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# Dynamic simulation of a supercritical helium discharge through a deported safety device for fusion reactor cryogenic systems

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## Context

- Safety demonstration of cryogenic systems in future fusion reactors
- No scientific calculation tool qualified to perform safety evaluation of fusion reactor
- CATHARE** : Reference tool for safety evaluation of Pressurized Water Reactor (PWR)
- 2-fluid and 6 equation model (Mass, Momentum and Energy balance equations)
- Qualified for water on pressure and temperature range in PWR with separate effect tests and integral loop tests
- Thermodynamic and transport properties of helium are available in the code (REFPROP V9.2 NIST)
  - **Need to evaluate results given by CATHARE with supercritical helium**

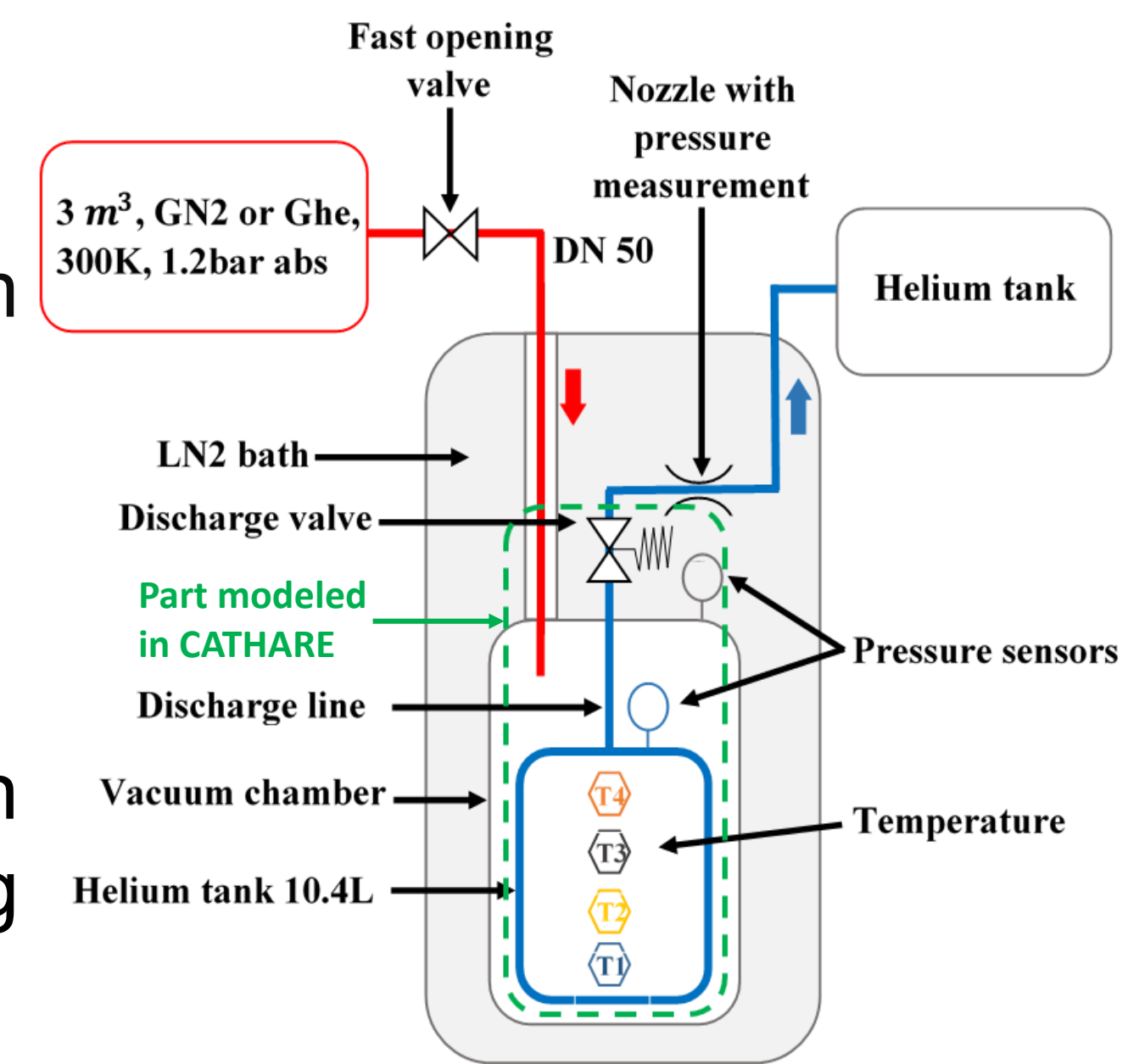


Accidental transients on tokamak reactor have been identified to perform first validation tests on CATHARE

