Incineration of Plutonium in PWR Using Hydride Fuel

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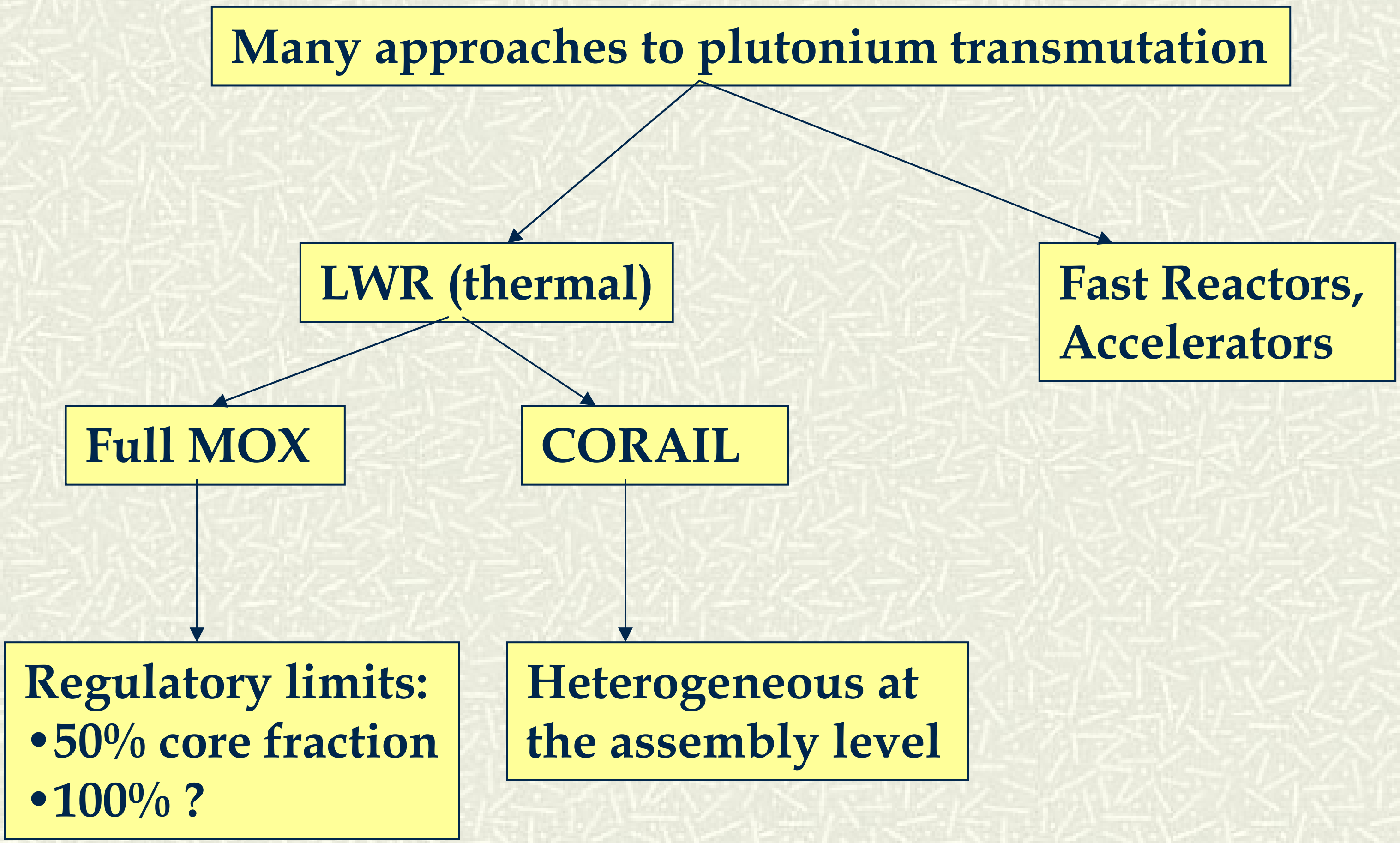
Pu transmutation overview



Issues with Pu transmutation

- Smaller β
- Smaller Boron worth
- Smaller CR worth
- Higher void/ mod feedback

But …

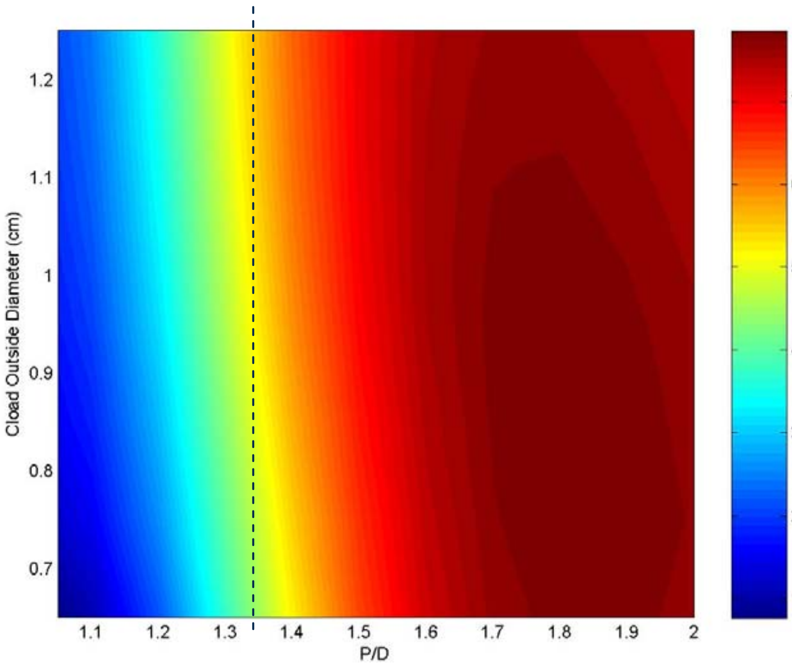
- BR3 in Belgium operated with 70% MOX in the core;
- EDF successfully conducted a "load-follow" experiment with MOX

The case for hydrides

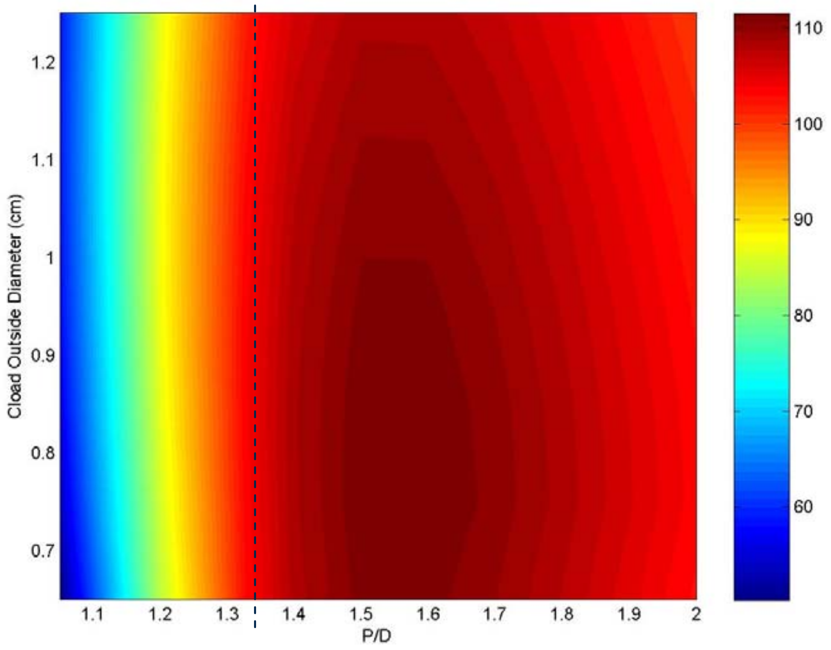
Efficient transmutation of Pu requires higher H/HM (softer spectrum)

Attainable burnup (GWD/tHM)

