Safety analysis on beam dump

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Safety group

SSTAC meeting, July 23, 2015

Topics:

1. *Overview on Beam Dump*
2. *Description of cooling circuit*
3. *Safety philosofy*
4. *BD safety system: definition of shut-down signals*
5. *Critical safety aspects: accident scenario*

Overview on Beam Dump

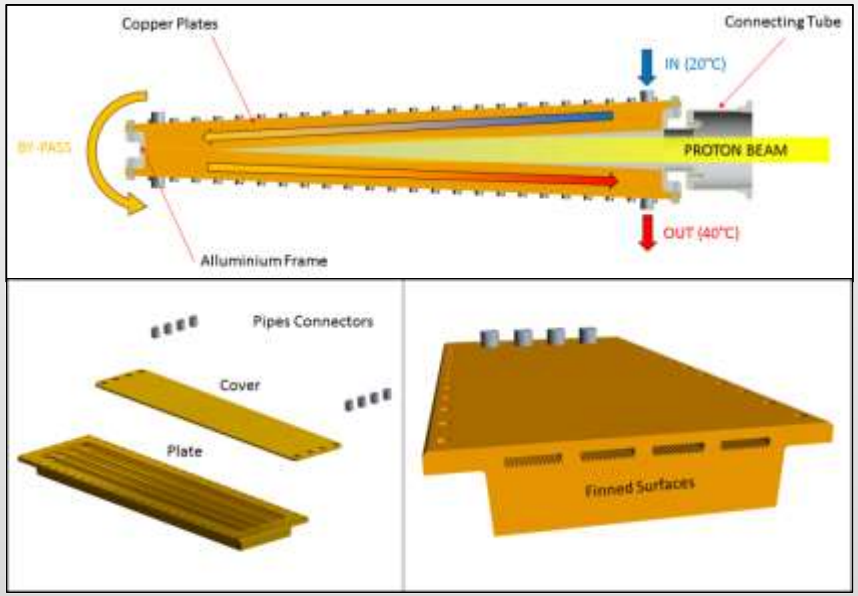
Ref. E. Boratto

INPUT

Water propreties
at reference T:
ρ , μ , c , λ

Hydraulic properties:
Q_{tot}= 2400 l/h
v = 1,25 m/s

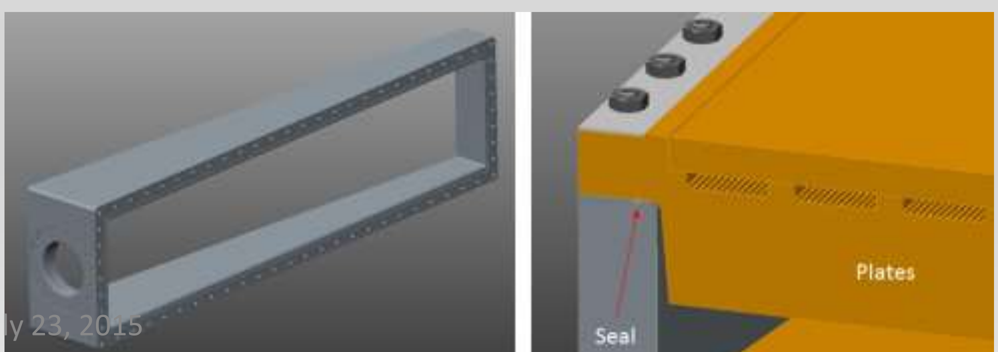
Heat Dissipation P = 52,5 kW



OUTPUT

Fluyd dynamic
parameters:
Re, Nu, Pr

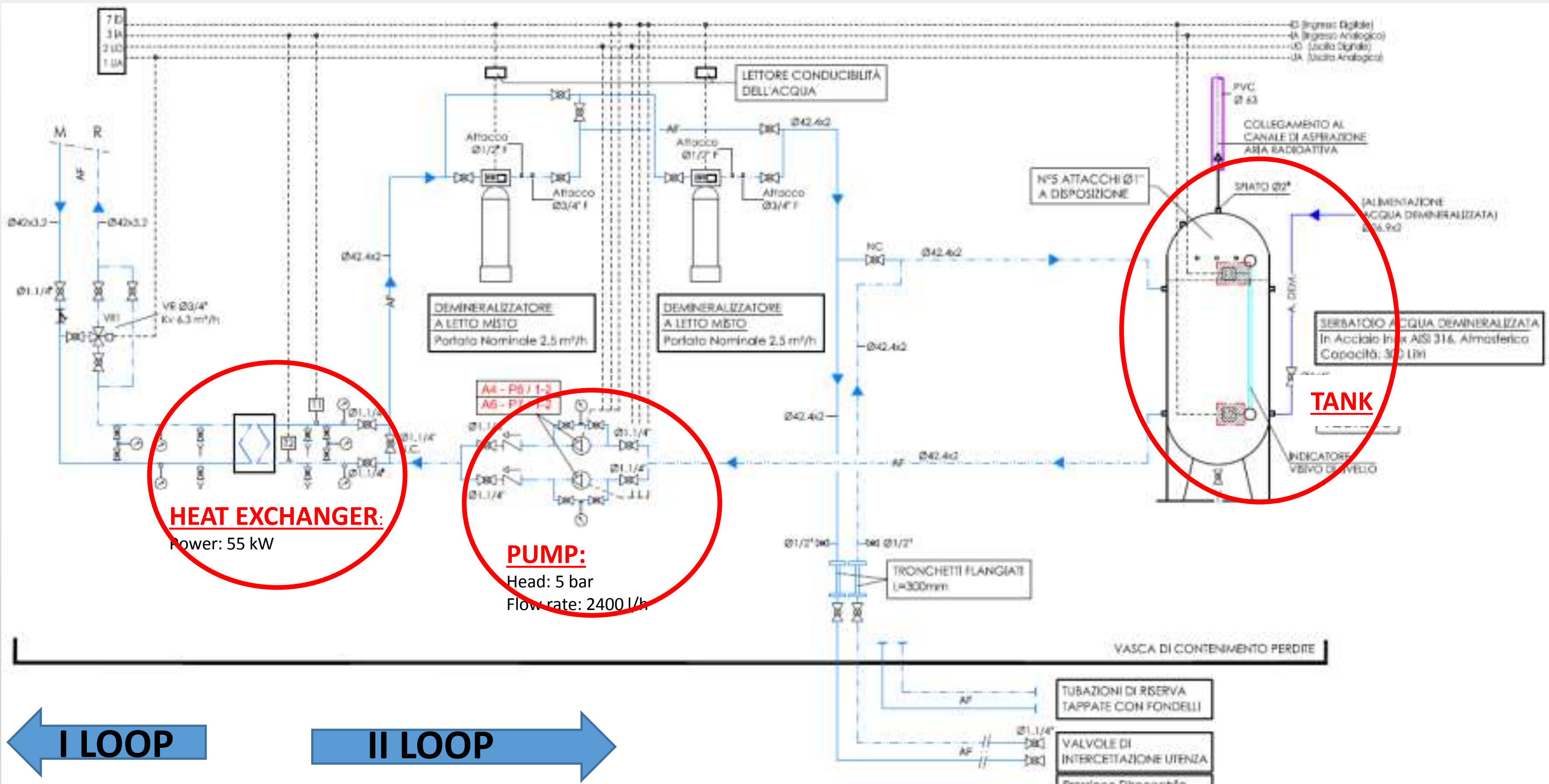
Δt = 20° C
HTC = 7000 W $m^{-2}K$
(dittus-boelter)



