STUDIECENTRUM VOOR KERNENERGIE
CENTRE D'ÉTUDE DE L'ÉNERGIE NUCLÉAIRE

RELAP MODEL

OF

THE SPALLATION LOOP

MYRRHA draft 2

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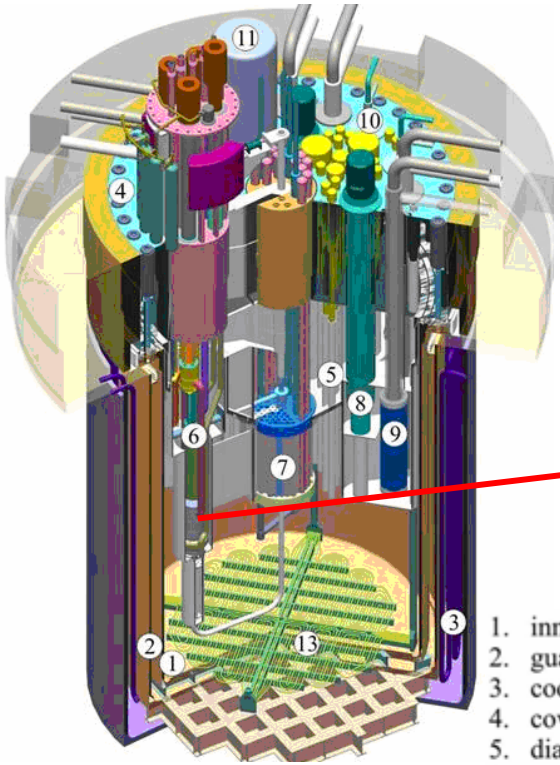
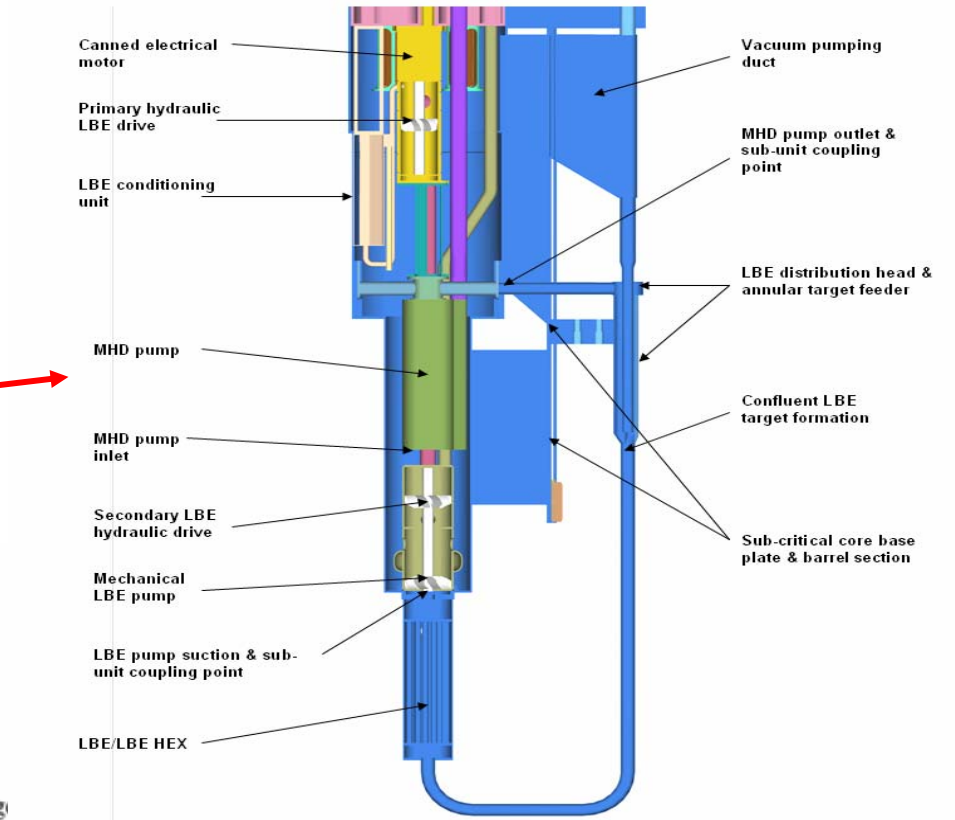
Schedule