MOX

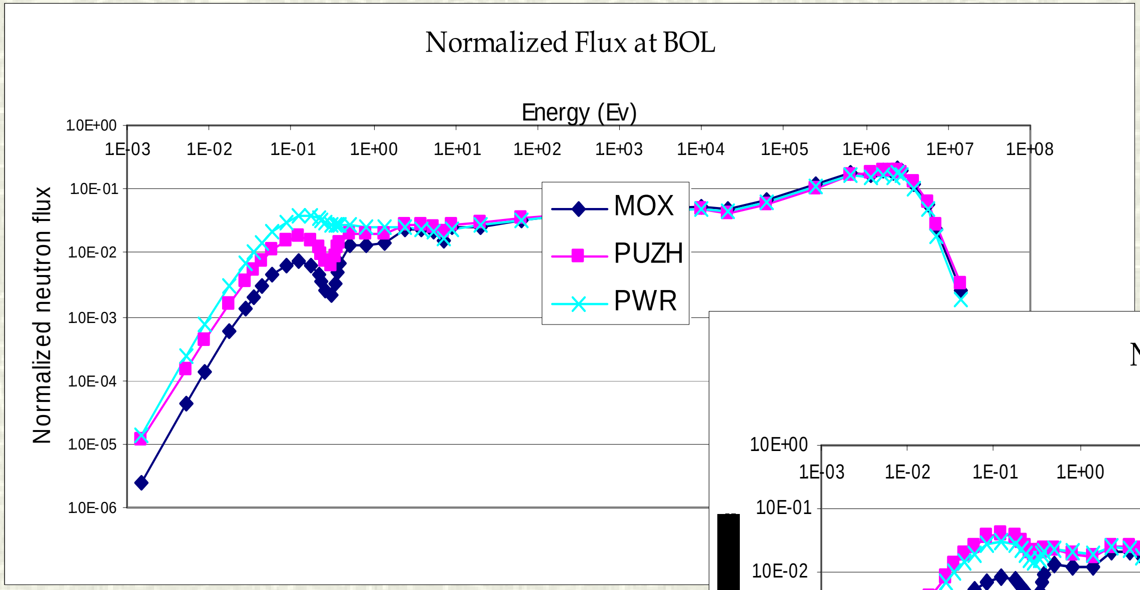


PuH_2-U-$ZrH_{1.6}$ (PUZH)



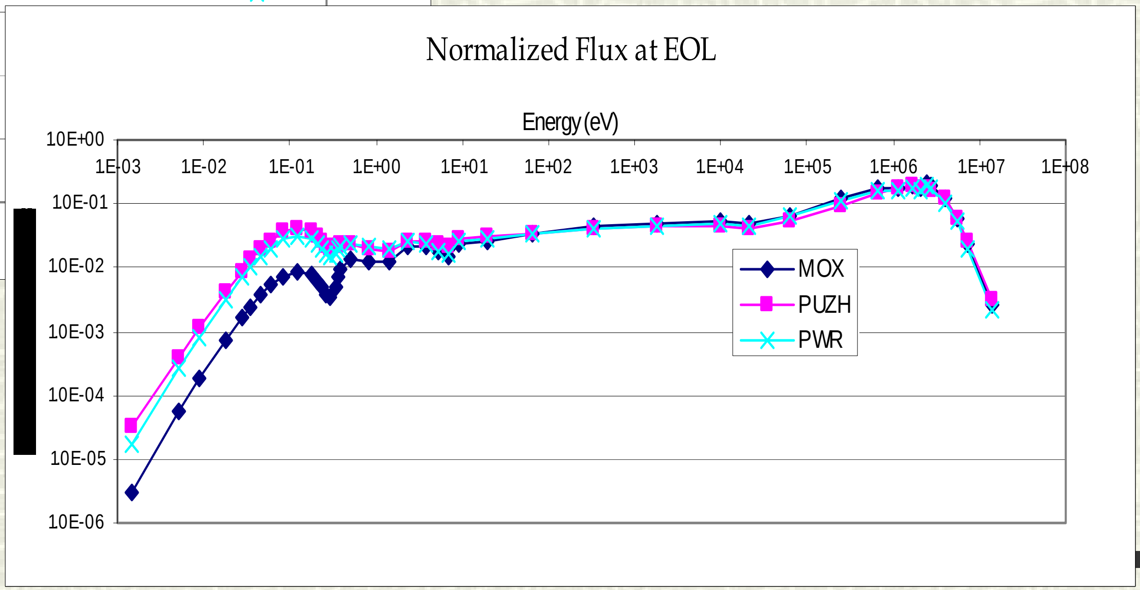
The case for hydrides (cont…)

Hydrides offer higher H/HM for a given P/D → softer spectrum



Reference geometry (0.95cm; p/d=1.326)

PuH_2 U $ZrH_{1.6}$ = PUZH



Issues to be addressed

- Attainable burnup
  with negative reactivity coefficients using soluble boron

- Transmutation effectiveness

versus MOX

Presentation overview

- Methodology
- Assumptions and constraints
- Results: MOX feasibility region
- Results: PUZH feasibility region
- Results: Focus on the reference pin cell
- Discussion: why PUZH is better than MOX