The vacuum is ensured by suitable INDIUM gaskets disposed along the perimeter of the Al grafs.

Description of cooling circuit

Provisional lay out

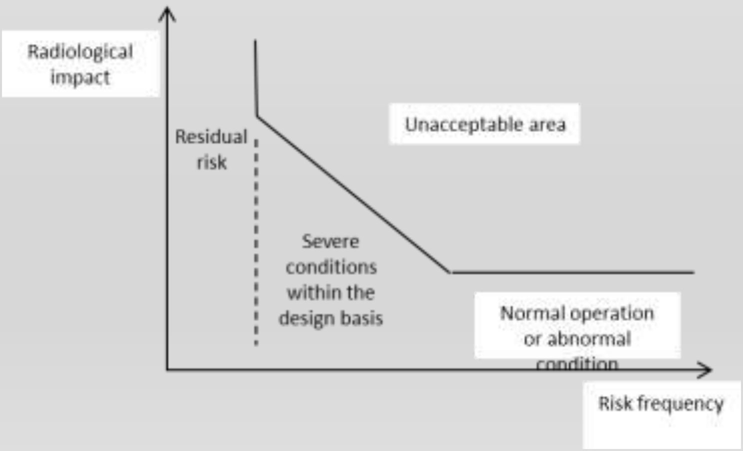


Radioactive water

Safety philosofy (1)

Safety functions (International Nuclear Safety Advisor Group 12 - IAEA) **adapted to SPES**:

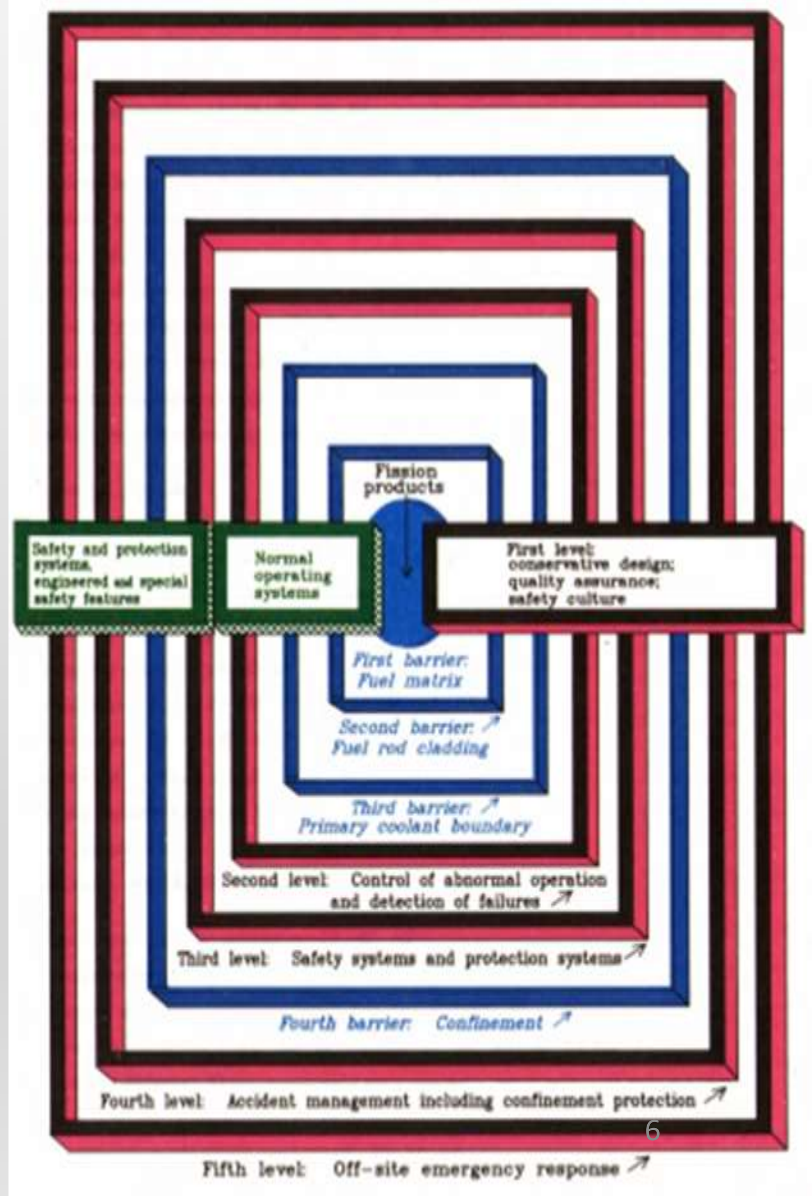
- *Confinement of radioactivity (barriers)*
- *Limits on dose (radioprotection)*
- *Control of nuclear reaction (stop proton beam)*
- *Heat removal from beam dump (cooling system)*



Safety philosofy (2)

Defence in depth for SPES (beam dump config.):

1. *Primary barrier: Cooling System and Vacuum*
2. *Local shielding around BD*
3. *Concrete wall of A6 bunker*
4. *Ventilation system (dynamic barrier)*



