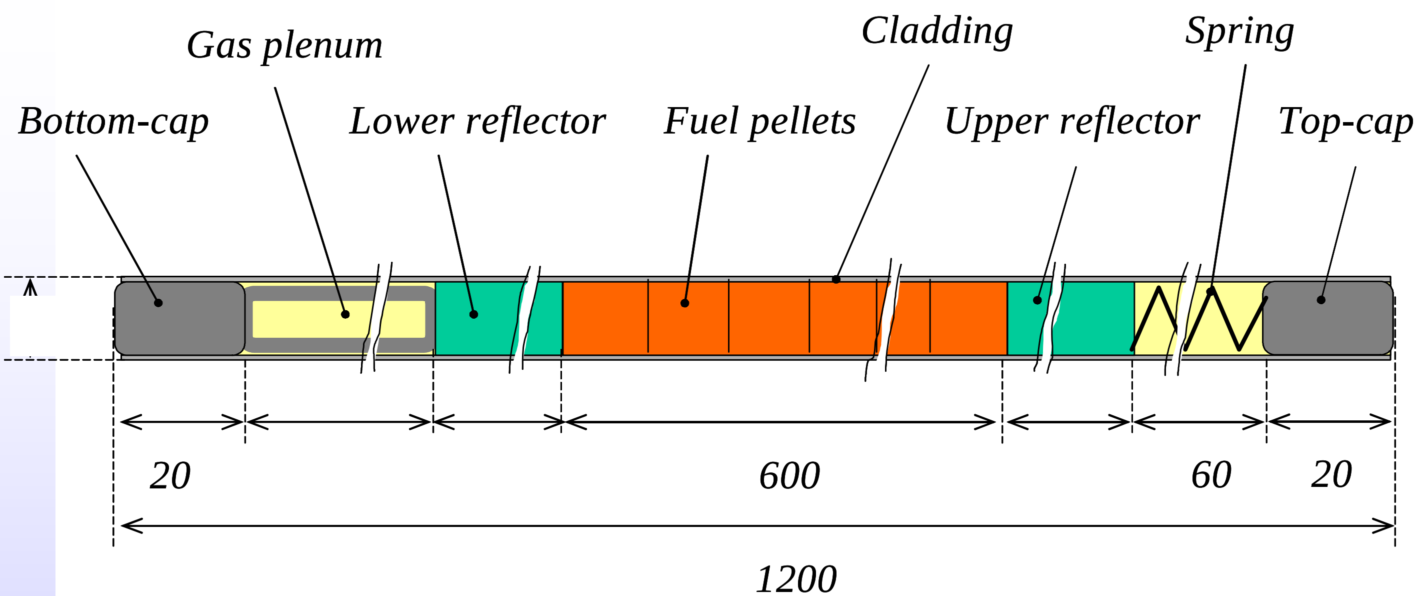
Operation time-table:

• irradiation cycle duration	90 days
• cold period between the cycles	30 or 90 days

2.3. Irradiation conditions:
Neutron flux regime



3.1. Fuel pin pre-design



- Fuel column: MOX or IMF
- Reflector segments: MgO or ZrO_2
- Gas plenum (bottom + top): He: 1-5 bar (STP)
- Cladding: FMS T91

3.2. Fuel pin pre-design:
Driver zone pellets

- Diameter/height: 5.35 x 6 mm
- Composition:
  - ❑ $(Pu_{0.3}U_{0.7})O_{2-x}$ MOX: 30 wt.% Pu in HM
- Density 95 % TD
- Initial fuel isotopic vectors: PWR spent fuel, burnup 33 MWd/kg HM, 10 years of storage.

PLUTONIUM

Isotope	Content wt.%
^{238}Pu	1.27
^{239}Pu	61.88
^{240}Pu	23.50
^{241}Pu	8.95
^{242}Pu	4.40

URANIUM

Isotope	Content wt.%
^{234}U	0.003
^{235}U	0.404
^{236}U	0.010
^{237}U	0
^{234}U	99.583

3.3. Fuel pin pre-design: IMF target pellets

- Diameter/height: 5.85 x 6 mm
- Composition:
  - 40 vol.% $(Cm_{0.1}Am_{0.5},Pu_{0.4})O_{2-x}$ + 60 vol.% ZrO_2
  - 40 vol.% $(Cm_{0.1}Am_{0.5},Pu_{0.4})O_{2-x}$ + 60 vol.% MgO
- Density 90 % TD
- Initial fuel isotopic vectors: 2nd strata (FUTURE).

PLUTONIUM

Isotope	Content wt.%
^{238}Pu	5.06
^{239}Pu	37.91
^{240}Pu	30.31
^{241}Pu	13.21
^{242}Pu	13.51