- Spallation loop description (reminder)
- Relap model (version mod 3.2 β) equivalence
- Challenges and problems to solve
- First results :
  - Steady-state with and without power
  - Transient with a stop of the mechanical pump

Spallation loop description (reminder)

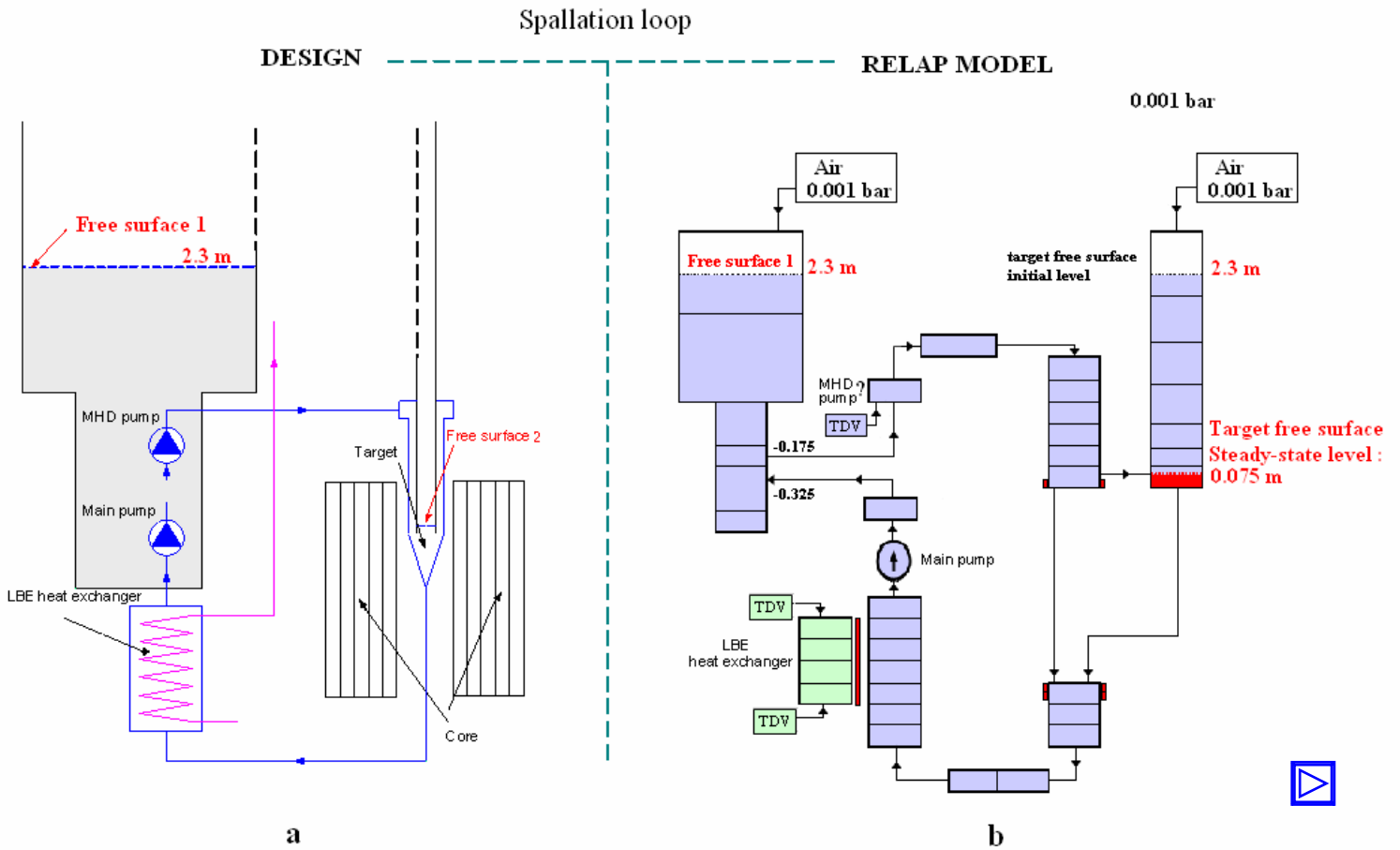


1. inner vessel
2. guard vessel
3. cooling tubes
4. cover
5. diaphragm
6. spallation loop
7. sub-critical core
8. primary pumps
9. primary heat exchang
10. emergency heat exchangers
11. in-vessel fuel transfer machine
12. in-vessel fuel storage
13. coolant conditioning system



Spallation unit lifted from the main vessel

Design & RELAP model equivalence



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Challenges

1. RELAP Model of the target itself
