The XT-ADS core design

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SCK•CEN

Acknowledgements

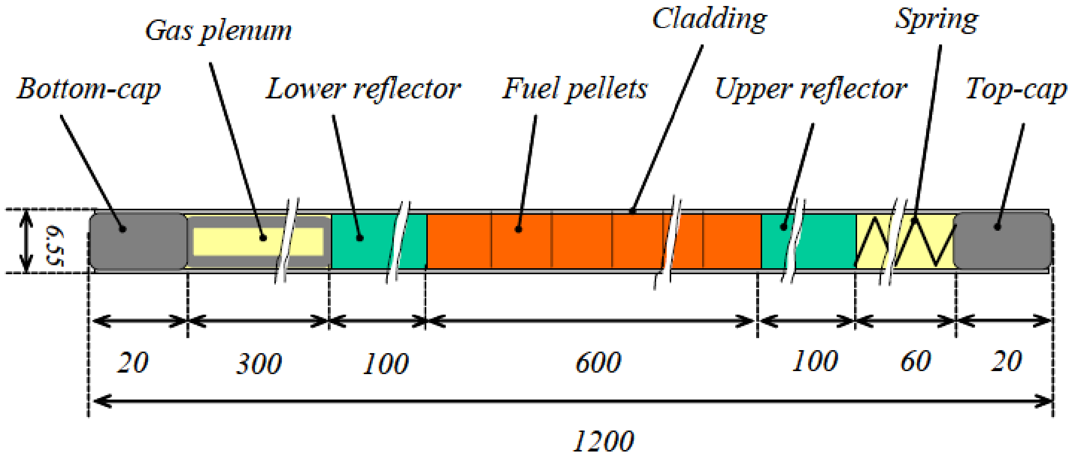
- This is the work of
  - The MYRRHA team at SCK•CEN
  - The MYRRHA Support team at SCK•CEN
  - Domain 1 of EUROTRANS (and especially Work Package 1.2 and Work Package 1.4)
  - A successful collaboration with JAEA

In short: people who want to see this machine constructed!

Contents

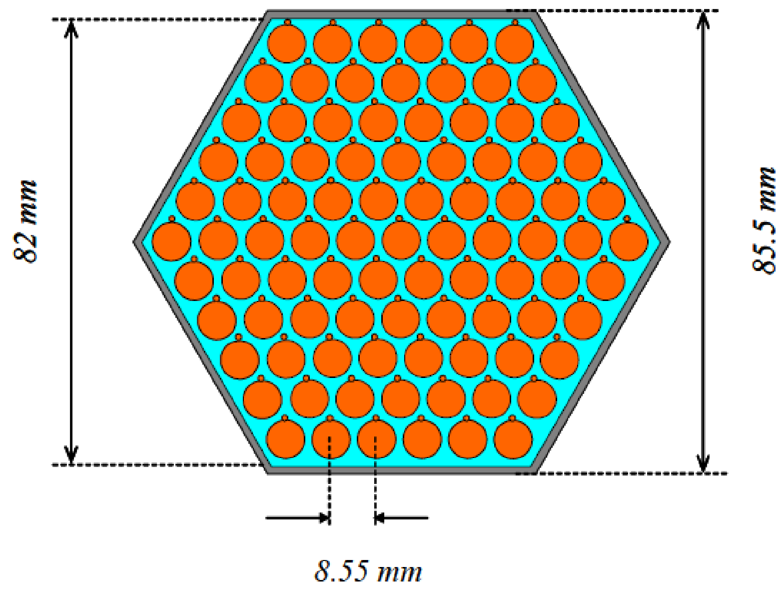
MYRRHA Draft 2
Fuel pin & assembly

- MOX 30 wt% Pu
- Solid pellets D 5.40 mm
- Clad: T91 OD 6.55 mm
- Neutron reflector (YSZ)
- Gas plenum
- Caps



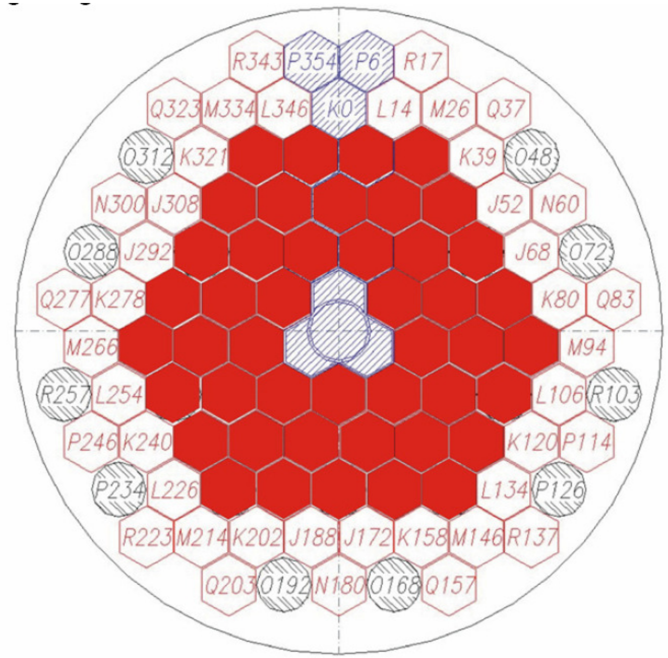
MYRRHA Draft 2
Fuel assembly

- Pin pitch: 8.55 mm
- P/D = 1.305
- 91 pins
- Wrapper thickness: 1.75 mm
- Inter FA space: 2 mm



MYRRHA Draft 2 core layout

- 45 Fuel assemblies
- Lattice 99 positions
- 350 MeV x 5 mA proton beam
- k_{eff} = 0.955, k_s = 0.960
- P = 52 MW_{th}
- Peak linear power: 352 W/cm
- Hot pin Φ_{tot}: $4 \cdot 10^{15}$ n/cm^2.s
- Hot pin $\Phi_{>1MeV}$: $0.8 \cdot 10^{15}$ n/cm^2.s
- Hot pin $\Phi_{>0.75\ MeV}$: $1 \cdot 10^{15}$ n/cm^2.s