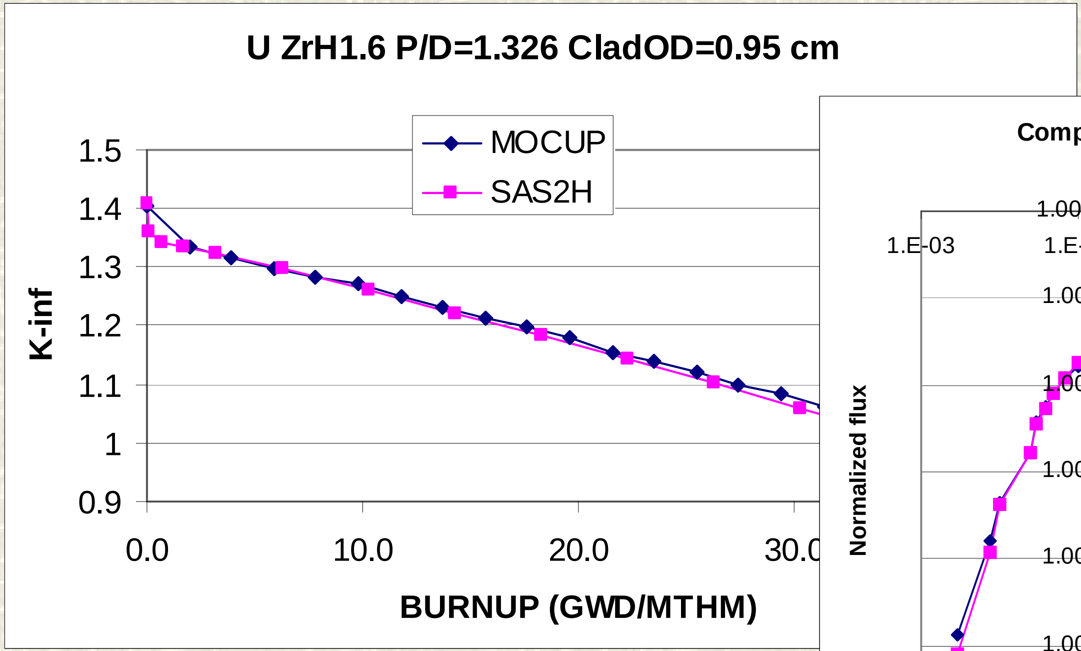
Methodology: Approach

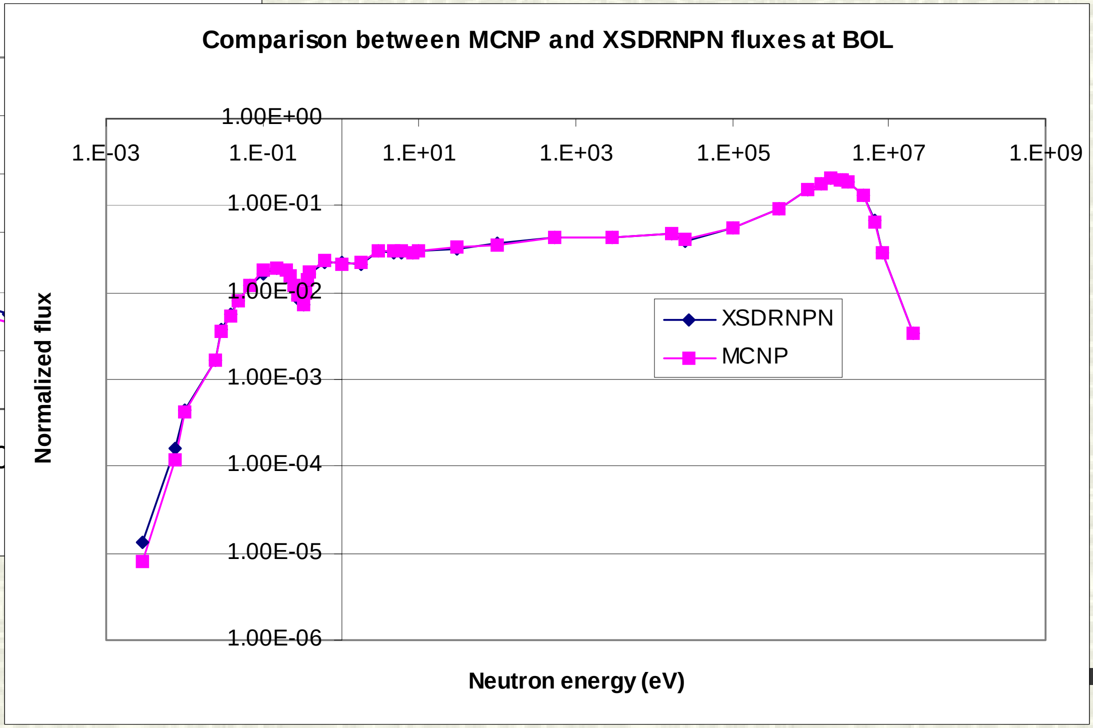
1. Cover wide range of geometries: find BU (3-batches) and reactivity coefficients (for both MOX and PUZH):
   - Design variables:
     - fuel rod diameter (D)
     - Pitch-to-diameter ratio (P/D)
   - Reactivity control: soluble boron (no burnable poison)
   - Constraints: Doppler, MTC, Void ρ coefficient < 0
     k_∞ (3-batch average @ discharge) = 1.05

2. Focus on the reference geometry (if feasible) and compare MOX and PUZH for:
   - Fraction of Pu incinerated
   - Decay heat
   - Neutron source intensity [spontaneous fission and (α,n)]
   - Fiss Pu/tot Pu ratio
   - MA/Pu ratio

Methodology: Benchmark

All the calculations are performed in single pin geometry with SAS2H: benchmarked with MOCUP and found reliable for hydrides and plutonium





Methodology

<u>**Question:**</u>
How to best compare MOX and PUZH performance?

<u>**Answer:**</u>
Use the "indifferent method"

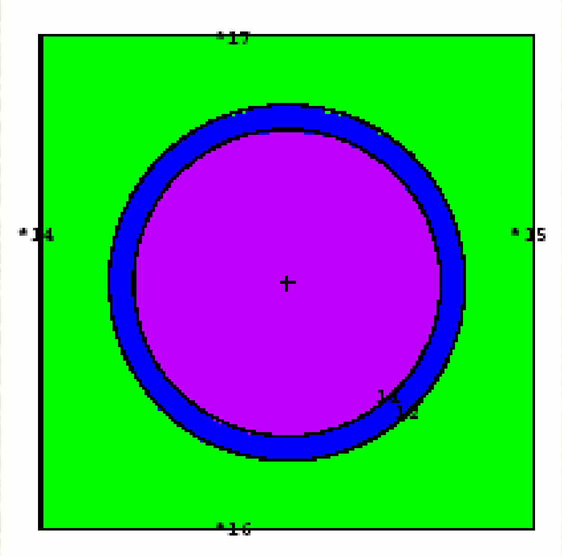
PWR cycle length 1350 EFPD with 5% enrichment
Utilities will likely want the same cycle length with Pu, both with MOX and PUZH.

… find the amount of Pu (for a given Pu vector) that satisfy the 1350 EFPD requirement.

Methodology: Reference unit cell

Reference unit cell:

Clad OD = 0.95 cm
P/D = 1.3261
Fuel diam. = 0.8192 cm
Clad ID = 0.8357 cm
Pitch = 1.25 cm
Power density = 36.138 W/gHM

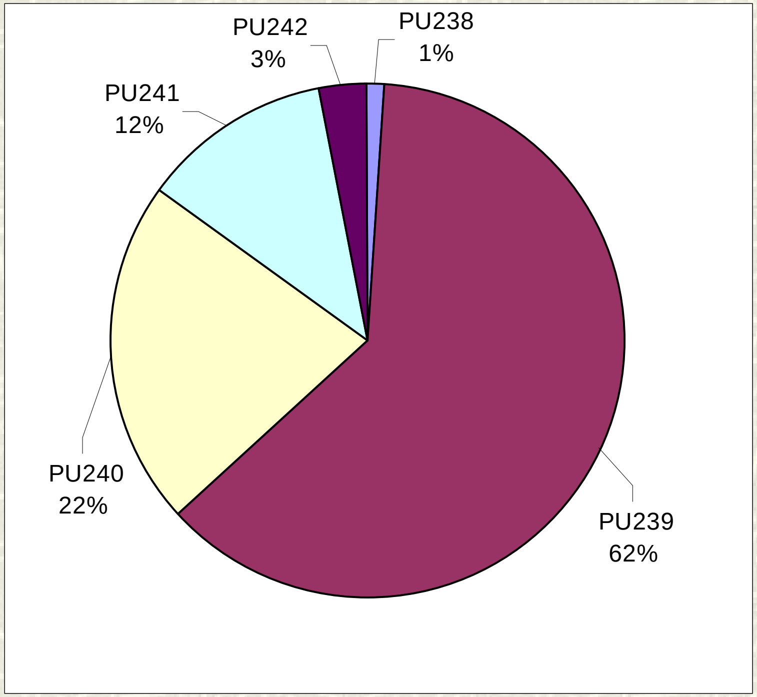


Methodology: Composition

For both MOX and PUZH
U is depleted (0.25% enriched)

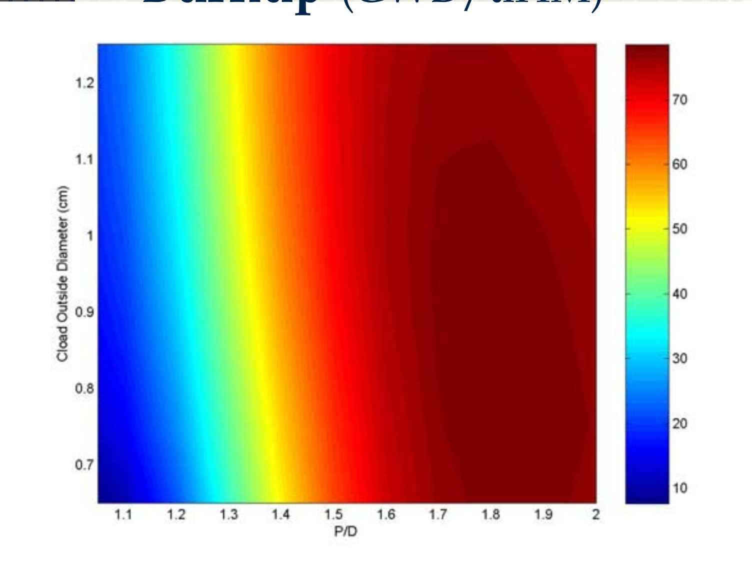
	MOX	PUZH
TOT Pu	2.134E-03	1.587E-03
Tot U	2.130E-02	9.834E-03
Pu atom fraction	9.109	13.894