2. Non condensable pressure control above the free surfaces :

   DESIGN: vacuum of 10^{-3}mb (0.1 Pa) above the two free surfaces

   → Is it possible with RELAP ?
3. flow and free surface target level and stability :
   - In steady-state : target free surface level adjustment :
     - Rough with the mechanical pump velocity
     - Fine tuning with a MHD (magneto-hydrodynamic) pump controlled by a regulator PID
   - In transient : designed with the MHD pump

   → equivalent model for RELAP ?
4. Power increase from 0 to 1.43 MW in 1 second!…..

   → Distribution of the power and heat evacuation model ?

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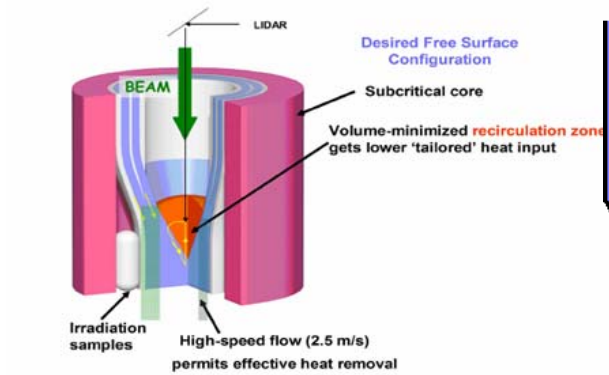
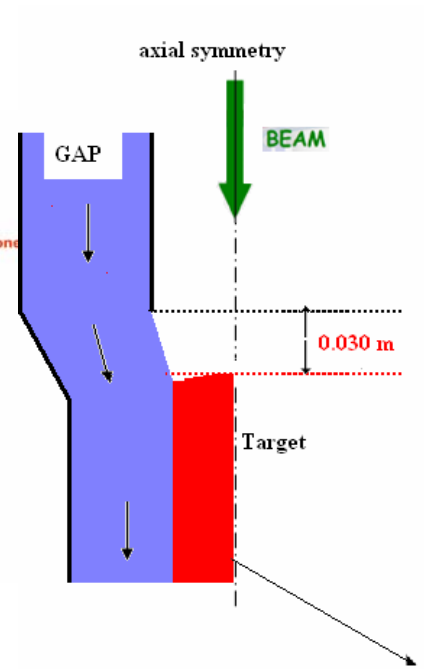
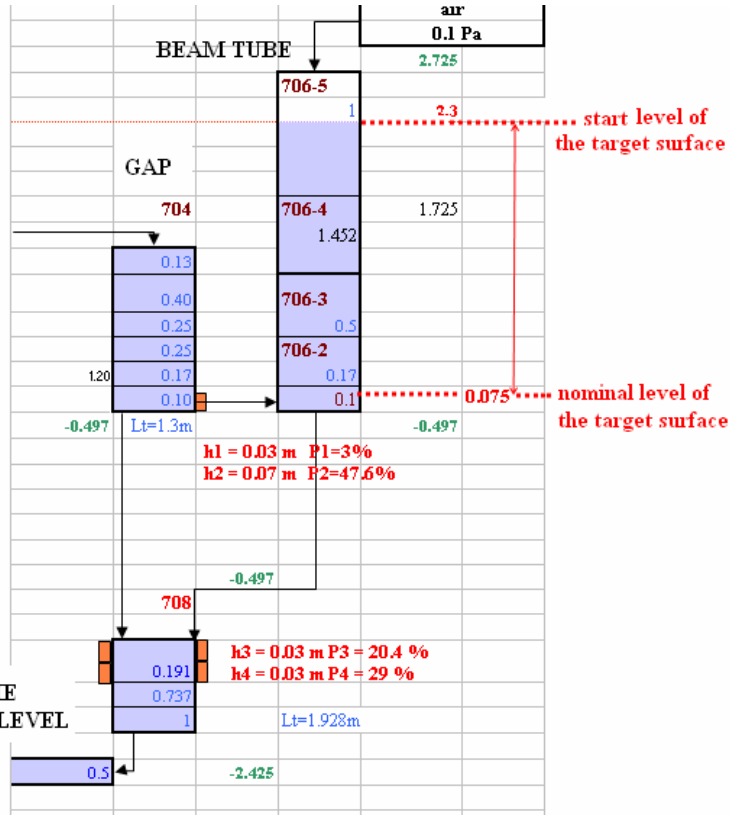
1. Target free surface model



