Preventing Thermal Runaways of LENR Reactors

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Temperature activated reactions

- **Several authors report that the LENR power increases with the temperature.**

Temperature activated reactions

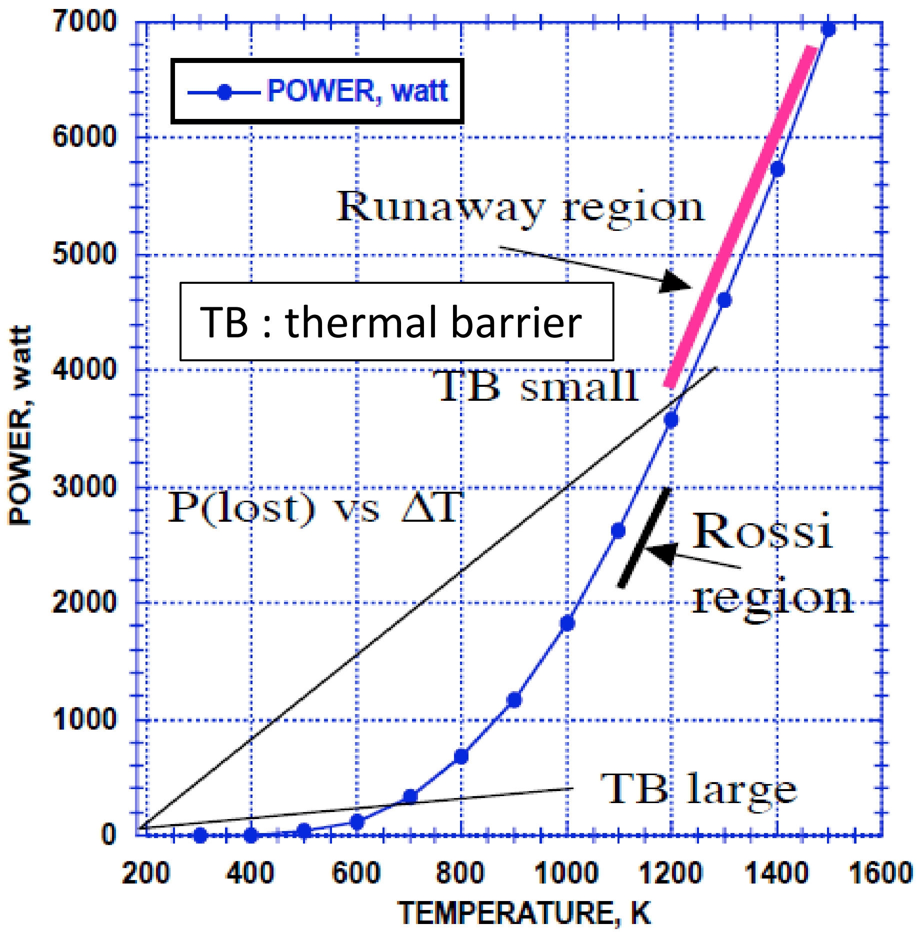
- **The temperature dependence is described by an Arrhenius law**

- **The rate of a process, for instance heat-producing reactions, is a function of an activation energy *E* and the temperature *T* :**

$$w = A.exp(-E/kT)$$

- **With :**
  - ***w*** **: heat production power ($W.m^{-3}$)**
  - ***A*** **: pre-exponential factor**
  - ***E*** **: activation energy**
  - ***k*** **: Boltzmann's constant**
  - ***T*** **: absolute temperature of the reactive medium.**

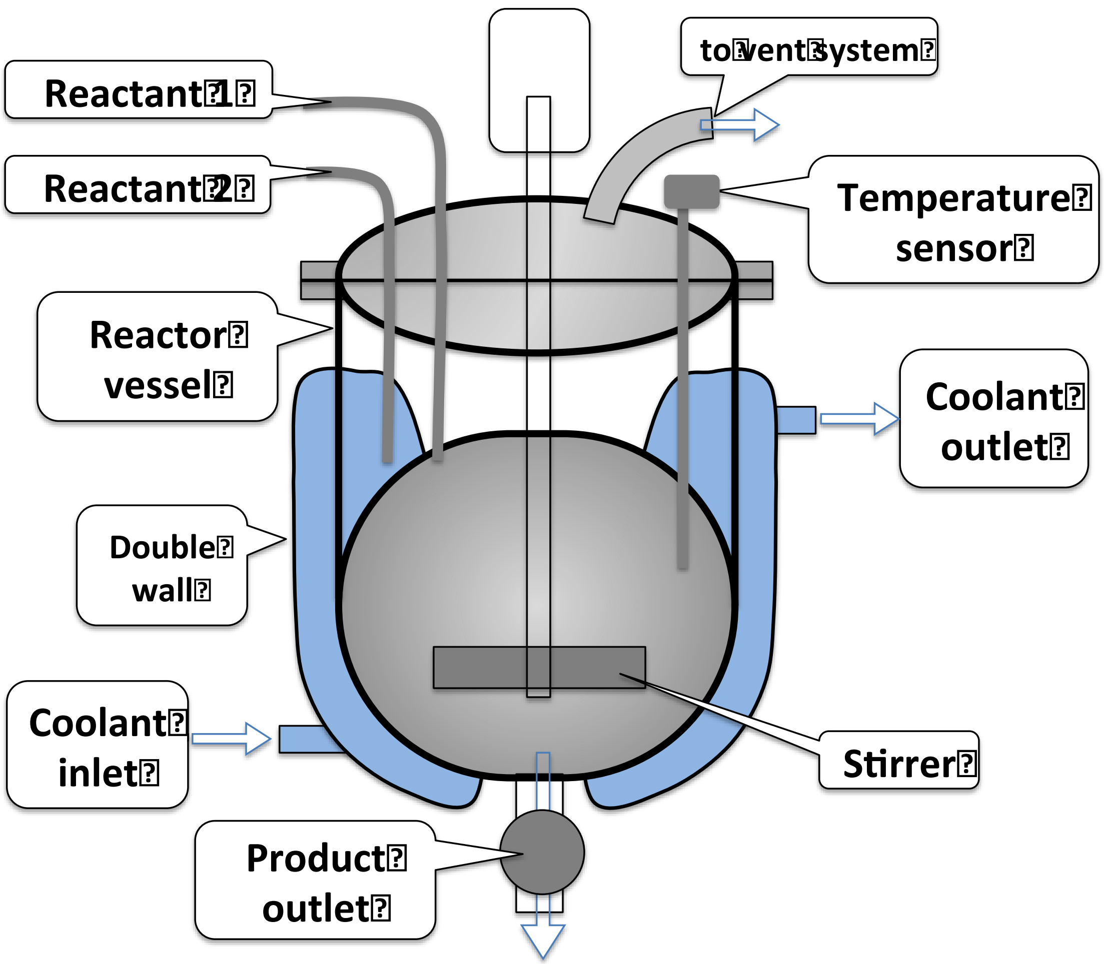
How to control such a reactor ?



Storms – How Basic Behavior of LENR can Guide. A Search for an Explanation, JCMNS, **20** (2016), 105-143

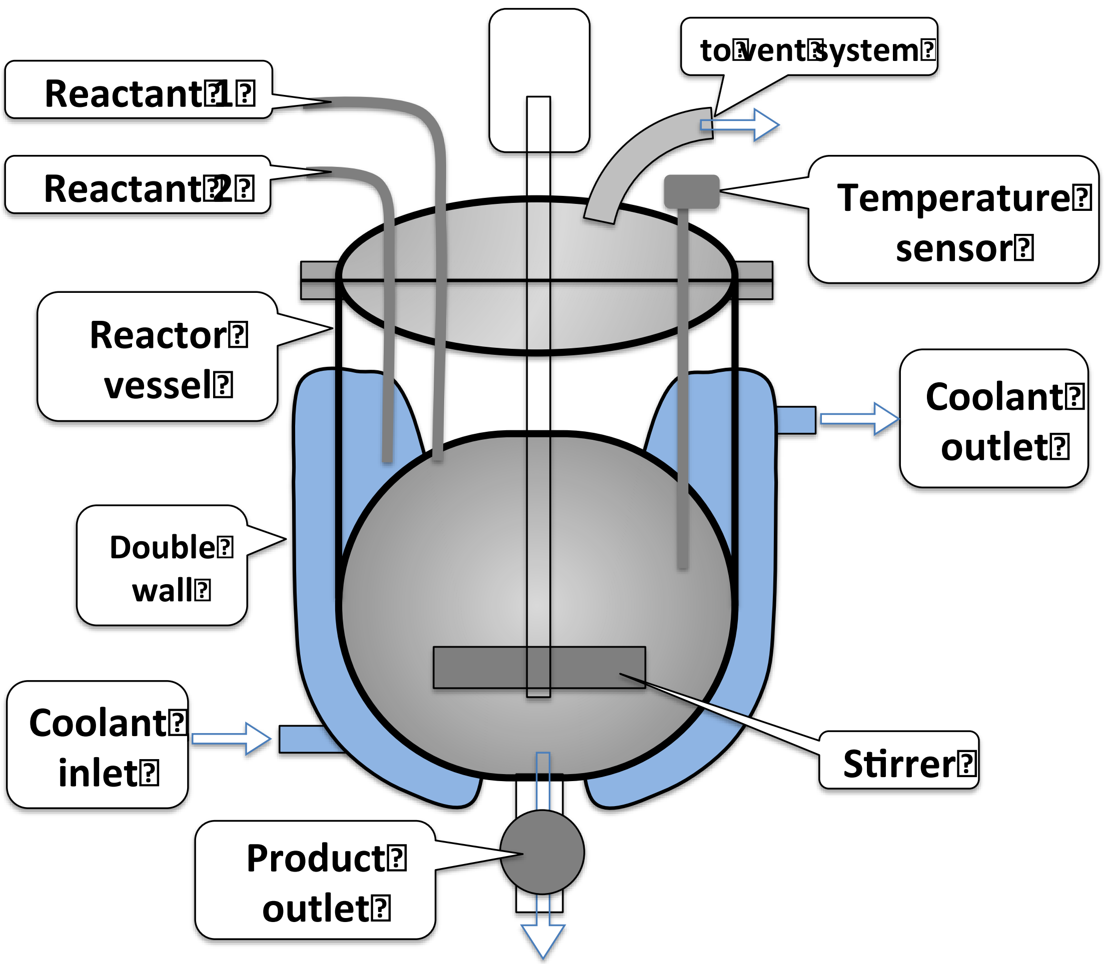
- **The stability of T activated reactors is frequently discussed with a diagram similar to this one**
- **Such diagrams refer to the operation of batch reactors in the chemical industry**

Batch reactor



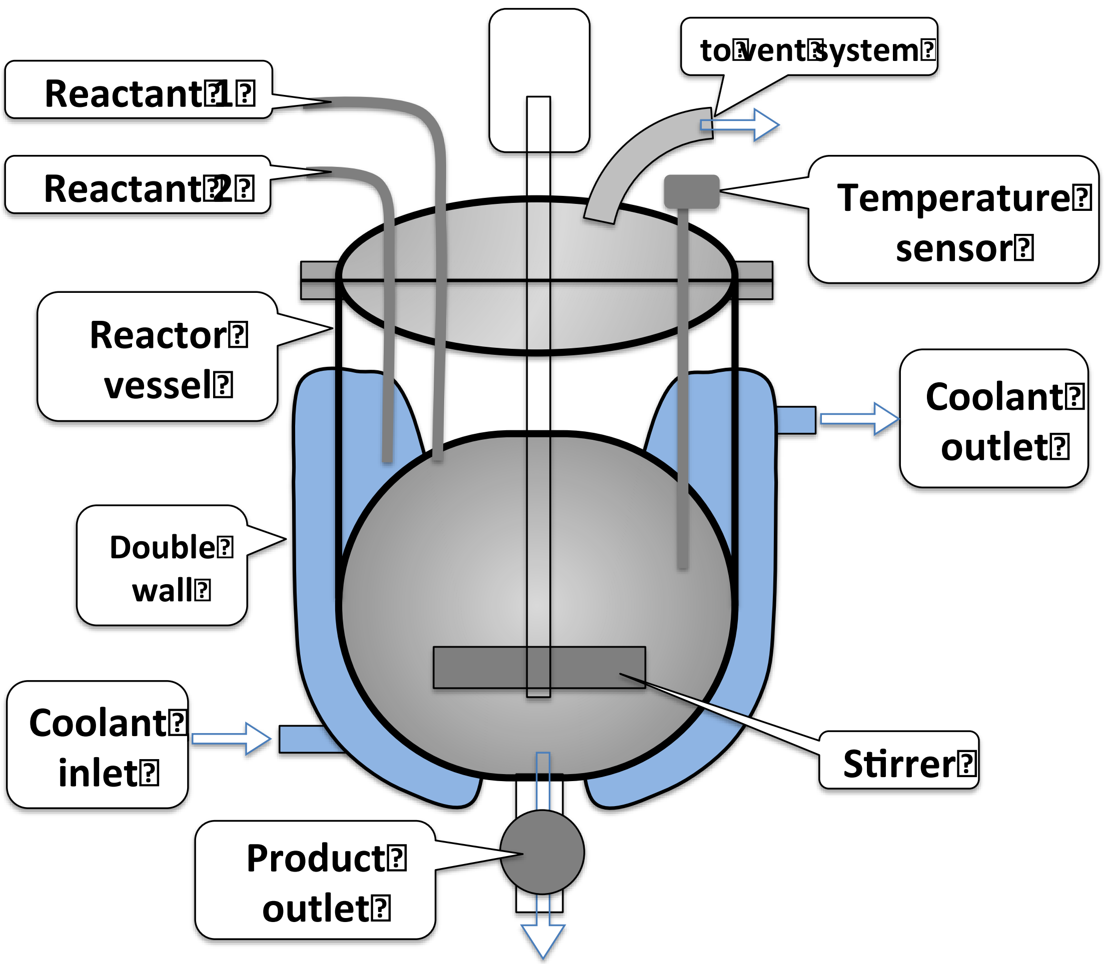
- Largely used for synthesis of many different chemical products
- The reactor is loaded with the reactants, the reaction is completed, the products are unloaded

