Eidgenössische Technische Hochschule Zürich
Swiss Federal Institute of Technology Zurich

Spallation Drilling for Deep Heat Mining

July 2, 2007

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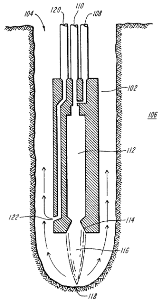
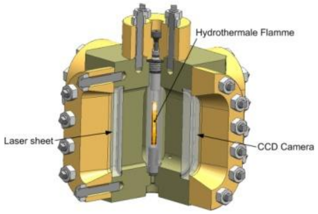
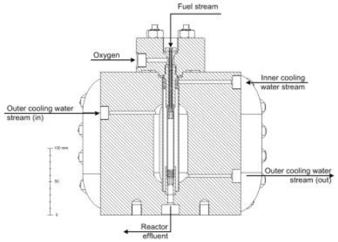
Overview



Spallation Drilling

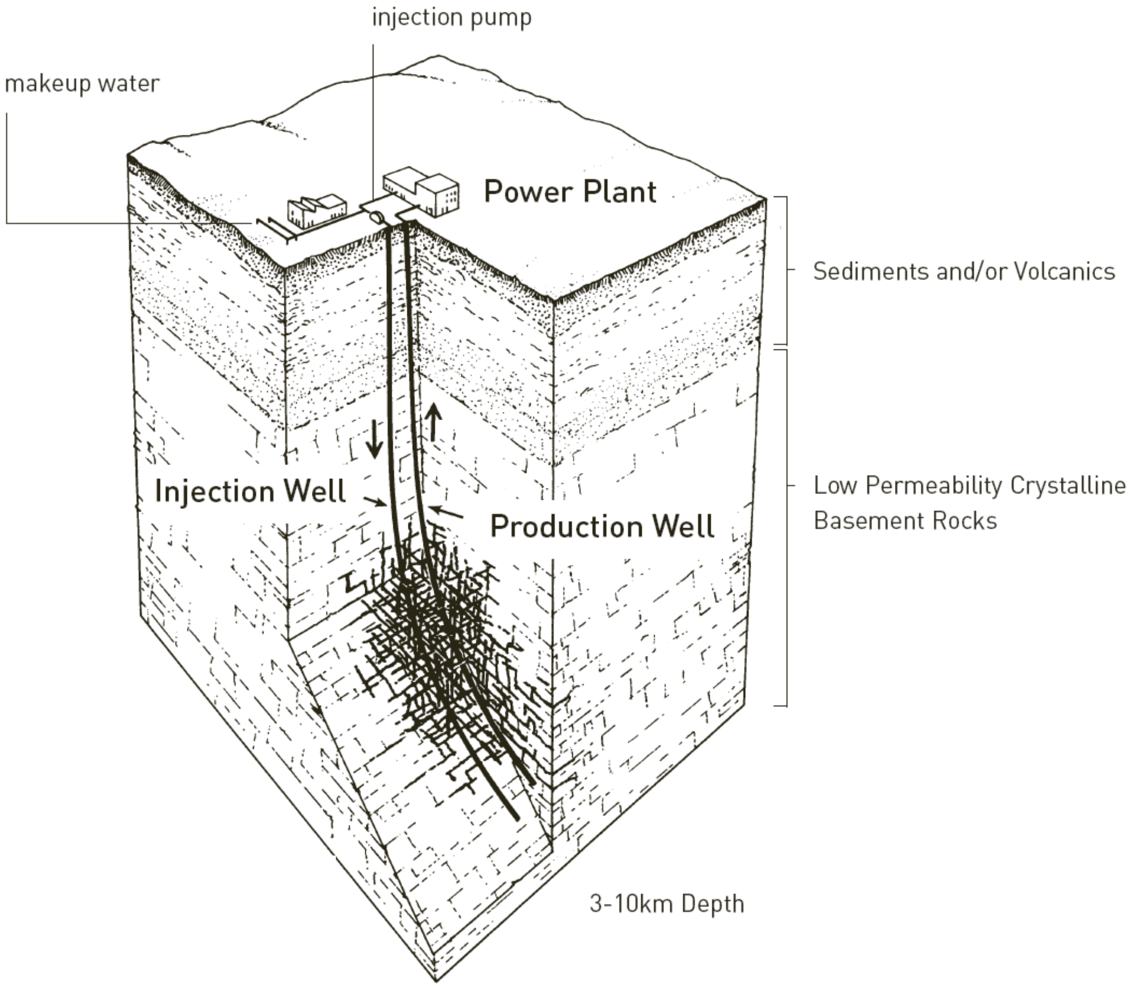


Previous Work: SCWO