Plutonium vector loaded

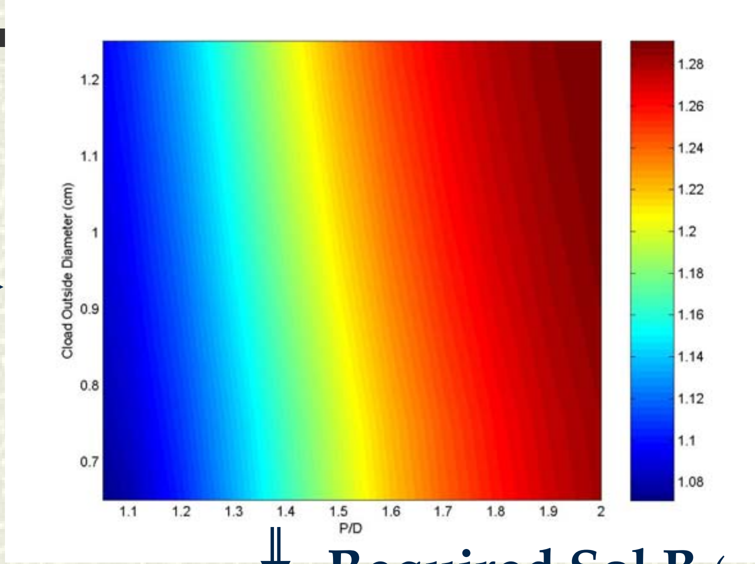


Results: MOX

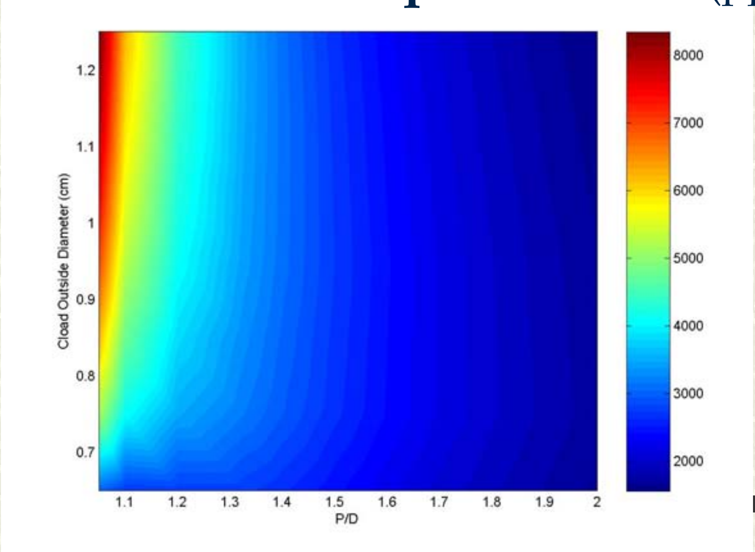
Burnup (GWD/tiHM)



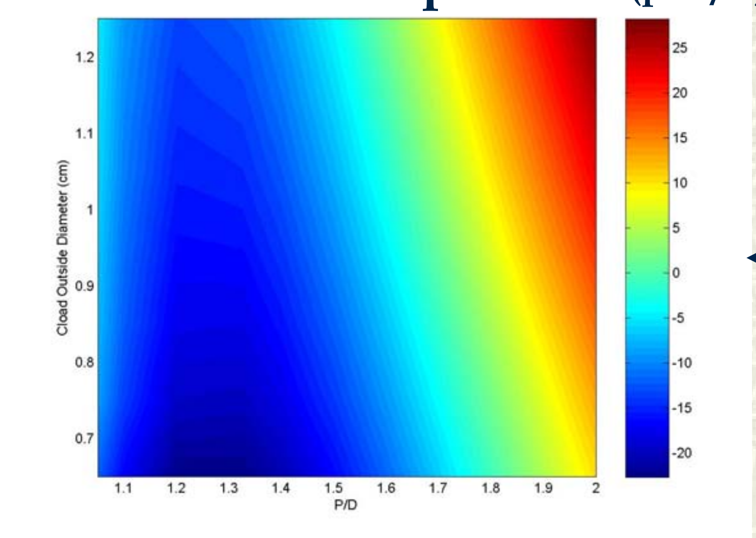
BOL Kinf



Required Sol B (ppm)

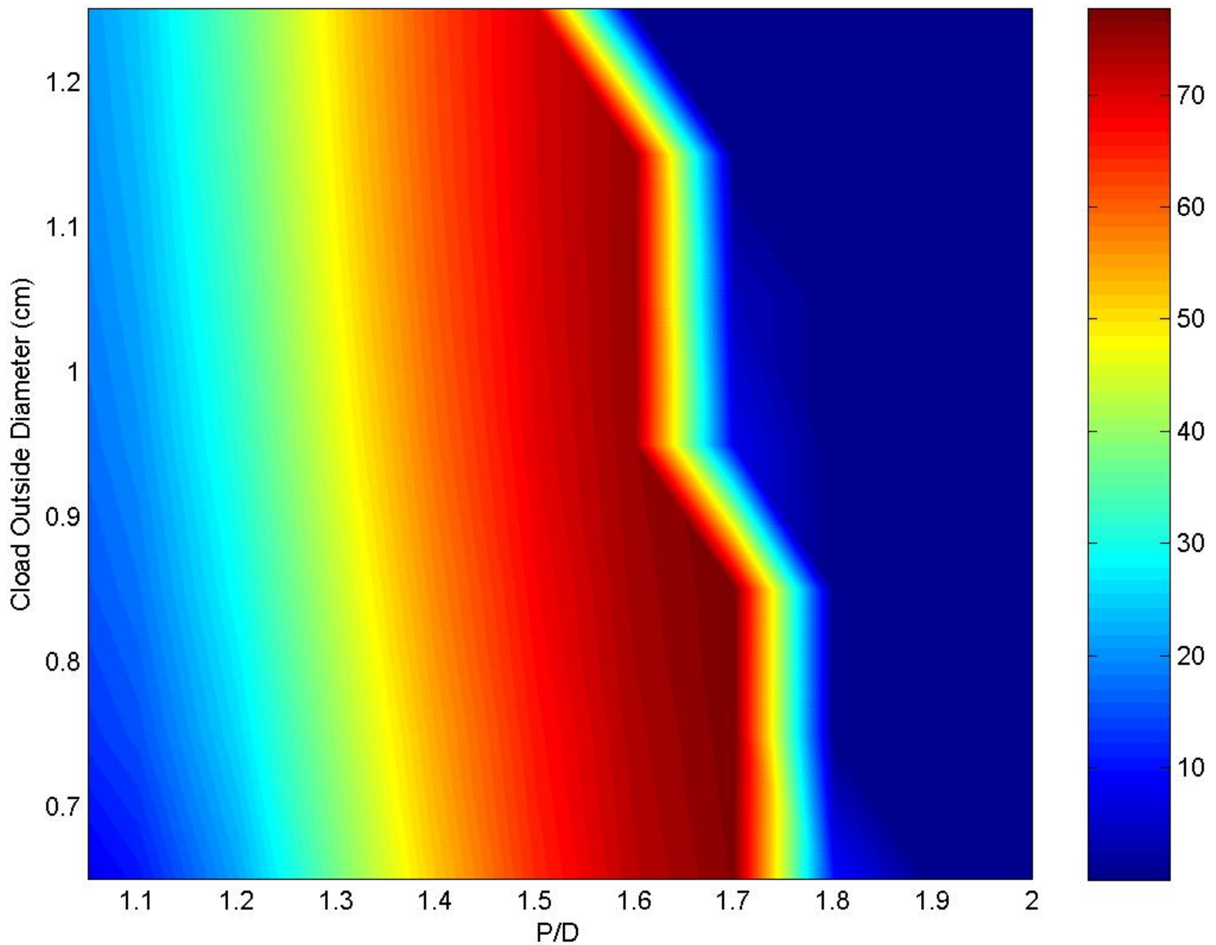


BOL Coolant temp. coeff. (pcm/K)



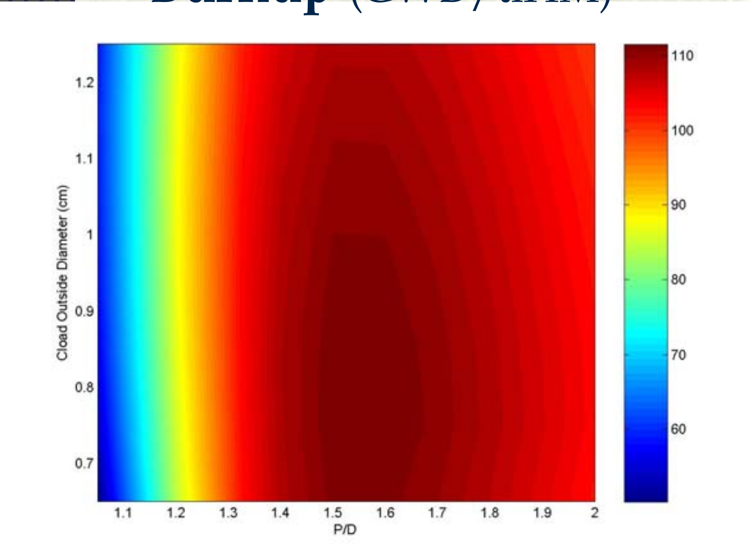
MOX practically achievable burnup

(GWD/tiHM)

