DE LA RECHERCHE À L'INDUSTRIE

SAFETY DEVICE SIZING

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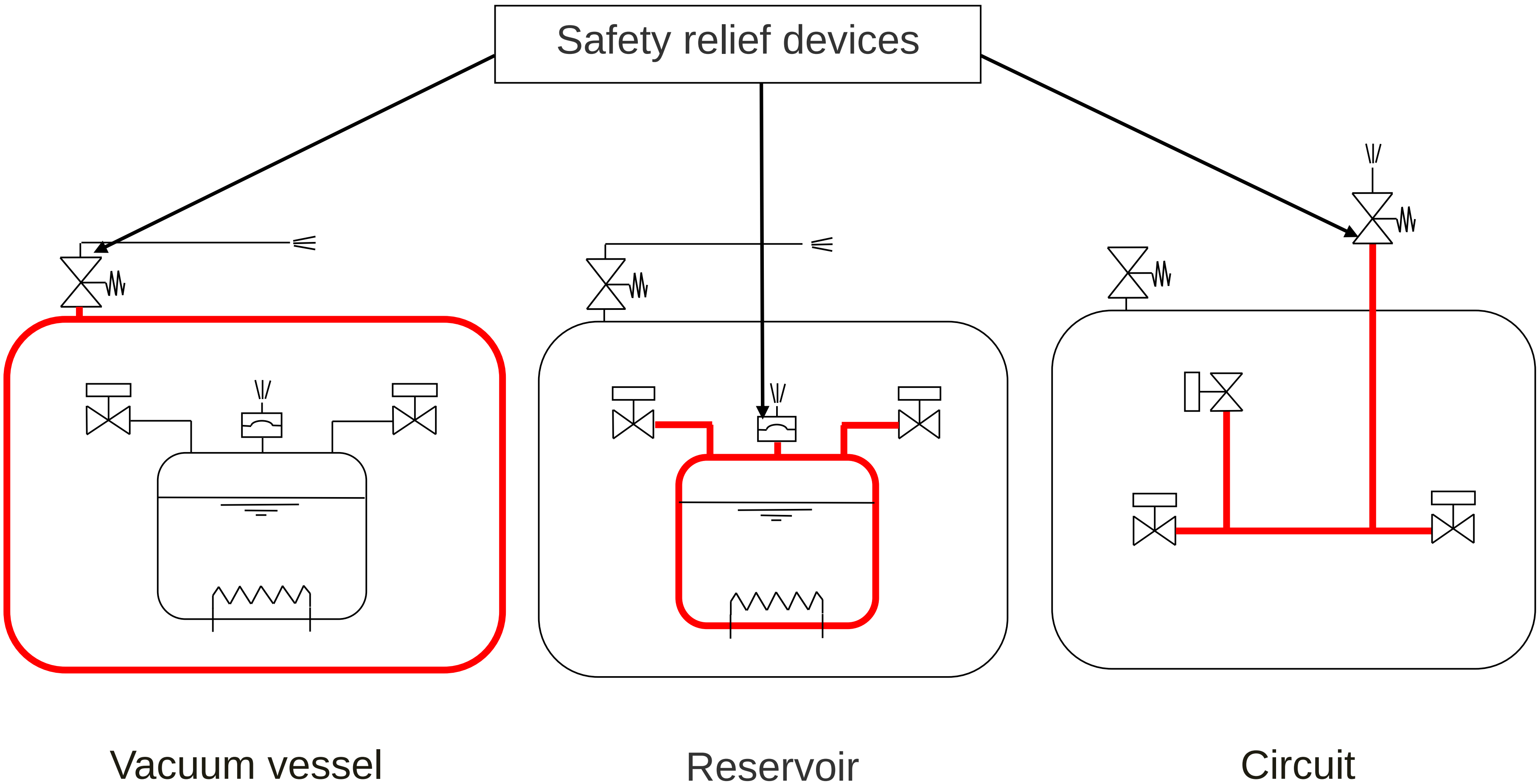
http://www.techniques-ingenieur.fr/base-documentaire/environnement-securite-th5/securite-par-secteur-d-activite-et-par-technologie-42159210/securite-en-cryogenie-be9814

Structure of the article:

