The XT-ADS core design

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SCK•CEN

AccApp09, Morning Satellite Meeting IV, “MYRRHA/XT-ADS”

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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

1. MYRRHA Draft2
2. A safety concern
3. New fuel pin and fuel assembly
4. Clean core configuration
5. Reference core
6. Analysis of irradiation capabilities
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
- Pin pitch: 8.55 mm
- P/D = 1.305
- 91 pins
- Wrapper thickness: 1.75 mm
- Inter FA space: 2 mm
45 Fuel assemblies
Lattice 99 positions
350 MeV x 5 mA proton beam
$k_{\text{eff}} = 0.955$, $k_s = 0.960$
$P = 52 \text{ MW}_{\text{th}}$
Peak linear power: 352 W/cm
Hot pin $\Phi_{\text{tot}}$: $4 \cdot 10^{15}$ n/cm$^2$.s
Hot pin $\Phi_{>1\text{MeV}}$: $0.8 \cdot 10^{15}$ n/cm$^2$.s
Hot pin $\Phi_{>0.75\text{ MeV}}$: $1 \cdot 10^{15}$ n/cm$^2$.s
Increased proton energy

- 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
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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”

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Unit</th>
<th>XT-ADS Value</th>
<th>MYRRHA Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Proton beam energy</td>
<td>MeV</td>
<td>600</td>
<td>350</td>
</tr>
<tr>
<td>Proton beam current</td>
<td>mA</td>
<td>2.33 †</td>
<td>5</td>
</tr>
<tr>
<td>Proton beam deposited heat</td>
<td>MW</td>
<td>1.40</td>
<td>1.75</td>
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<tr>
<td>Total neutron yield per incident proton</td>
<td></td>
<td>15.3</td>
<td>6.0</td>
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<tr>
<td>Neutron source intensity</td>
<td>$10^{17}$ n/s</td>
<td>2.23</td>
<td>1.9</td>
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<tr>
<td>Initial fuel mixture</td>
<td>MOX</td>
<td>(U-Pu)O$_2$</td>
<td>(U-Pu)O$_2$</td>
</tr>
<tr>
<td>Initial (HM) fuel mass</td>
<td>kg</td>
<td>857</td>
<td>514</td>
</tr>
<tr>
<td>Initial Pu enrichment</td>
<td>wt%</td>
<td>31.5</td>
<td>30</td>
</tr>
<tr>
<td>$k_{\text{eff}}$</td>
<td></td>
<td>0.95324</td>
<td>0.95521</td>
</tr>
<tr>
<td>$k_S$</td>
<td></td>
<td>0.95711</td>
<td>0.96007</td>
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<tr>
<td>MF = $1/(1-k_S)$</td>
<td></td>
<td>23.31</td>
<td>25.04</td>
</tr>
<tr>
<td>Source importance $\phi^*$</td>
<td></td>
<td>1.095</td>
<td>1.127</td>
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<tr>
<td>Thermal power</td>
<td>MW</td>
<td>56.75 ‡</td>
<td>51.75 ‡</td>
</tr>
<tr>
<td>Specific power</td>
<td>kW/kgHM</td>
<td>66.22</td>
<td>101</td>
</tr>
<tr>
<td>Peak linear power (hottest pin)</td>
<td>W/cm</td>
<td>253</td>
<td>352</td>
</tr>
<tr>
<td>Average linear power (hottest pin)</td>
<td>W/cm</td>
<td>146</td>
<td>252</td>
</tr>
<tr>
<td>Max $\Phi_{\text{total}}$ in the core near hottest pin</td>
<td></td>
<td>3.31</td>
<td>4.1</td>
</tr>
<tr>
<td>Max $\Phi_{&gt;1\text{MeV}}$ in the core near hottest pin</td>
<td>$10^{15}$ n/(cm².s)</td>
<td>0.53</td>
<td>0.8</td>
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<tr>
<td>Max $\Phi_{&gt;0.75\text{MeV}}$ in the core near hottest pin</td>
<td></td>
<td>0.72</td>
<td>1.0</td>
</tr>
</tbody>
</table>

(†) 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
Added two extra rows

Evaluation of
- Steel pins
- Boron carbide pins
- Combination

Too penalizing for the core performances!
- 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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<tr>
<td>Max $\Phi_{&gt;0.75\text{MeV}}$ in the core near hottest pin</td>
<td></td>
<td>0.66</td>
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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

- Reshuffle (in to out)
- Shuffle (out to in)
- w/o Shuffle

Burn up (days)

Criticality (keff)
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Induced damage in steel material
- 31 rod lattice
- In-Pile-Loop
- In C74 position
Dpa rate: 17-18.5 dpa/year (avg 17.6)
• 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
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6. Updated target design
New XT-ADS nozzle design

**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

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, ...)

[Diagram of XT-ADS target loop design]
Design drawings
Irradiation damage
Target outer wall

- Similar to cladding
- Only He rate is higher
  - Due to high energy protons
Irradiation damage
Target outer wall

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