Batch reactor



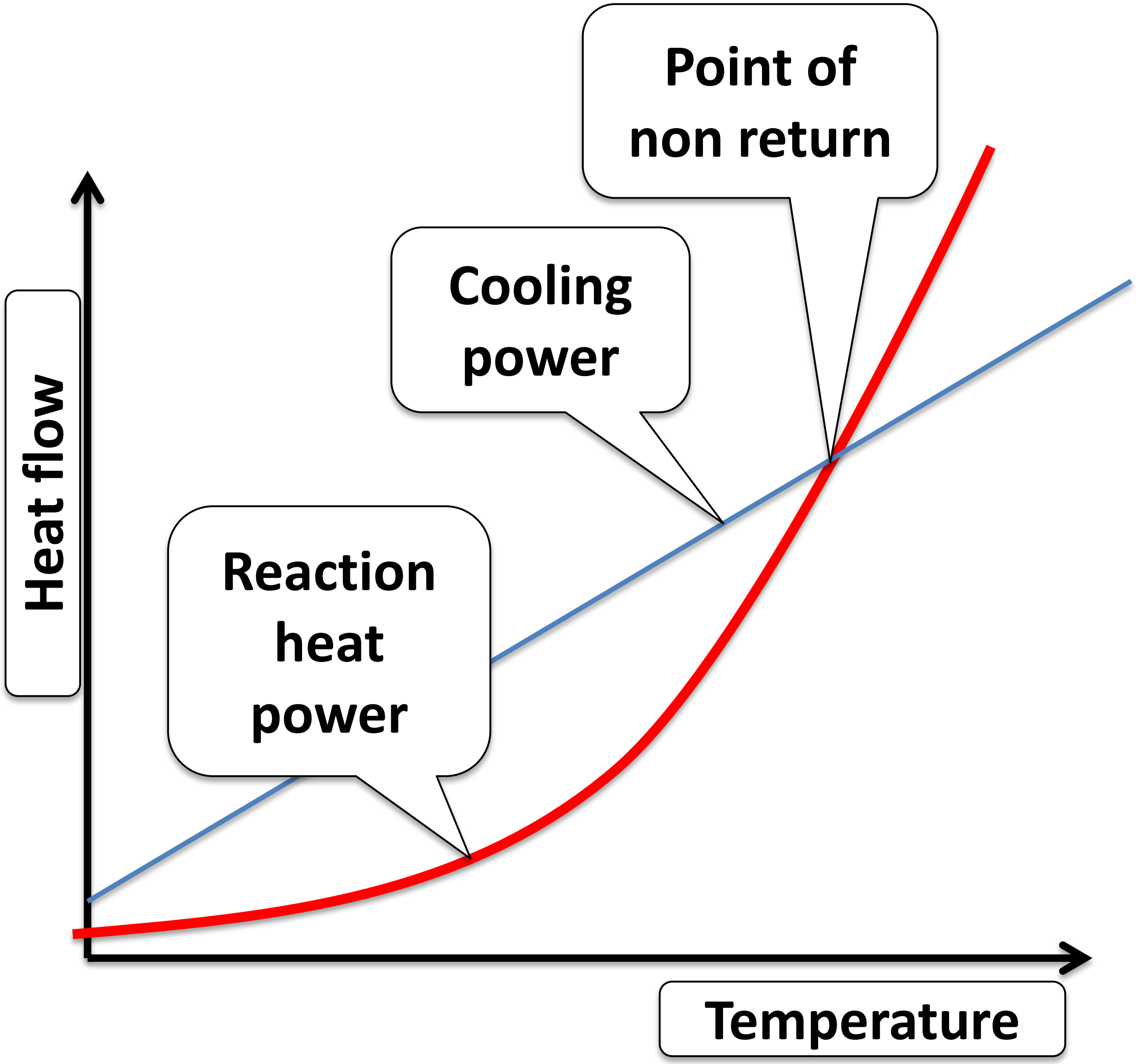
- **Endothermic reaction: Reaction controlled by heating, no problem**
- **Exothermic reaction: If temperature goes out of control, things may go wrong**

Batch reactor control



- **Temperature is controlled by the combination of wall cooling and stirring to enhance heat exchange between charge and wall**

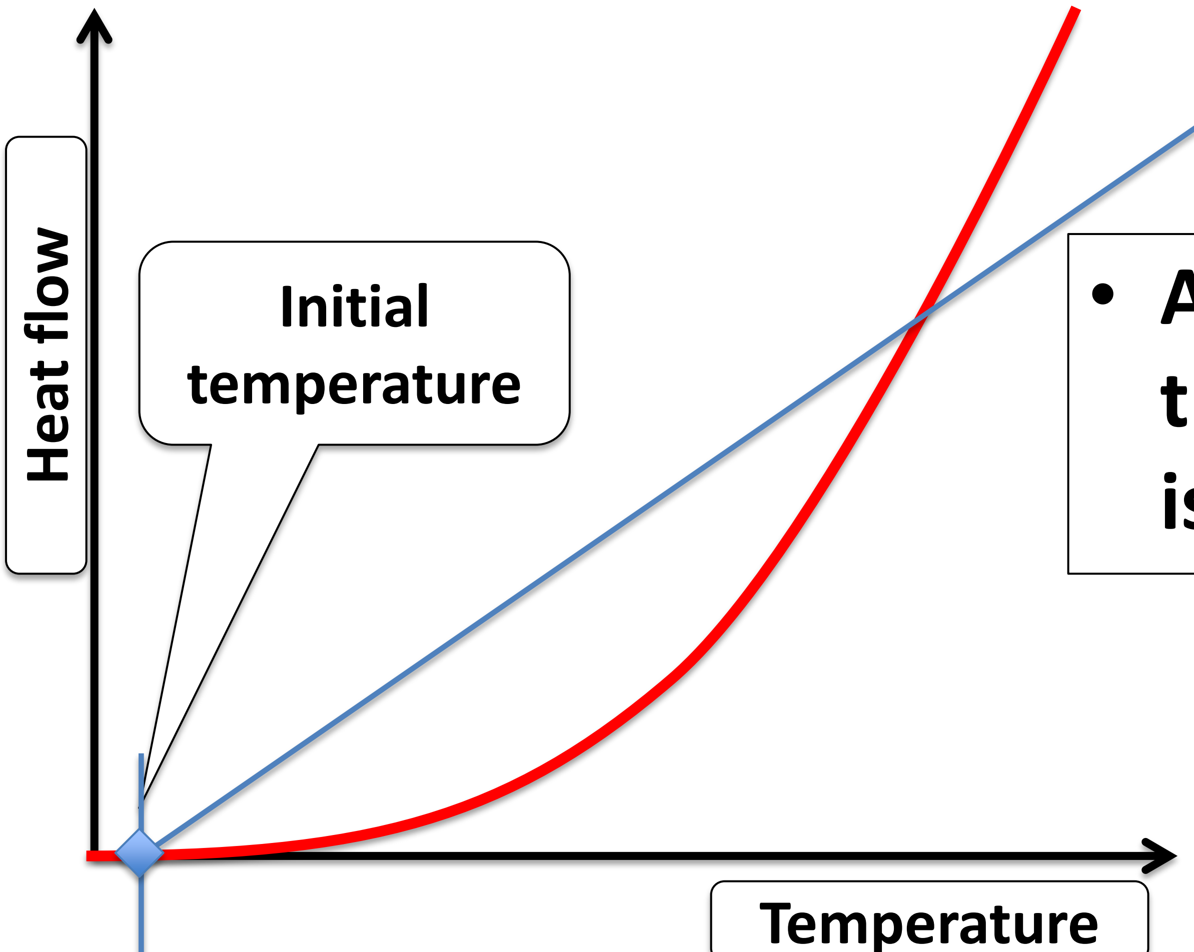
Batch reactor control



Basics:

- Temperature must be maintained below the point of non return at any time

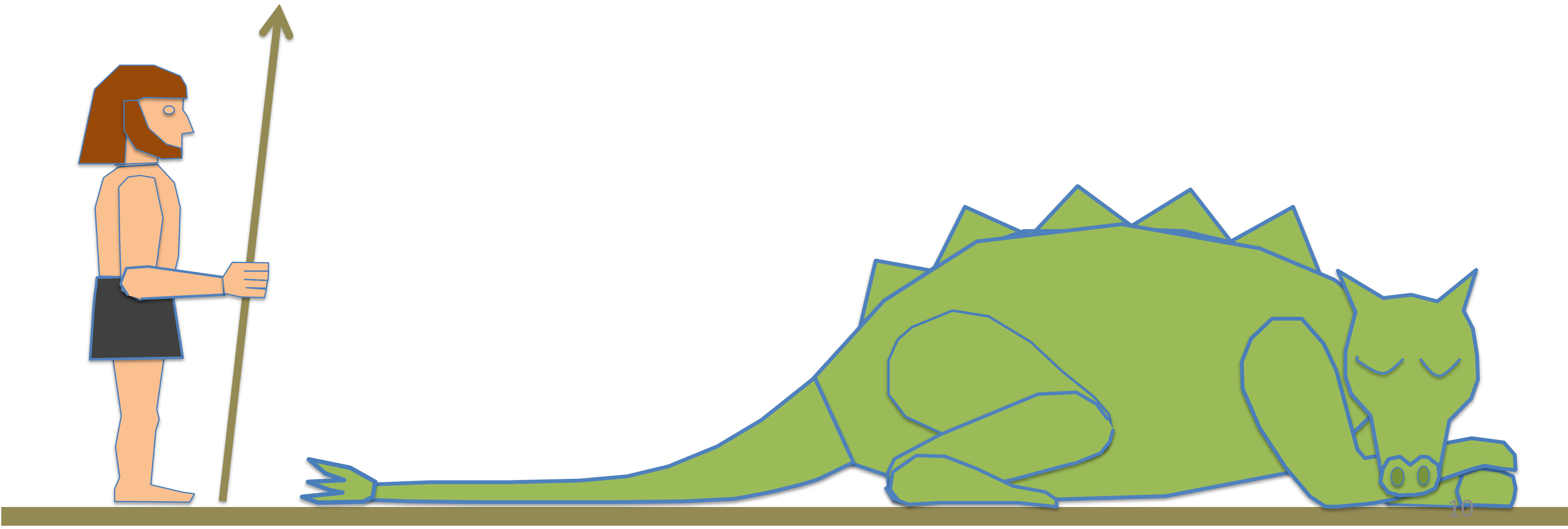
How to start the reaction ?