1. Cryogenic safety in operation (rules)
2. Accidental heat loads
   - 2.1 - System to be protected
   - 2.2 - Accidental situations and heat load
3. Method for sizing any safety relief device

English version will be available soon

2.1 - SYSTEM TO BE PROTECTED



Examples of configurations

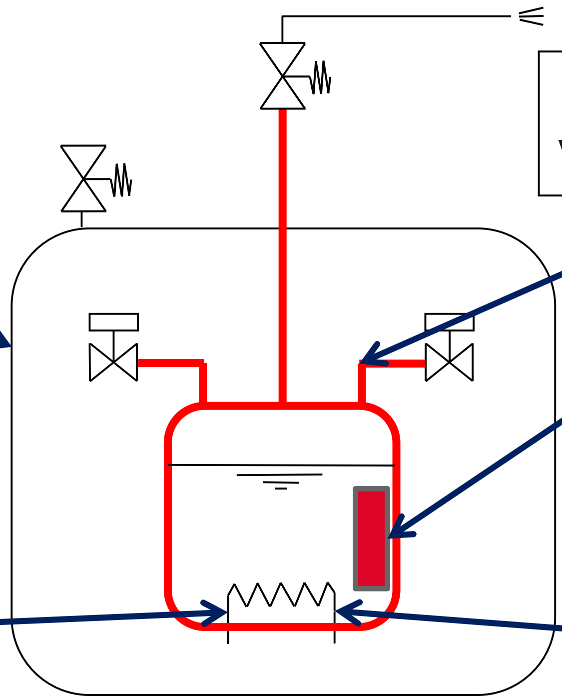
2.2 - ACCIDENTAL SITUATIONS

Examples of accidental situations (=> Overpressurisation):

Single failure : only one initiator event

Air inlet => loss of vaccum

Leak of cryogenic fluid: loss of vaccum



Quench of a supraconductive coil

Electric heater: Maximum power

Immersed heat exchanger: (sudden Inlet of hot fluid)

The most probable and severe event has to be considered for sizing the safety relief device

2.2 - HEAT LOAD IN CASE OF AIR LOSS OF VACUUM

- Bibliographic study of experimental heat fluxes ϕ for **the main cryogenic fluids (He, H2, Ne, N2, O2, Ar)** at P_{atm}

- Physical analysis of the experimental results

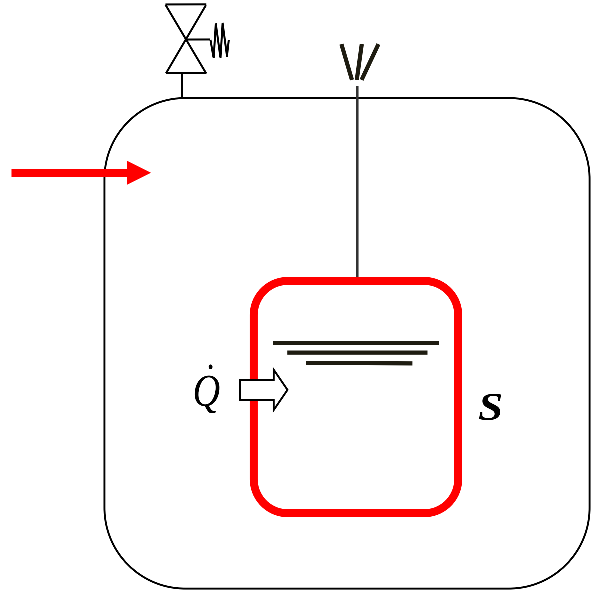
Heat flux data as function of number of layers (MLI) are given in the article…

ϕ Heat flux inlet on the system

S Cold surface exchange

$\dot{Q}$ Heat power

Air inlet



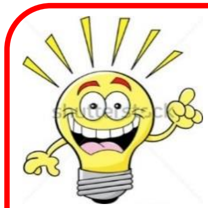
$$\dot{Q} = \phi . S$$

3 - METHOD FOR SIZING THE SAFETY DEVICE
Reservoirs, circuits, and vacuum chamber

Input data : Fluid, heat load $\dot{Q}$, initial conditions (P_i, ρ_i, T_i, N_i),discharge pressure (P_0), geometry of the system

3 steps…..