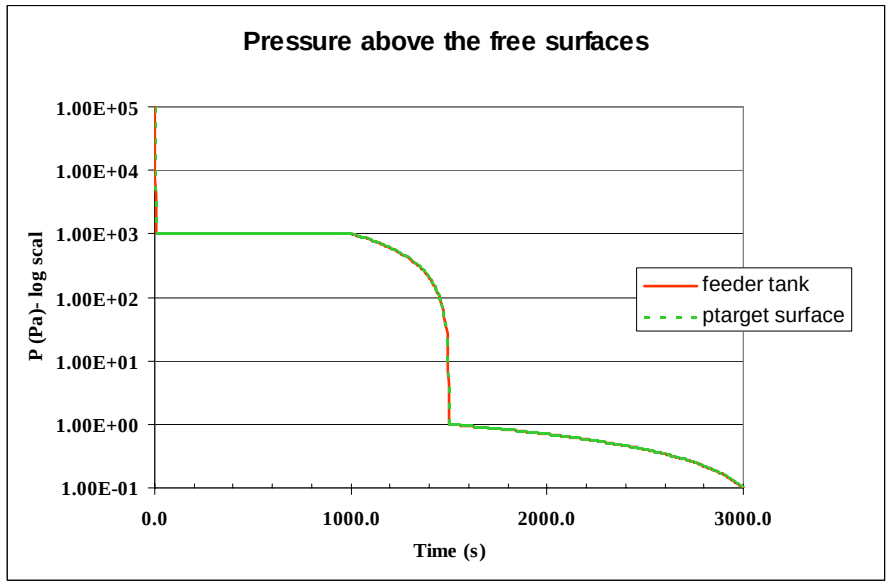
Schematics of the axis-symmetric windowless target configuration





2. Pressure above the Two free surface

- Minimum pressure of the non condensable gas that the code will accept :
  - Problem of Iteration non convergence :
    - Big step of internal energy between the gas and the liquid metal LBE at the 2 free surfaces
    - 1 Pa is recommended by the manual and 0.1 Pa (10-3mb)
    - it is designed



Possible if :

The steady state starts with an atmospheric pressure; 1.0e+05 Pa which decreases very slowly to 0.1 Pa. A very little time step (0.001s) is required.

3. Target free surface level adjustment and control

DESIGN :

- **Rough : mechanical pump and MHD : action on the pump velocity**
- **Fine : MHD pump : acceleration or deceleration of the flow**

Measure of the free surface level variations by a LIDAR (LIght Detection And Ranging)

RELAP SOLUTIONS :

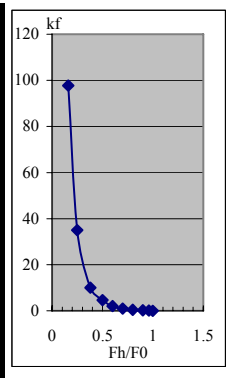
In Steady-state:

Control by a Time dependent junction (TDJ) which adds or removes a little LBE in function of the target level. The TDJ is placed before the annular gap.