- After loading, the temperature is low

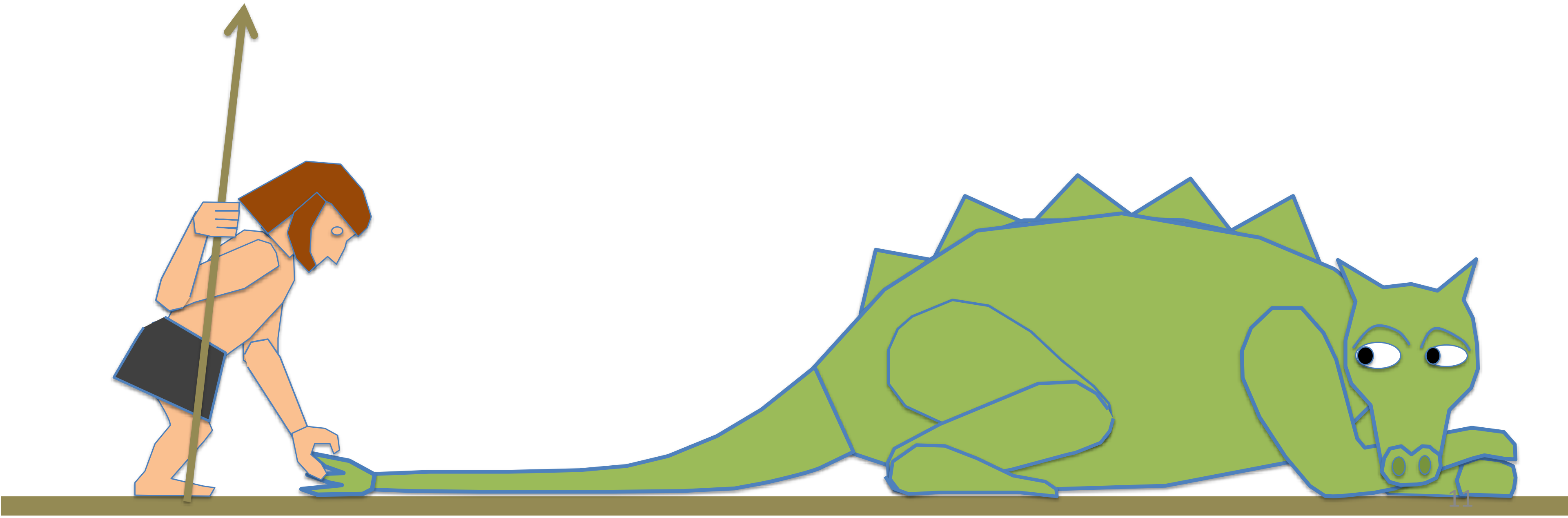
How to start the reaction ?

- As long as the temperature is low, the reaction has no reason to start

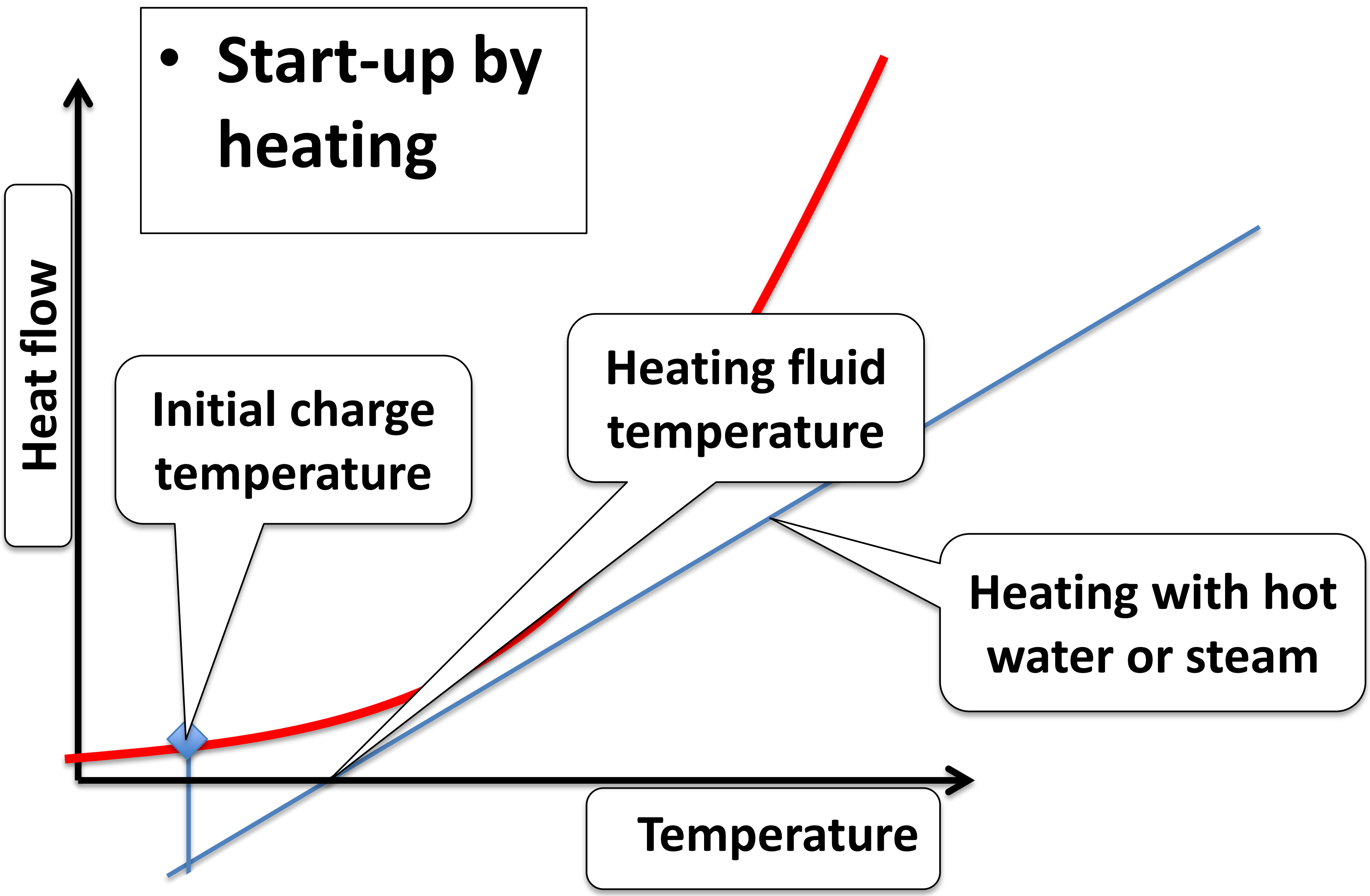


How to start the reaction ?

- To start the reaction you have to tease the dragon's tail

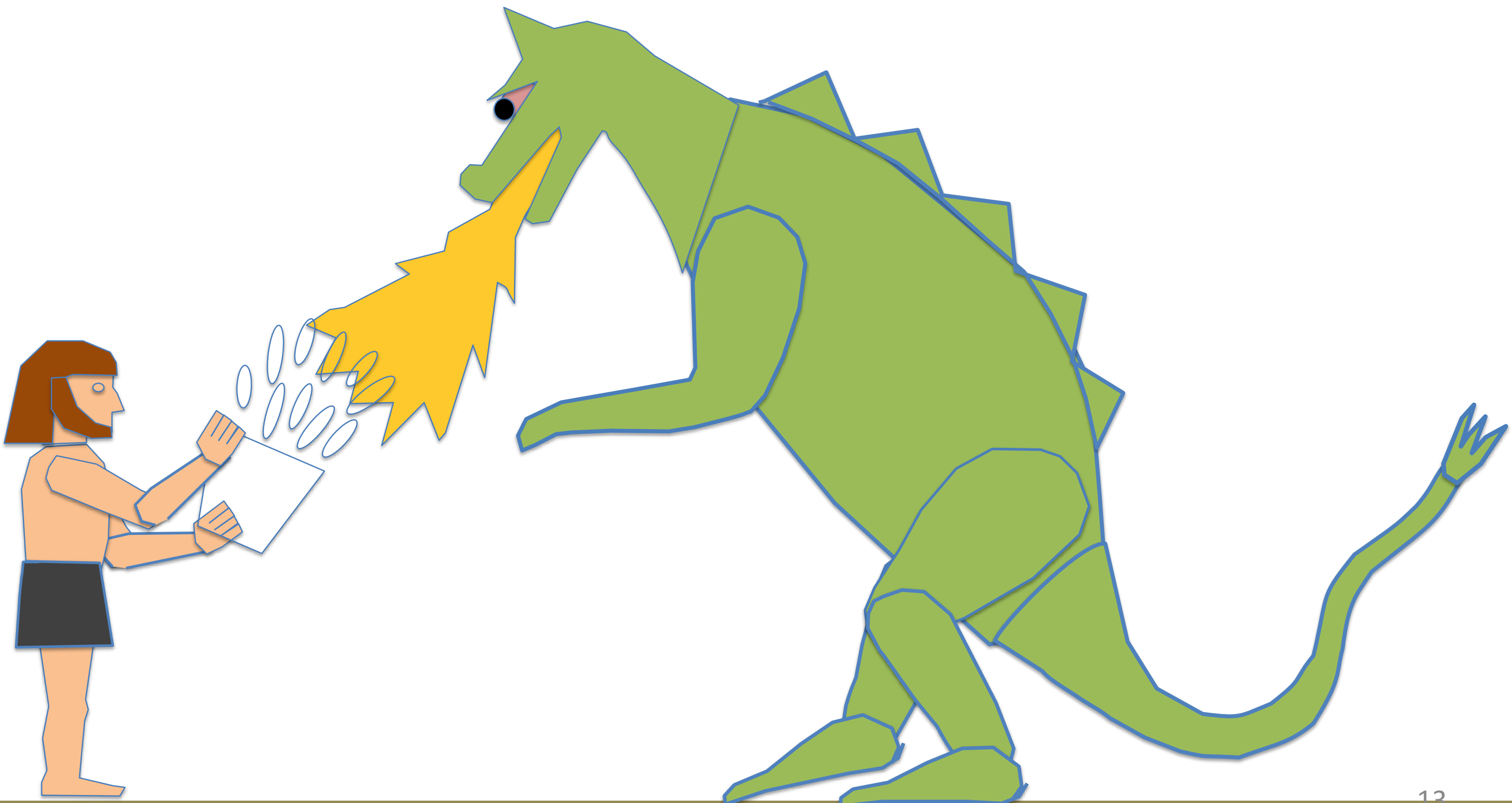


How to start the reaction ?



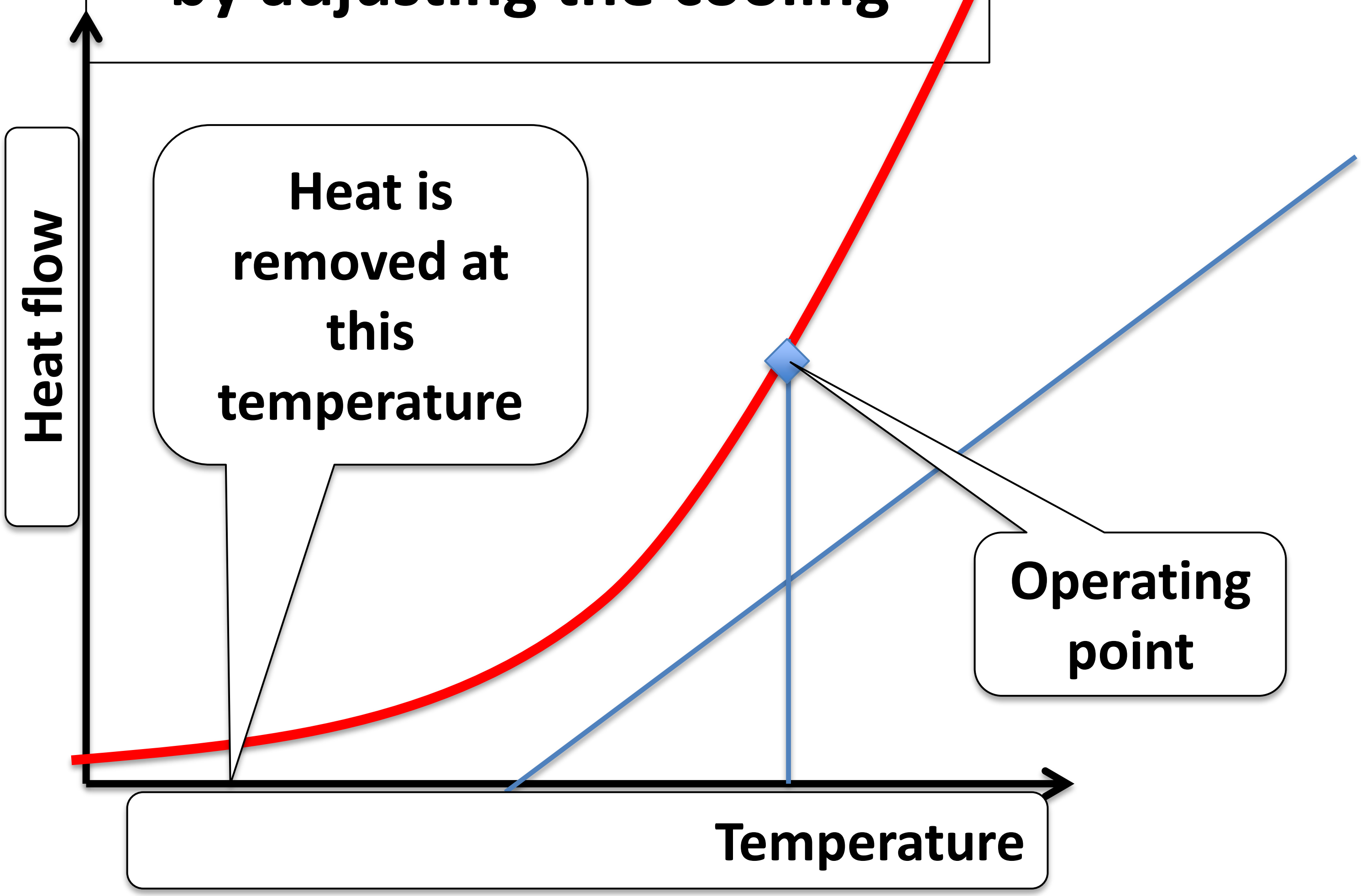
How to control the reaction ?