- Step 1 : Determination of the discharged mass flow rate $\dot{m}_0$



Calculate a mass flow rate that leads to a maximum section A. This section have to limit the pressure at P_0 during all the discharge transient

$$\dot{m}_0 = \frac{\dot{Q}}{v\left(\frac{\partial h}{\partial v}\right)_{P_0}}$$

$$h' = v\left(\frac{\partial h}{\partial v}\right)_{P_0}$$

h' is expressed depending on the thermodynamic state conditions of the system: **sub-cooled liquid**, **two phase liquid-vapor**, **superheated vapor and supercritic fluid**

CASE 1: SUPERCRITICAL DISCHARGE (P0>PC)

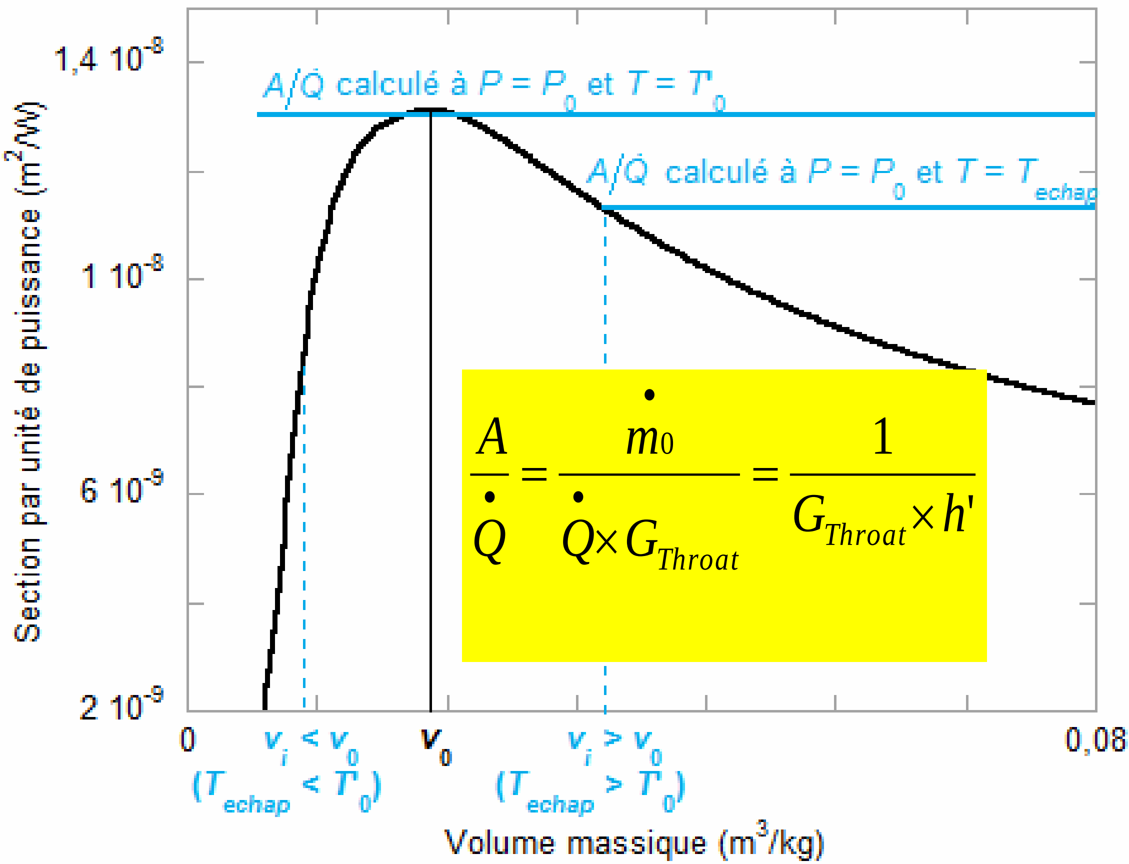
Section for an ideal safety device for a discharge at contant pressure 4 bar

$$h' = v\left(\frac{\partial h}{\partial v}\right)_{P_0, T}$$

Standards NF-EN 13648-3

T'_0 such as $\dfrac{\sqrt{v}}{v\left(\dfrac{\partial h}{\partial v}\right)_{P_0}}$ max