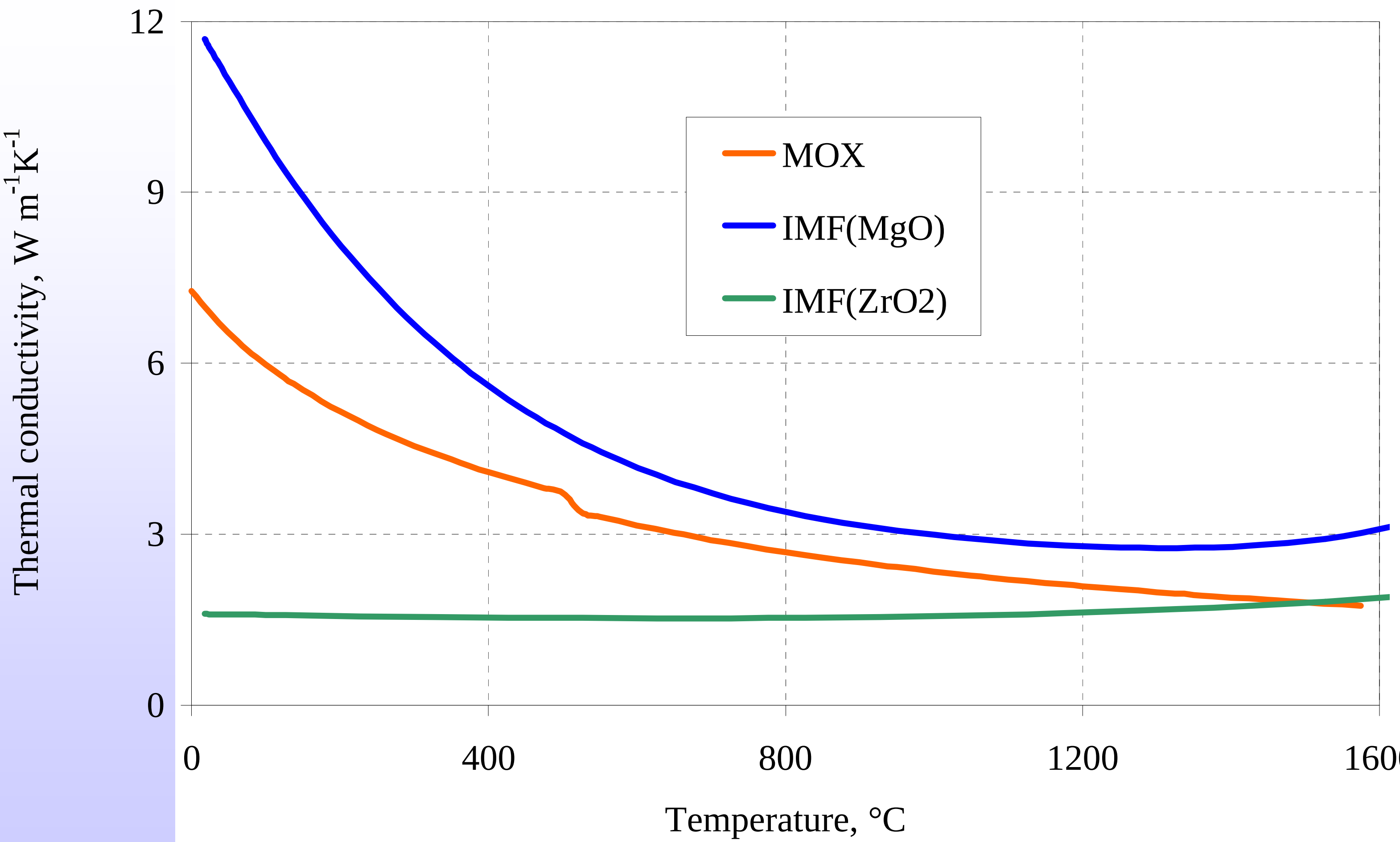
AMERICIUM

Isotope	Content wt.%
^{241}Am	66.67
^{243}Am	33.33

CURIUM

Isotope	Content wt.%
^{244}Cm	90.00
^{245}Cm	10.00

3.4. Fuel pin pre-design: Thermal conductivity (BOL)



4. Code MACROS-II

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Fresh fuel storage

⇓

⇓

Base – irradiation

⇓

Intermediate storage

⇓

Re – fabrication

⇓

Re – irradiation

⇓

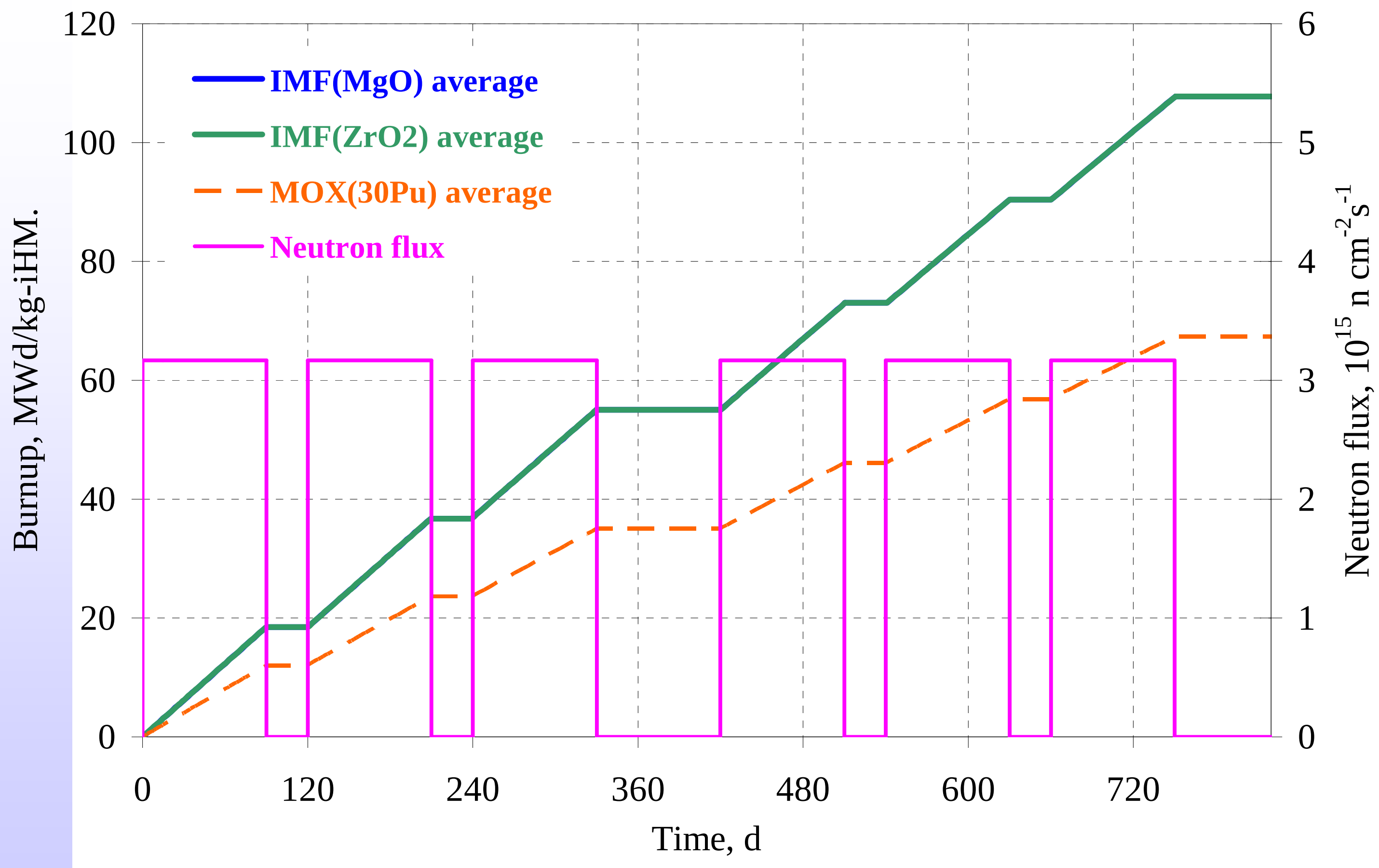
…

⇓

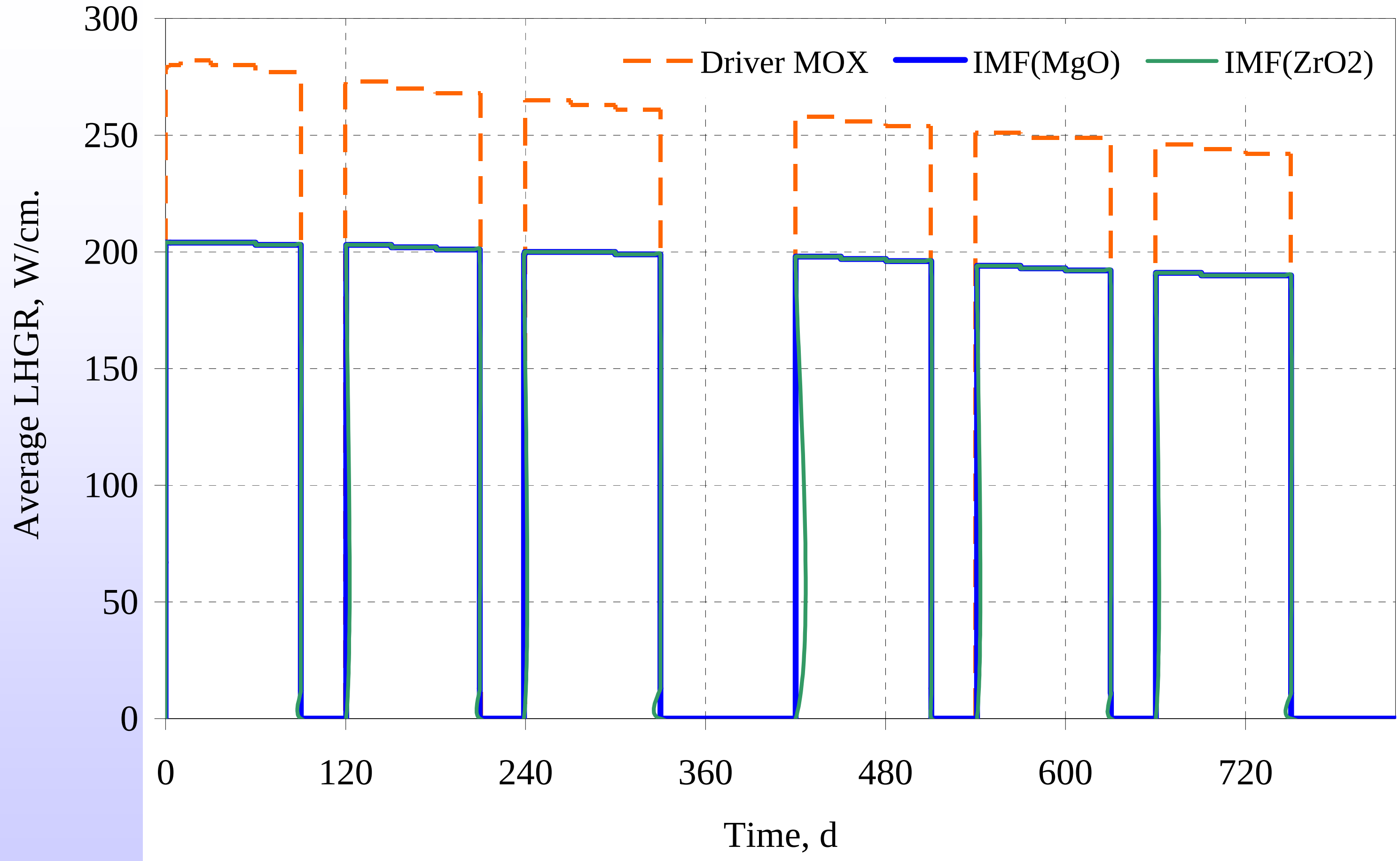
Post – irradiation storage

- MACROS (2000)
  - MACROS = PLUTON + ASFAD
    - UO_2, $UO2+Gd_2O_3$
    - LWR and Halden HBWR
- **MACROS-II (2004)**
  - New burnup/depletion module (PLUTON 2MG)
  - Mechanistic modelling
  - He production and release
  - Effects of heterogeneity
  - Fuels: UO_2, MOX, IMF with MA
  - Spectra: LWR, FR, ADS, …
  - **Successfully validated with:**
    - FUMEX-II IAEA benchmark (high burnup LWR fuels)
    - OECD benchmark (MOX behaviour in HRP experiment)
    - DOMO irradiation experiment (UO_2, MOX)
    - To be validated with EFFTRA data (IMF with MA)