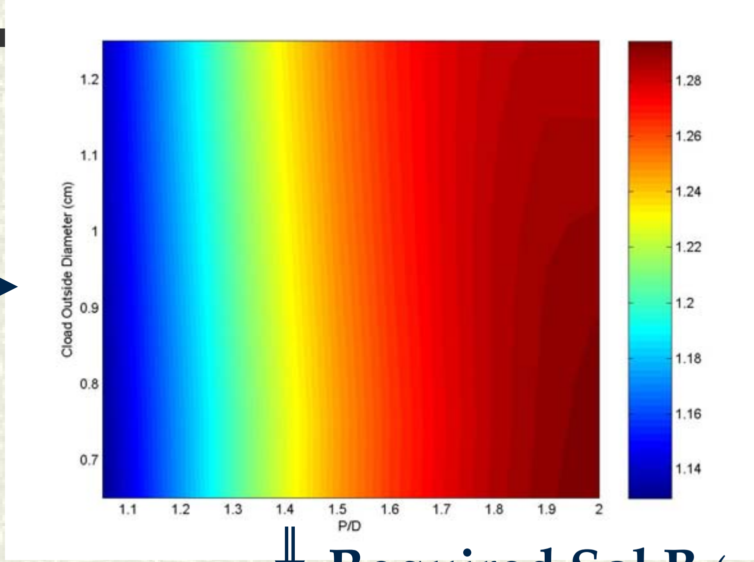


Results: PUZH

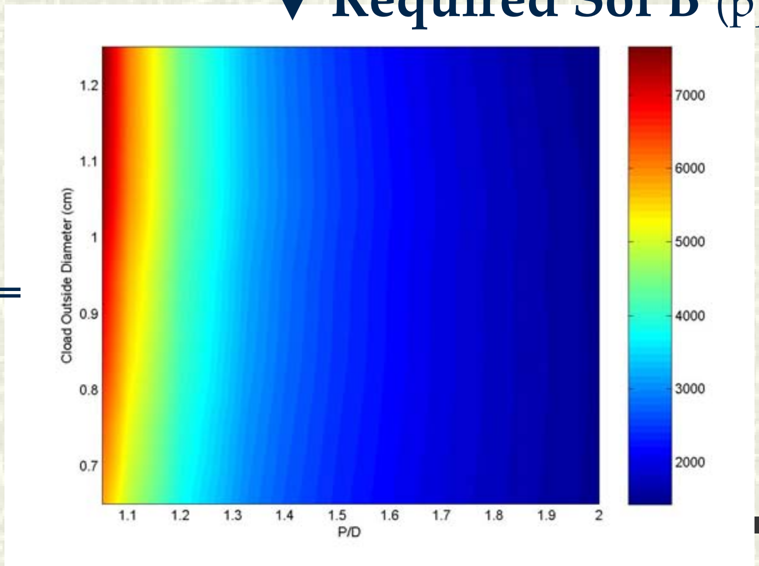
Burnup (GWD/tiHM)



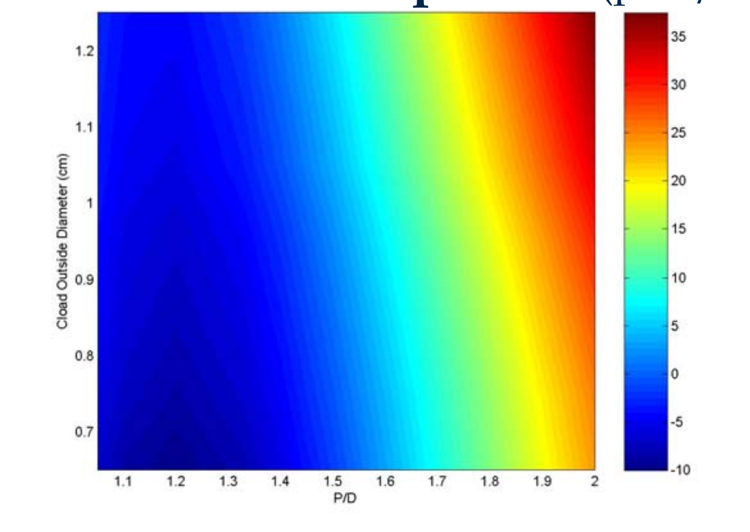
BOL Kinf



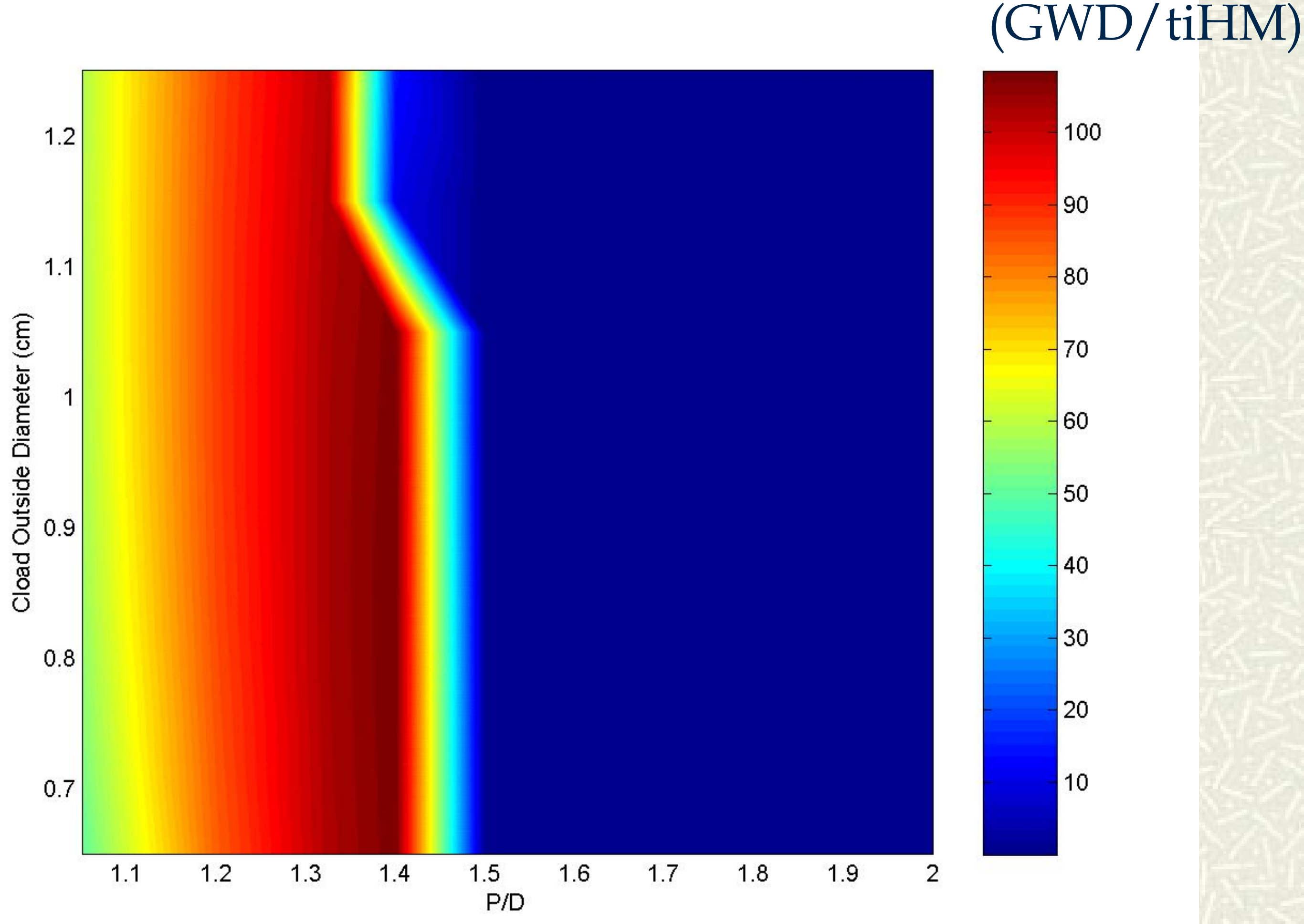
Required Sol B (ppm)



BOL Coolant temp. coef. (pcm/K)