The section A presents a maximum for $v_0 = v(P_0, T'_0)$



$$\frac{A}{\dot{Q}} = \frac{\dot{m}_0}{\dot{Q} \times G_{Throat}} = \frac{1}{G_{Throat} \times h'}$$

In the article's CEA

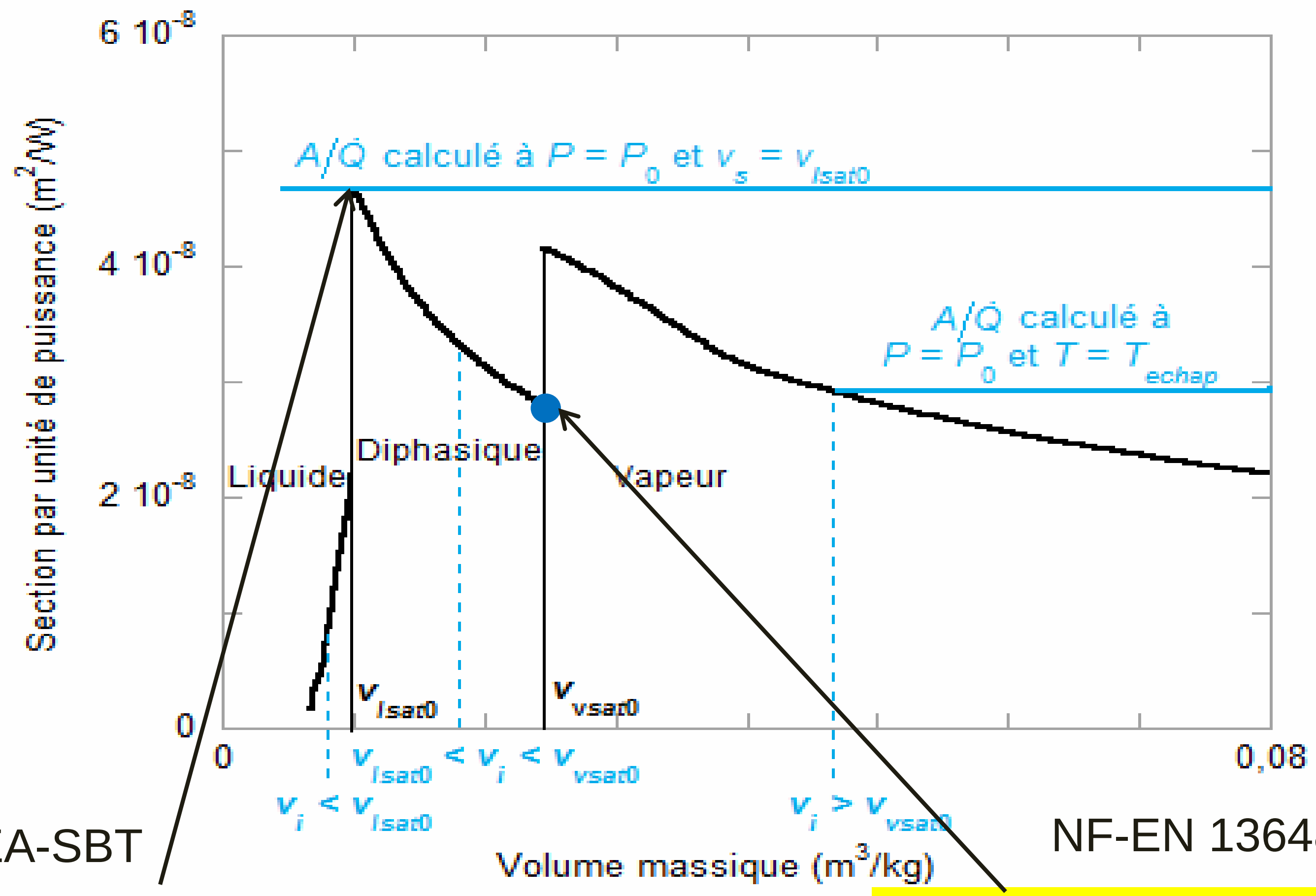
$$T_{vent} = T(v_i, P_0)$$

$$T = \max(T_{vent}, T'_0)$$

$$h' = v\left(\frac{\partial h}{\partial v}\right)_{P_0, T}$$

CASE 2: SUBCRITICAL DISCHARGE (P0 <PC) EX HELIUM)