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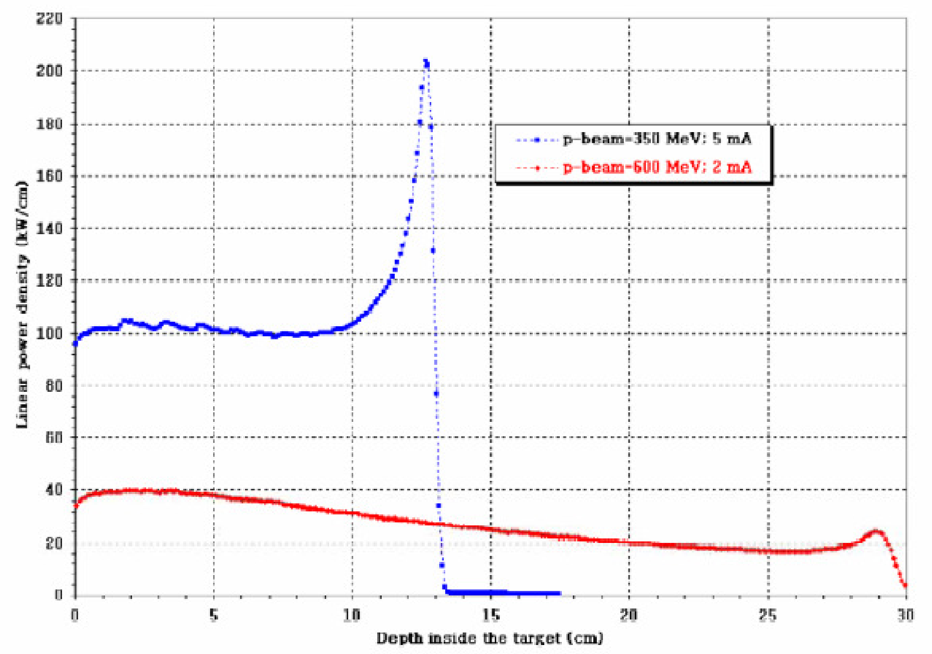
Increased proton energy

MYRRHA

- At 350 MeV Bragg peak is significant
  - Heat production
  - Recirculation
- Switch to 600 MeV
  - I = 2 – 2.5 mA
  - Lower total power
  - Higher n/p



Contents

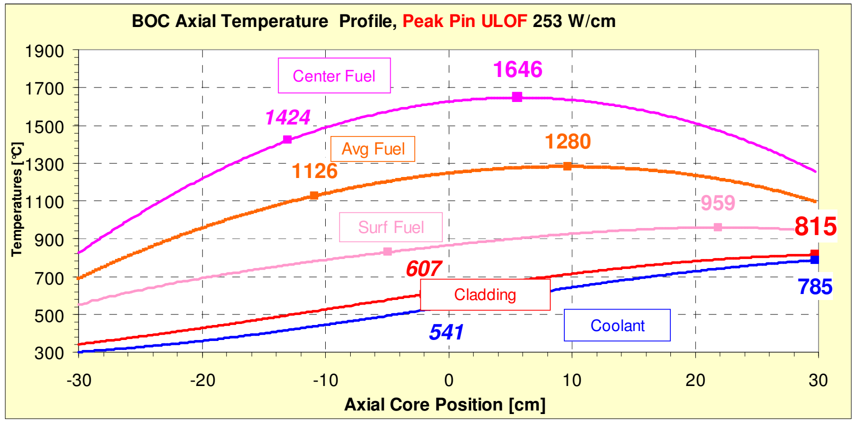
1. MYRRHA Draft2
2. **New fuel pin and fuel assembly**
3. Clean core configuration
4. Reference core
5. Analysis of irradiation capabilities

MYRRHA Draft 2
Safety analysis

- ULOF was worst case scenario (grace time)
- No problem with the fuel
  - Safety limit of 2500°C is not reached
- Clad (T91) does have a problem
  - Safety limit of 700°C is reached
    - After 10s for ULOF
    - After 10min for ULOHS

ULOF analysis

- Increase coolability in case of ULOF
  - Drastic increase of natural circulation potential
  - Reduction of the pressure drop over the core
  - Target value: 1000 mbar
- Consequences:
  - Larger pin pitch
  - Larger assembly pitch



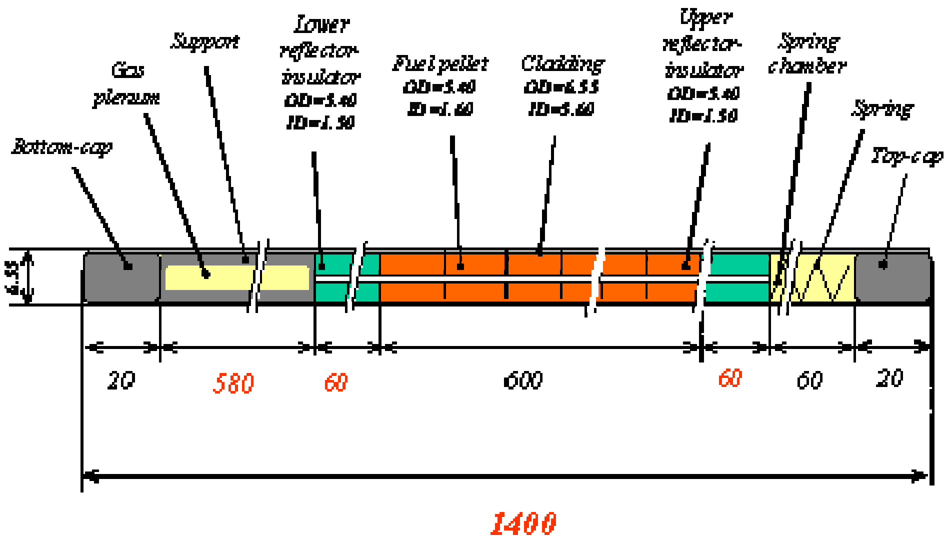
ULOF analysis

- Risk at an ULOF is clad failure due to
  - High temperature
  - Fission gas pressure build-up

- Decision to increase the gas plenum
  - Larger fuel pin
  - Height of fuel assembly increases
  - Core height increases

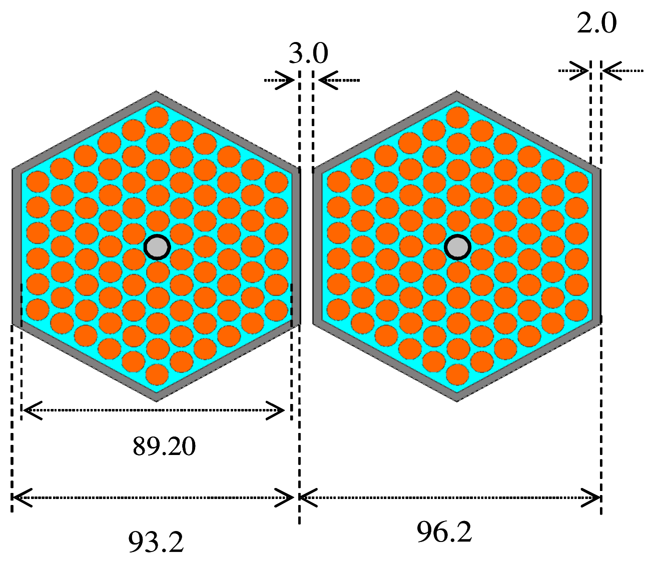
XT-ADS
A new fuel pin

- Pellet with central hole
- Increased gas plenum
- Reduced YSB reflector
- Total height = 1400mm
  - (+200 mm)