- **Taming the dragon with water cooling**



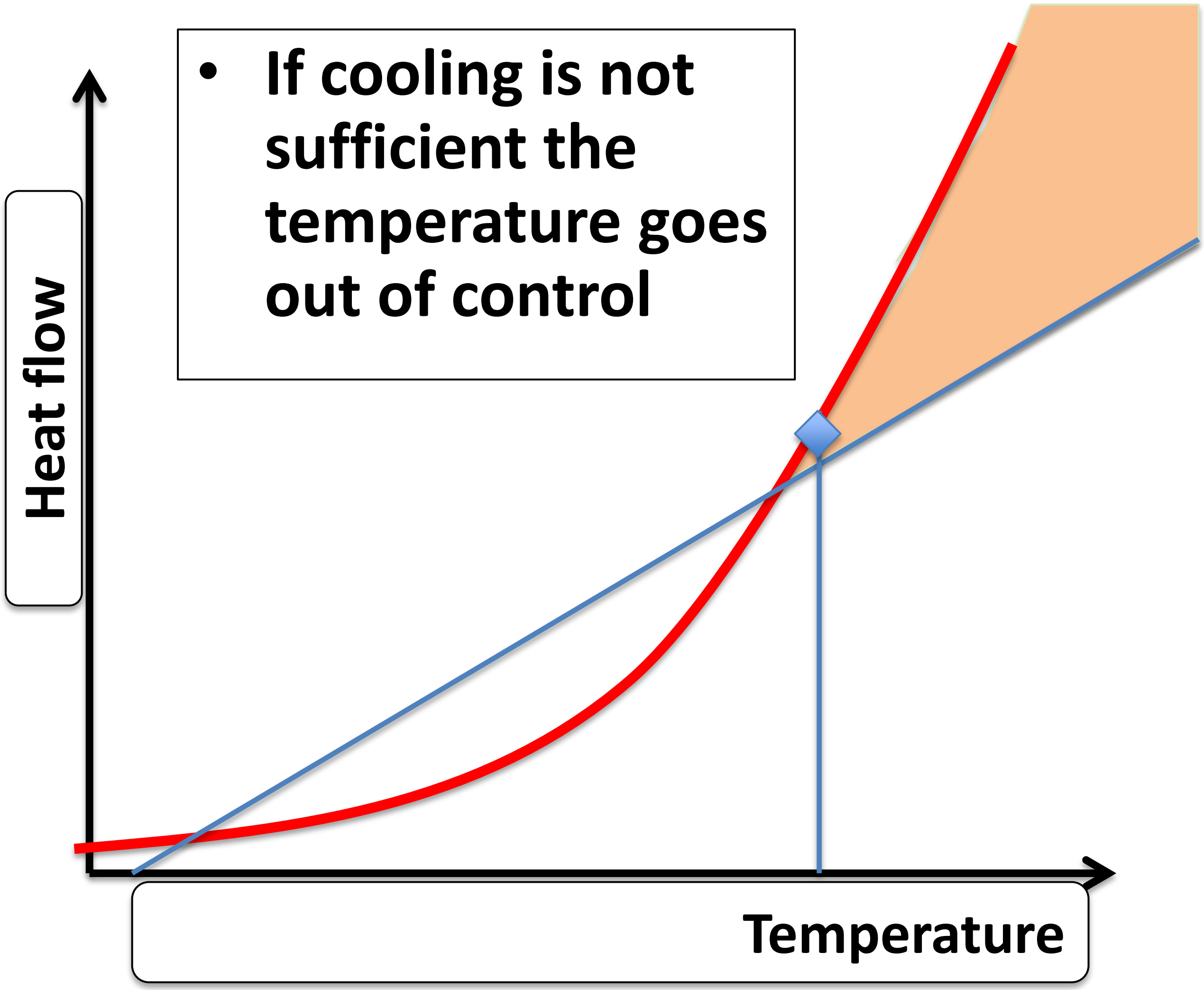
How to control the reaction ?

- Reaction rate is controlled by adjusting the cooling



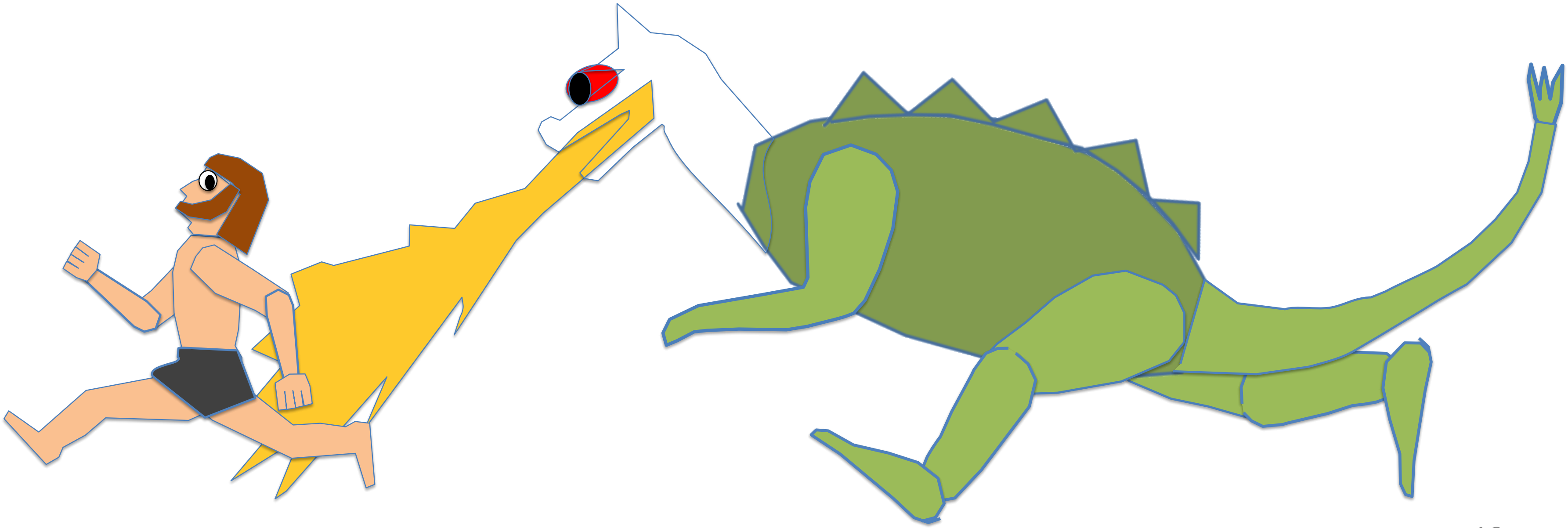
Loss of control

- If cooling is not sufficient the temperature goes out of control



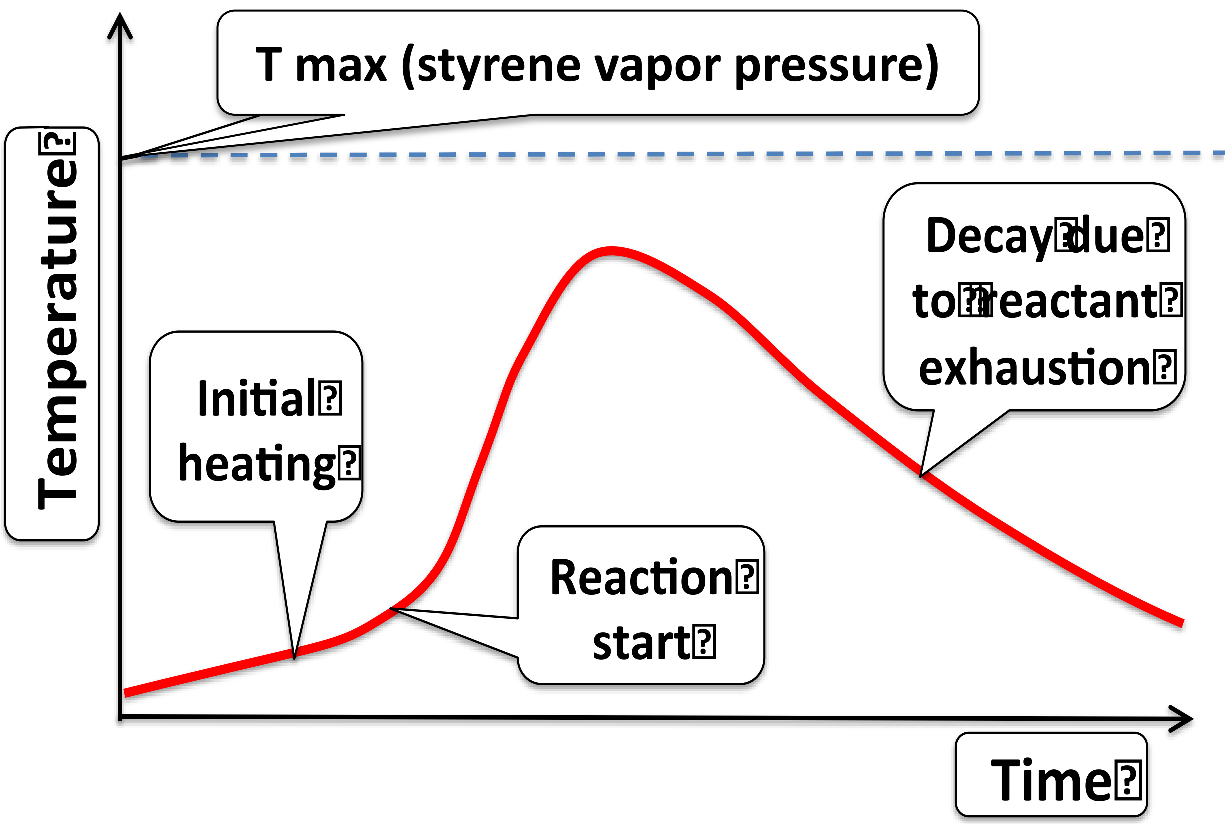
Loss of control

RUNAWAY !



Role of thermal inertia

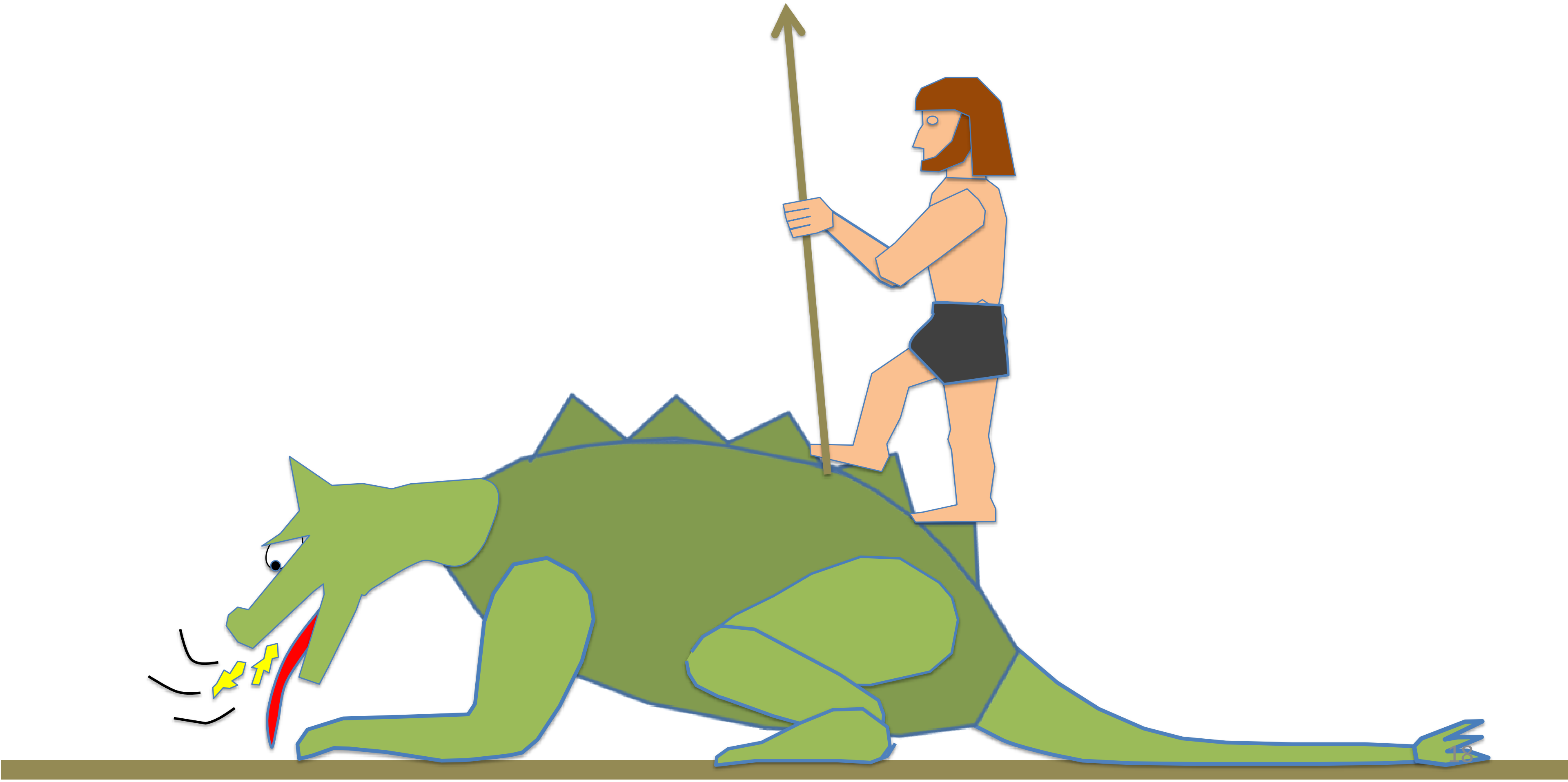
- <u>Example: Polystyrene polymerization</u>
- Reactor loaded with reactants at the beginning of the operation « All on board »