Section for an ideal safety device for a discharge at contant pressure 2 bar



CEA-SBT

$$\dot{m}_0 = \frac{\dot{Q}}{v_{lsat0}}\left(\frac{v_{vsat0} - v_{lsat0}}{h_{lv0}}\right)$$

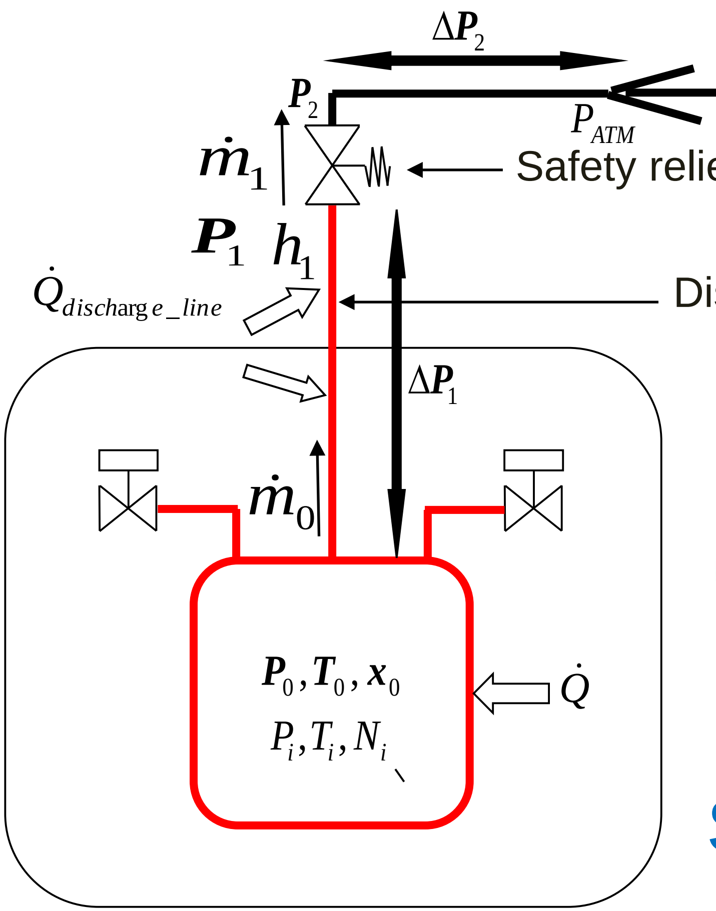
1/h'

NF-EN 13648-3

$$\dot{m}_0 = \frac{\dot{Q}}{v_{vsat0}}\left(\frac{v_{vsat0} - v_{lsat0}}{h_{lv0}}\right)$$

THERMODYNAMIC CONDITIONS AT UPSTREAM /DOWNSTREAM OF THE SAFETY DEVICE

- Step 2: Calculation of the thermodynamic conditions, mass enthalpy h_1 and the pressures P_1 and P_2



- Pressure drop calculation to determine ΔP_1 and ΔP_2
- Energy balance to determine mass enthalpy h_1

Long discharge line $\dot{m}_0 \neq \dot{m}_1$

Expansion and change state due to $\dot{Q}_{discharge\_line}$

See the article for more details…..

3 - METHOD FOR SIZING THE SAFETY DEVICE (3)

- <u>Step 3</u> : Calculation of **<u>the minimum</u>** section A of the safety relief device

$$A = \frac{\dot{m}}{G \times K_d}$$

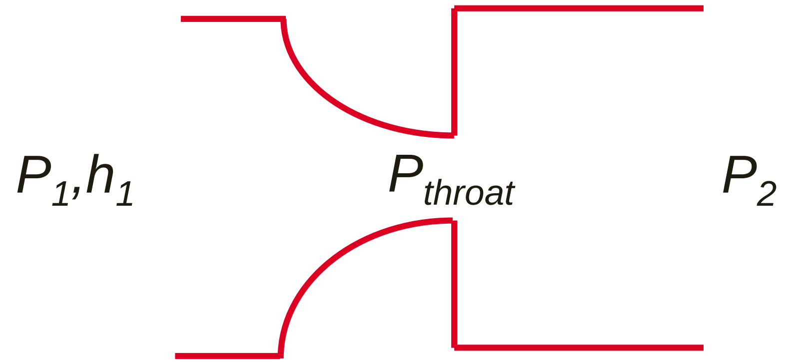
$\dot{m}$ Mass flow rate to discharge ($\dot{m}_0$ or $\dot{m}_1$)