XT-ADS
A new FA

- Pin pitch: 9.17 mm
- P/D = 1.40
- 90 fuel pins
- 1 instrumentation pin
- Wrapper thickness: 2 mm
- Inter FA space: 3 mm



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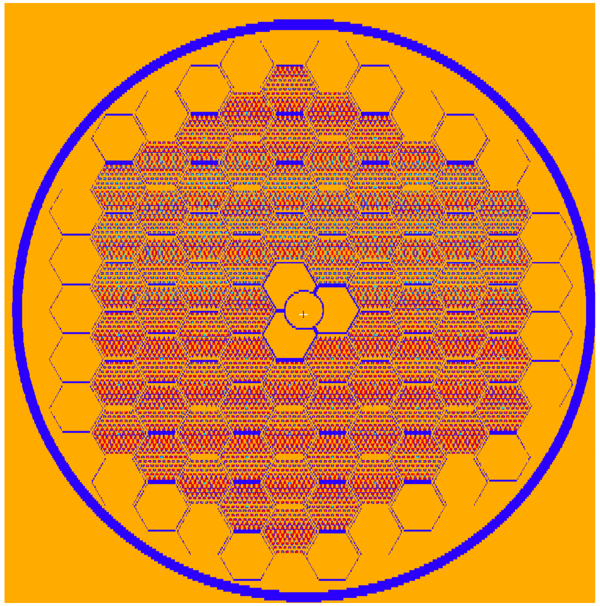
XT-ADS
"Clean core"

Parameter	Unit	XT-ADS Value	MYRRHA Value
Proton beam energy	MeV	600	350
Proton beam current	mA	2.33 †	5
Proton beam deposited heat	MW	1.40	1.75
Total neutron yield per incident proton		15.3	6.0
Neutron source intensity	10^{17} n/s	2.23	1.9
Initial fuel mixture	MOX	$(U\text{-}Pu)O_2$	$(U\text{-}Pu)O_2$
Initial (HM) fuel mass	kg	857	514
Initial Pu enrichment	wt%	31.5	30
k_{eff}		0.95324	0.95521
k_S		0.95711	0.96007
$MF = 1/(1-k_S)$		23.31	25.04
Source importance φ^*		1.095	1.127
Thermal power	MW	56.75‡	51.75‡
Specific power	kW/kgHM	66.22	101
Peak linear power (hottest pin)	W/cm	253	352
Average linear power (hottest pin)	W/cm	146	252
Max Φ_{total} in the core near hottest pin	10^{15} n/(cm².s)	3.31	4.1
Max $\Phi_{>1MeV}$ in the core near hottest pin	10^{15} n/(cm².s)	0.53	0.8
Max $\Phi_{>0.75}$ MeV in the core near hottest pin	10^{15} n/(cm².s)	0.72	1.0

(†) Normalised to fuel power density of 700 W/cm³ (‡) 210 MeV/fission



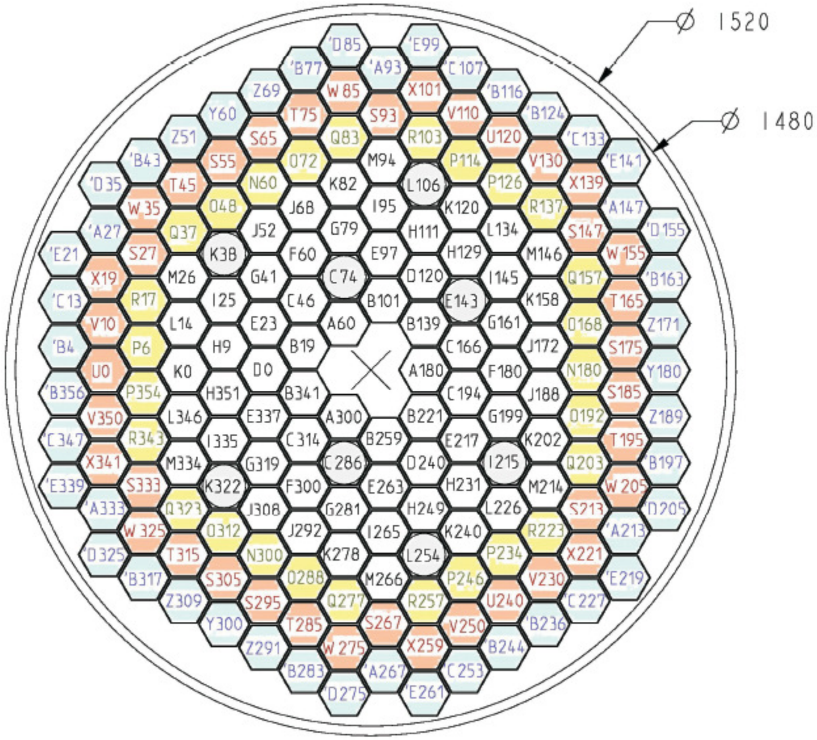
XT-ADS
"Clean core"

- Damage on inner vessel structures?
  - Core barrel
  - Core support plate
- From DM4-Demetra
  - Guidelines (some debate on realism…)

- Resulted in an exercise to maximally protect the core barrel

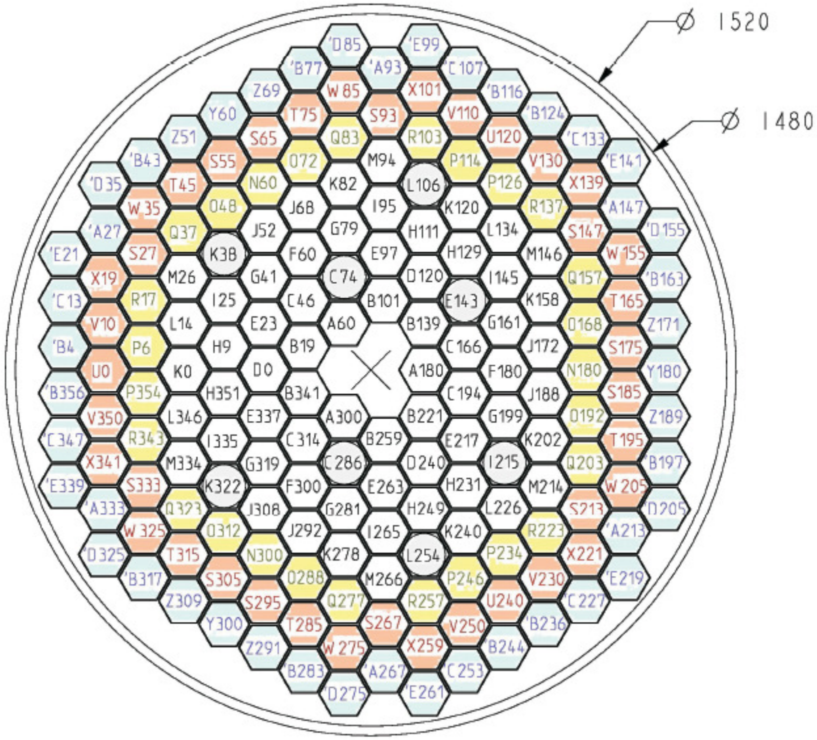
XT-ADS
Avoiding irrad. damage

- Added two extra rows
- Evaluation of
  - Steel pins
  - Boron carbide pins
  - Combination
- Too penalizing for the core performances!