5.1. Results of modeling:
Flux and burnup evolution



5.2. Results of modelling:
Linear heating rate



5.3. Results of modelling:
Initial temperature

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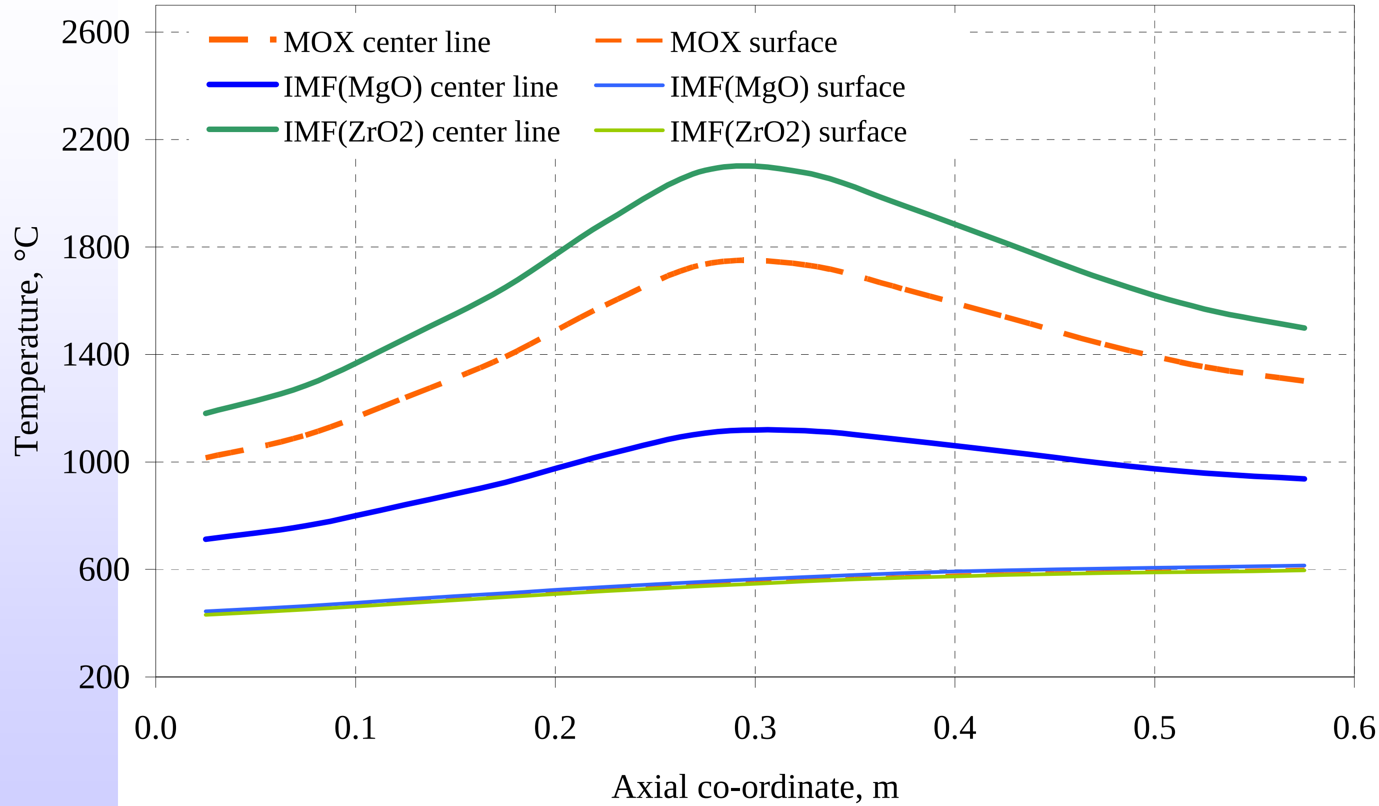
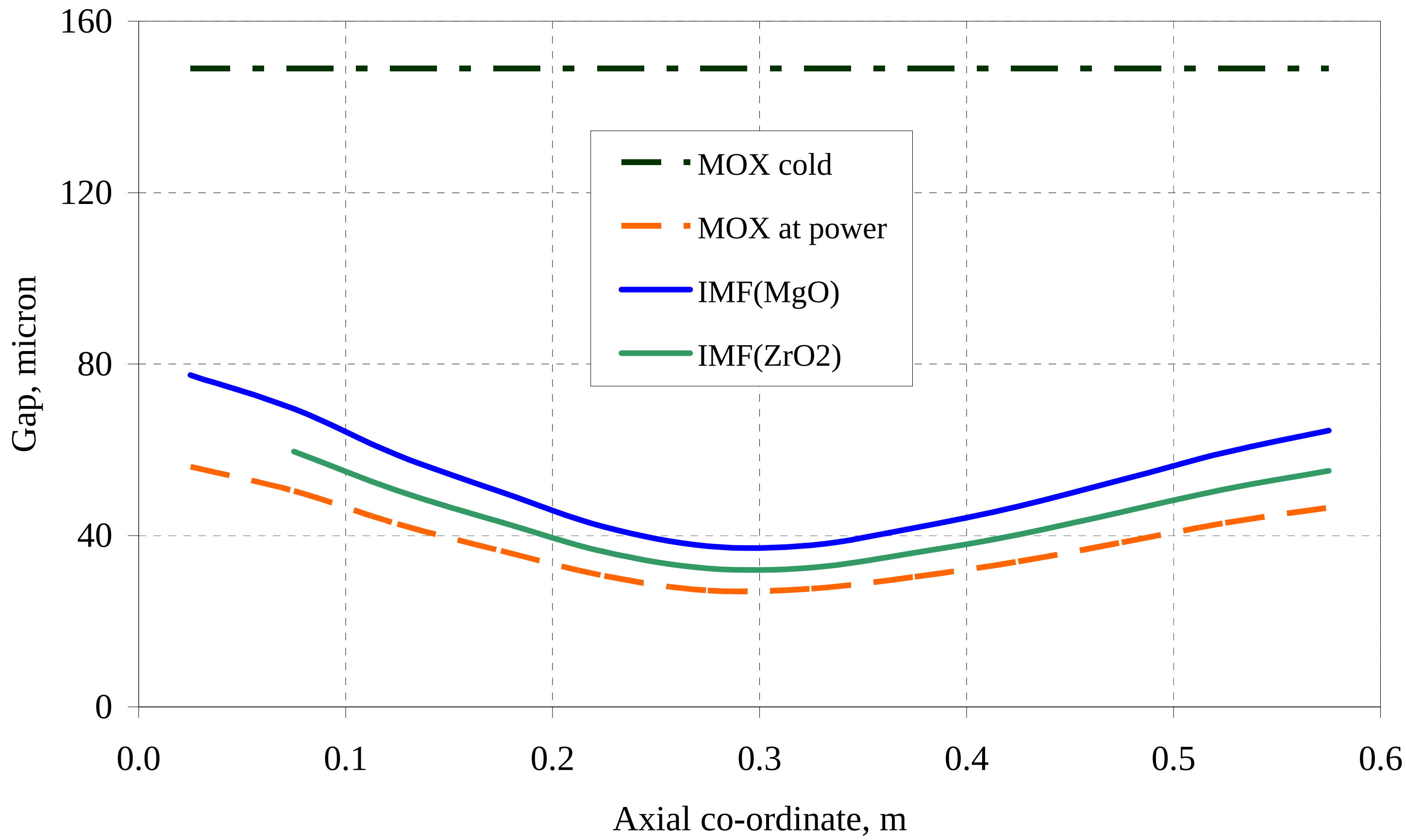
MYRRHA