G Mass flux

K_d Discharge coefficient, depends on the geometry of the safety relief device and thermodynamic state of the fluid at upstream

G model : Isentropic expansion of flow in a short nozzle

$$G = \rho_{throat} \times \sqrt{2 \times (h_1 - h_{throat})}$$



Generic model (API 520):

- Valid for all thermodynamic states of the fluid upstream of the safety device
- Takes into account the possible phase change of the fluid during the expansion (evaporation / condensation)

SOFTWARE TOOL FOR SIZING SAFETY RELIEF DEVICE

- Software was developped several years ago at SBT using a first method

- This software has been updated to the content of the presented article

See presentation / talk of Jean-Marc Poncet

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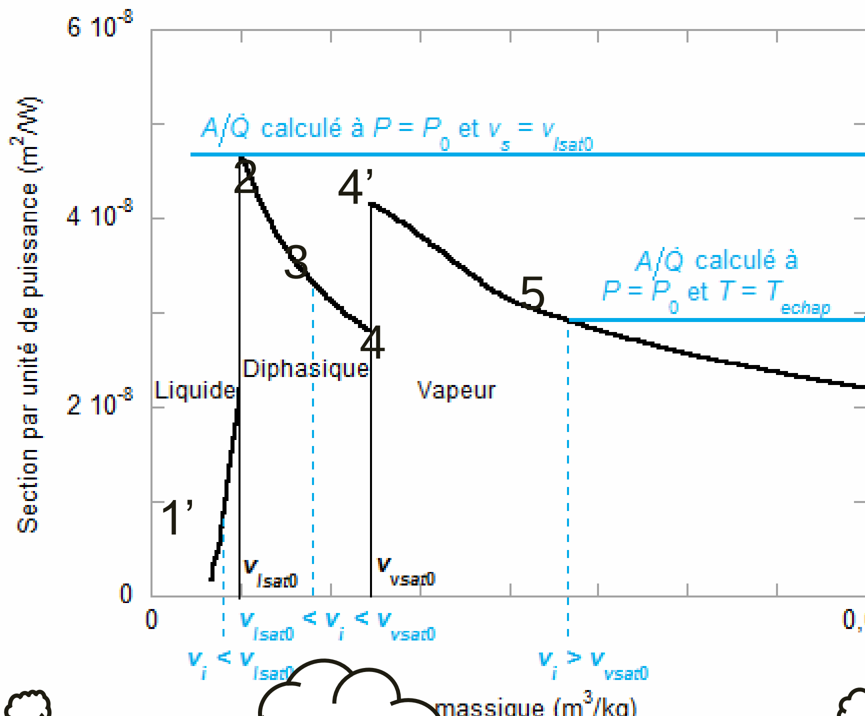
QUESTIONS