XT-ADS
Avoiding irrad. damage

- Simply empty hex cans
- Increased distance fuel assembly – core barrel halves dpa rate
- "Clean core"
  - 5.5 dpa/360 EFPDs
- This core
  - 2.3 dpa/360 EFPDs



XT-ADS
Reference core

- Goals MYRRHA/XT-ADS
  - Flexible fast-spectrum irradiation facility
  - Demonstration ADS “at power”
  - Demonstration of transmutation of MAs

- Dedicated 8 positions in the core to house “In-Pile-Loops”
  - Penetration through the lid
  - Irradiation conditions (flux, temperature, environment) can be fixed at customers wish

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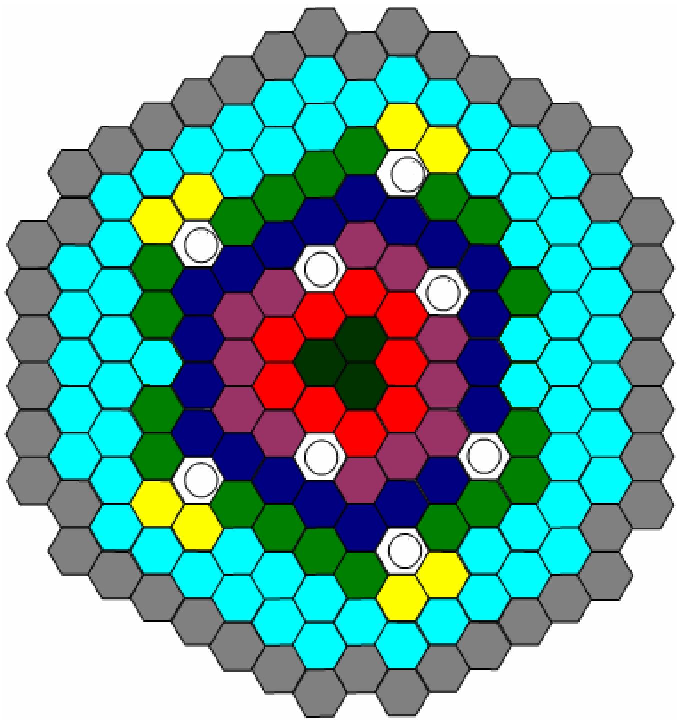
XT-ADS
Reference core

Parameter	Unit	Value
Proton beam energy	MeV	600
Proton beam current	mA	2.1
Proton beam deposited heat	MW	0.94
Total neutron yield per incident proton		15.3
Neutron source intensity	10^{17} n/s	2.23
Initial fuel mixture	MOX	$(U\text{-}Pu)O_2$
Initial Pu enrichment	wt%	35
k_{eff}		0.955
k_S =		0.960
MF = $1/(1-k_S)$		25
Source importance φ^*=		1.12
Thermal power	MW	57
Specific power	kW/kgHM	66.22
Peak linear power (hottest pin)	W/cm	225
Average linear power (hottest pin)	W/cm	146
Max Φ_{total} in the core near hottest pin		3.1
Max $\Phi_{>1MeV}$ in the core near hottest pin	10^{15} n/(cm^2.s)	0.50
Max $\Phi_{>0.75}$ MeV in the core near hottest pin		0.66



Cycle analysis

- Proposed cycle
  - 90 days operation
  - 30 days maintenance
  - 90 days operation
  - 30 days maintenance
  - 90 days operation
  - 90 days maintenance