Beam dump safety system

Logical scheme

Identify the top event

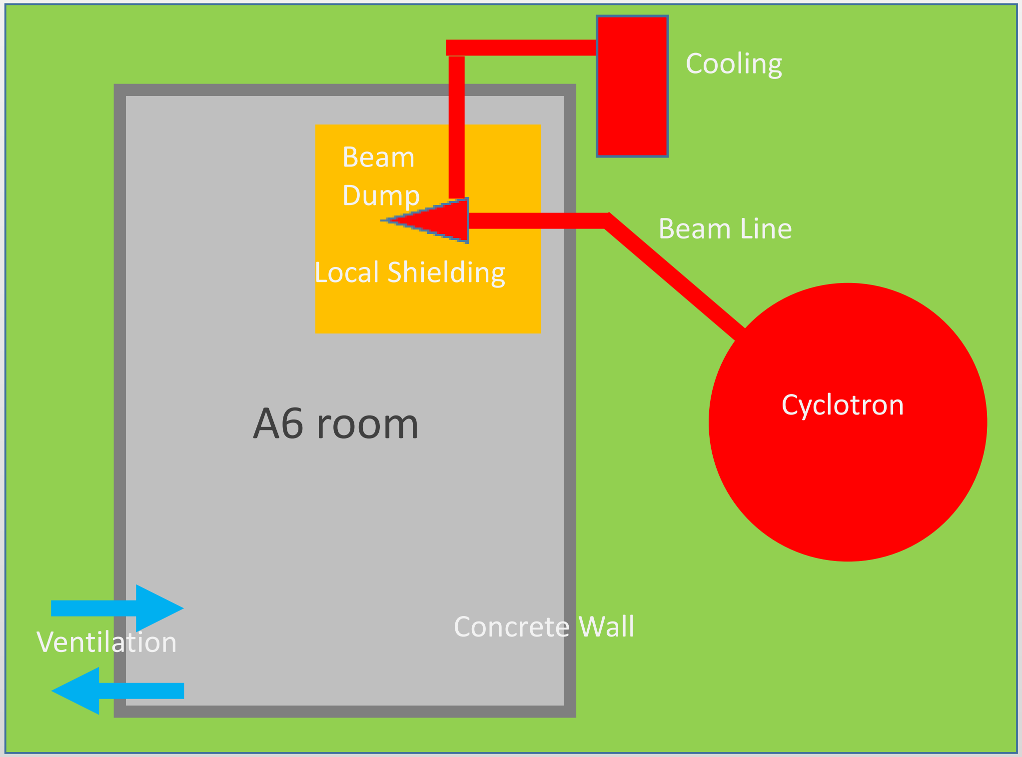
↓

Identify the physical quantities that control the evolution of accident

↓

FEM simulation and theoretical model to evaluate the interlock values

Beam dump safety system



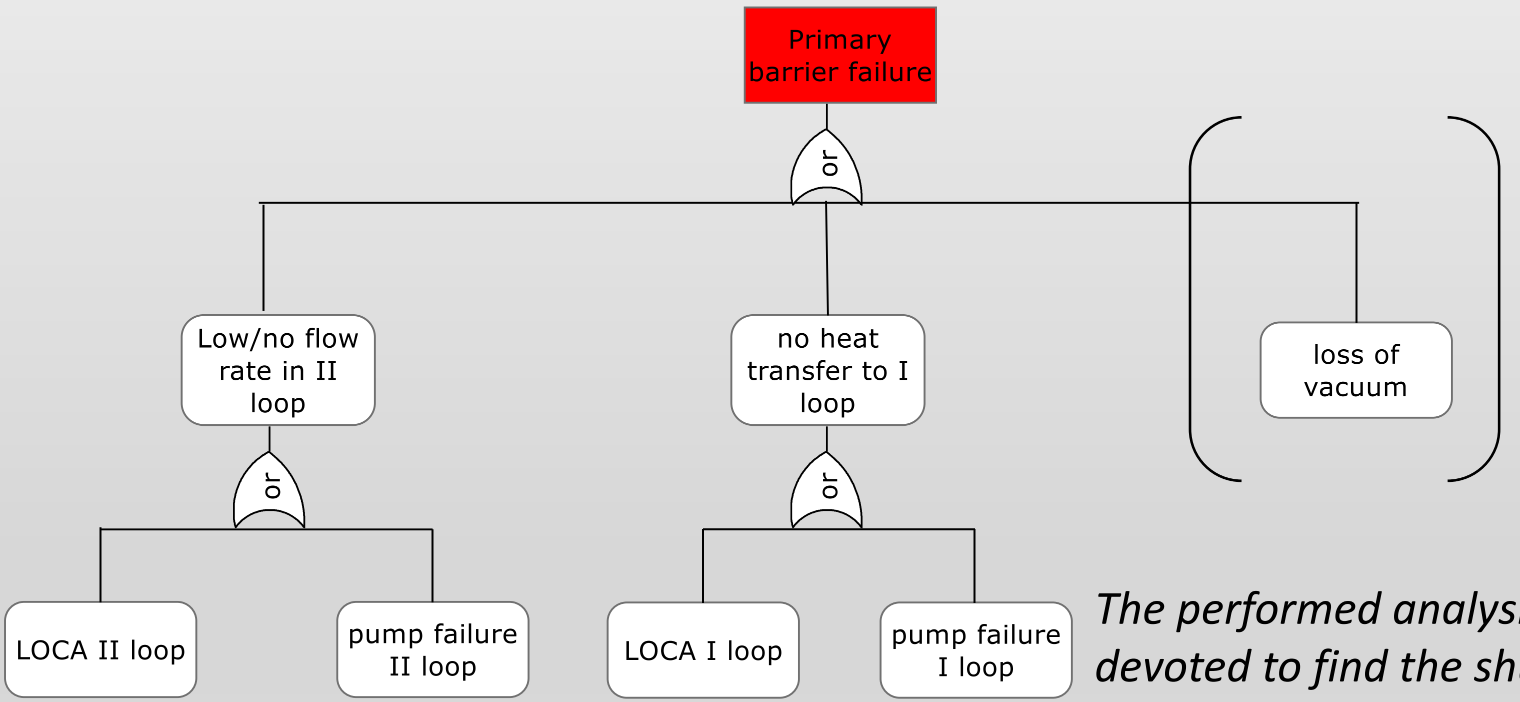
Goal of the Beam Dump Safety System

To confine:

1. the interaction of protons with matter
2. the activated products coming from this interaction inside the *primary boundary system*.