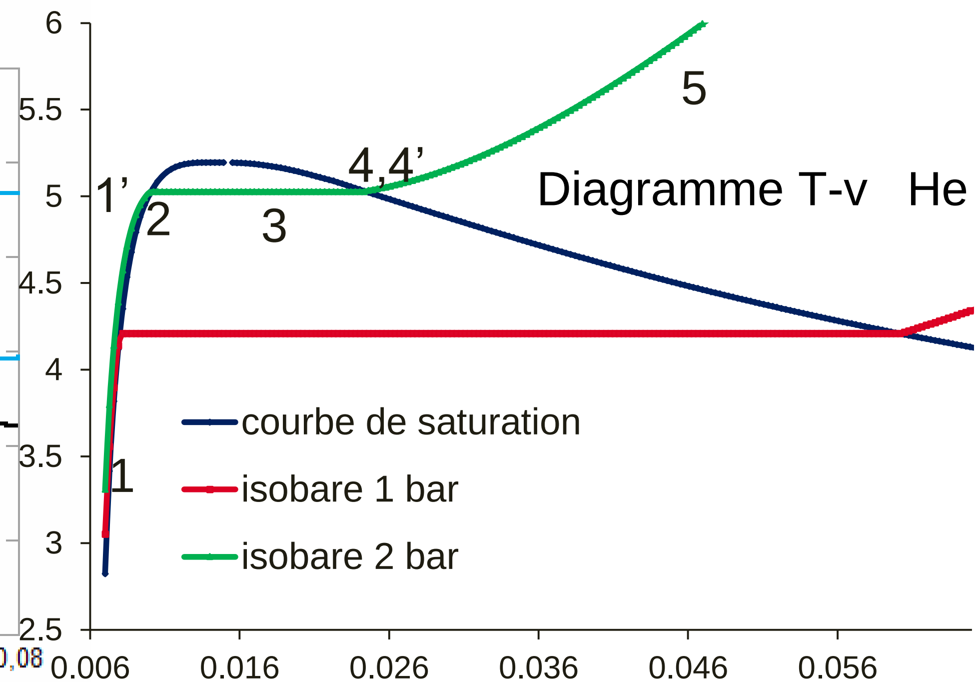
Thank you for your attention

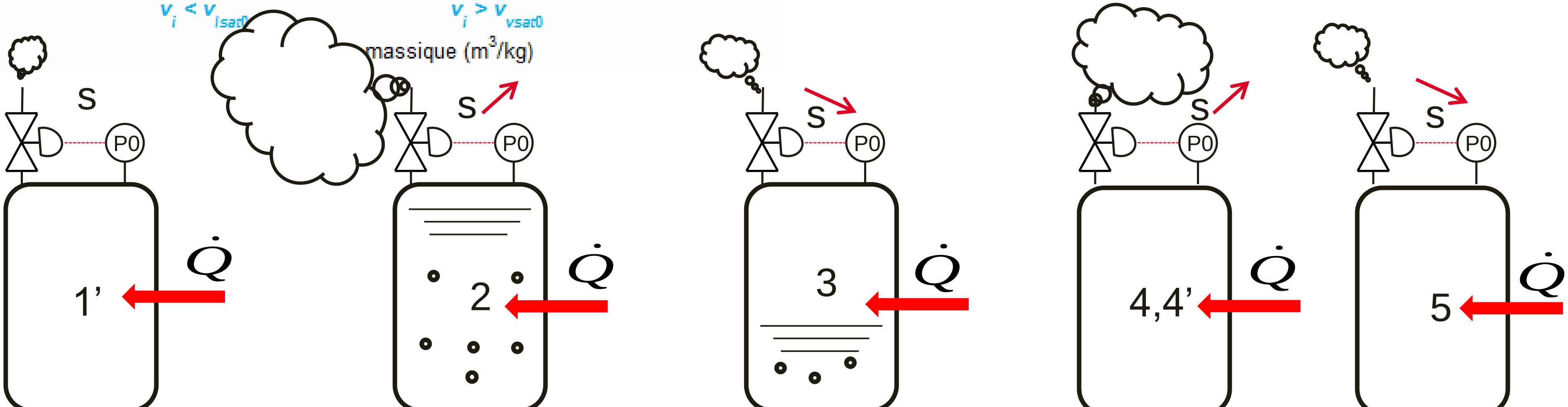
EXTRA SLIDES

SUBCRITICAL DISCHARGE (P0 <PC) (EXAMPLE FOR HELIUM)