- Quench of superconducting magnets
- **Heat load due to loss of insulating vacuum of cryogenic lines**

## First validation of the pressure and temperature increase in a supercritical Helium tank

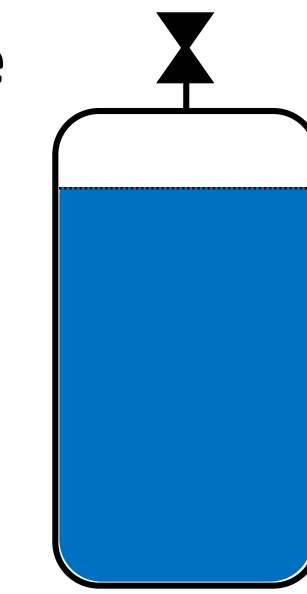
- Modelling of the “Cryostat Soupape” experiment
- Loss of insulating vacuum around a 10L liquid helium tank
- Discharge in supercritical state
- The heat flux received by the supercritical fluid is experimentally measured : **1,85 W/cm<sup>2</sup>**
  - The pressure and the mean temperature evolution calculated by CATHARE before the safety valve opening is consistent with experimental measurements



## Influence of a discharge line on the safety relief valve sizing

- Loss of insulating vacuum around a 100L liquid helium tank
- Cases **with and without adiabatic** discharge line
- 24000 W injected in the tank ( $1,85W/cm^2 \times S_{tank}$ )
- Allowed  $P_{max}=17,6$  bar

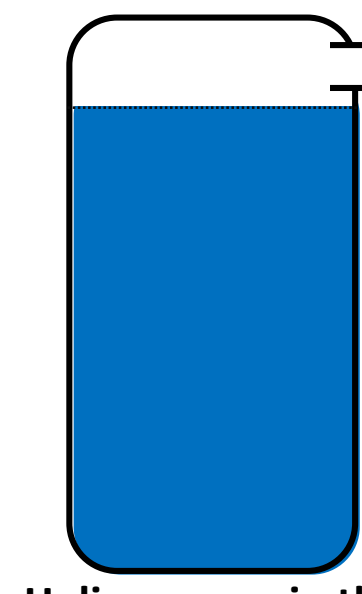
Reference case :



Initial Condition :  
 Liquid level = 90 %  
 P = 1bar  
 T = 4.2K  
 Total Helium mass = 11kg

Tank dimension :  
 Height = 1m  
 Inner diameter = 0.35m  
 Surface = 1.3m<sup>2</sup>  
 Volume = 96.2L