In transient : Objective : to reproduce the MHD behaviour, a Pressure drop DP negative or positive in function of the free surface target level.

Suggestions : 1. By a motor or servo valve whose the normal operation area is the valve area closed at 50% :

valve Idel'cik		v=2m/s	
Fh/F0	kf	DP	DP-DP50%
0	∞		
0.16	97.8	2.05E+06	1.96E+06
0.25	35	7.34E+05	6.38E+05
0.38	10	2.10E+05	1.13E+05
0.5	4.6	9.65E+04	
0.6	2.06	4.32E+04	-5.33E+04
0.7	0.98	2.06E+04	-7.59E+04
0.8	0.44	9.23E+03	-8.73E+04
0.9	0.17	3.57E+03	-9.29E+04
0.96	0.06	1.26E+03	-9.52E+04
1	0	0.00E+00	-9.65E+04



Target free surface level control
MHD pump

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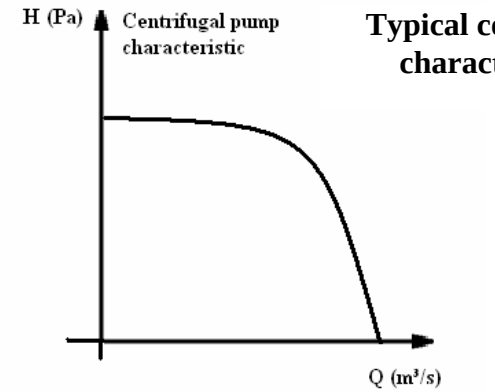
2. **Model of the MHD behaviour**

In RELAP there are 2 centrifugal pump model : Westinghouse or Bingham (homologous curves) and none is appropriated to model MHD pump behaviour.



Typical centrifugal pump characteristic curve

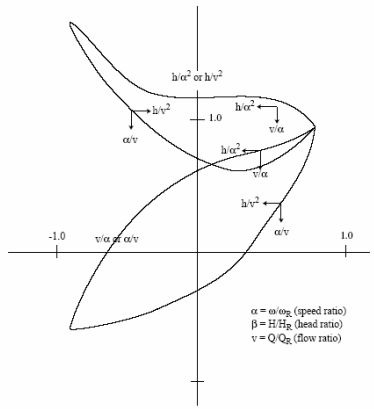
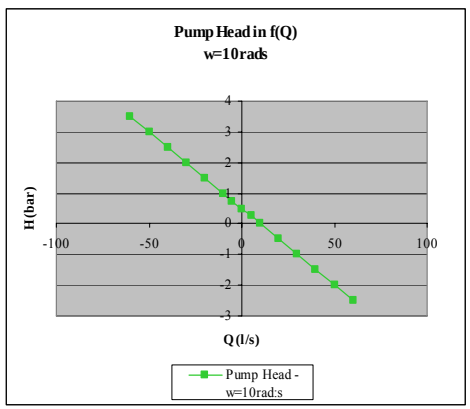
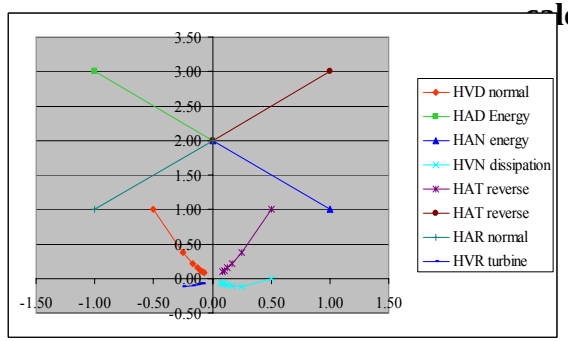


Figure 3.5-10 Typical pump homologous head curves.