- Characteristics
  - 13 pcm/EFPD loss
  - 1200 pcm per operational cycle

↓

20% loss in power

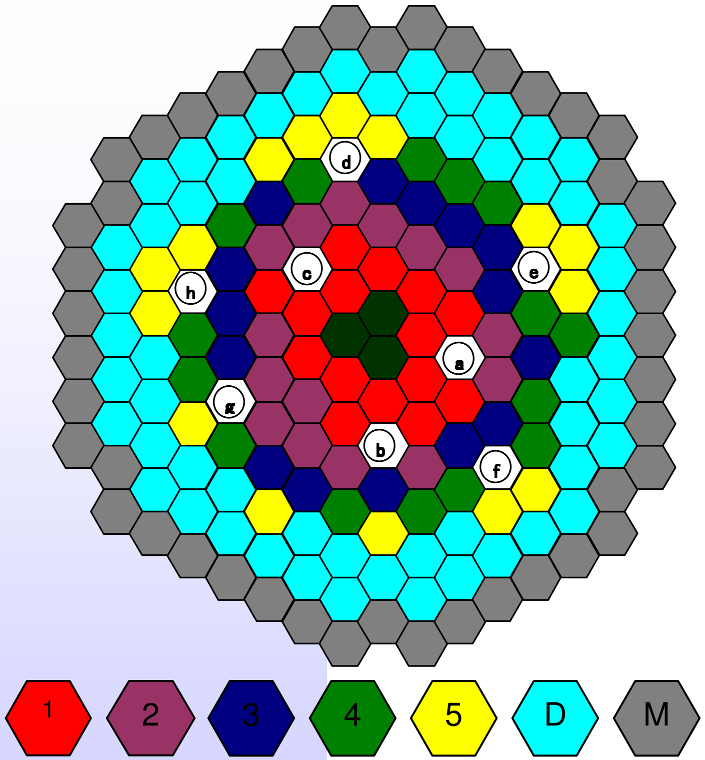
Or…

20% increase in beam

Or…

Compensate using burnable poison

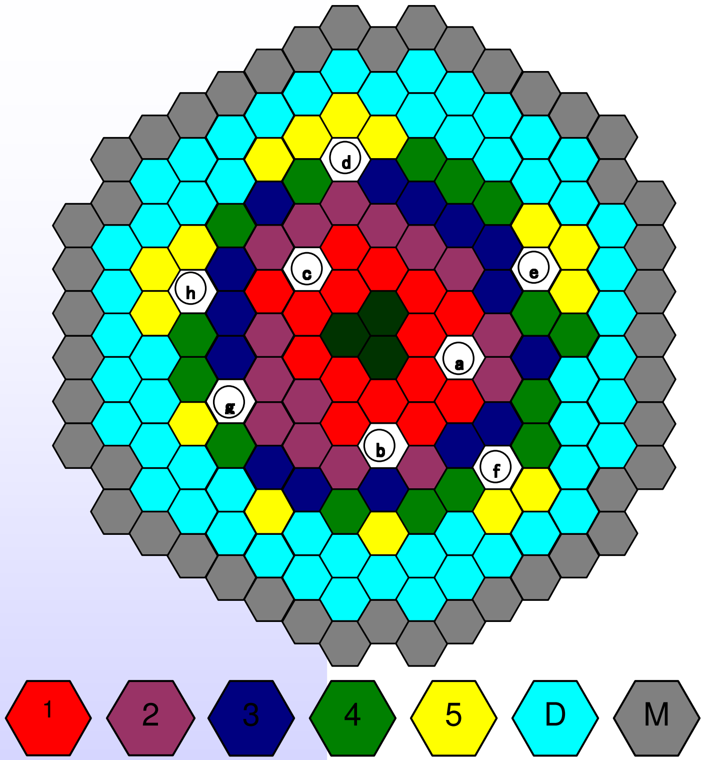
5-step cycle



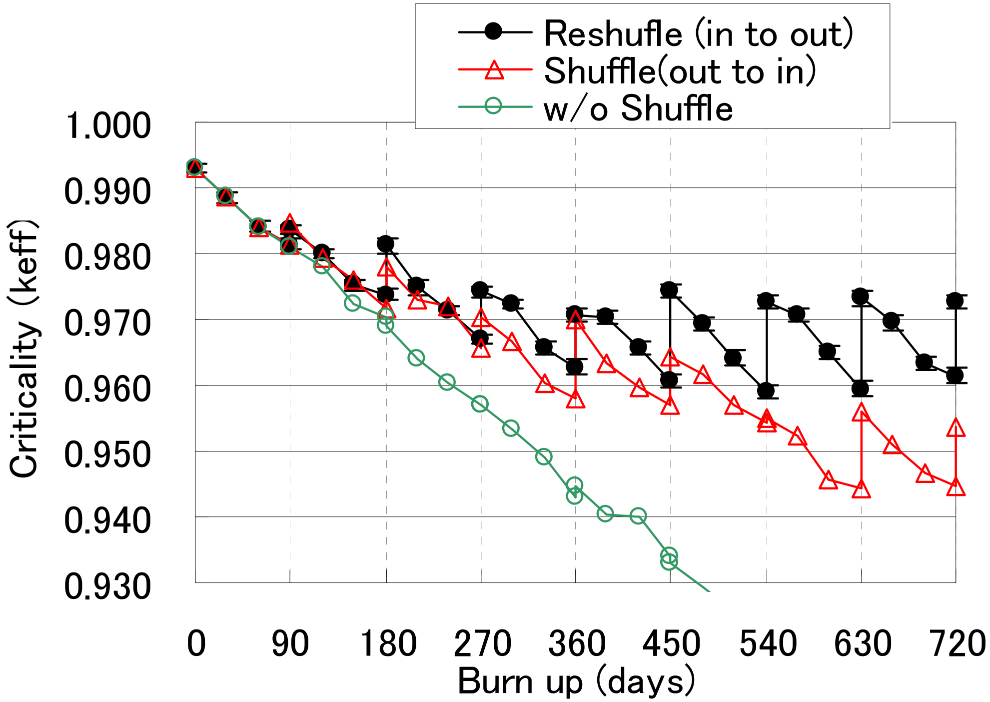
- Start with fresh core (75 fuel assemblies)
- Shuffle in 5 steps
- Question to be answered:

  Can we get to a stable cycle ?

5-step cycle



a
b
c
d
e
f
g
h
1
2
3
4
5
D
M



Reshufle (in to out)
Shuffle(out to in)
w/o Shuffle
Criticality (keff)
1.000
0.990
0.980
0.970
0.960
0.950
0.940
0.930
0
90
180
270
360
450
540
630
720
Burn up (days)