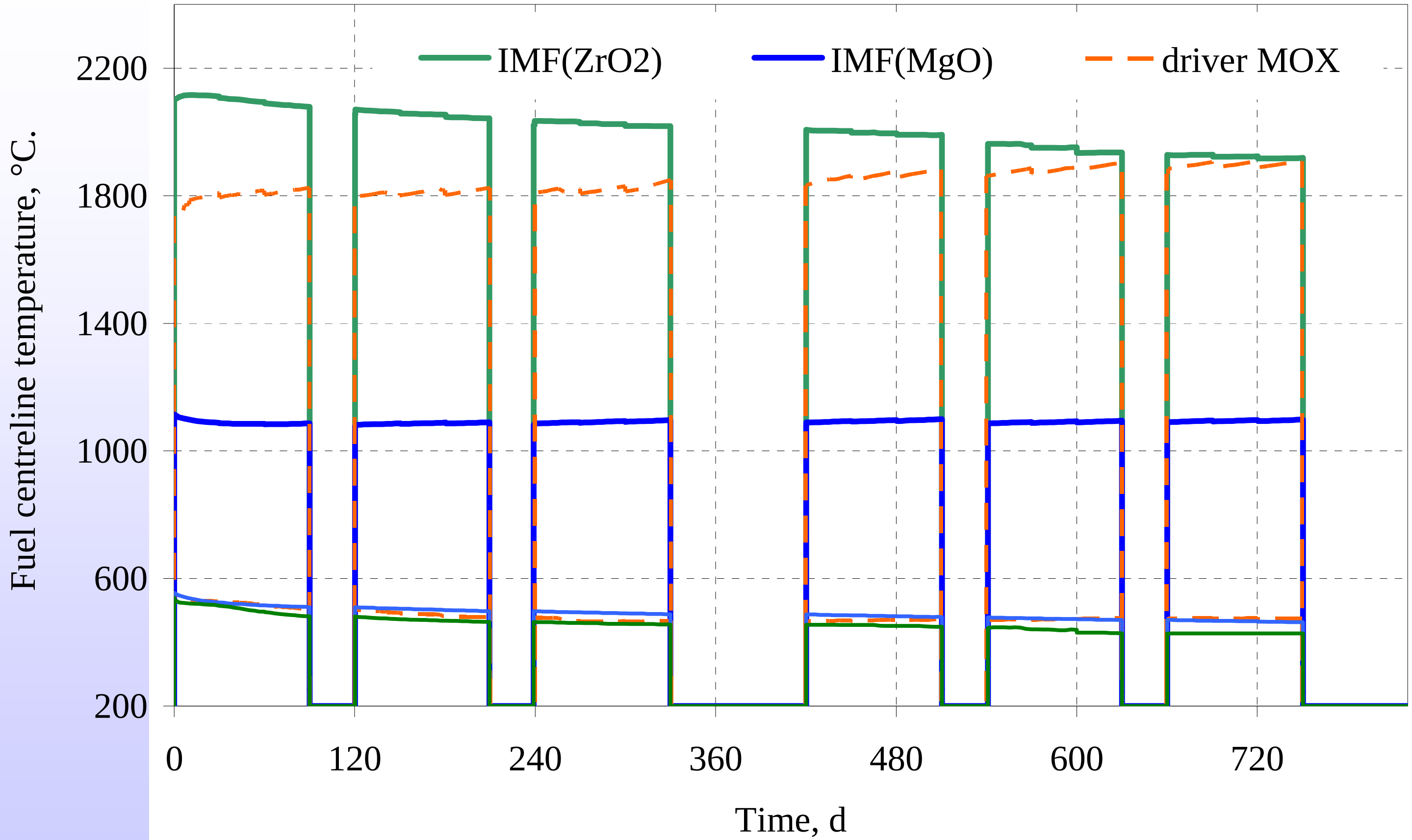
$T_{melt\ MOX}$ = 2685 °C; $T_{unstable\ IMF(MgO)}$ ~ 2000 °C; $T_{melt\ IMF(ZrO_2)}$ ~ 2500 °C



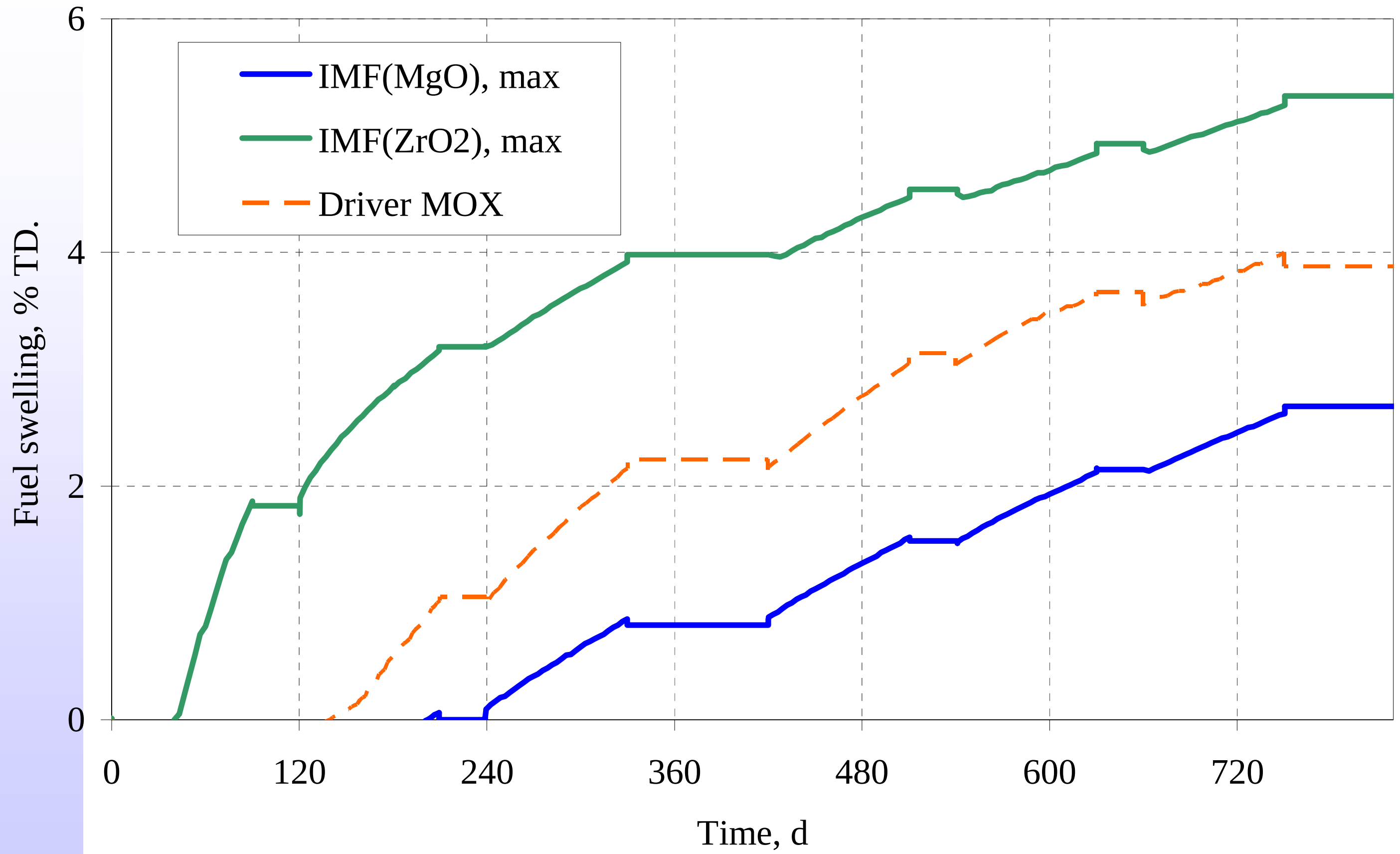
5.4. Results of modelling:
"Pellet-clad" gap at start