- T rises slowly because of thermal inertia
- T decays when reactants become exhausted

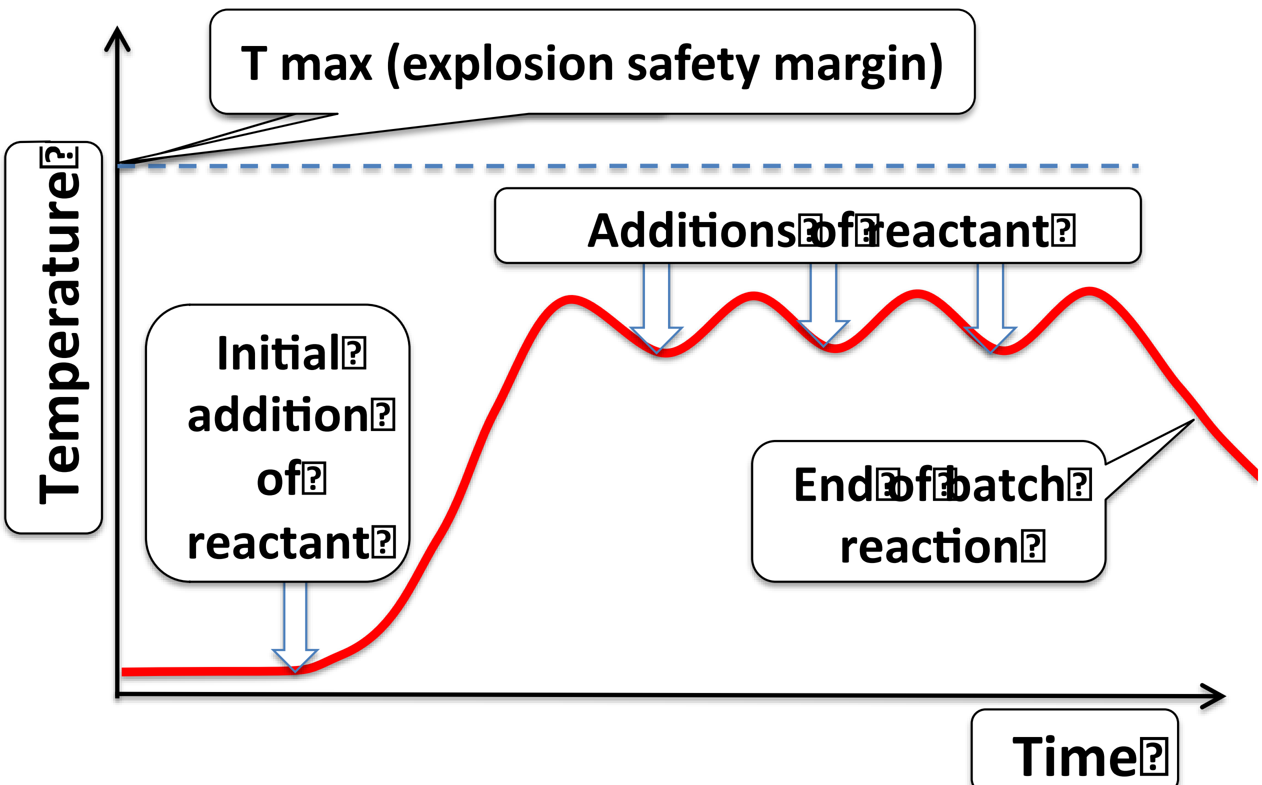
Control by thermal inertia

- **Exhausting the dragon**



Control of reactants input

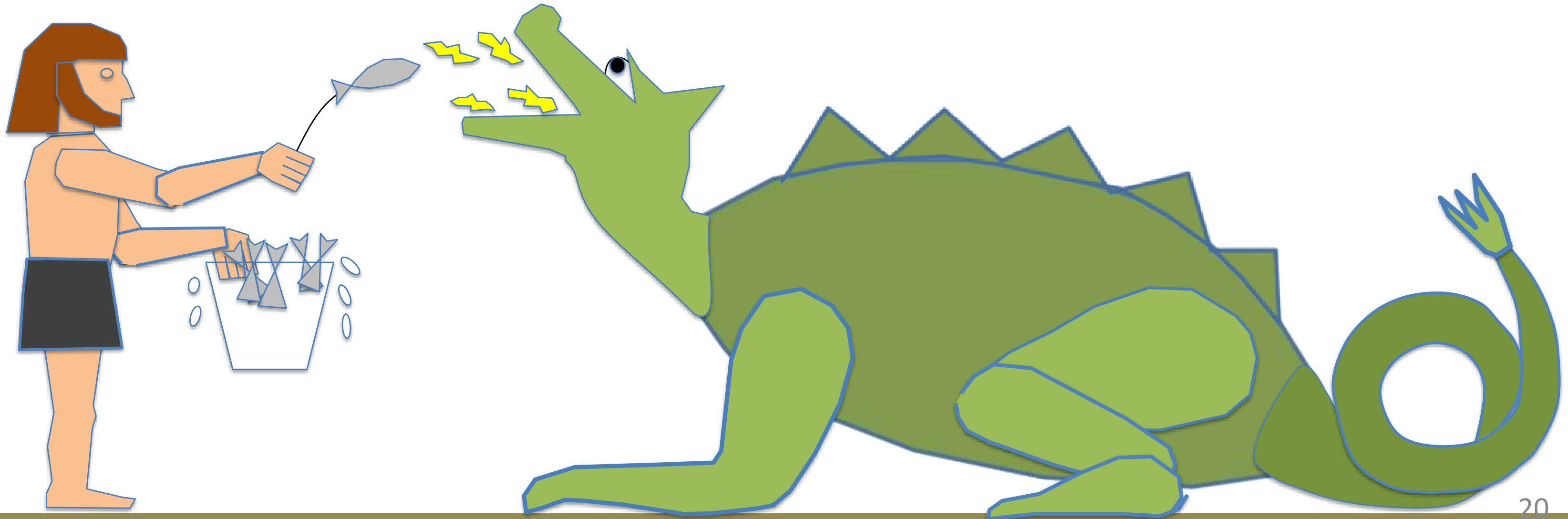
- <u>Example: Synthesis of nitroglycerin</u>
- Acid is added slowly to the charge



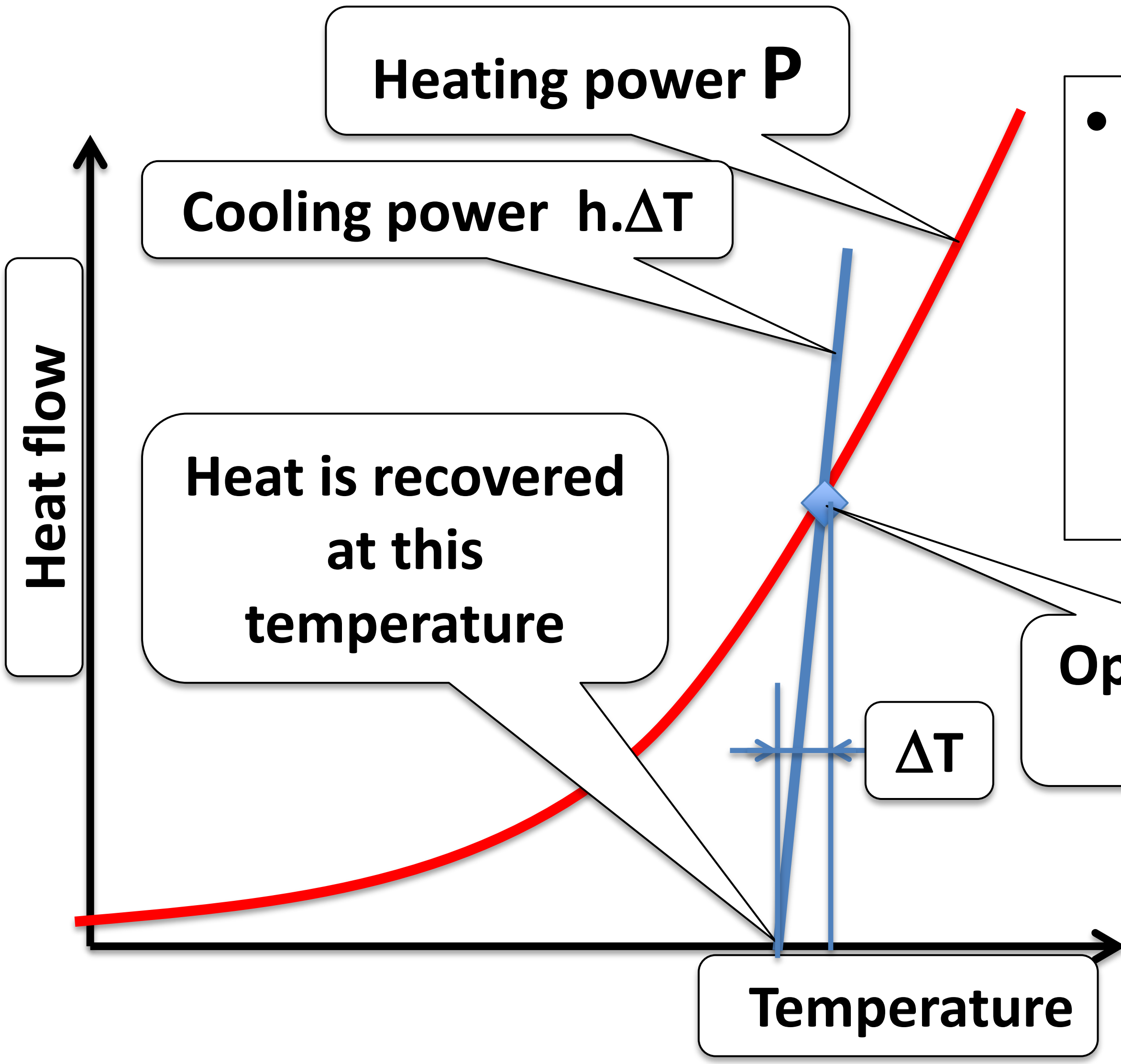
- Reaction start: 22°C
- If T> 30°C, the charge is dumped out in water