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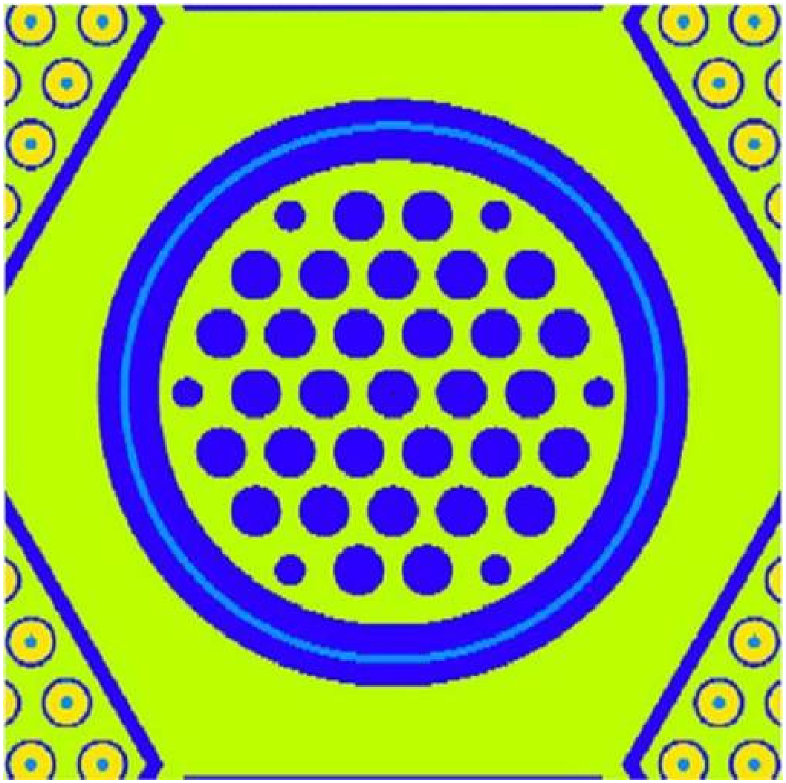
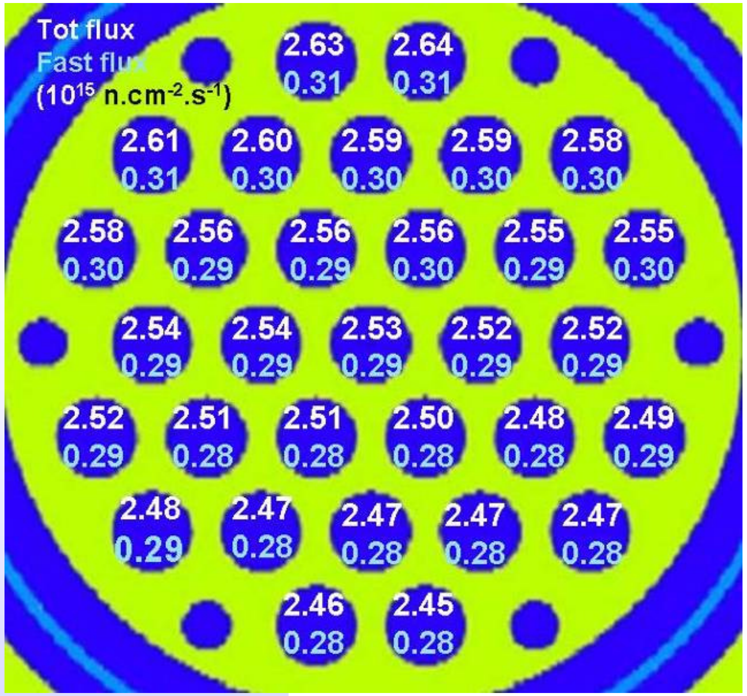
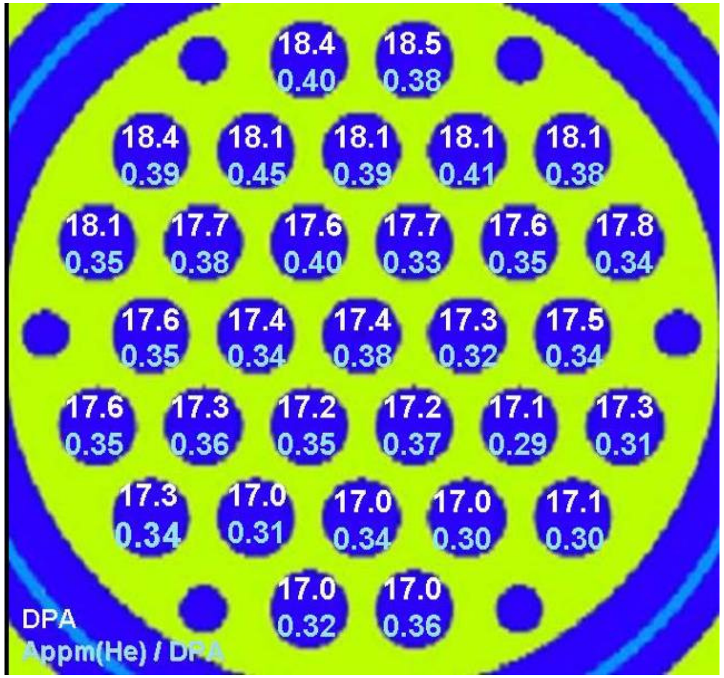
XT-ADS
Irradiation possibilities

- Induced damage in steel material
  - 31 rod lattice
  - In-Pile-Loop
  - In C74 position



XT-ADS
Irradiation possibilities

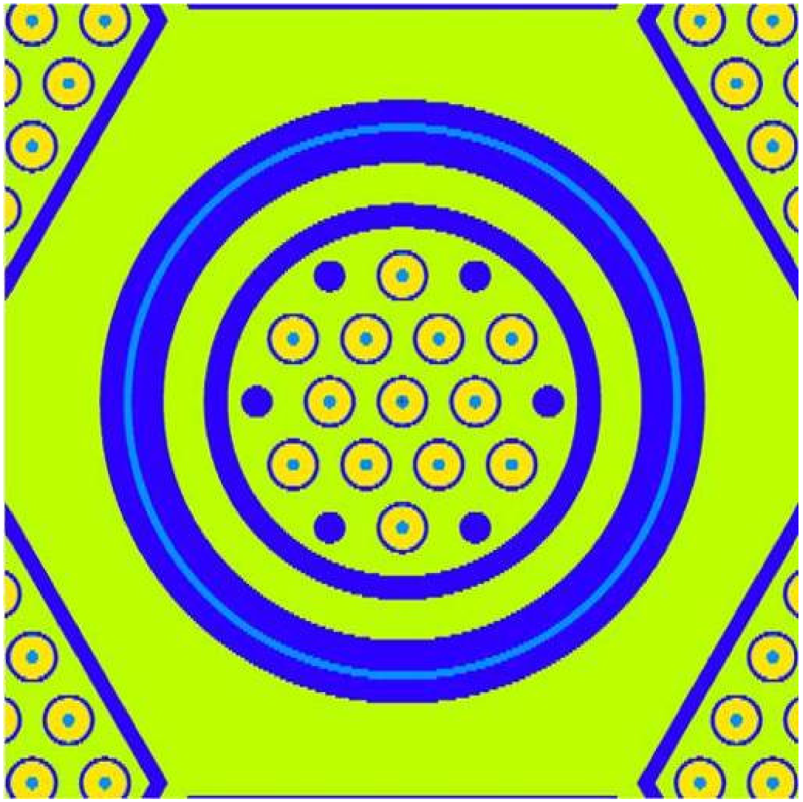




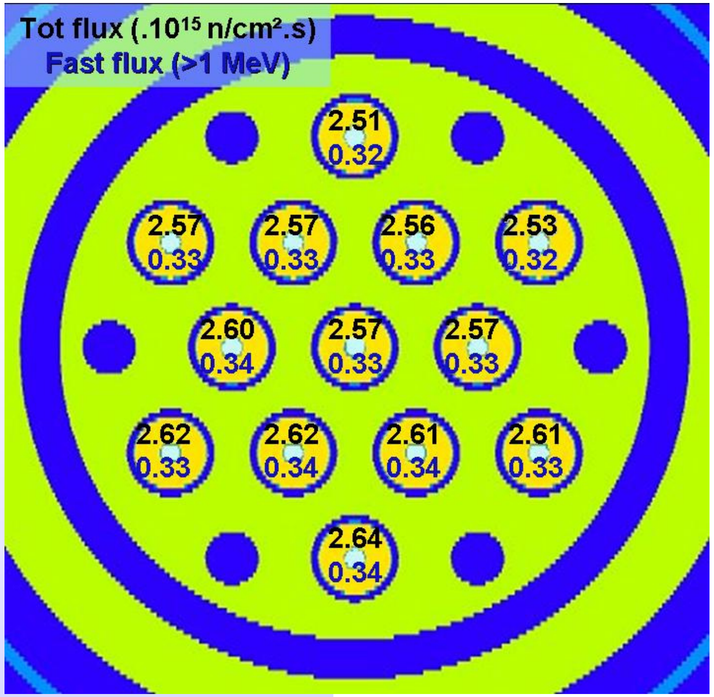
- Dpa rate: 17-18.5 dpa/year (avg 17.6)