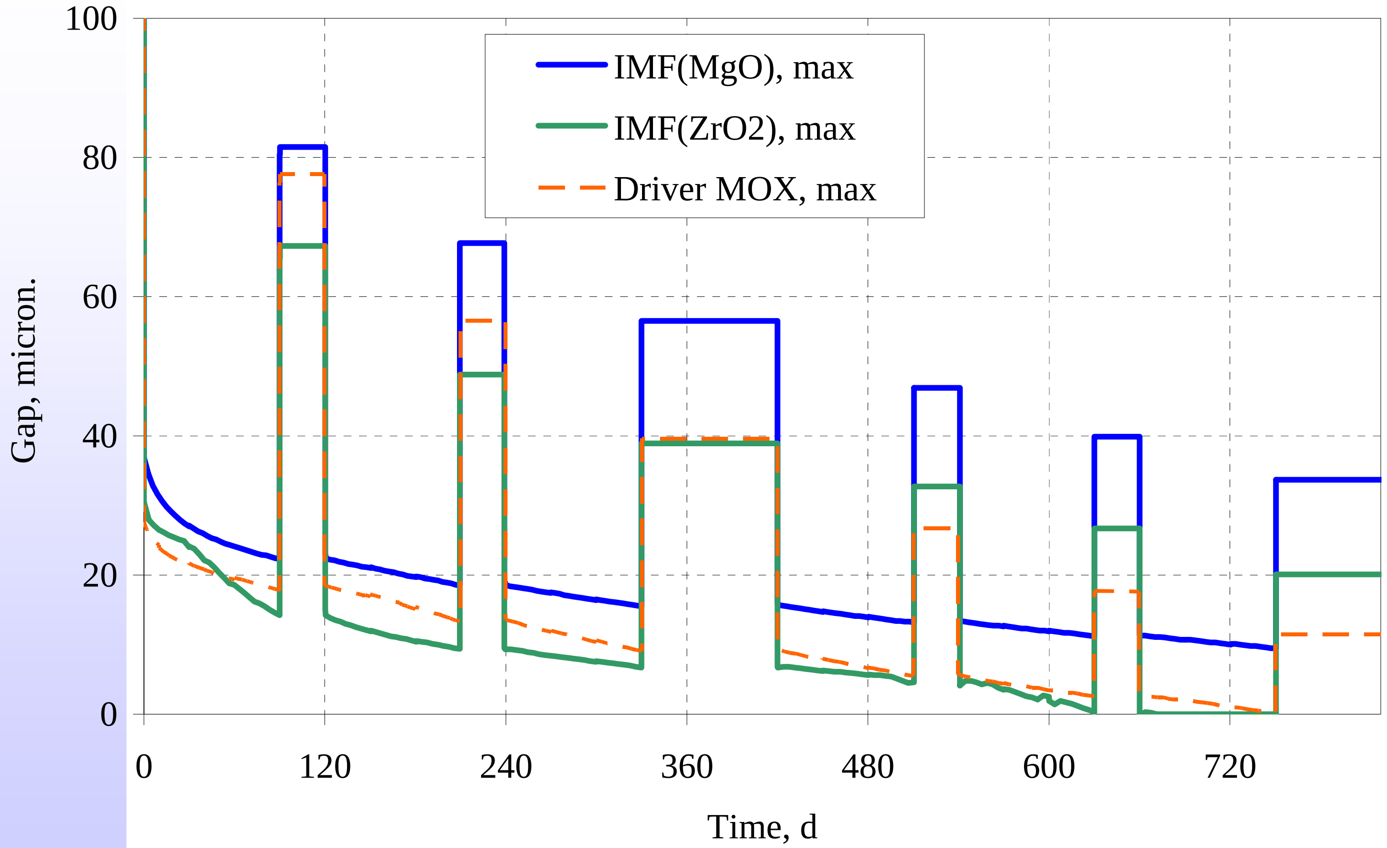
5.5. Results of modeling: Fuel temperature evolution