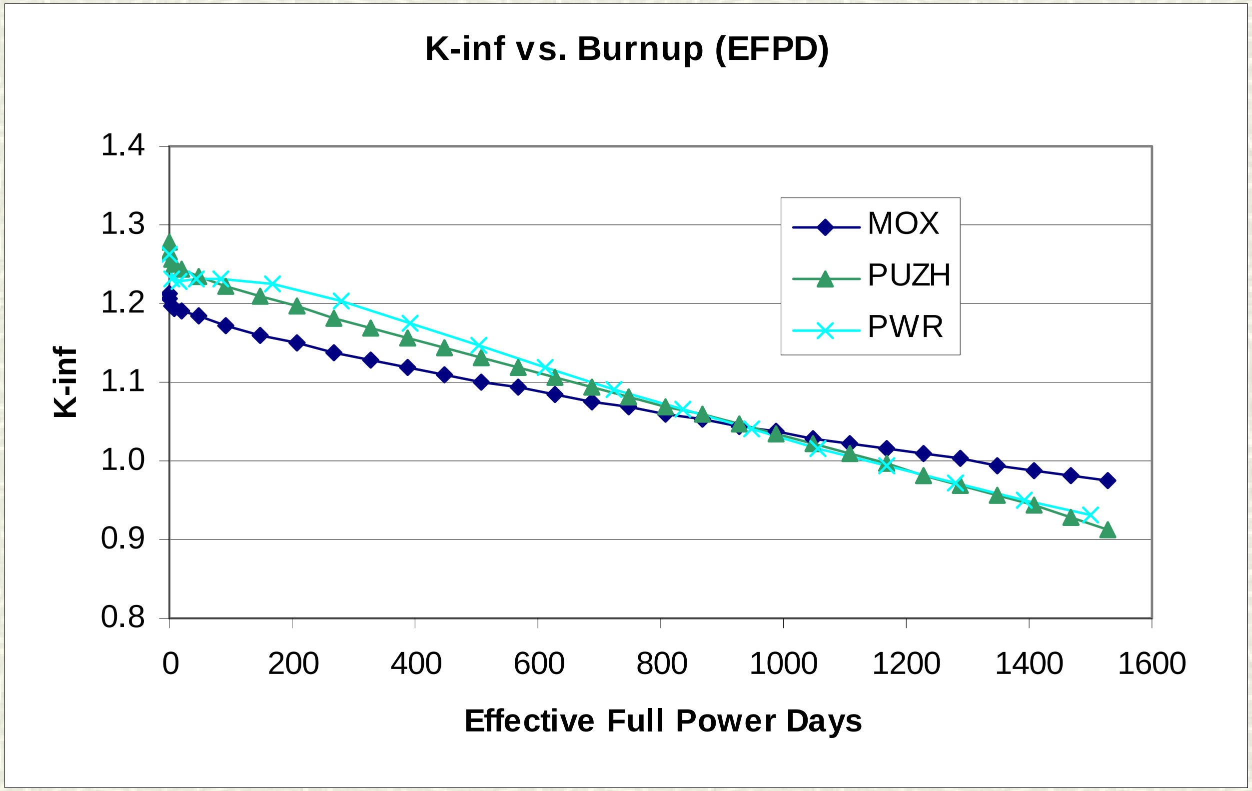


PUZH practically achievable burnup

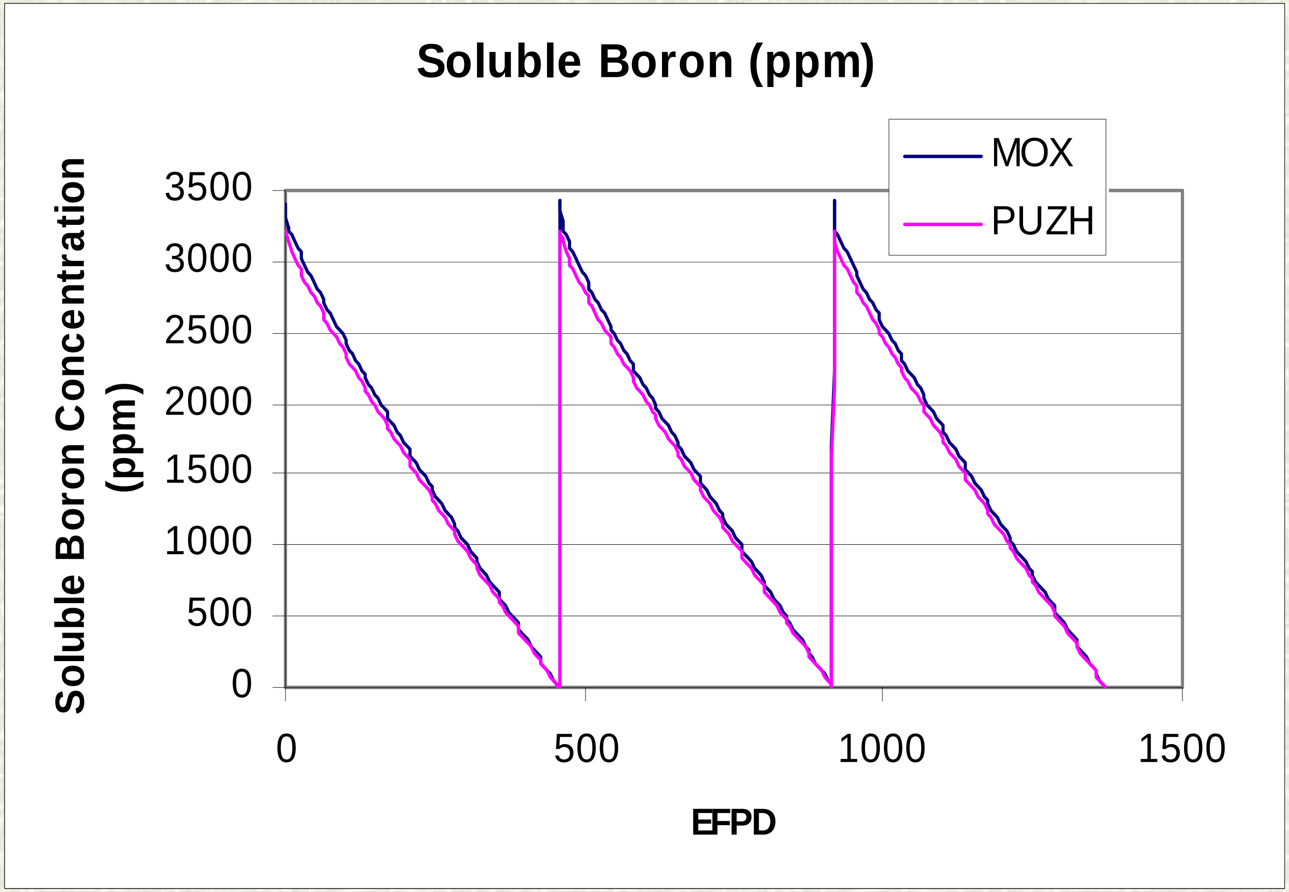


Result: k_∞ evolution; reference geometry

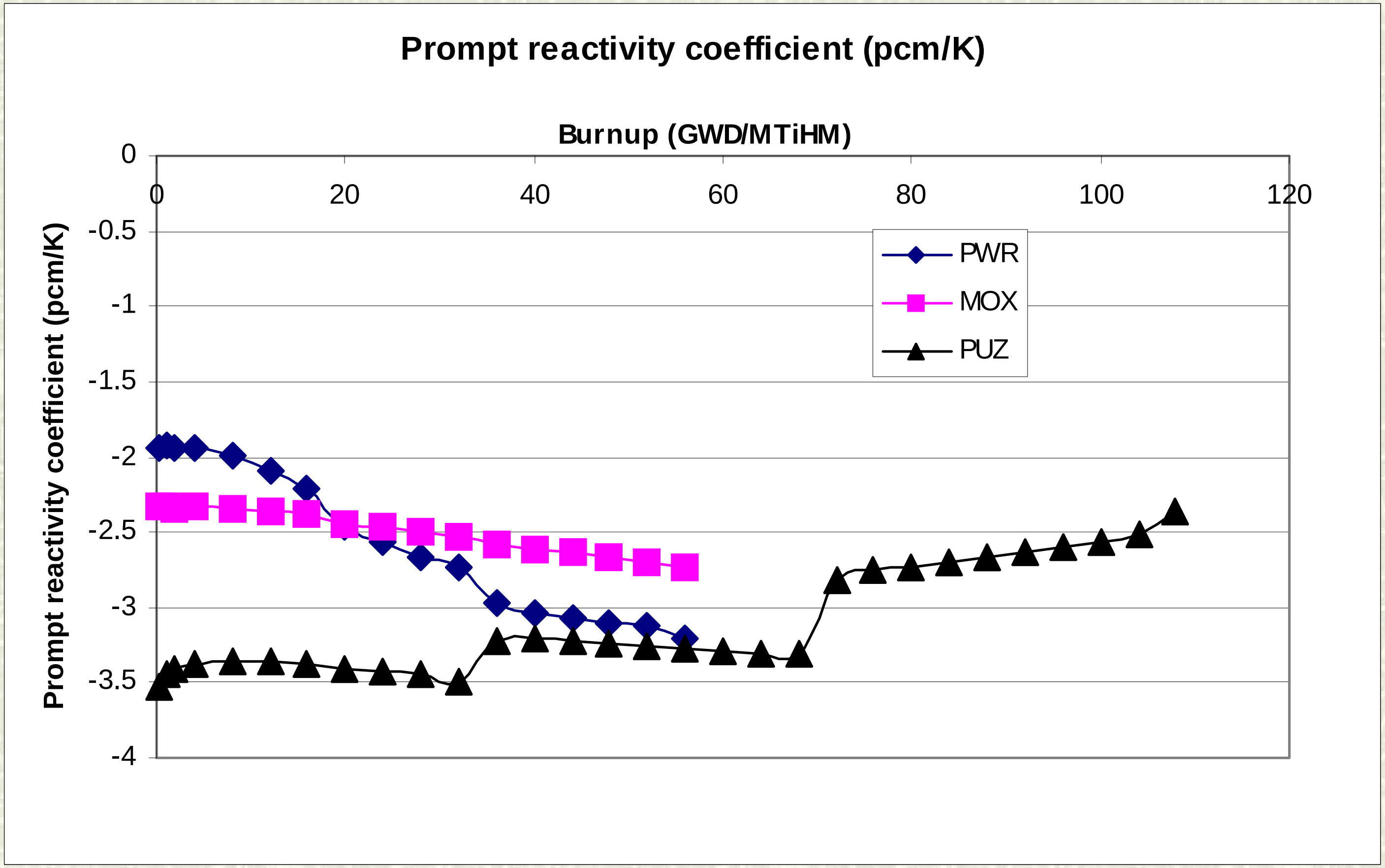
w/o B



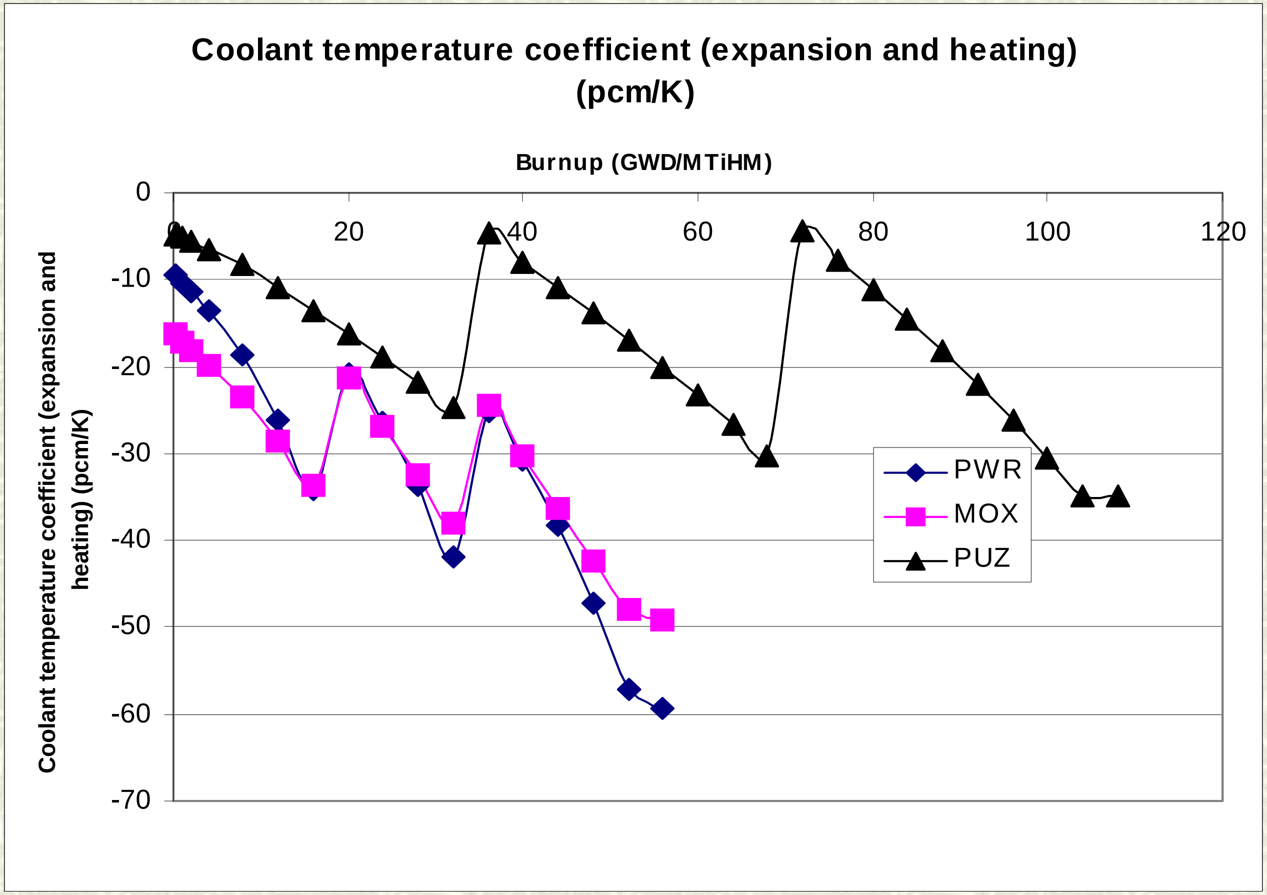
Result: Reference geometry



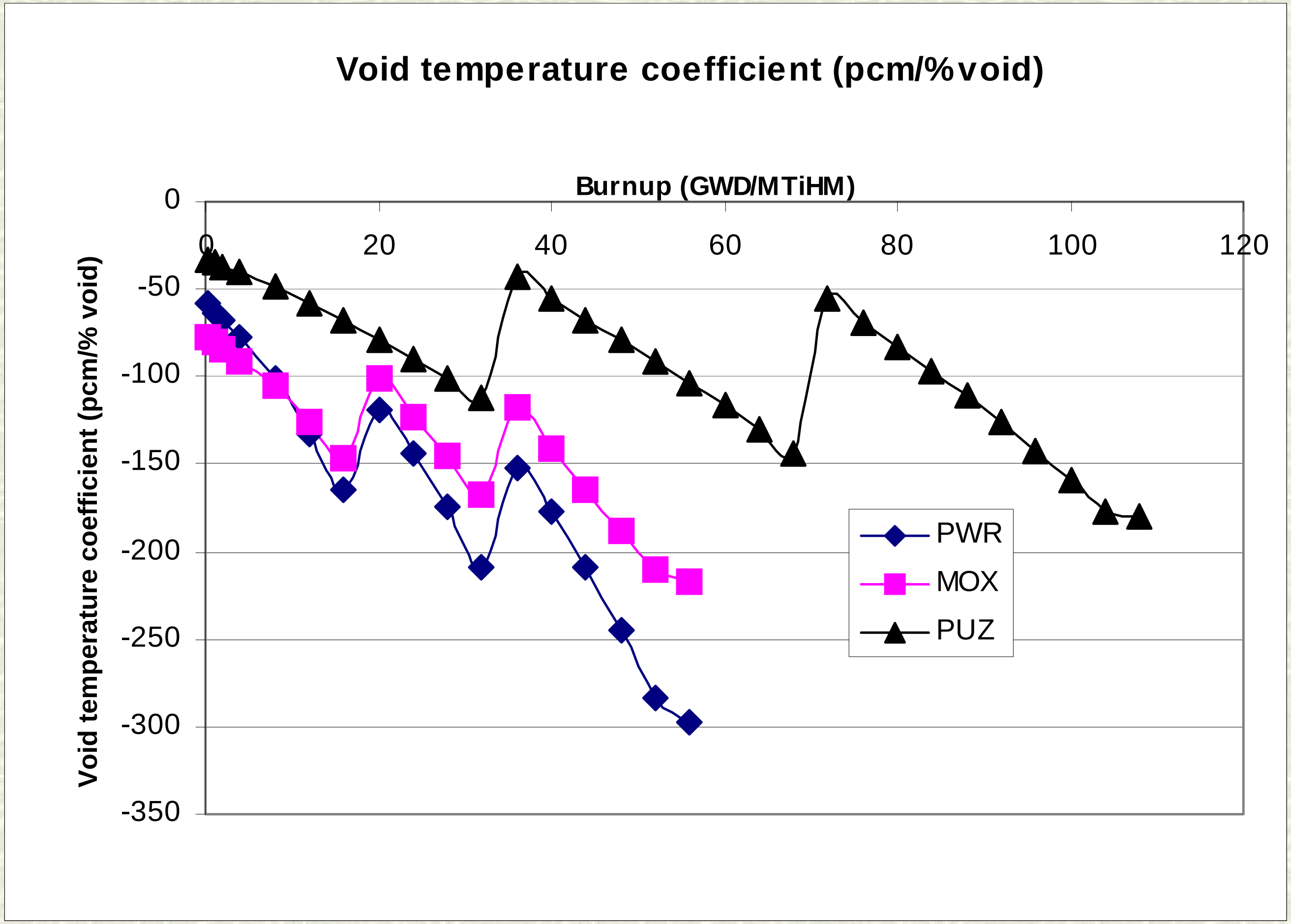
Result: Reference geometry



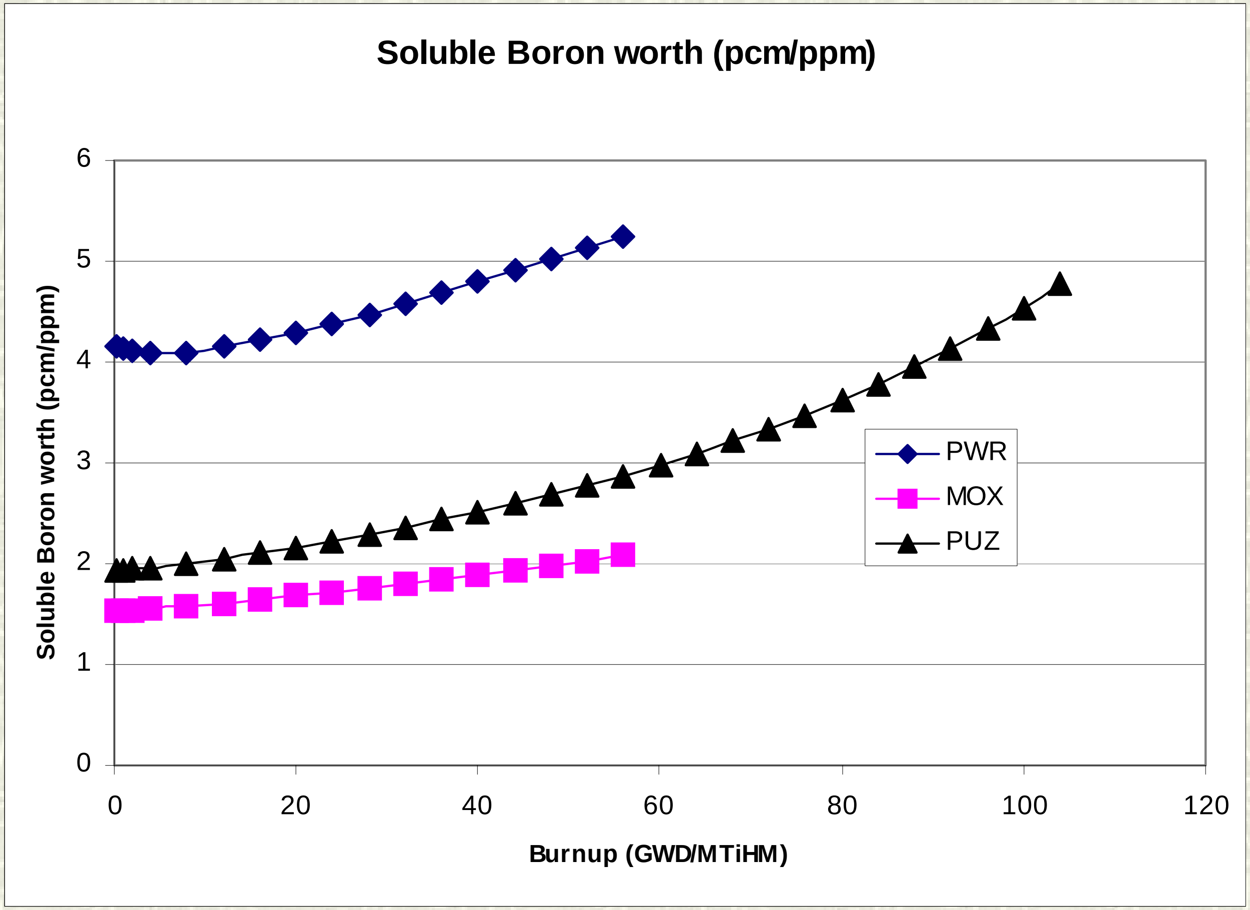
Result: Reference geometry



Result: Reference geometry



Result: Reference geometry



Transmutation performance reference geometry

PUZH vs. MOX:

For same energy production:

- 25% less Pu
- 50% less U
- 103 vs. 50 GWD/TiHM
- 50% vs. 24% fraction of Pu incinerated

Discharged	MOX	PUZH
g Pu/pin	115.00	50.30
g MA/pin	7.77	6.67
g Pu+MA /pin	122.77	56.97
Total n/s from Pu	91560	62892
Watts/pin	231.00	198.00
Ci/pin	72800	58700
fiss/tot Pu	0.629	0.44
MA/Pu	6.76 %	13.25 %
Spont n/s-g Pu	467.50	771.19
Tot n/s-g Pu	796.17	1250.34