Typical centrifugal pump homologous curves



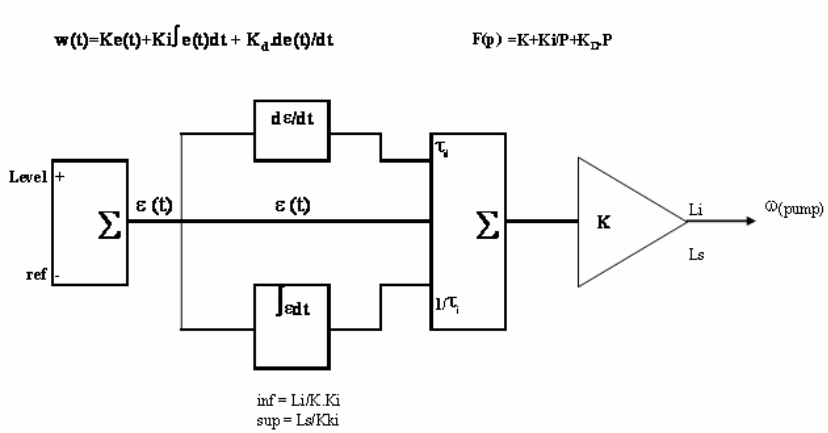
MHD pump, characteristic curve



Typical MHD homologous calculated curves

Mechanical and MHD pump regulation

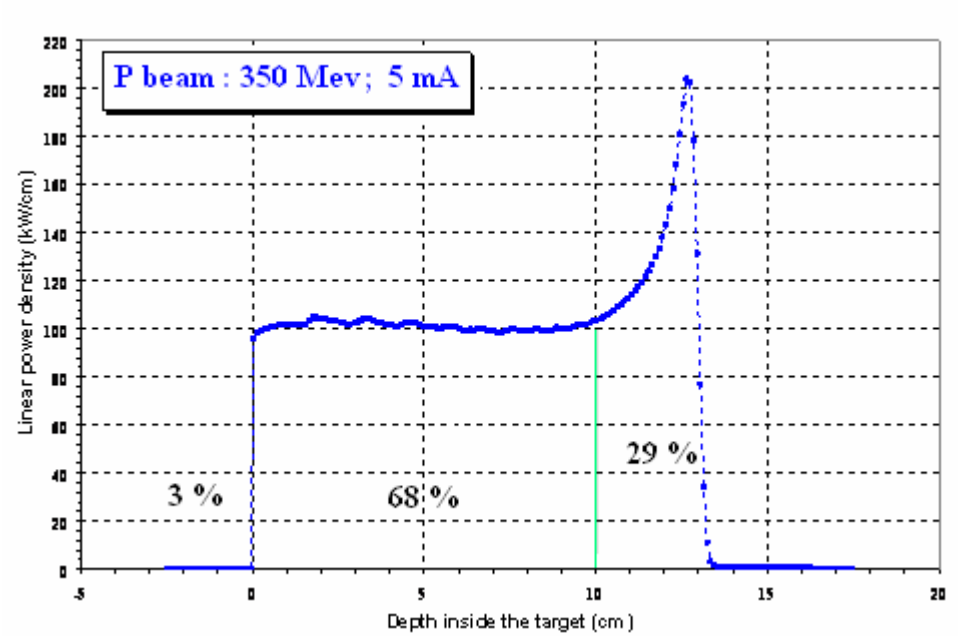
- The LBE free surface level is measured by a LIDAR, whose laser light is reflected from the target free surface. Its output controls the MHD pump via a PID (Proportional Integrator Differentiator) regulator.
- **PID**
  - **input : ε(t) (level error)**
  - **output : ω(τ) of the pump**



constants K, τ_i and τ_d to be determined !