Beam dump safety system

<u>The right question</u>: ***How can the primary barrier fail?***



The performed analysis is devoted to find the shutdown signals coming from cooling system

Beam dump safety system: Temperature

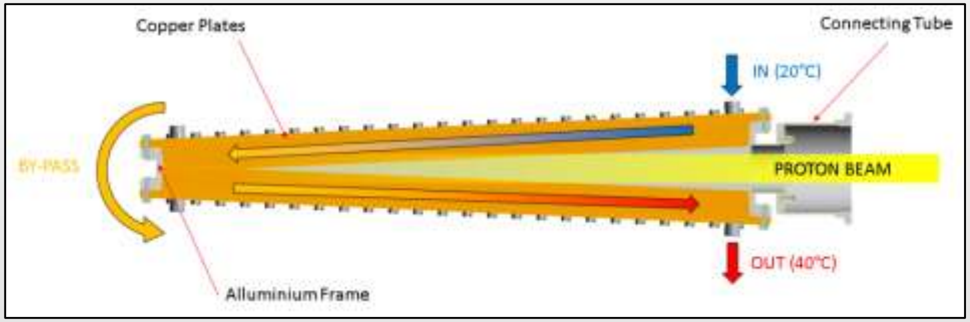
Thermal analysis: FEM results

Goal: define the hot spot during the operating condition

Steady state analysis

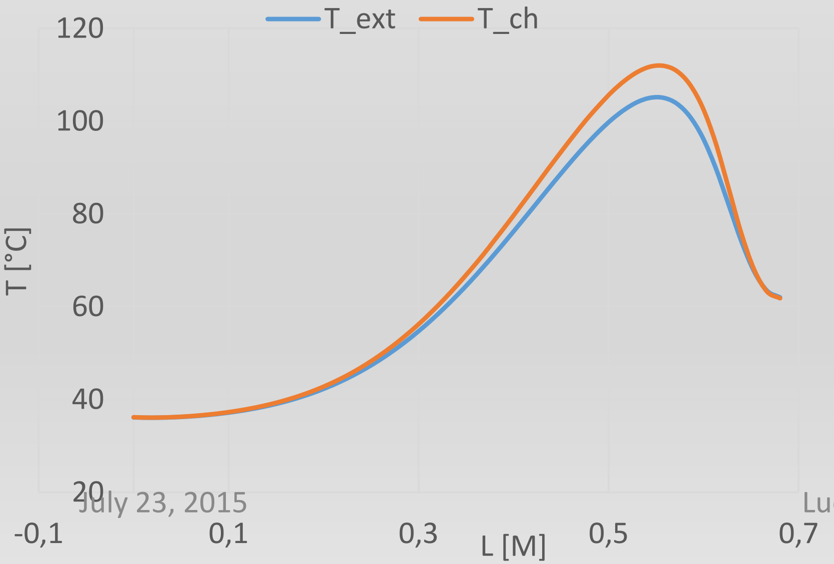
HP:

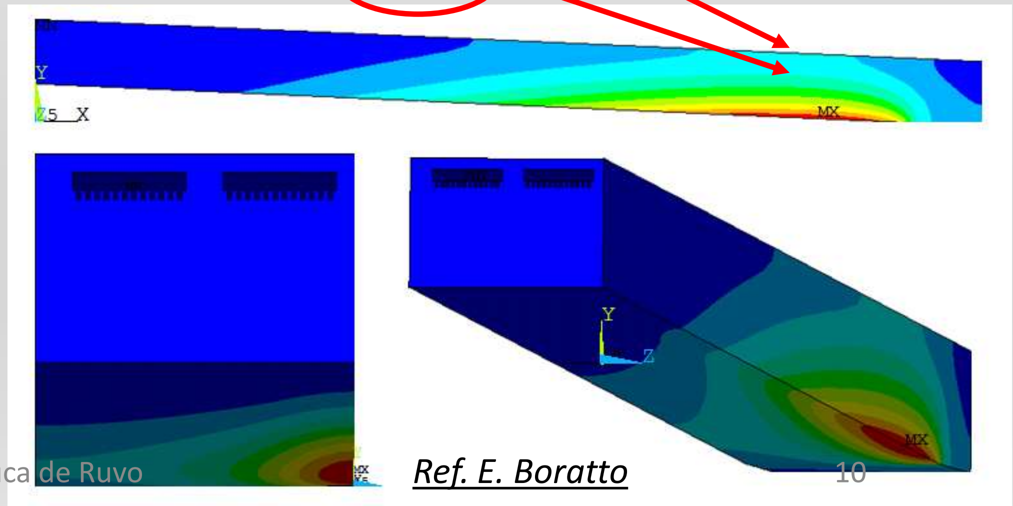
- Water HTC: 7000 W/°C m^2
- Fully developed turbolent flow
- Thermal power: 52.5 kW



Hot spot:

- $T_{ext}^{max} = 105\ °C$
- $T_{ch}^{max} = 112\ °C$



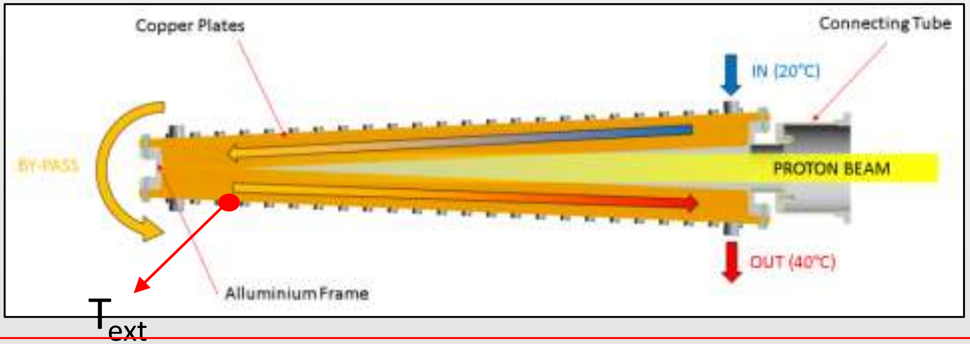


Ref. E. Boratto

Beam dump safety system: Temperature

H2O sat

T [°C]	P [MPa]
100	0,101
105	0,120
110	0,143
115	0,169
120	0,199
125	0,232
130	0,270
135	0,313
140	0,361
145	0,416
150	0,476
155	0,543
160	0,618



According to FEM:

$$T_{termc} = T_{ext}^{max} = T_{ch}^{max} - \Delta T$$

<u>Measuring T by ext. termocouple it is possible to estimate the temperature inside the channel wall.</u>

Constrains in temperature:

1. T wall in cooling channel in the hot spot < T saturation of water (low HTC)
2. T Indium gasket < T melting In (156°C)

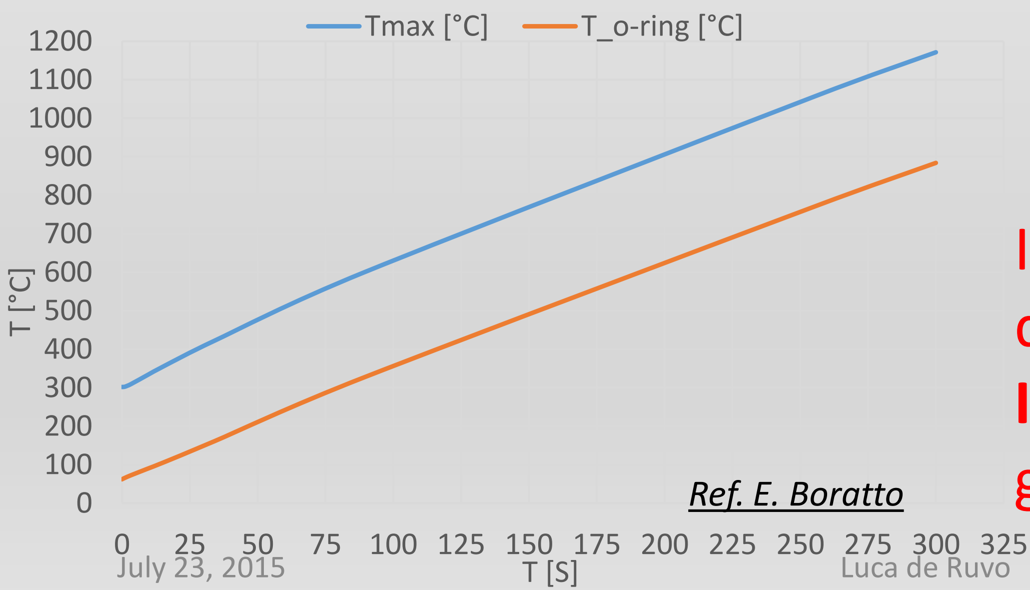
Beam dump safety system: Temperature

Thermal analysis: FEM results

Goal: to estimate the time avaiable before having a primary barrier failure in case of LOCA.
Transient analysis

HP:

- No water in channels



Ref. E. Boratto

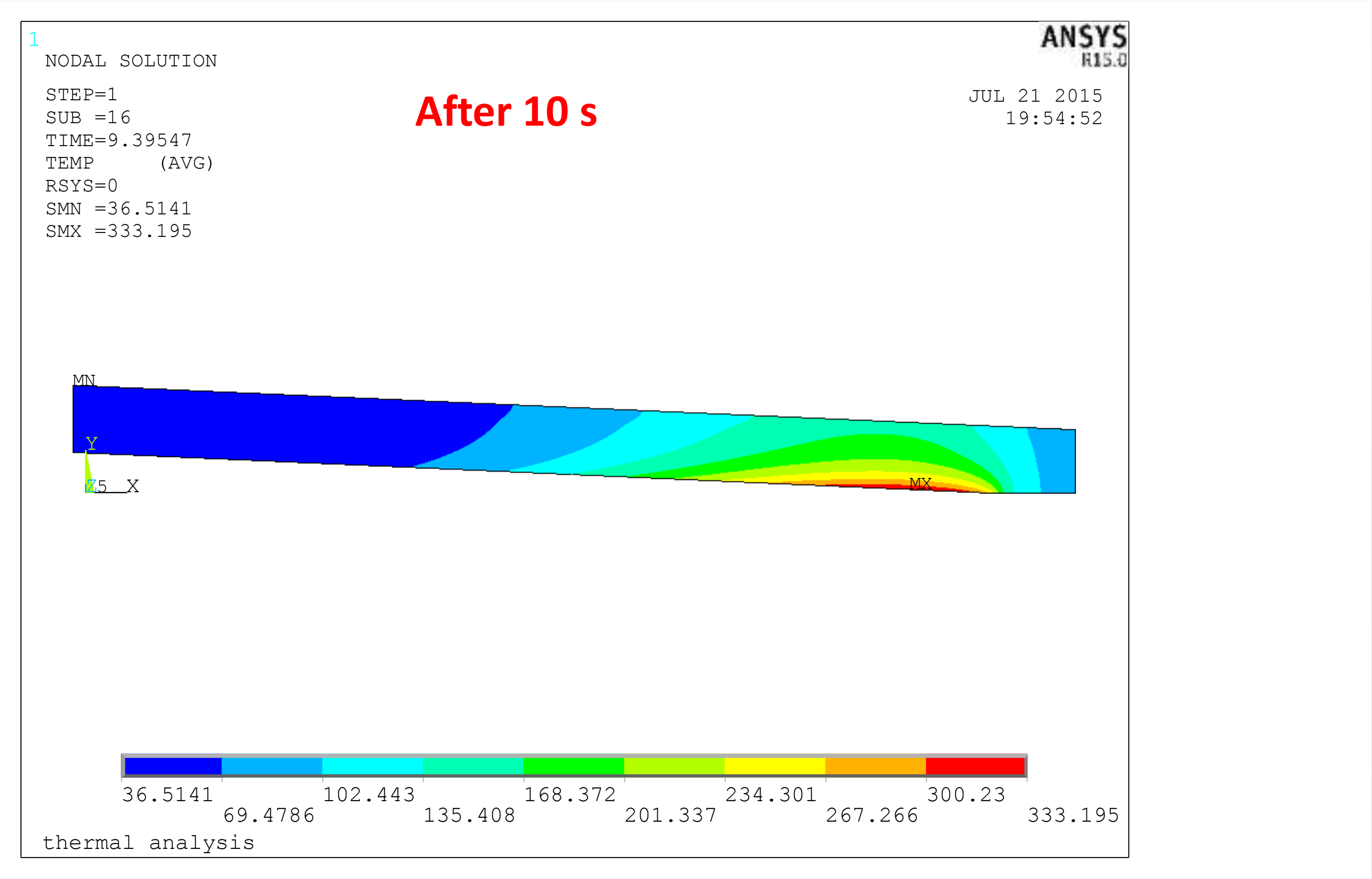
Hot spot:

- $T_{Cu}^{melt} after\ 300\ s$
- $T_{In}^{melt} after\ 10\ s$

In case of *critical heat flux* the driving parameter is the **Indium temperature** (vacuum gasket)