Control of reactants input

- **Feeding the dragon slowly**



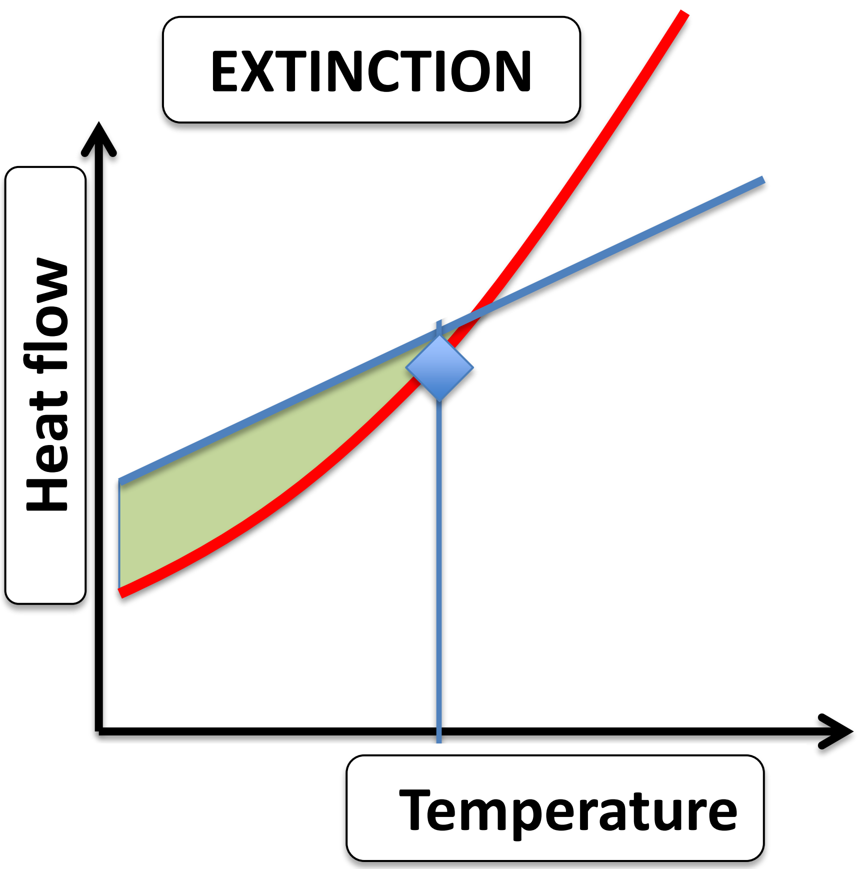
Control with a large heat exchange



- Reaction is controlled by adjusting the coolant temperature

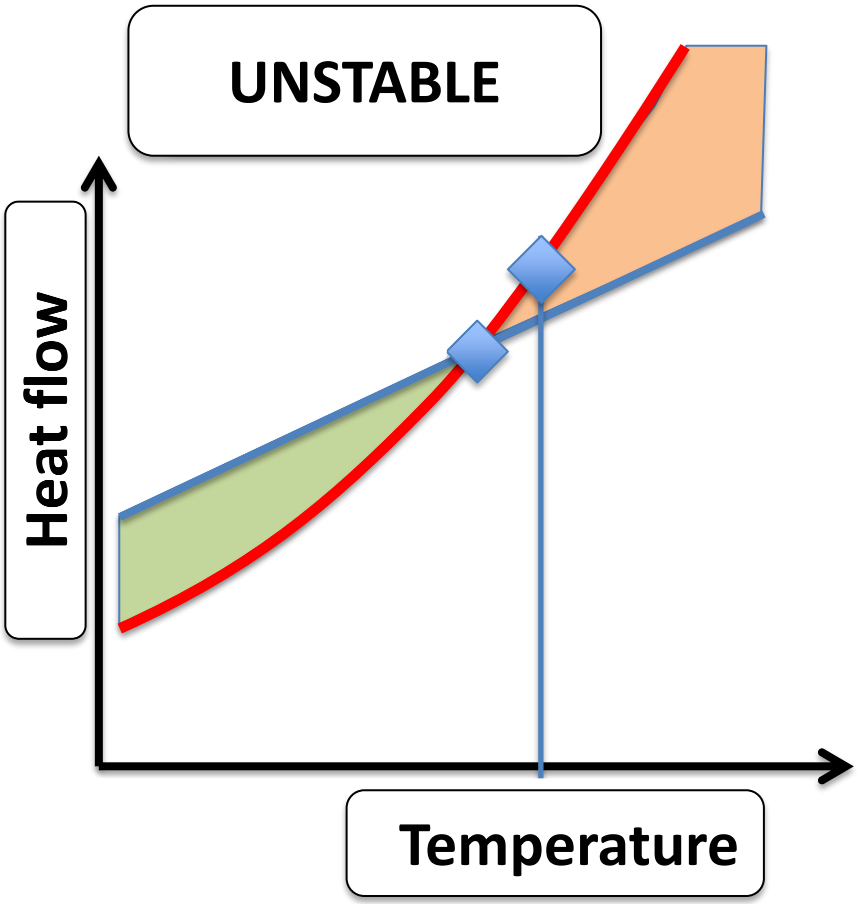
Stability

$$dP/dT > h_{cooling}$$



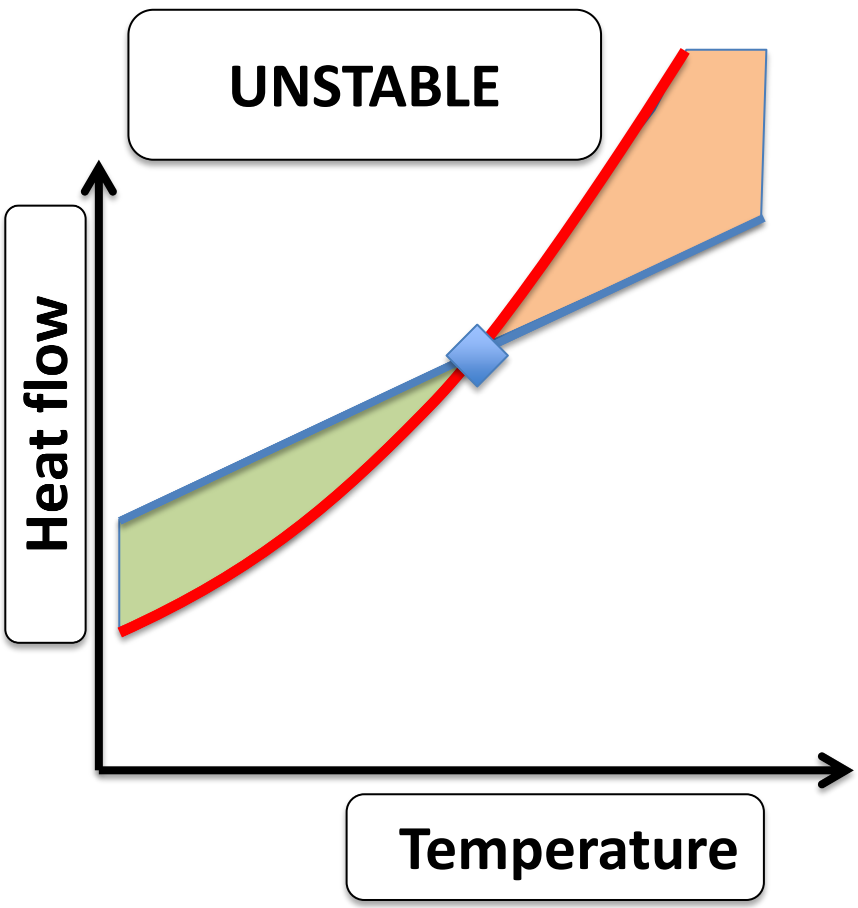
Stability

$$dP/dT > h_{cooling}$$

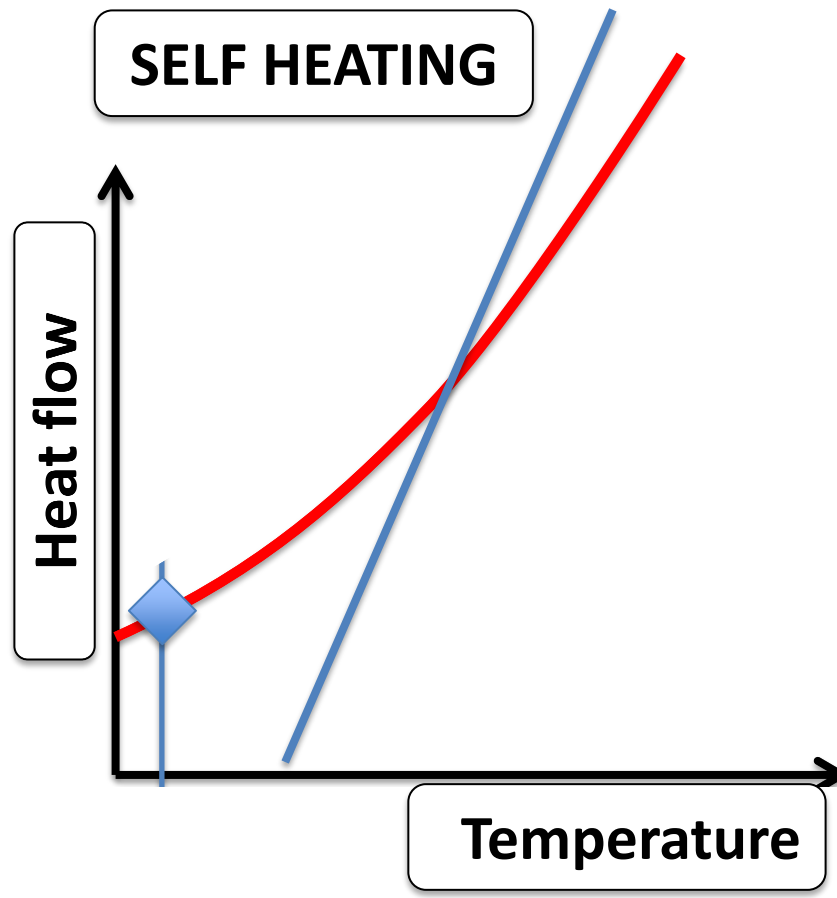


Stability

$dP/dT > h_{cooling}$



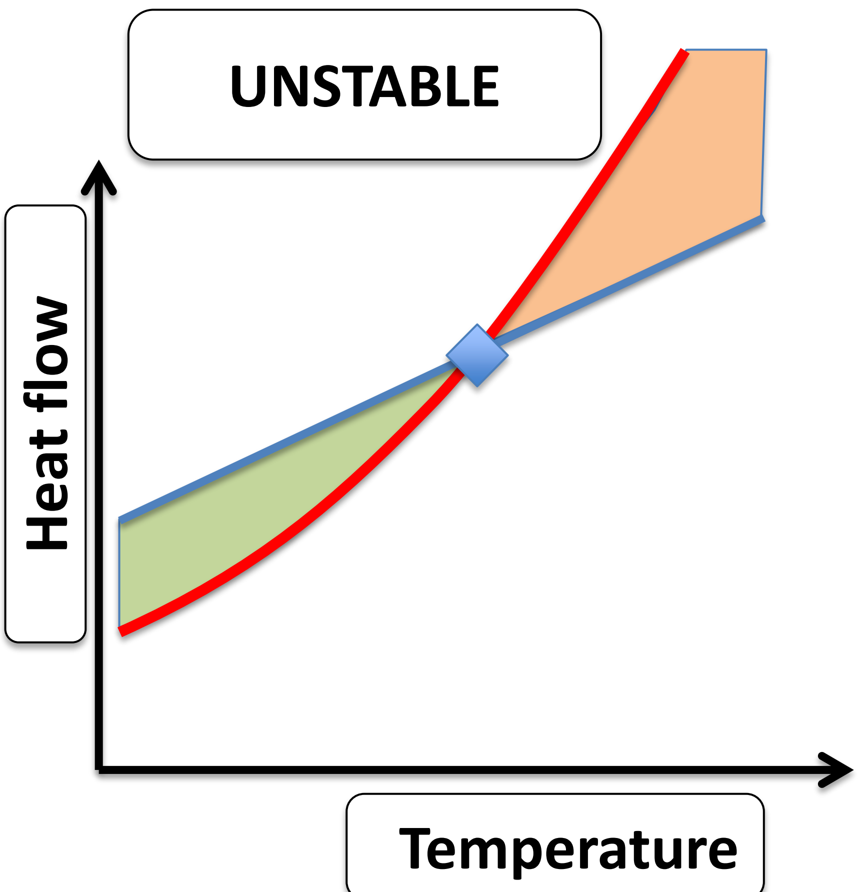
$dP/dT < h_{cooling}$

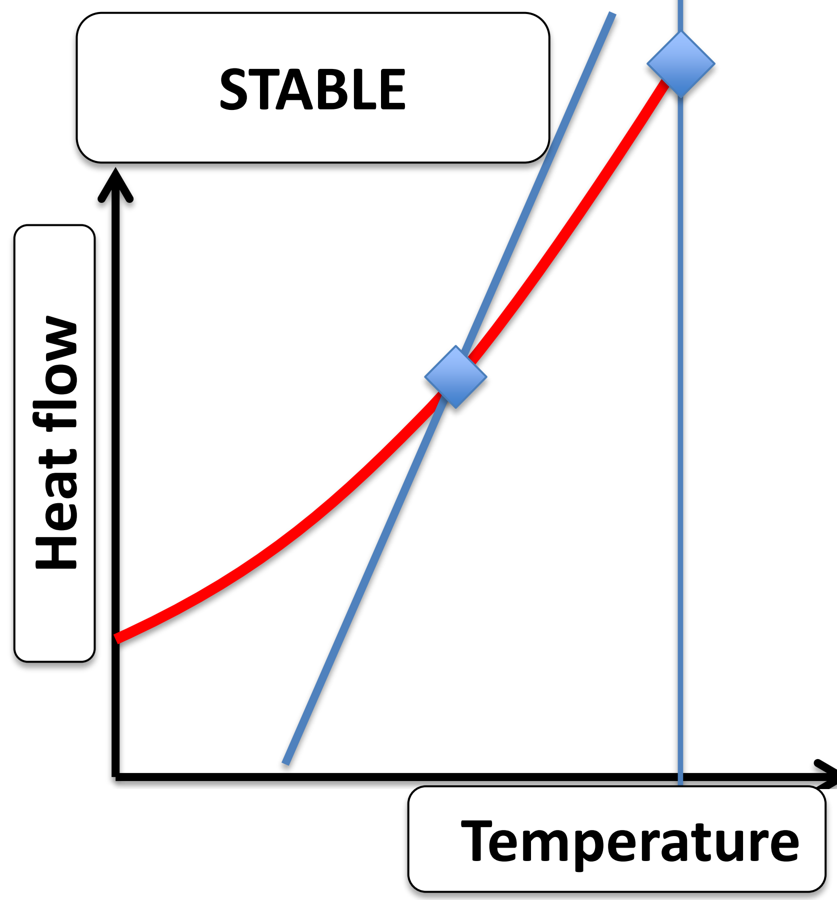


Stability

The reactor is stable if $h_{cooling} > dP/dT_{heating}$

$dP/dT > h_{cooling}$	$dP/dT < h_{cooling}$





Differences between LENR Reactor and Batch Reactor

- LENR : Reaction is continuous
- Thermal inertia can only help during transients
- Activation energy may be high, so that temperature sensitivity may be high
- Heat is preferably recovered at high temperature (for conversion efficiency)