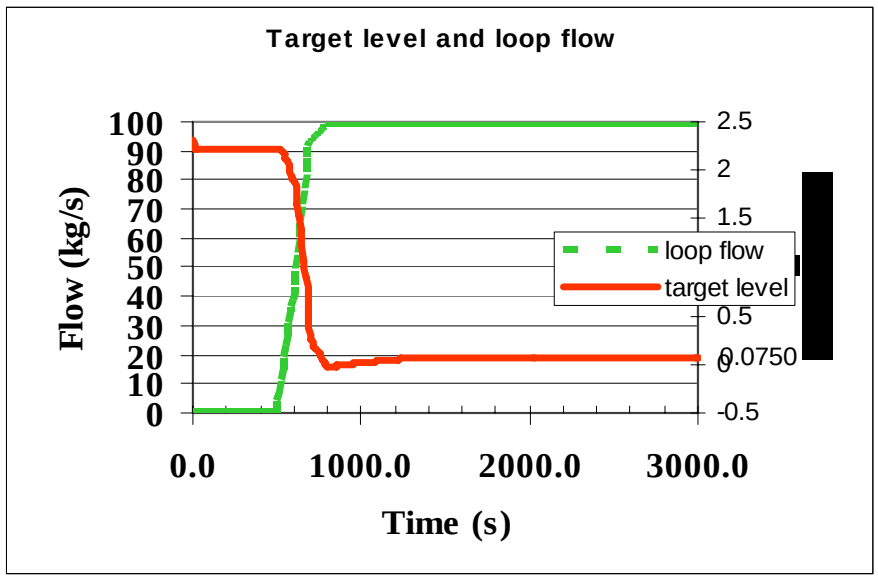
Power distribution in the target

- 4 structures, in the target
- Flux distribution :
  - h1 : 0.03 m, 3 % of the heat
  - h2 : 0.07 m, 0.7*68 %
  - h3 : 0.03 m, 0.3*68 %
  - H4 : 0.03 m, 29%
- Exchange surface is chosen to limit the Temp outlet. (0.118m²)