5.6. Results of modeling:
Fuel swelling

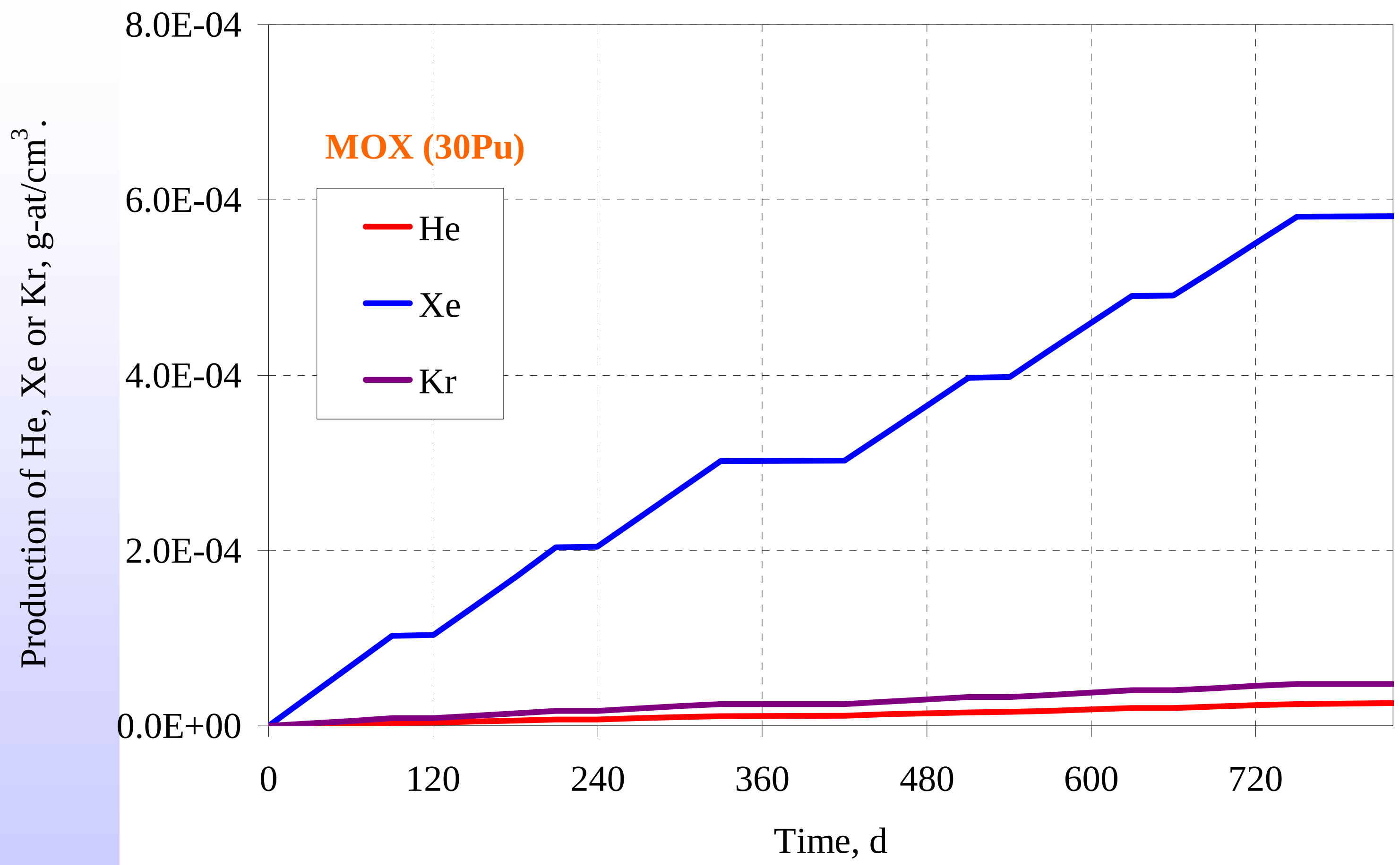


5.7. Results of modeling: Pellet-clad gap closing



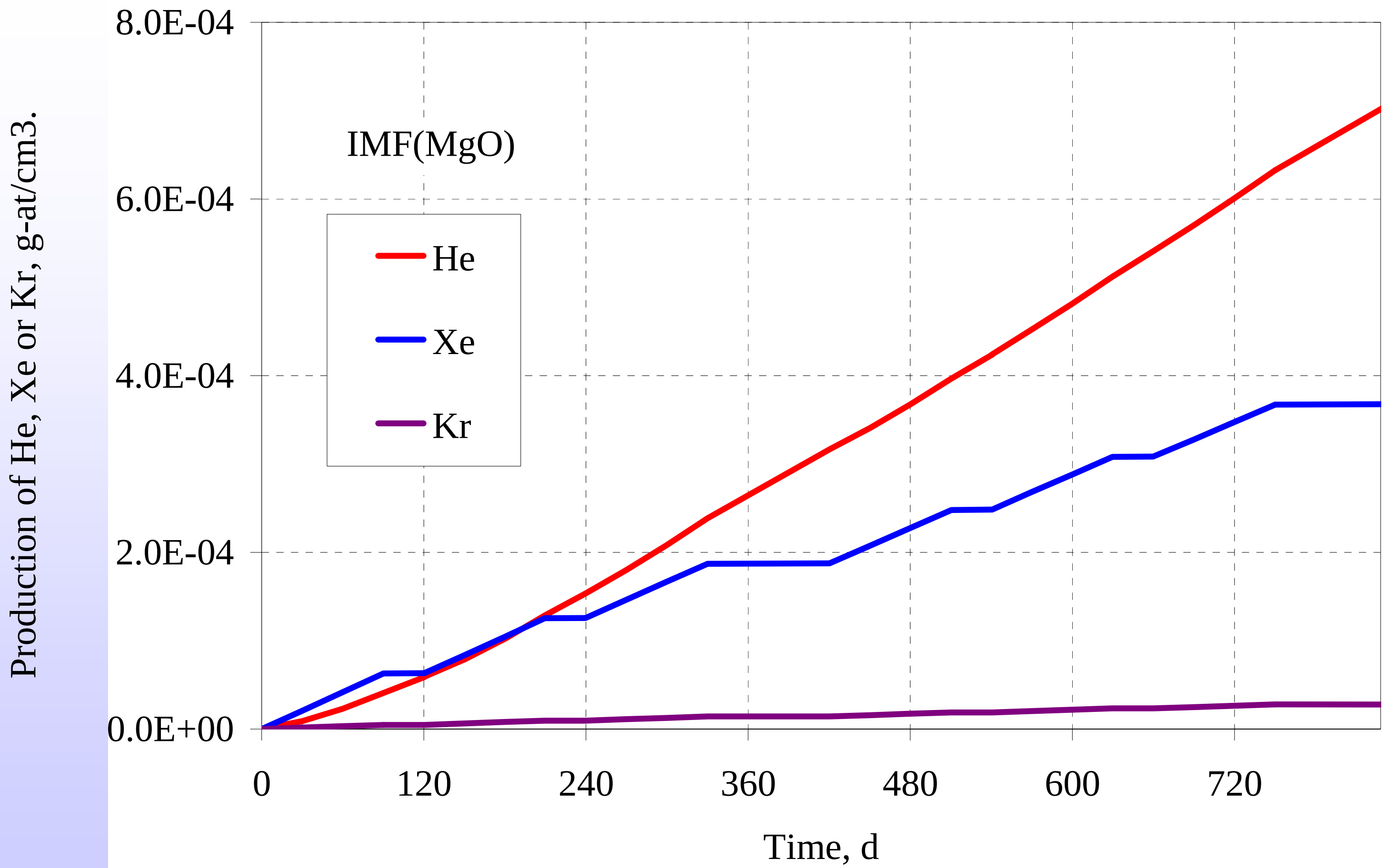
5.8. Results of modeling:

Xe, Kr and He production in MOX

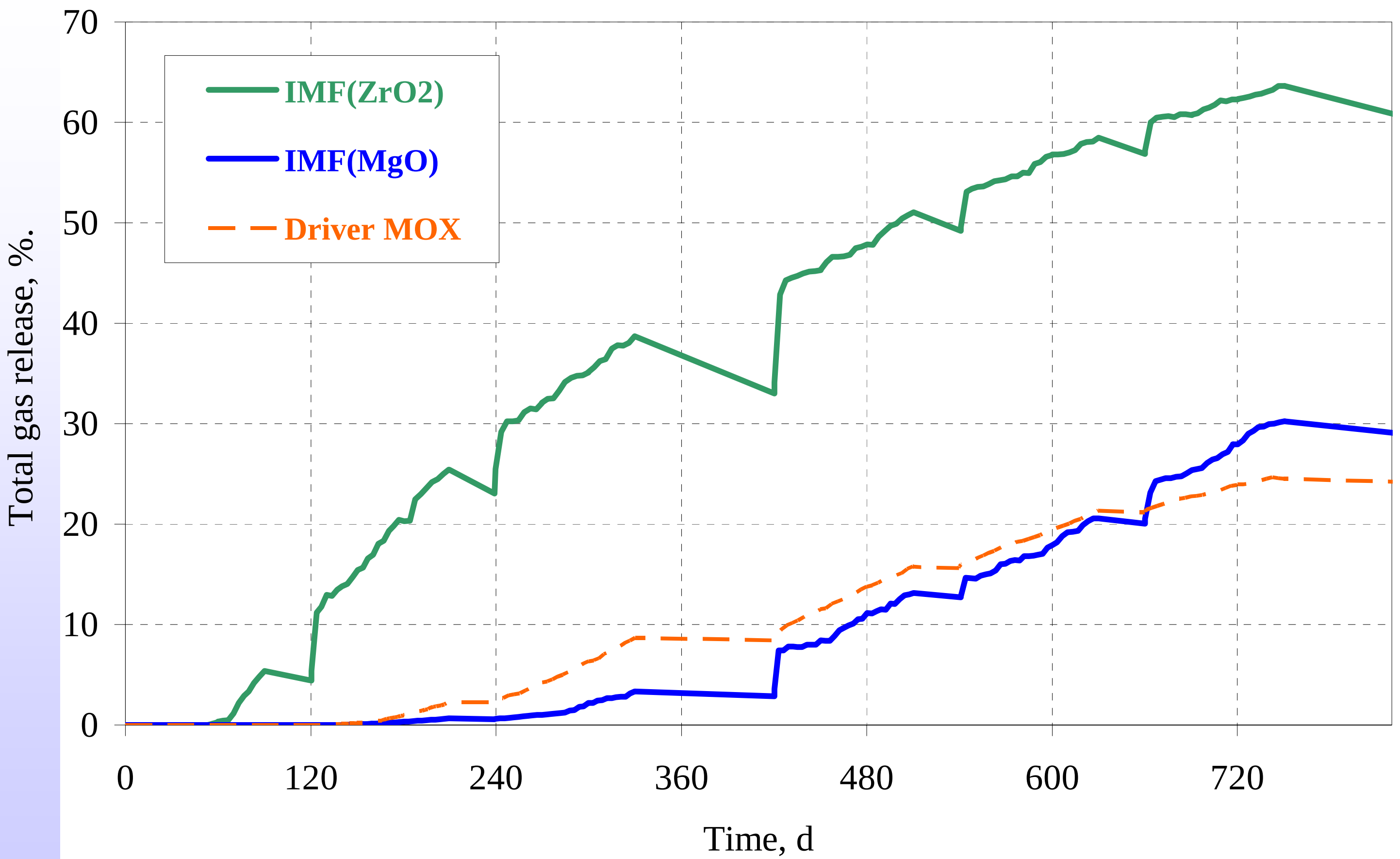


5.9. Results of modeling:

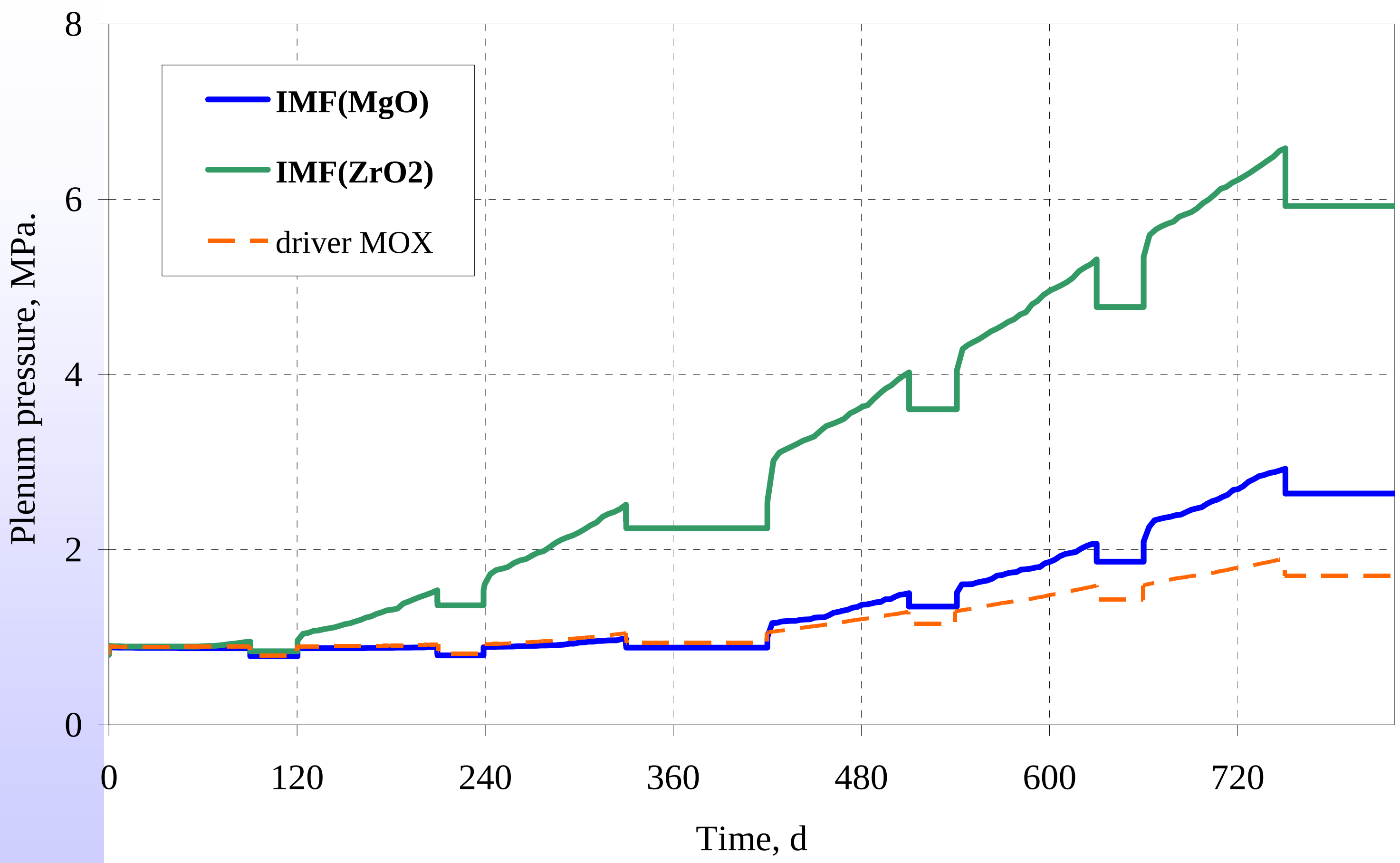
Xe, Kr and He production in IMF



5.10. Results of modeling: Release of noble gases



5.11. Results of modeling:
Gas pressure in the rods



6. Conclusions

- The fuel performance code MACROS-II developed for modelling of IMF fuel behaviour in ADS is under validation and testing at the SCK·CEN.
- Prognosis of the behaviour of two CERCER IMF pins with $(Am,Cm,Pu)O_{2-x}$ fuel and MgO and ZrO_2 matrices in the sub-critical core of ADS MYRRHA was performed with this code.
- It was shown that both can withstand at least six cycles (540 EFPD) of operation without serious problems, reaching the representative burnup of 11 % FIMA. IMF with MgO matrix can operate at higher fission rates and has better safety margins.

Future steps

- Validation of the MACROS code with the data of EFTTRA and other irradiation experiments performed with MA containing fuels.
- Application in IP EUROTRANS for fuel design and modelling.