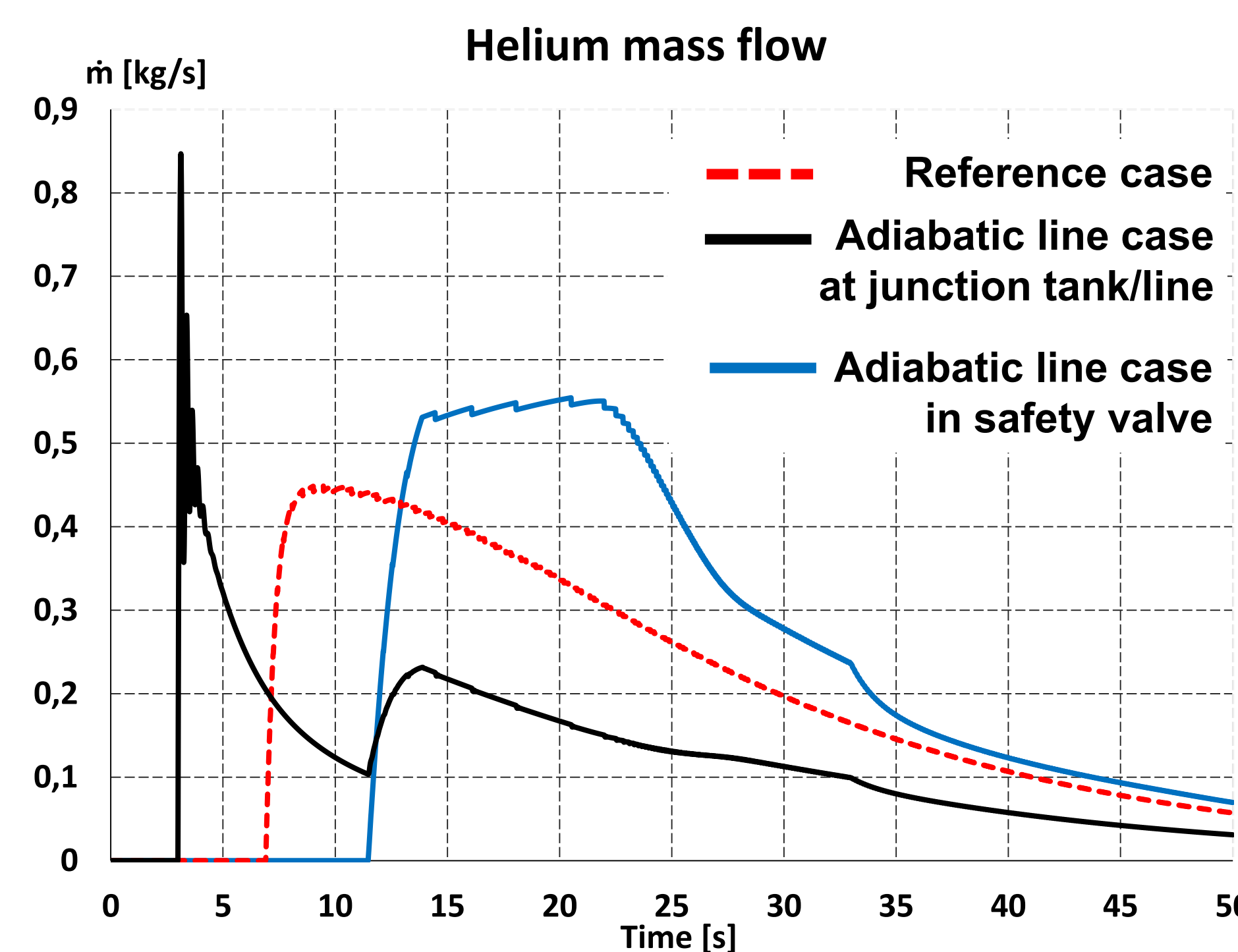