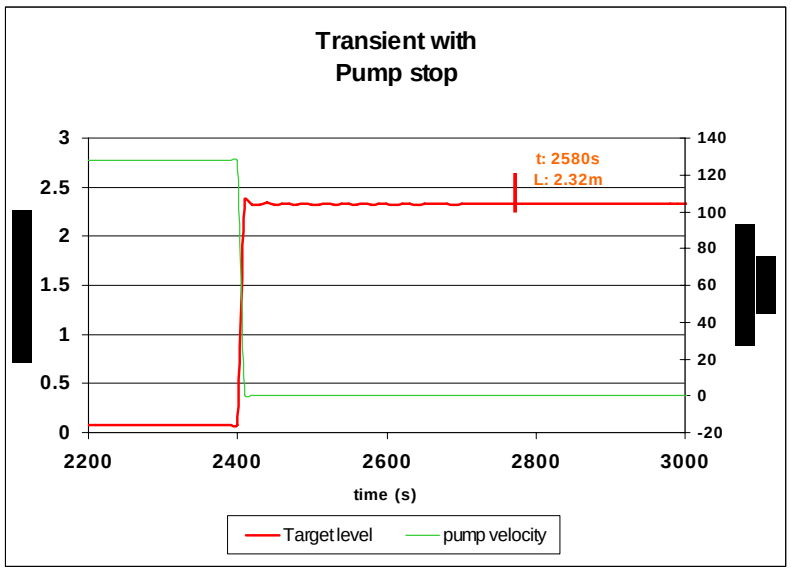


First results

Steady-state and transient at P = 0 MW

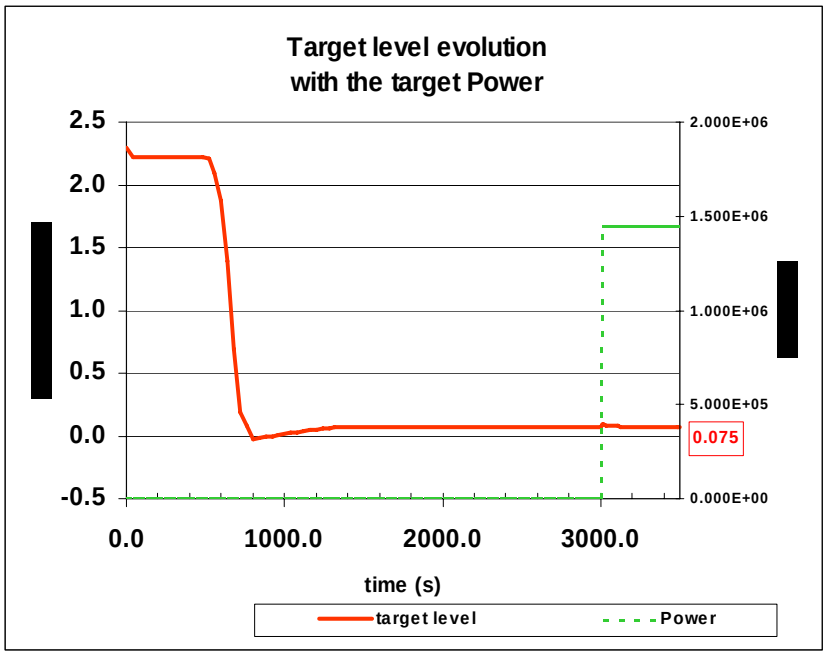


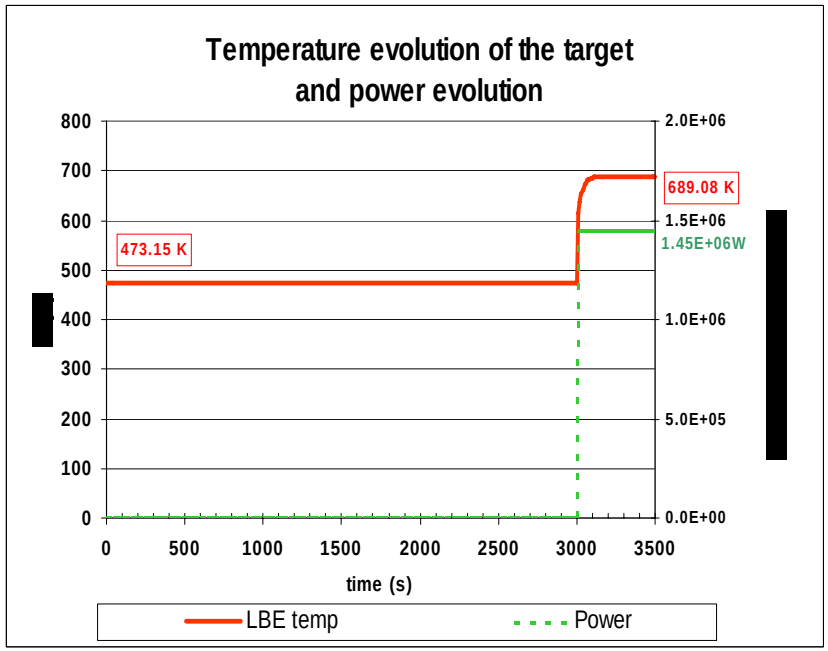
Evolution of the pump flow and the target level



Evolution of the target level after the mechanical pump stopping

First results (2)
Steady-state at P = 1.43 MW





Evolution of the target free surface level with the power

Temperature evolution with the power

Problem with the pressure above the free target :

- with 0.1 Pa, the code stops for “Iteration no convergence”.
- with 1000 Pa : no problem

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Conclusions

- The work is still in progress. Some problems were solved: pressure above the target free surface, evolution of the free surface level after a pump stop and stabilization of the level when power is injected. When no power is released in the target, a stable steady state is obtained with a pressure as low as 0.1 Pa above the free surfaces. However, as soon as power is added, large energy discontinuities appear, that are not tolerated by the code. Setting a pressure of 1000 Pa above the free surfaces constitutes a good compromise between the model and the design requirements and allows to reach a stable steady state.
- With the present model, it is not possible to simulate all the accidental situations, especially those ones involving small changes of the target free surface level.

  At the present stage, a pump stopping or a power shut down or power increase can be simulated to give useful indications for example on the free surface target level behaviour and on the temperature variations.
- Improvement of the heat transfer between the re-circulation zone under the target free surface and the loop will be performed.
- The control of the target free surface level is acceptable with a time dependent junction which adds or removes a small quantity of LBE to adjust the free surface level in normal operation. With the action of a PID, the stability will be improved. The possibility to model the MHD pump is still under study