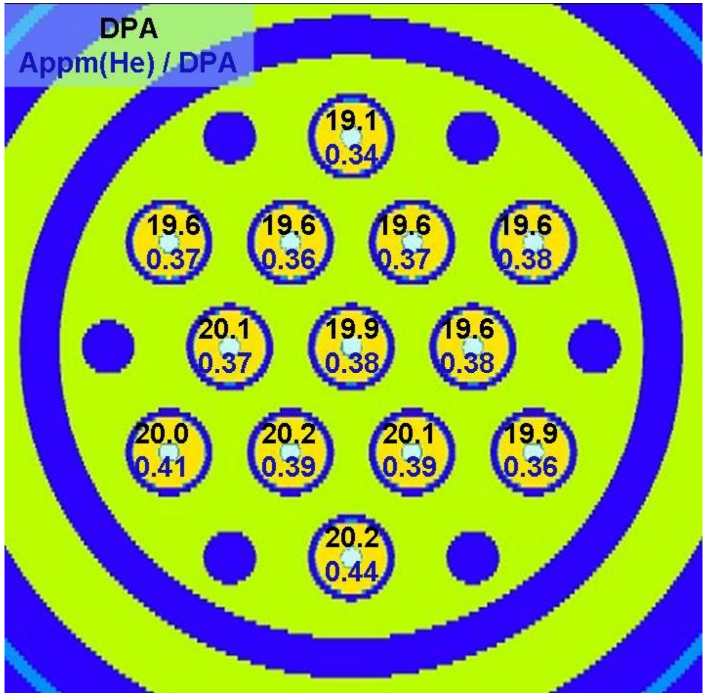
XT-ADS
Irradiation possibilities

- Induced damage in fuel clad material
  - 13 rod lattice
  - In-Pile-Loop
  - In K322 position



XT-ADS
Irradiation possibilities





- Dpa rate: up to 20 dpa/year

STUDIECENTRUM VOOR KERNENERGIE
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Contents

New XT-ADS nozzle design

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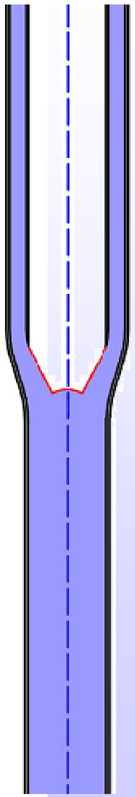
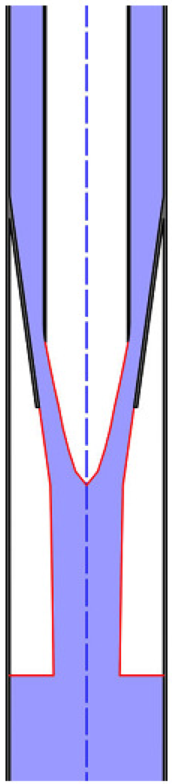
MYRRHA draft 2



- no flow detachment allowed
- height of the target free surface must be actively controlled by LIDAR measurement device and MHD pump
- drag enhancer by vertical ribs in the concentric feeder channel seems to cause a lot of turbulence at the target surface

XT-ADS



- flow detachment enforced
- shape and height of the target free surface determined by nozzle geometry and flow rate
  → extra free surface act as buffer during beam transients
  → no active control needed
- new drag enhancer design with 140 vertical fins and accelerating flow
  → less turbulent flow and thus improved target surface stability

XT-ADS target loop design

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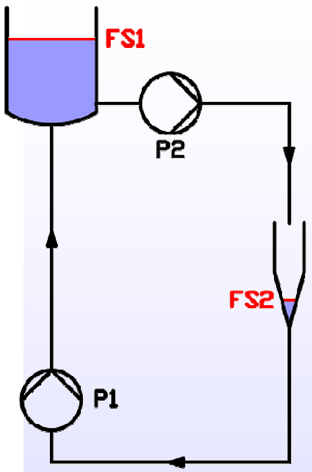
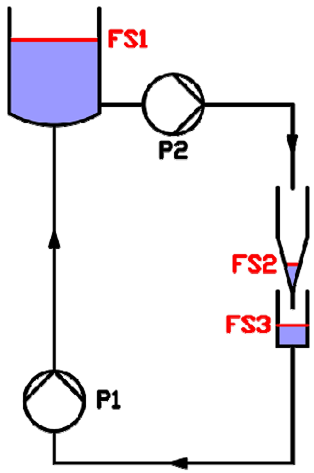
CENTRE D'ÉTUDE DE L'ÉNERGIE NUCLÉAIRE

MYRRHA draft 2



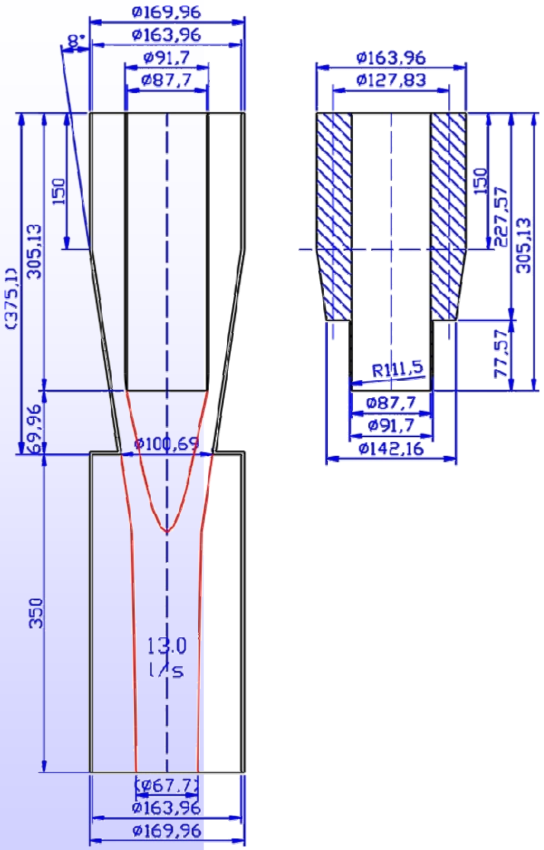
- pump P1: mechanical impeller type
- pump P2: MHD type that has to react within 10ms to compensate for sudden beam transients