Beam dump safety system: Temperature

Thermal analysis: FEM results



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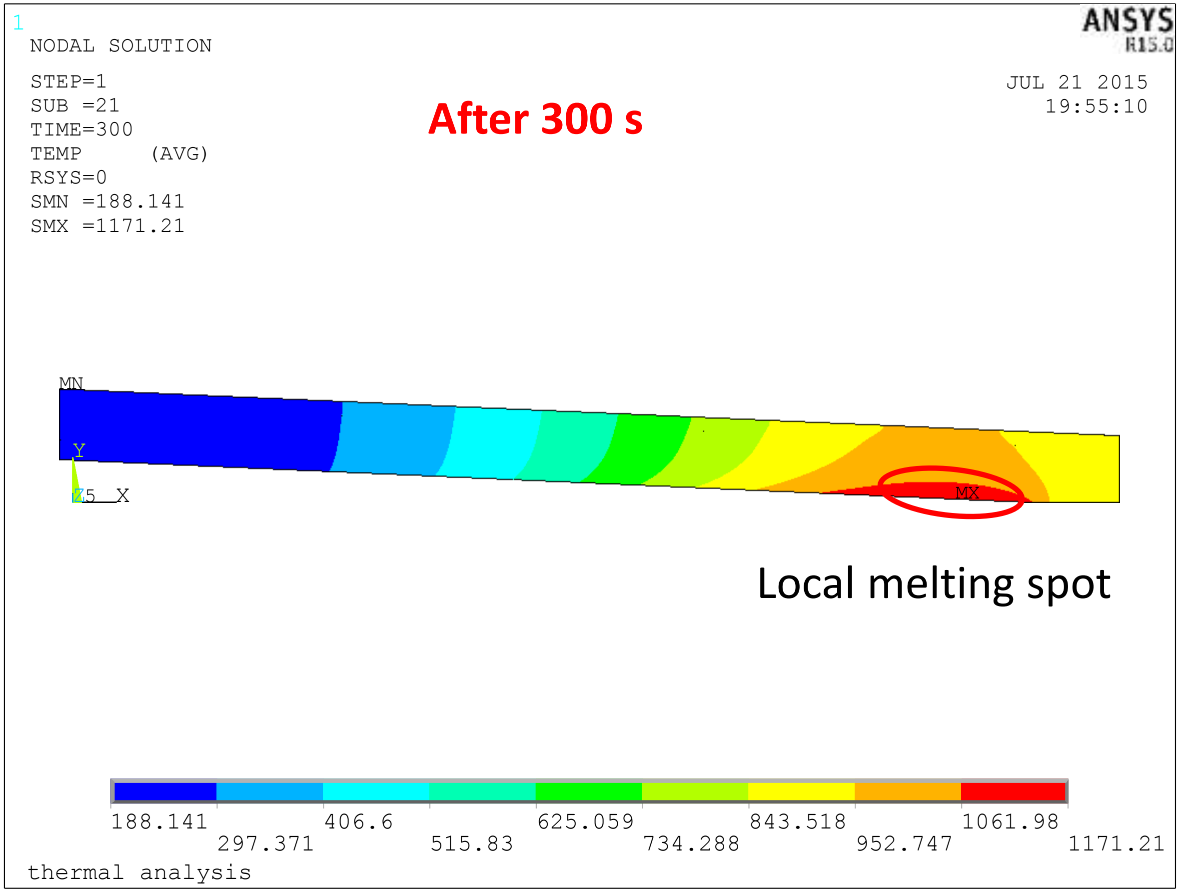
Beam dump safety system: Temperature

Thermal analysis: FEM results



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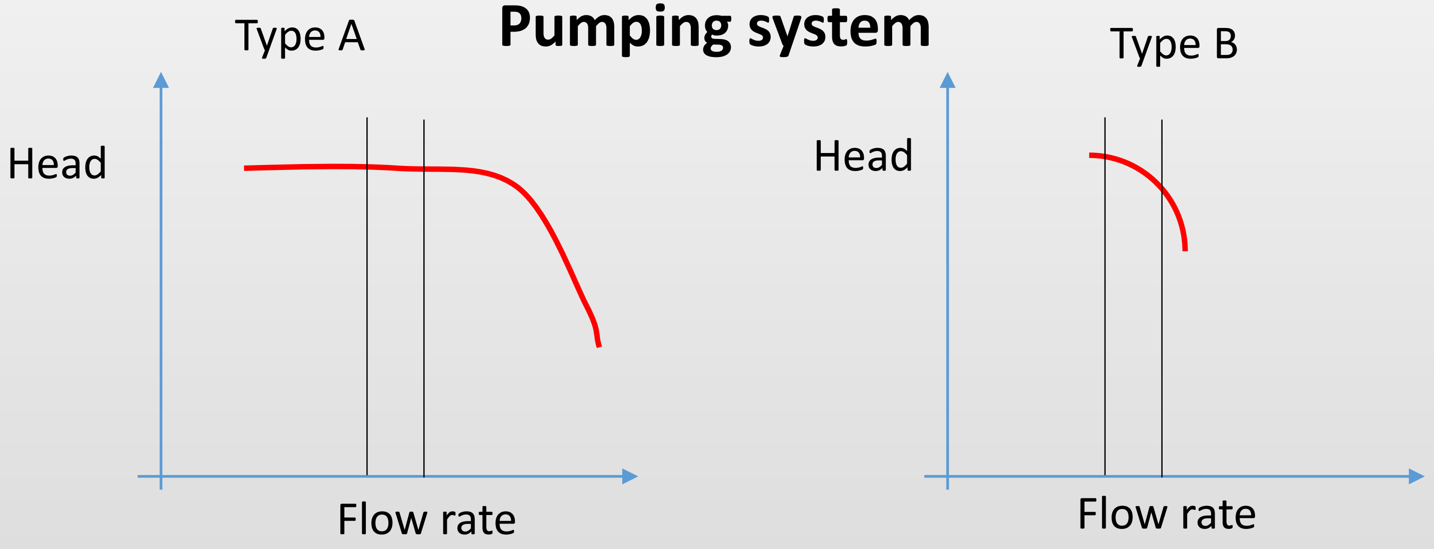
Beam dump safety system: Pressure