Ideas for New Project

Deep Heat Mining



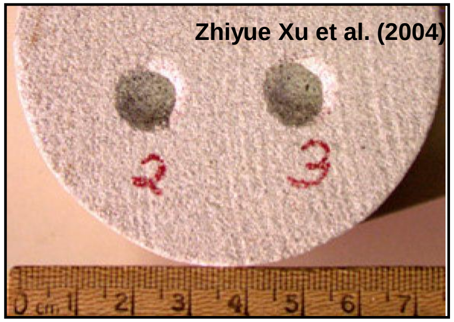
The Future of Geothermal Energy, MIT press, 2006

Spallation Drilling

Conventional drilling

Spallation Drilling

Flame jet spallation

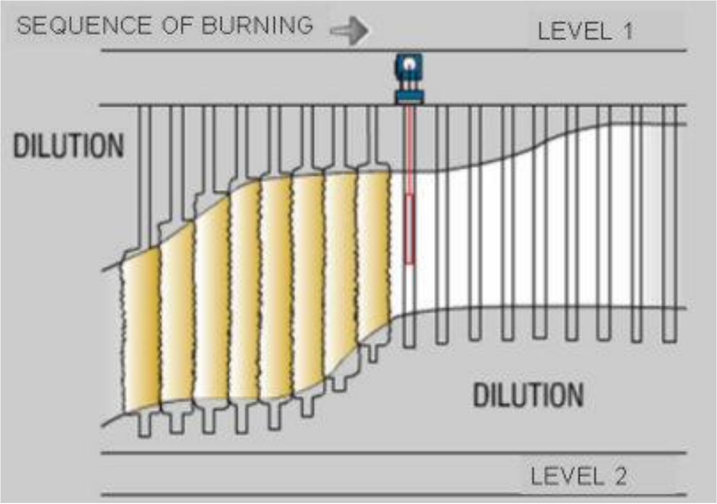


Zhiyue Xu et al. (2004)

Holes spalled by a pulsed Laser

Spallation Drilling

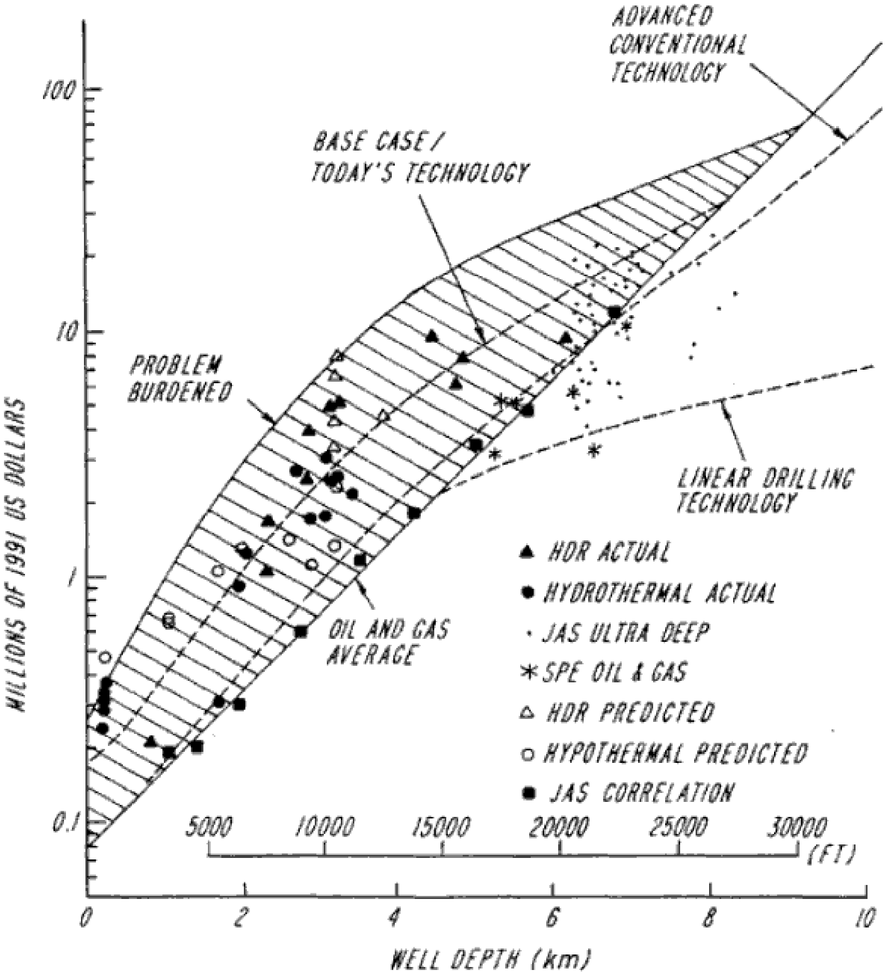
„Thermal Fragmentation“ is used in Russia:



Surface mining:
Narrow vein ore extraction

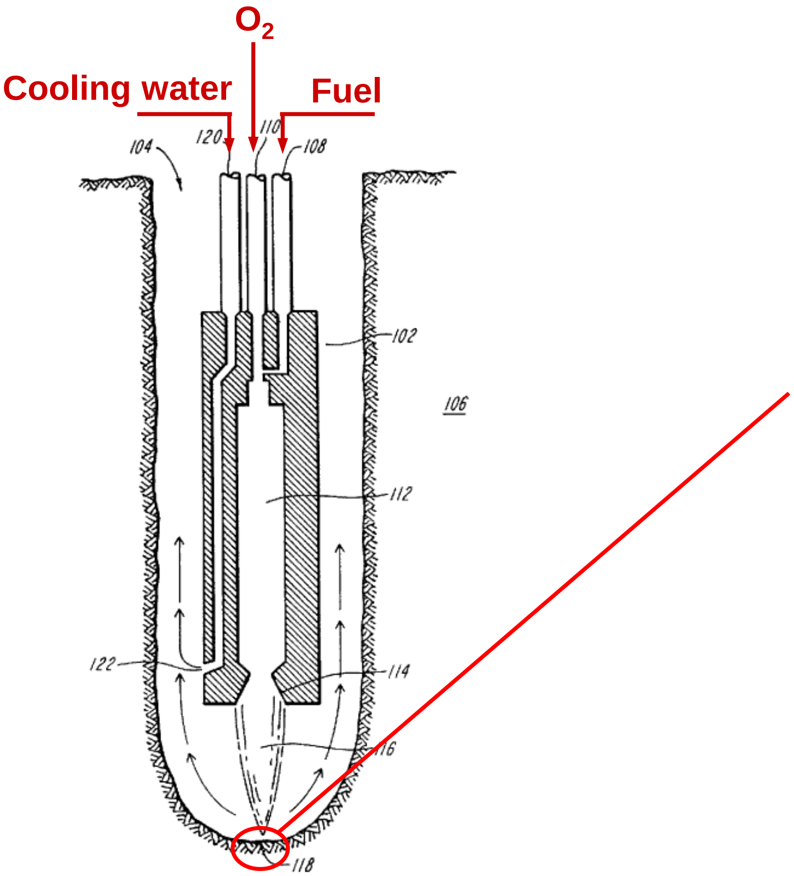
Thermal drilling device

Spallation Drilling: Costs

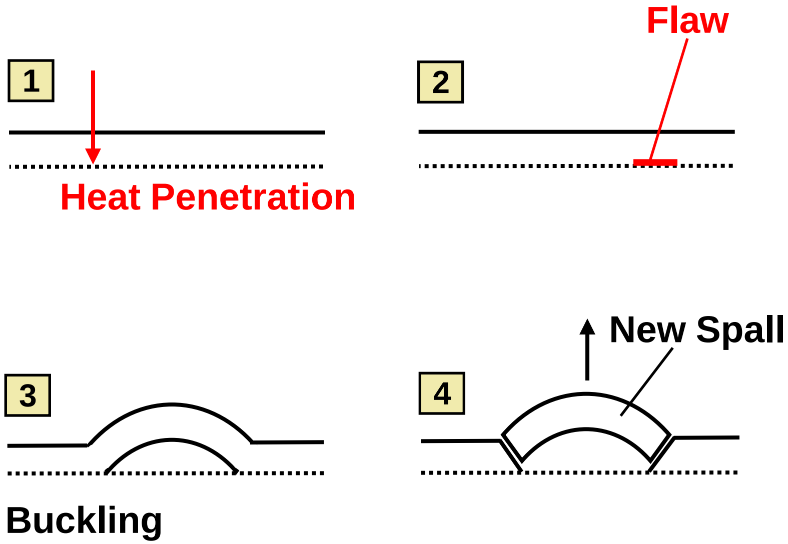


US Patent, Potter et al.,1998

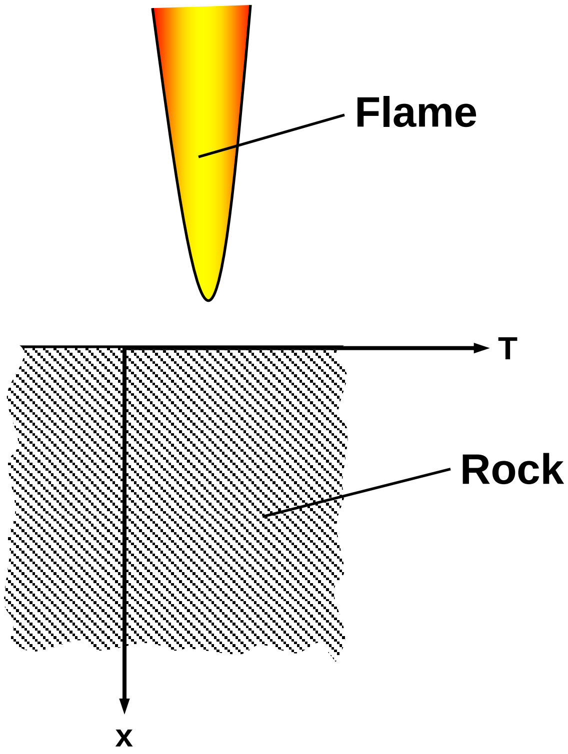
Spallation Drilling: Principle



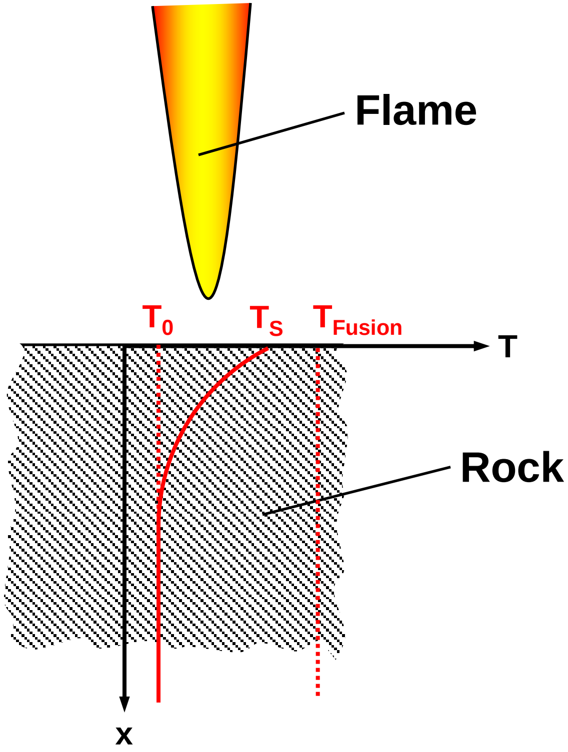
US Patent, Potter et al.,1998