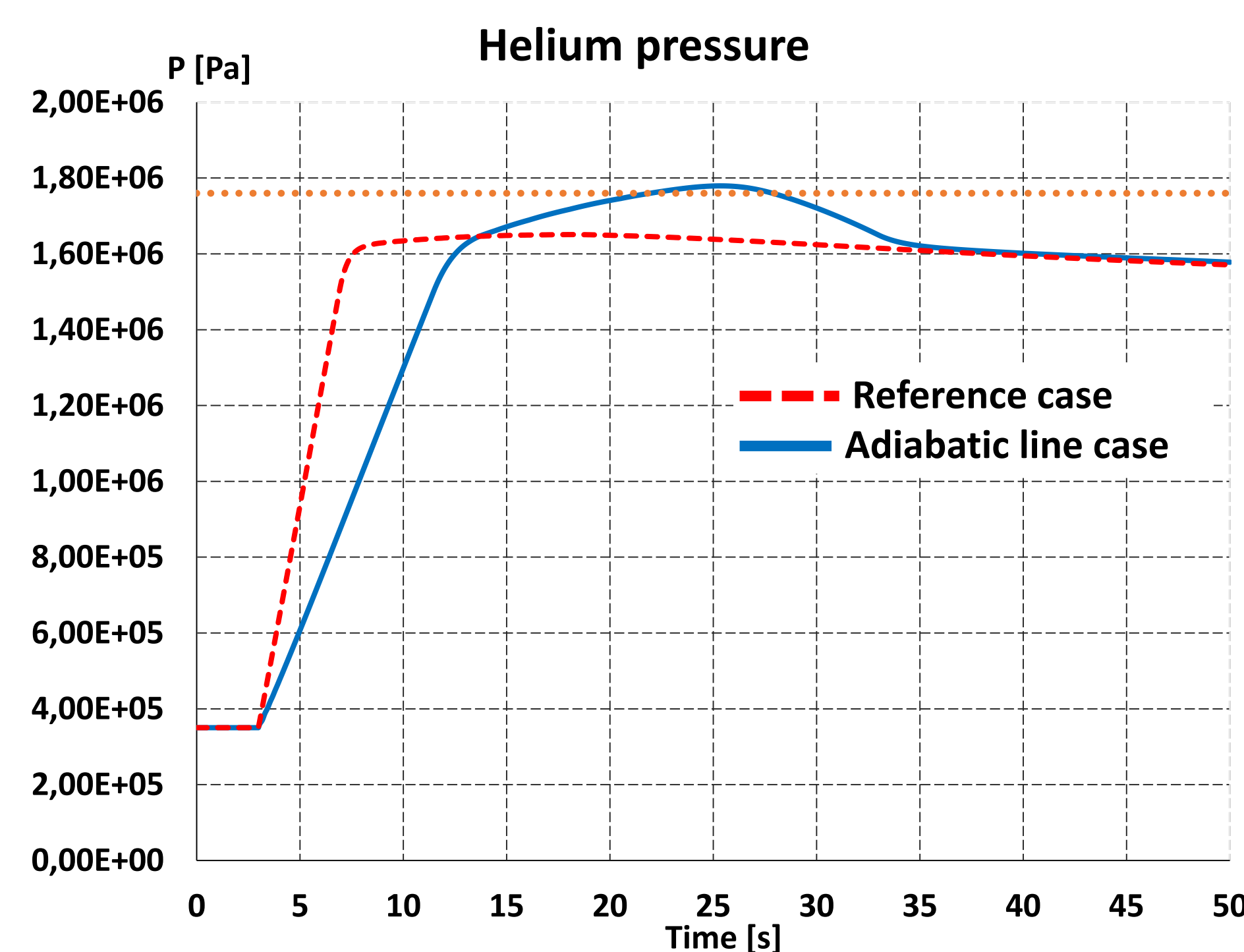
Case with a discharge line :