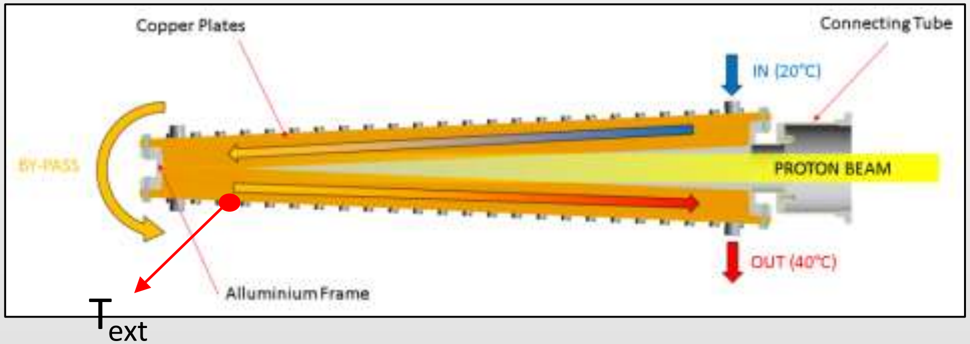
Pumping system

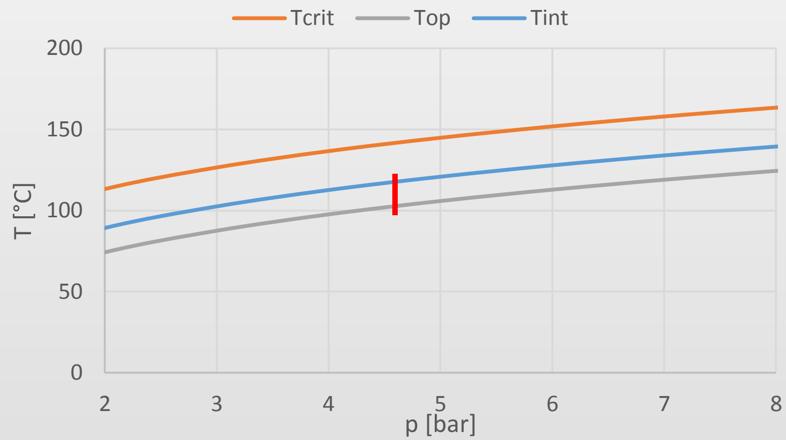


What should drive in the choose of pumping system (safety by design)
Hp: LOCA between pump and beam dump (worst case):

A. Small variation in m doesn't produce variation in p, if type A pump (best stability)
B. Small variation in m produces variation in p, if type B pump (possible instability)

Beam dump safety system: summary





1. $T_{ext} < T_{ext\,max}$
2. $P > P_{min}$
3. Cooling Flow rate > m_{min} $(P_{th} = c_p \dot{m}(T_{out} - T_{in}))$

(items 1 and 2: redundancy)

Shut down of cyclotron

- High T_{ext}
- Low pressure water channel
- Low cooling flow rate

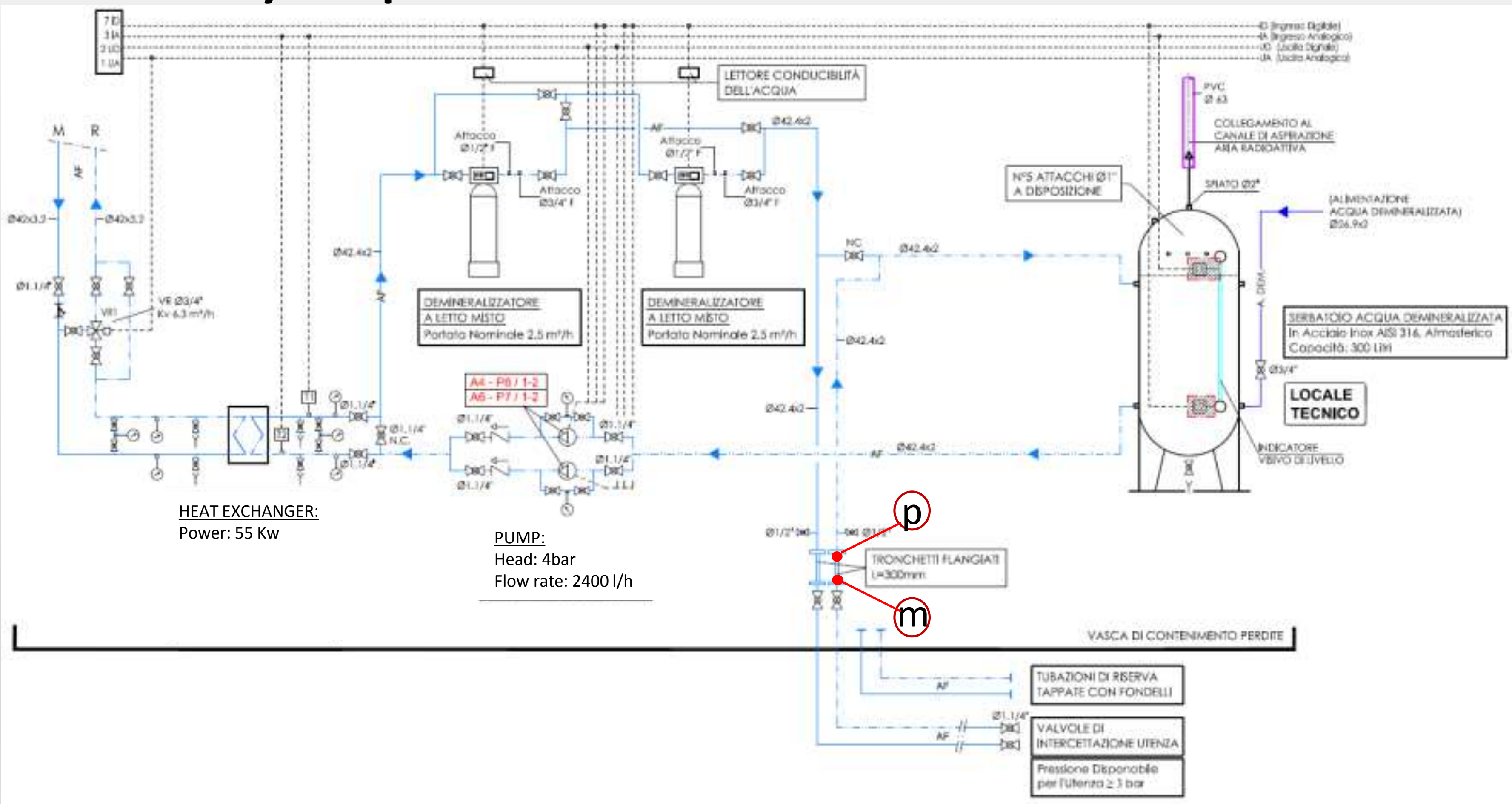
Beam dump safety system

Definition of the interlock values for the cooling system

Physical quantity	Measuring device	Location	Operational value	Critical threshold for safety	Interlock set point
Pressure	Barometer	Cooling loop	5 bar	4 bar	4,5 bar
Flow rate	Flowmeter	Cooling loop	2400 l/h	1900 l/h	2200 l/h
Temperature	Termocouple type K	Beam dump	105 °C	144 °C	120 °C

Beam dump safety system

Where they are placed?