- **Reference to the thermal behavior of batch reactors is inappropriate**

Continuous reactors

- In the chemical industry some reactors are designed for continuous operation

- Example : Production of synthetic fuels by the **Fischer-Tropsch process**

Fischer-Tropsch Process

- Production of synthetic fuels from $CO+H_2$ gas
- Reaction (synthesis of alkanes - simplified) :

$$\mathbf{nCO + (2n+1)H_2 \text{ ------> } C_nH_{2n+2} + nH_2O}$$

$$\mathbf{\Delta H = -n.165kJ}$$

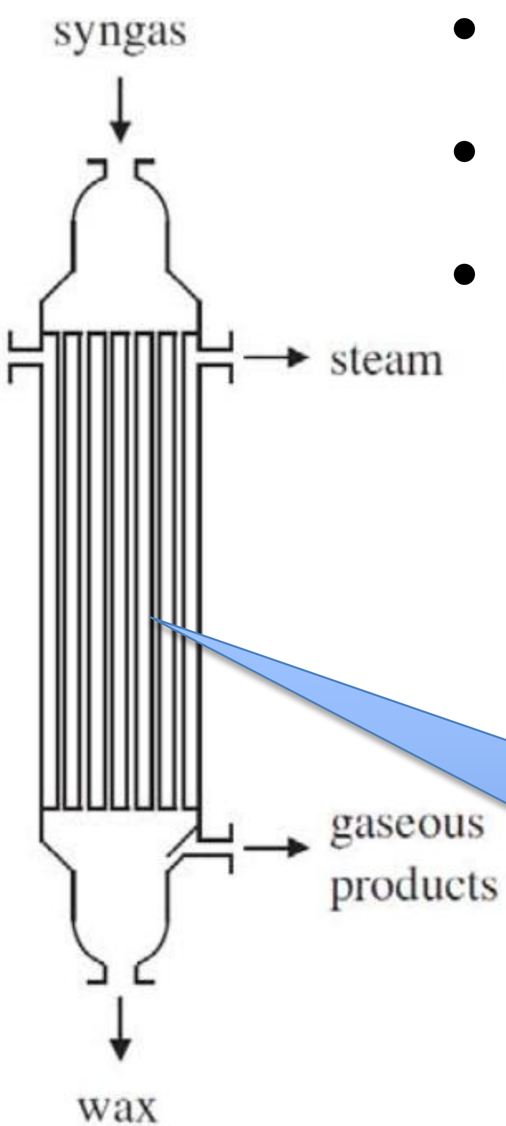
- Yields a blend of hydrocarbons : methane, gasoline, distillates, waxes, etc.
- The proportions depend on the type of catalyst (Fe-Co-Ni) and the process conditions (pressure and temperature)

Fischer-Tropsch Reactors

- FT reactors must be designed to allow an efficient control of the heat flow:

1. The reaction is highly exothermic
2. The temperature must be maintained in a narrow range to produce the valuable hydrocarbons

Fischer-Tropsch Reactors



- **Example:**
- **Multitube reactor ARGE design**
- **2000 tubes dia 50mm**
  - **Main features:**
    - **High heat transfer capability**
    - **Initial heating and heat removal by a hot fluid (steam)**

Fischer-Tropsch Reactors

Figure 14: Velocys microtubular reactor.

- **Some concepts utilize microchannels technology to ensure a very high heat exchange and a uniform temperature in the reactor**

Multitube design

Multitube design is already used in the nuclear industry to guarantee the high heat flux required This design provides an efficient heat transfer, limits the surface temperature of the tubes and avoids water splitting

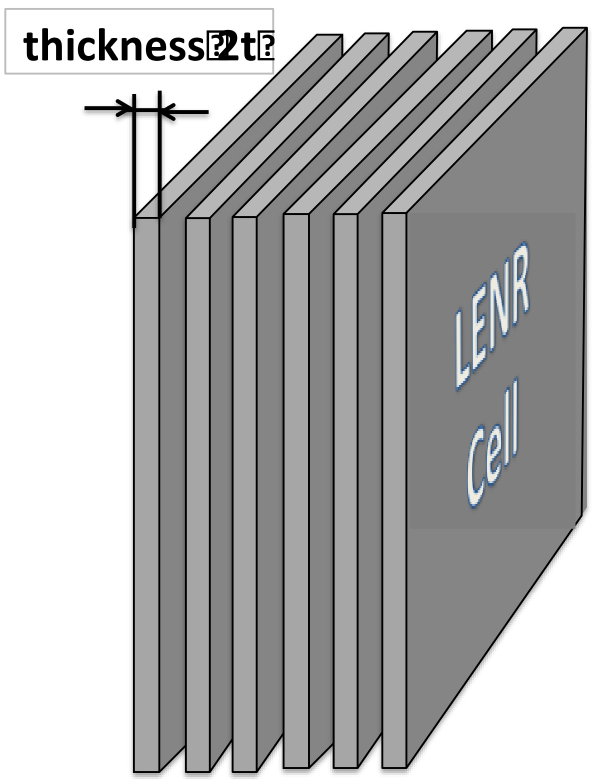
Nuclear fuel assembly for a PWR

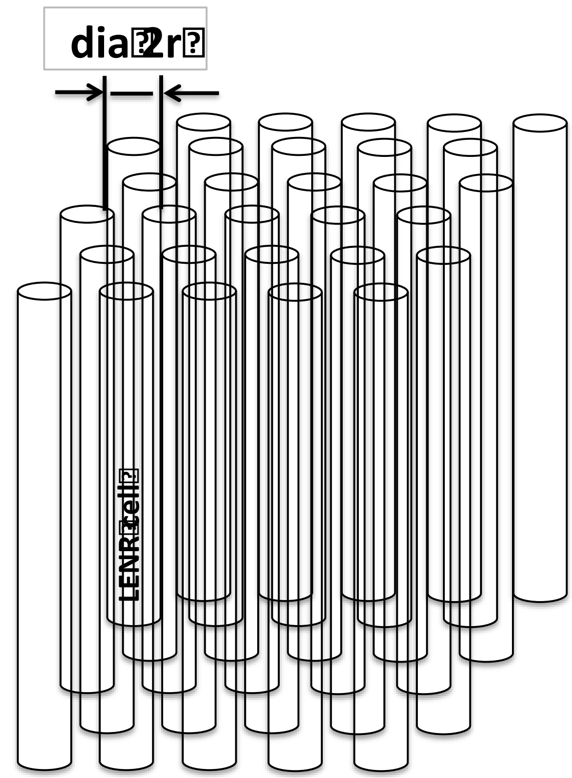
Potential design LENR systems

- **LENR reactors can be controlled via the cooling fluid temperature**
- **Additional control possible for some types of reactors via gas pressure, electrical excitation input, etc.**
- **If the reactor is sensitive to the temperature, a high heat exchange design is compulsory**

Plate and tubular types LENR reactors

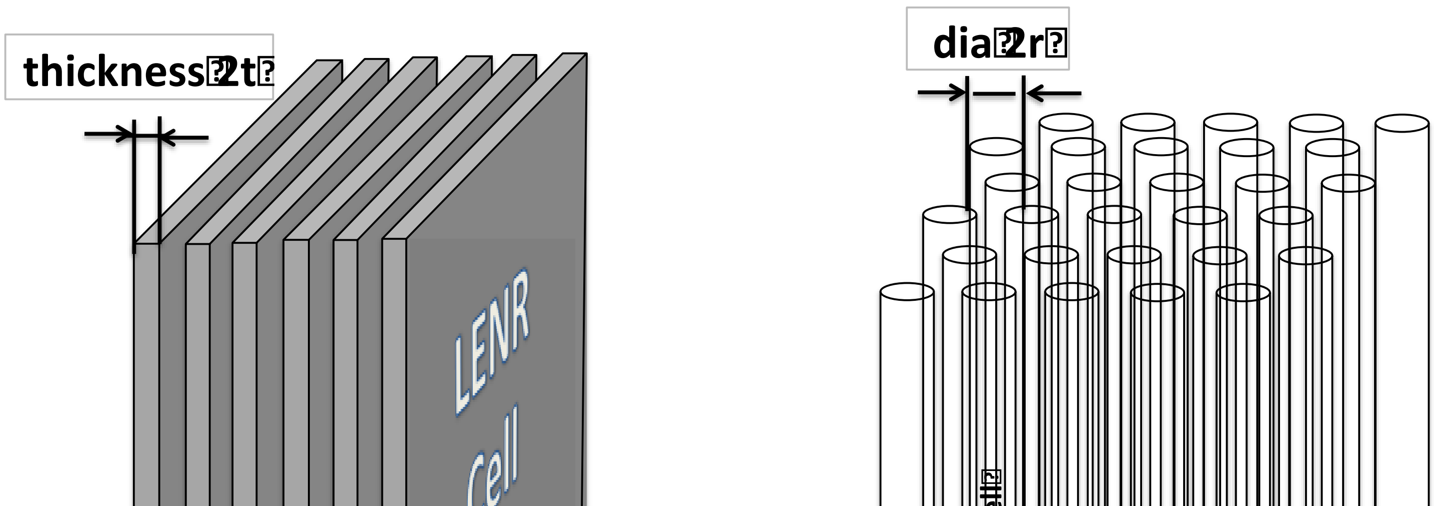
Cells immerged in a forced flow of cooling fluid





Condition for stability ?

Plate and tubular types LENR reactors

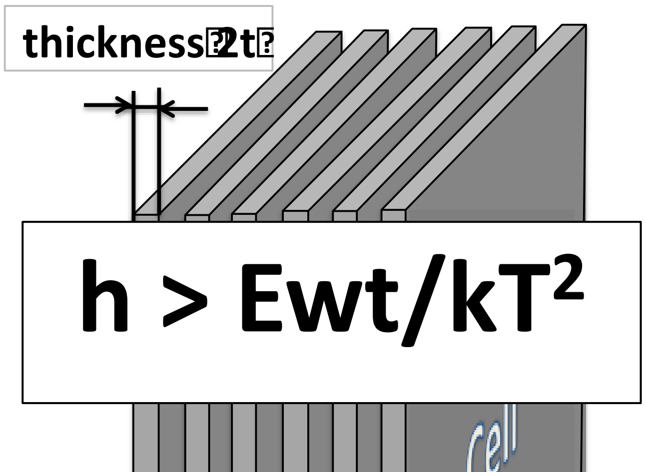


Hypotheses:

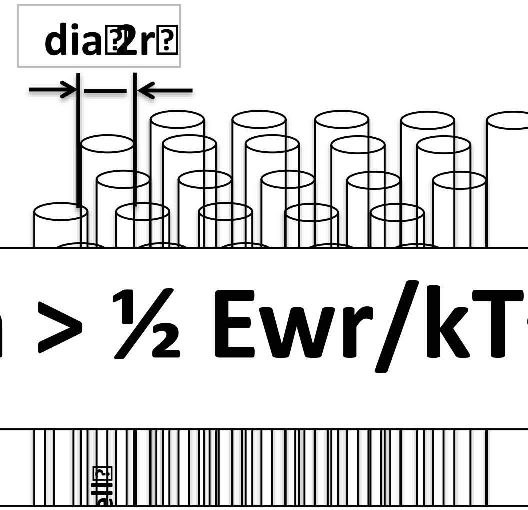
LENR specific power :	w ($W.m^{-3}$)
Arrhenius' law activation energy :	E (J)
Operating temperature :	T (K)
Heat exchange coefficient :	h ($W.m^{-2}.K^{-1}$)