Initial Condition :  
 Liquid level = 90 %  
 P = 1bar  
 T = 4.2K  
 Total Helium mass = 12,3kg (> 11,3% to take into account additional mass of Helium gas in the discharge line)

### In case of an adiabatic discharge line :

- Same safety valve for both cases, size according applicable standards for a tank (Section = 43,3 mm<sup>2</sup>)



### In case of a heat load on the discharge line :

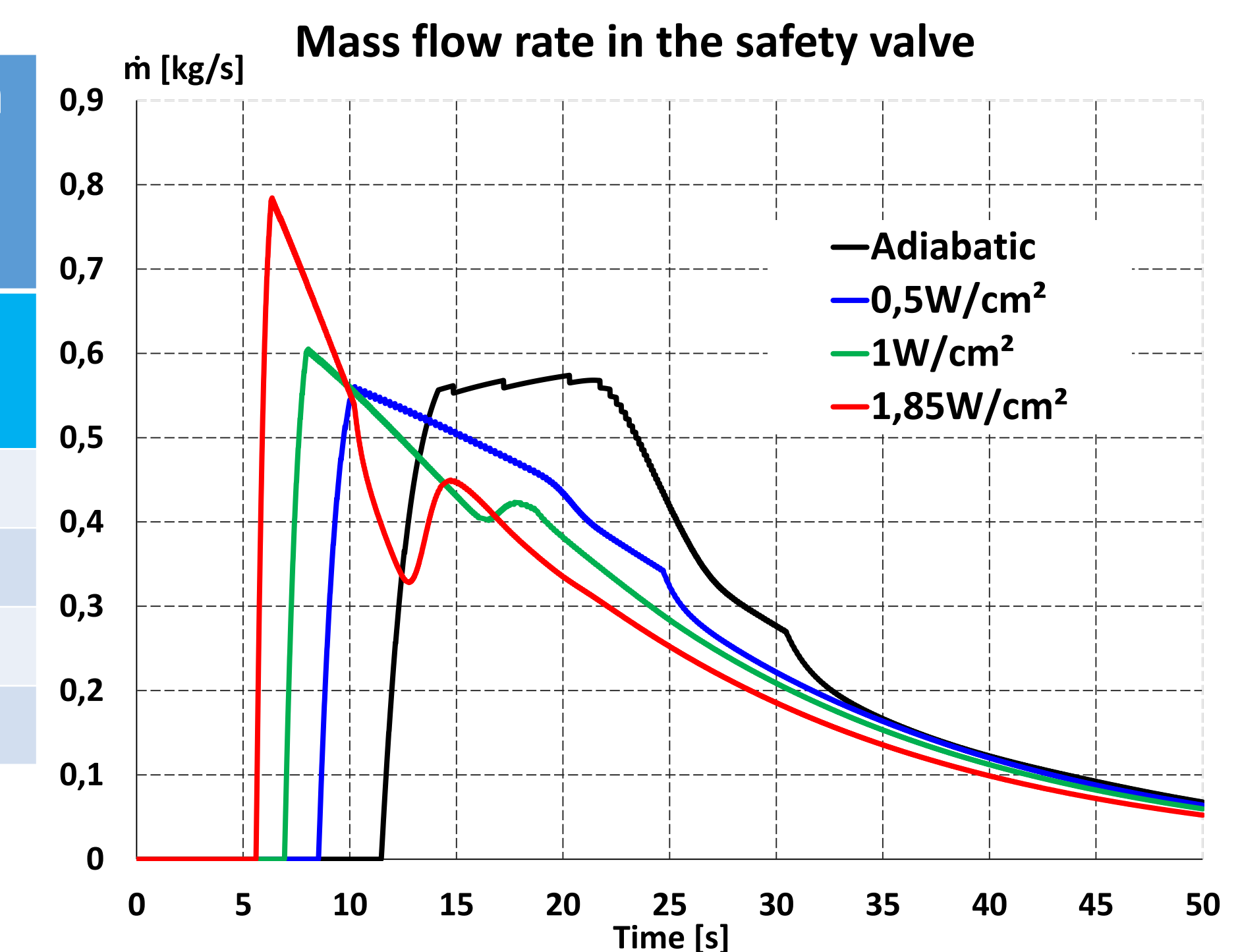
- Uniform heat flux are applied along the discharge line
- For each heat flux, the safety valve section is adapt to insure a max pressure of  $P_{max} = 17,6$  bar in the tank

Heat flux applied to the discharge line	Total power received by the fluid in the discharge line [W]	Maximal mass flow rate through the relief valve [kg/s]	Valve section [mm <sup>2</sup> ]
Reference (no line)	0	0,45	43,3
0 W/cm <sup>2</sup>	0	0,57	45.4
0.5 W/cm <sup>2</sup>	15 700	0,56	63.6
1 W/cm <sup>2</sup>	31 400	0,6	78.4
1.85 W/cm <sup>2</sup>	58 100	0,78	113.1

- **The heat flux received by the line must be well determined to correctly size the valve**

- With a heat flux on the discharge line, the section of the safety relief valve must be oversized because of :

- The additional heat input on the line
- The decreased of the sonic density and velocity in the valve throat with Helium heating



**Conclusions**

- CATHARE gives satisfactory results with supercritical helium
- Results on deported safety valve show the relevance of using CATHARE
- Using applicable standards for tank can lead to undersized the valve section with a discharge line
- The heat flux received in the discharge line must be determined to size correctly the safety relief valve

**Perspectives**

- Characterize the heat flux received by a forced flow SHe cryoline.
- Improve CATHARE validation with helium and implement required models
- **Launch of a Ph.D program “Experimental and numerical study of accidental heat loads in cryogenics devices of large instrument”**