Spallation Drilling: Theoretical Approach



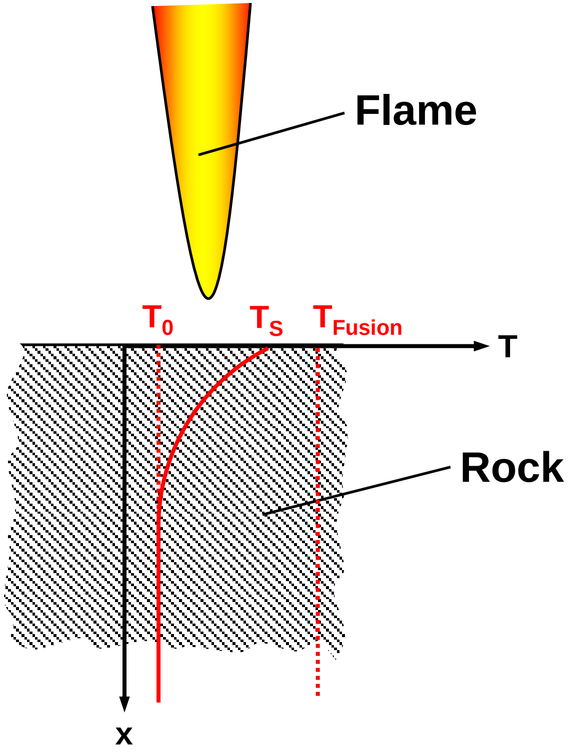
Spallation Drilling: Theoretical Approach



$$\Delta T_s = T_s - T_0$$

rock temperature change at spallation

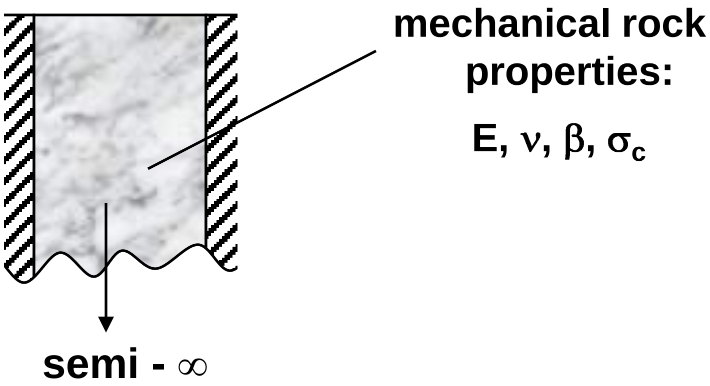
Spallation Drilling: Theoretical Approach



$$\Delta T_s = T_s - T_0$$

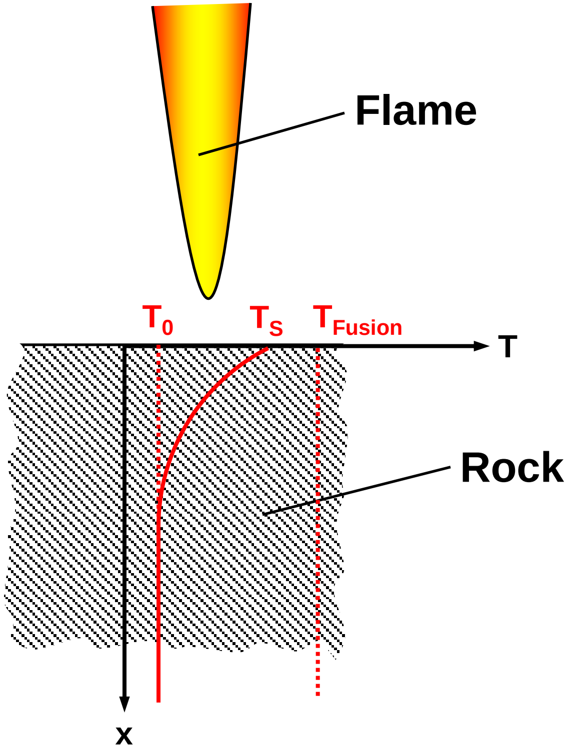
rock temperature change at spallation

1. A very simple approach for ΔT_S (Gray, 1965)



$$\boxed{\Delta T_S = \frac{(1-\nu)\cdot\sigma_c}{\beta\cdot E}}$$

Spallation Drilling: Theoretical Approach



$$\Delta T_s = T_s - T_0$$

rock temperature change at spallation

2. A more elaborate approach for ΔT_S

(Rauenzahn and Tester, 1989)