Section for an ideal safety device for a discharge at contant pressure 2 bar







DISCHARGE MAS FLOW AT CONSTANT PRESSURE P0
EXPRESSION OF THE FUNCTION H' IN TWO PHASES STATE

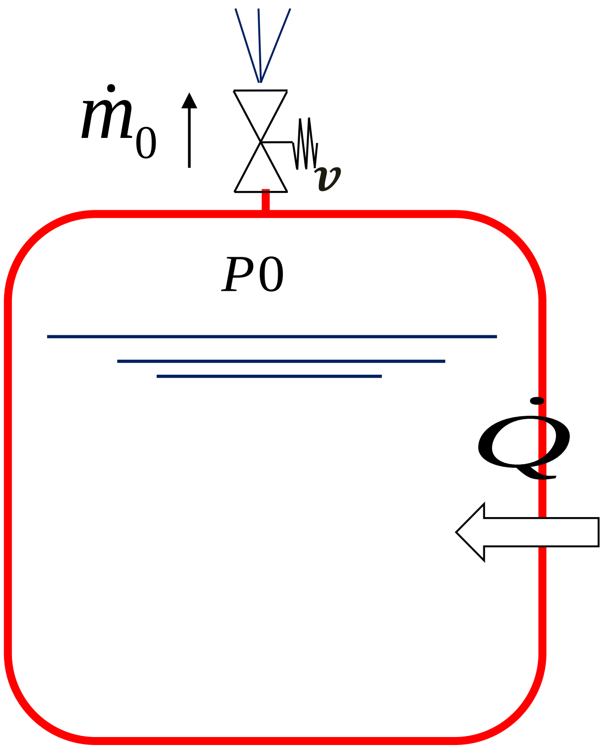
$$x = \frac{v - v_{vsat0}}{v_{vsat0} - v_{sat0}}$$

$$h = x \, . \, h_{vsat0} + (1 - x) . \, h_{lsat0}$$

$$v\left(\frac{\partial h}{\partial v}\right)_{P0} = v\left(\frac{h_{lv0}}{v_{vsat0} - v_{lsat0}}\right)$$

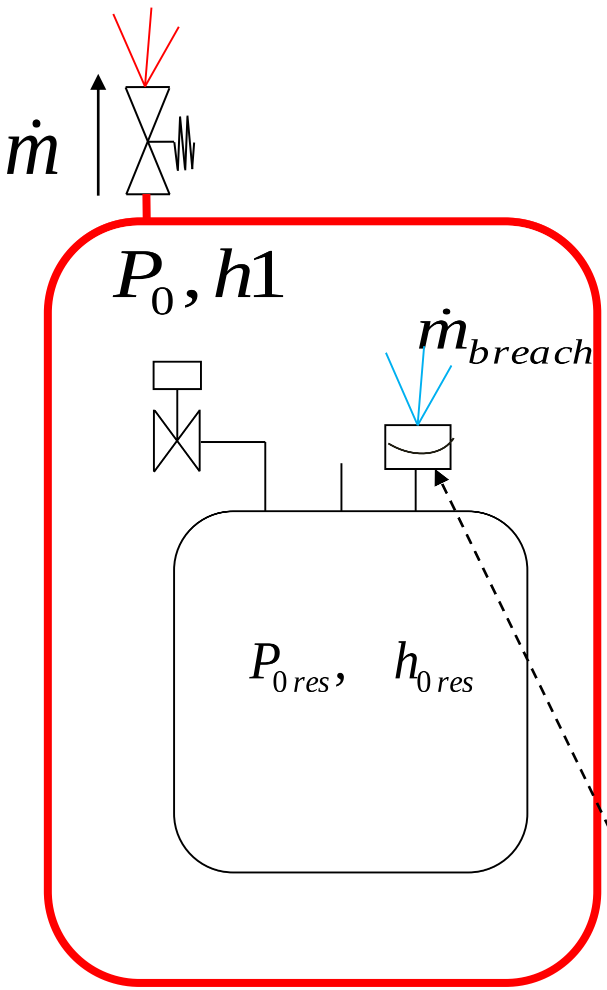
h_{lv0} : Latent heat at P0

v_{lsat0}, v_{vsat0} } Specific volume of the vapeur and the liquid at saturation and pression P0



but that must be taken to v to calcule the flow $\dot{m}_0$

DISCHARGE MASS FLOW RATE OF A DEVICE PROTECTING A VACUUM VESSEL



- Identify the weak point of the cryogenic circuit that might become the source of the leak into the vacuum vessel and define the «breach» area

  A_{breach}

  (compensation below, connection, weld, burst disc…)

- Non accumulation of cryogenic fluid in the vacuum vessel

$$\dot{m} = \dot{m}_{breach}$$

$$\dot{m}_{breach} = A_{breach} \cdot G(P_{0res}, h_{0res})$$

Example: Leakage through a burst disc of the tank