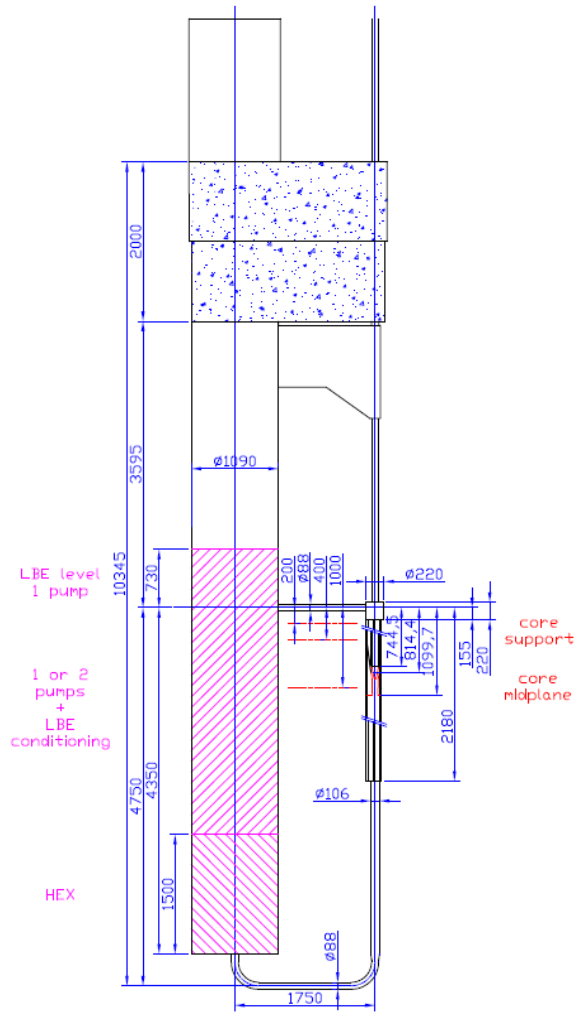
XT-ADS



- pump P1: MHD type
  → no moving mechanical parts in the LBE
  → improved reliability of the system
- pump P2: MHD type
  → no need for rapid reaction to beam transients (relaxed pump specifications)
  → only needed to compensate for slow changes in the loop (changes in pipe friction, pump efficiency, …)

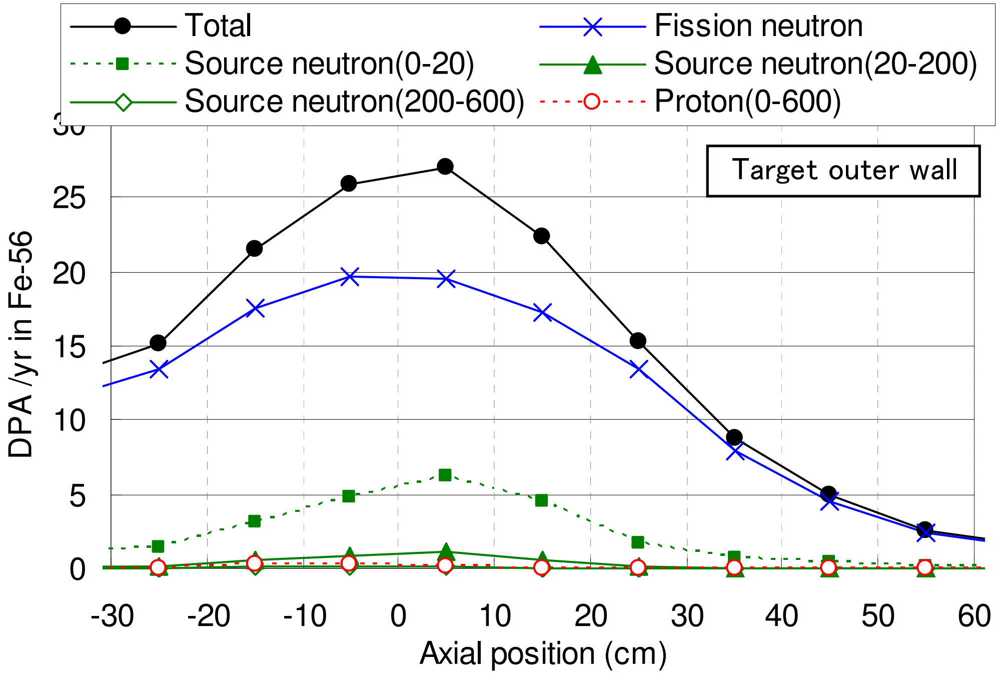
Design drawings





Irradiation damage
Target outer wall

- Similar to cladding
- Only He rate is higher
  - Due to high energy protons



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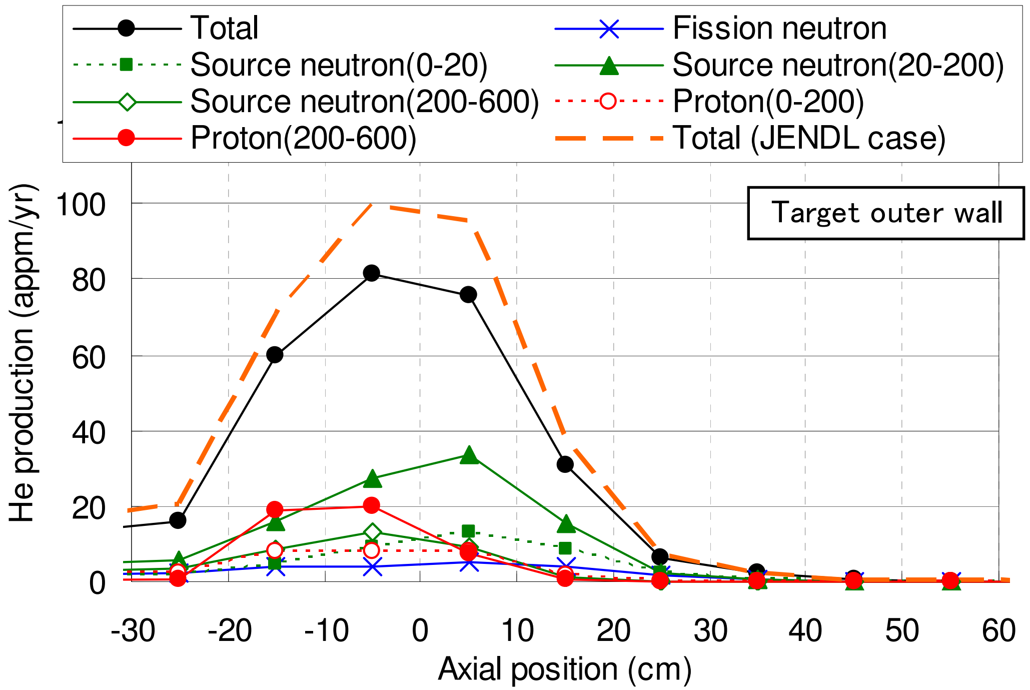

Conclusions

- The design has matured a lot since “Draft 2”
- Feedback from
  - Safety
  - Design engineers
  - Neutronics
  - Thermal hydraulics
  - Accelerator
- **Let’s go even further in CDT !**