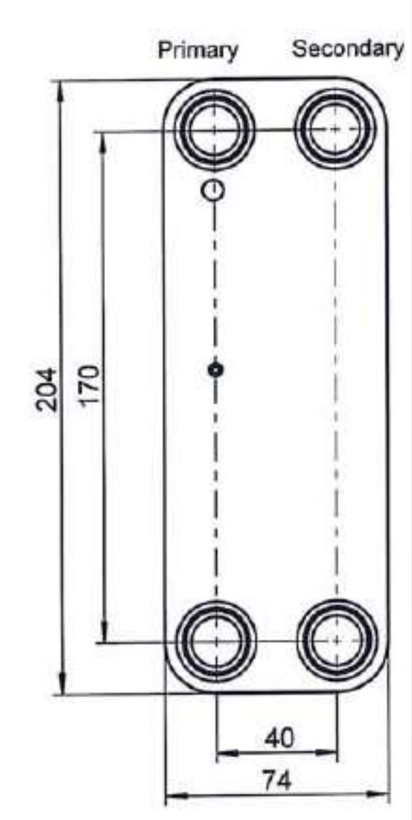
Critical safety aspects: accident scenario

Failure of Heat Exchanger

Critical safety aspects: accident scenario

Plate Heat Exchanger (AISI 316L, stainless steal brazed)

I loop:
- Clean water
- P_{nom}= 3 bar



II loop:
- Radioactive water
- P_{nom}= 5 bar

Thermal power: 55 kW

At the EoB (some days) water is highly activated (some kBq/g)

In case of HEx failure some radioactive water could contaminate the I loop

Critical safety aspects: accident scenario

How credible this scenario is?

Equipment	Mean failure rate [10^{-6}/h]	Range [10^{-6}/h]
Plate HEx	20,7	19 - 22

Note on methodology

The exponential distribution is usually applied to data in the absence of other info and it is the most widely used in reliability work:

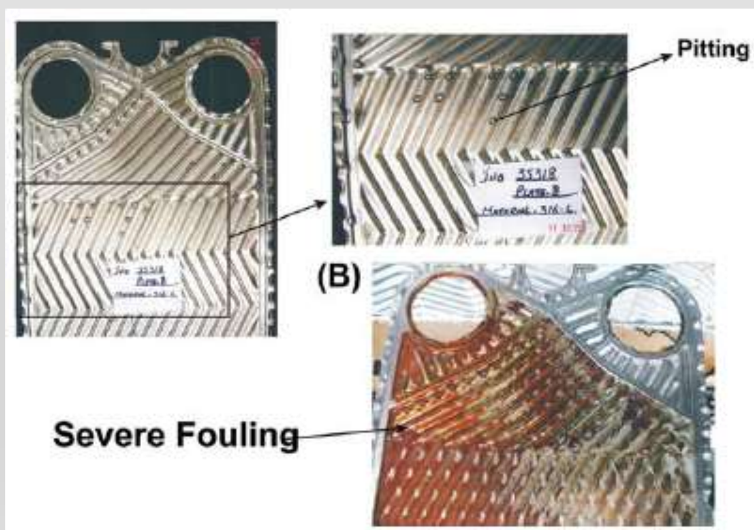
$$F(t) = 1 - e^{-\theta t}$$

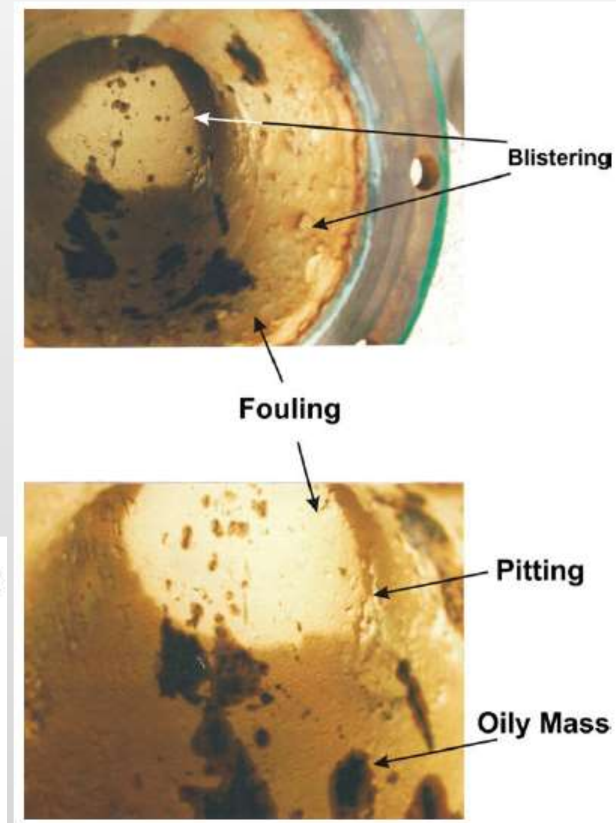
Data and theory from **Loss Prevention in the Process Industries: Hazard Identification - Lees**

Critical safety aspects: accident scenario

What causes heat exchanger failure?

- Fouling
- Corrosion (pitting, stress corrosion,…)
- Metal erosion
- Water hammer
- Vibration fatigue
- Thermal fatigue





Pictures from *Engineering Failure Analysis* 17 (2010) 886–893

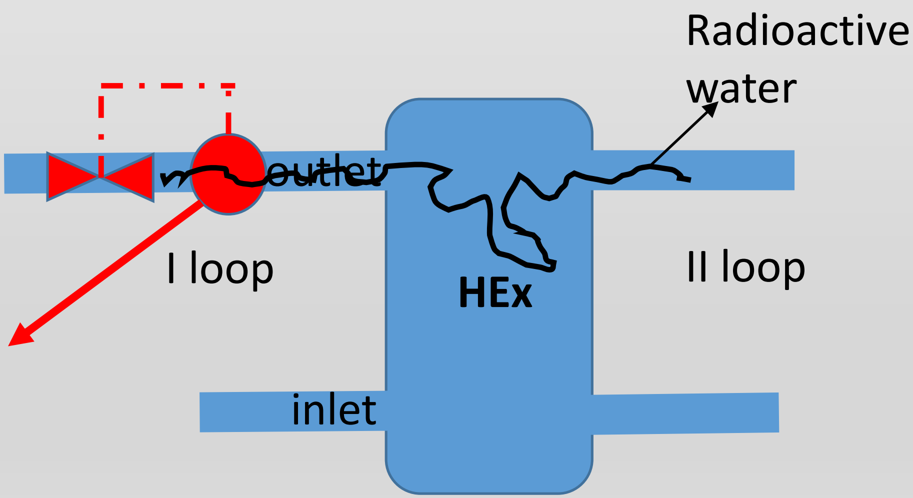
Critical safety aspects: accident scenario

Actions to implement for improving HEx life ?

- Water ph: 7 – 8,5
- Chloride < 5 ppm
- Filter to prevent sediment build-up
- Monitoring the the cooling water flow rate to prevent fouling
- Visual inspection (if possible)
- Chemical and/or mechanical cleaning (if possible)

…. and if everything goes wrong?

In-line gamma monitoring of I loop



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Thanks for attention

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