Plate and tubular types LENR reactors

Conditions for stability



$$h > Ewt/kT^2$$

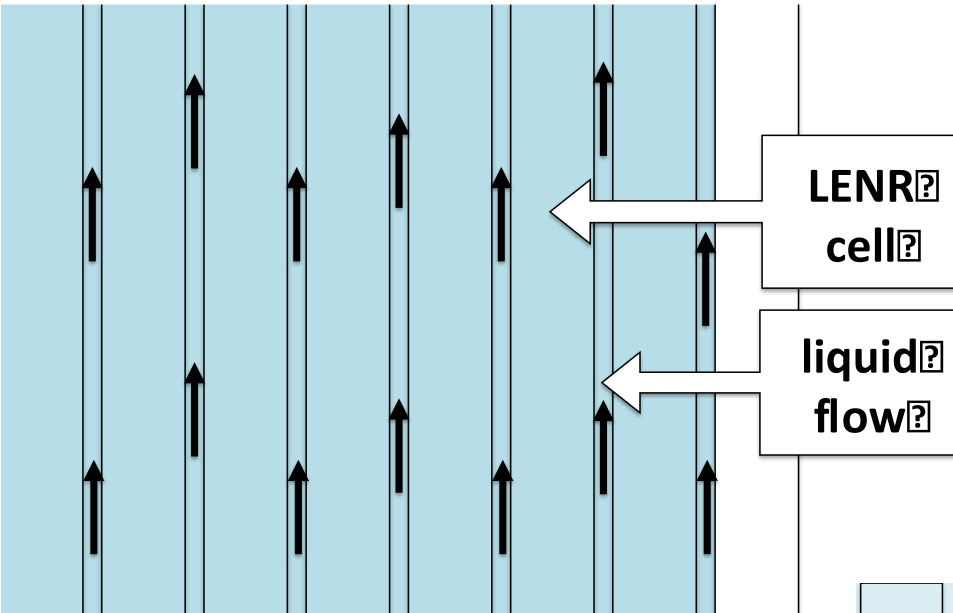


$$h > \frac{1}{2} Ewr/kT^2$$

Hypotheses:

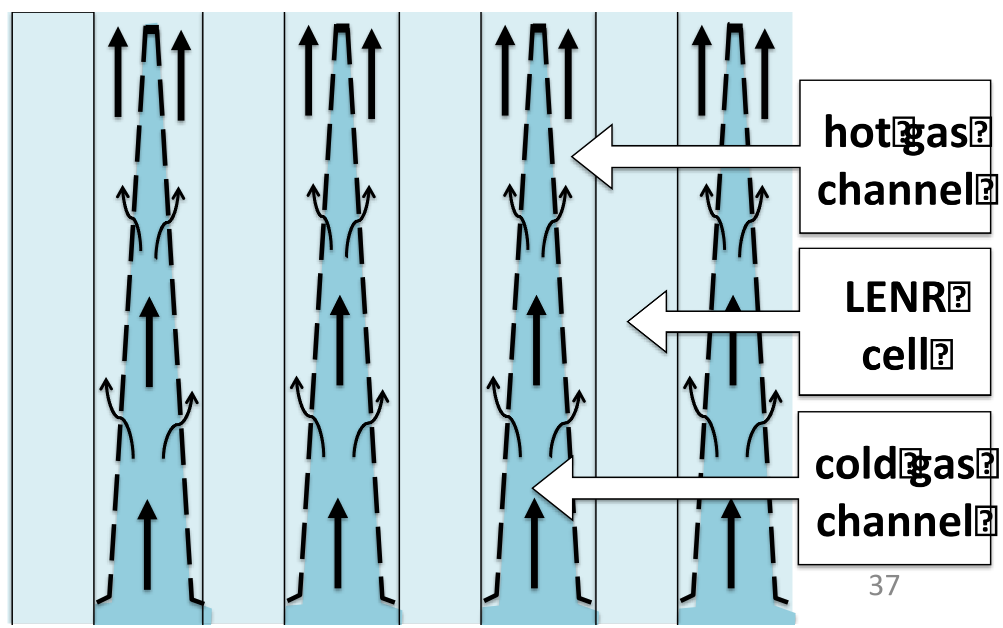
LENR specific power :	**w ($W.m^{-3}$)**
Arrhenius' law activation energy :	**E (J)**
Operating temperature :	**T (K)**
Heat exchange coefficient :	**h ($W.m^{-2}.K^{-1}$)**

LENR Reactor Heat Control



- Heat exchange by forced liquid flow and/or boiling liquid

- Heat exchange by forced organized gas flow



How to improve the COP ?

Temperature controlled reactor : COP = (Ein + Exs) / Ein

Small reactor : Low volume / surface ratio

High heat losses

Ein >> Exs

HIGH HEAT LOSSES

How to improve the COP ?

Temperature controlled reactor : COP = (Ein + Exs) / Ein

Cluster of many reactors : High volume / surface ratio

Low heat losses

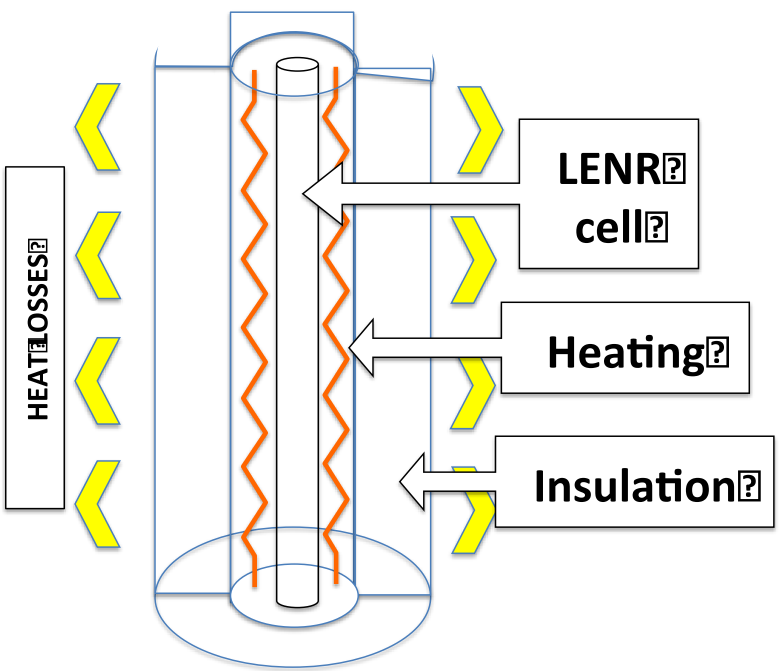
Exs >> Ein

HIGH HEAT LOSSES

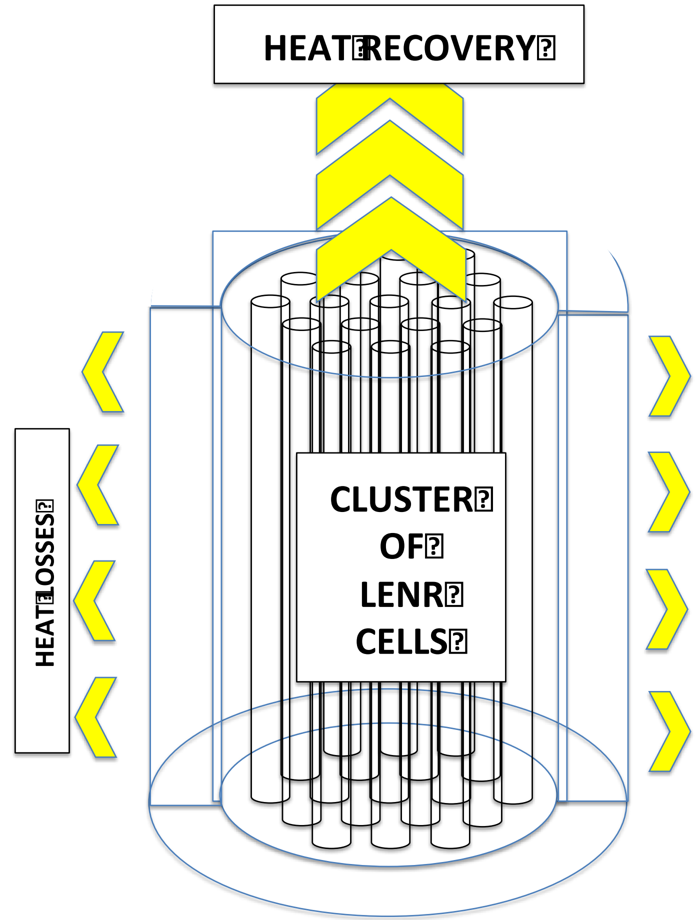
LOW HEAT LOSSES

How to improve the COP ?

Temperature controlled reactor : COP = (Ein + Exs) / Ein

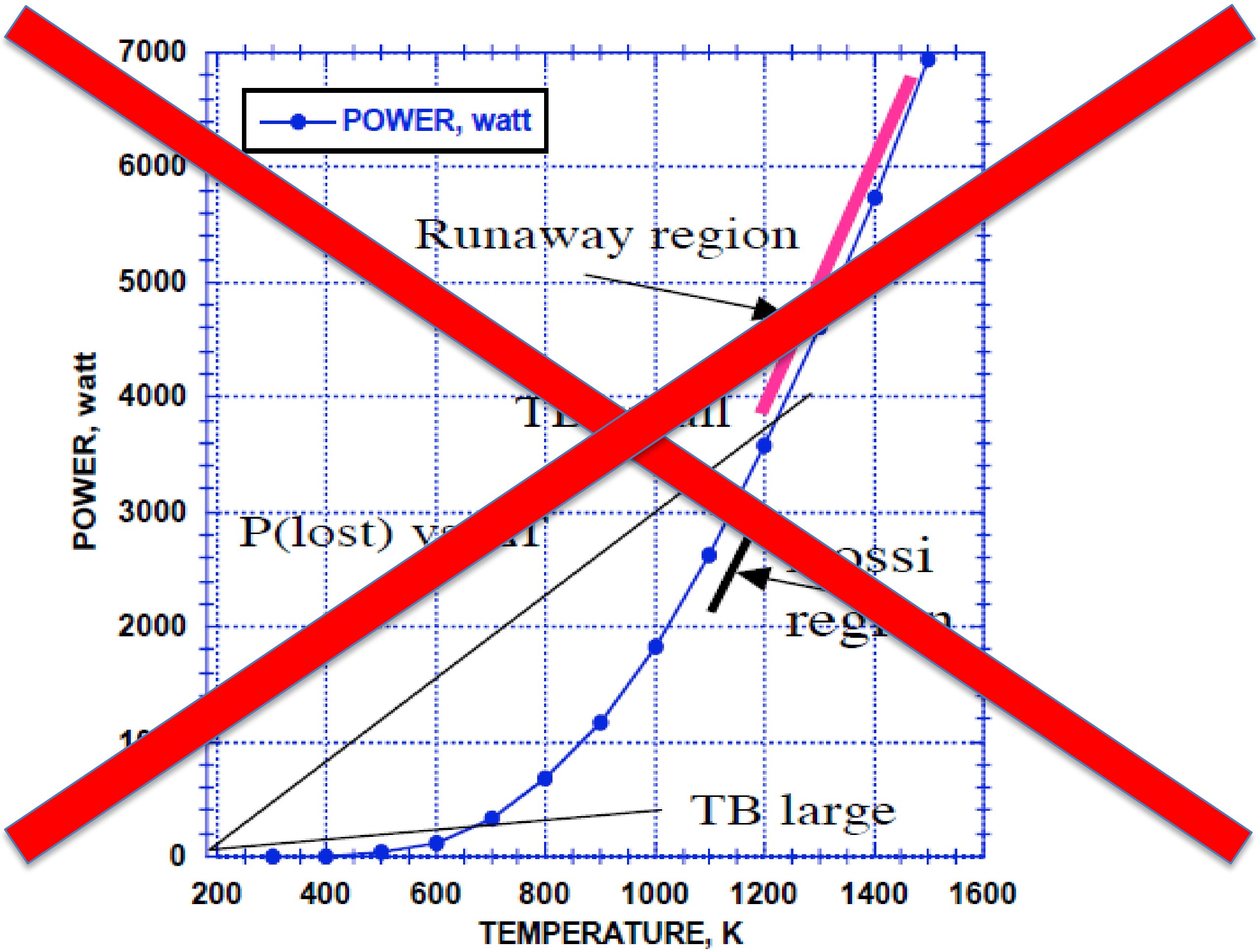


COP = 1.X



COP >> 1

Please do no longer refer to such diagrams for continous LENR reactors



Thank you for your attention