W/g Pu	2.01	3.94
W/g MA	29.71	29.71
W/g Pu+MA	1.88	3.48

Transmutation performance

Max Power Geometry: P/D=1.4, clad OD=0.65

	MOX	PUZH
Burnup GWD/MTiHM **:**	52.25	108.2
Pu incinerated	72%	45%
Pu remaining	28%	55%

Discharged	MOX	PUZH
g Pu/pin	49.80	21.70
g MA/pin	2.92	2.24
g Pu+MA /pin	52.72	23.94
TOT n from Pu	35543	22525
tot W/pin	191	148
Ci/pin	66564	50700
fiss/tot Pu	0.630	0.447
MA/Pu	5.86	10.30
spont n	461.06	739.14
n/gPu	713.71	1038.00
W/g Pu	3.84	6.82

Transmutation performance
Inert Matrix fuel: Reference Geometry

$PuH_2ZrH_{1.6}$

Attainable Burnup: 709.6 GWD/MTiHM
EFPD: 1398.5 (specific P: 507.40 W/giHM)

Pu incinerated = 78 atom%
but
Doppler becomes positive @ 900 EFPD
→50% incineration in one pass

With ThH_2 can get all reactivity worth negative

Discharged	$PuH_2ZrH_{1.6}$
g Pu/pin	25.5
g MA/pin	6.7
g Pu+MA /pin	32.2
TOT n from Pu	48386
tot W/pin	117
Ci/pin	20700
fiss/tot Pu	0.165
MA/Pu	26.2
spont n/gPu	1296
n/gPu	1897
W/g Pu	4.6

Conclusions

- Hydride fuels provide higher H/Pu ratio → softer spectrum without having to reduce D, increase P or use more water rods

Compared to MOX fuel of same dimensions and cycle length, use of PuH_2-$ZrH_{1.6}$ fuel offers:

- 100% higher burnup: 103 vs. 50 GWD/TiHM
- Larger fractional transmutation: 50% vs. 24% fraction of Pu
- Worse Pu quality: 44% fissile isotopes vs. 63%
- Larger MA/Pu ratio: 13.25 % vs. 6.76 %
- Stronger neutron source intensity and decay heat per gm Pu
- But lower neutron source intensity and decay heat per fuel assembly

Conclusions (cont.)

- Inert matrix hydride fuels might enable even higher Pu incineration per pass

- Particularly promising are ThH_2 containing hydride fuels – they provide negative reactivity coefficients up to high burnups and thereby offer high fractional incineration of Pu

It is recommended to consider hydride fuels for recycling Pu in LWR