Temperature profile:

$$T(x) = \Delta T_s \cdot exp(-u \cdot x / a) + T_{r0}$$

Heat flux at surface:

$$\dot{q} = -\lambda \left.\frac{dT}{dx}\right|_{x=0} = \rho \cdot c_p \cdot u \cdot \Delta T_s$$

Compressive stress load:

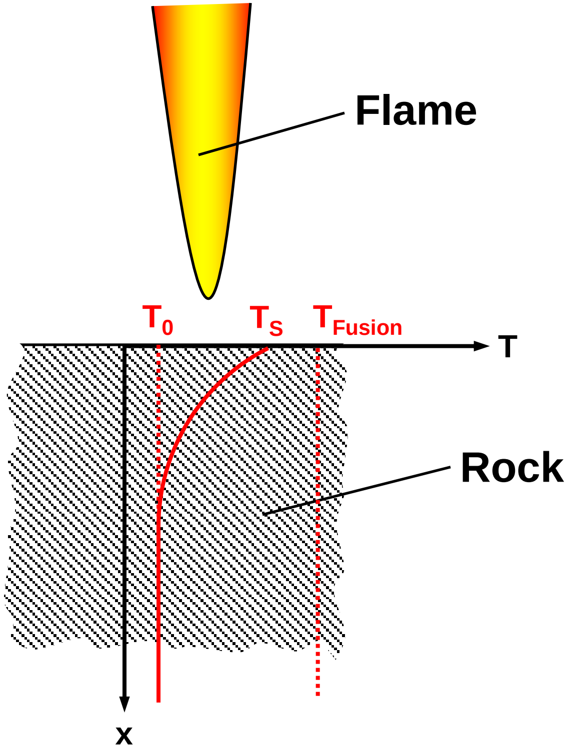
$$\sigma_s = \frac{\beta \cdot E \cdot \Delta T_S}{(1-\nu)}$$

Weibull distribution (theory of failure):

$$G(\sigma) = 1 - \exp\left[- \int_0^V \left(\frac{\sigma}{\sigma_0} \right)^m dV \right] = 0.5$$

median condition

Spallation Drilling: Theoretical Approach



$$\Delta T_s = T_s - T_0$$

rock temperature change at spallation

2. A more elaborate approach for ΔT_S

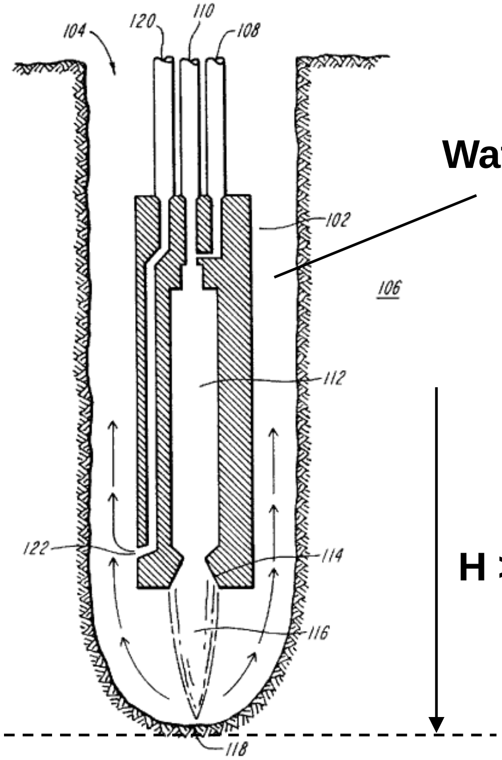
(Rauenzahn and Tester, 1989)

$$\Delta T_S = \left[\left(\frac{\dot{q}}{\rho \cdot c_p} \right)^3 \cdot \left(\frac{(1-\nu)\cdot\sigma_o}{\beta \cdot E} \right)^m \cdot \left(\frac{2 \cdot (0.693)}{\pi \cdot C_L{}^2} \right) \cdot \left(\frac{m}{a_r} \right)^3 \right]^{m+3}$$

$\dot{q}$	**Heat flux to plate**
σ_0, m	**Weibull parameters**

Link to LTR

Supercritical conditions downhole

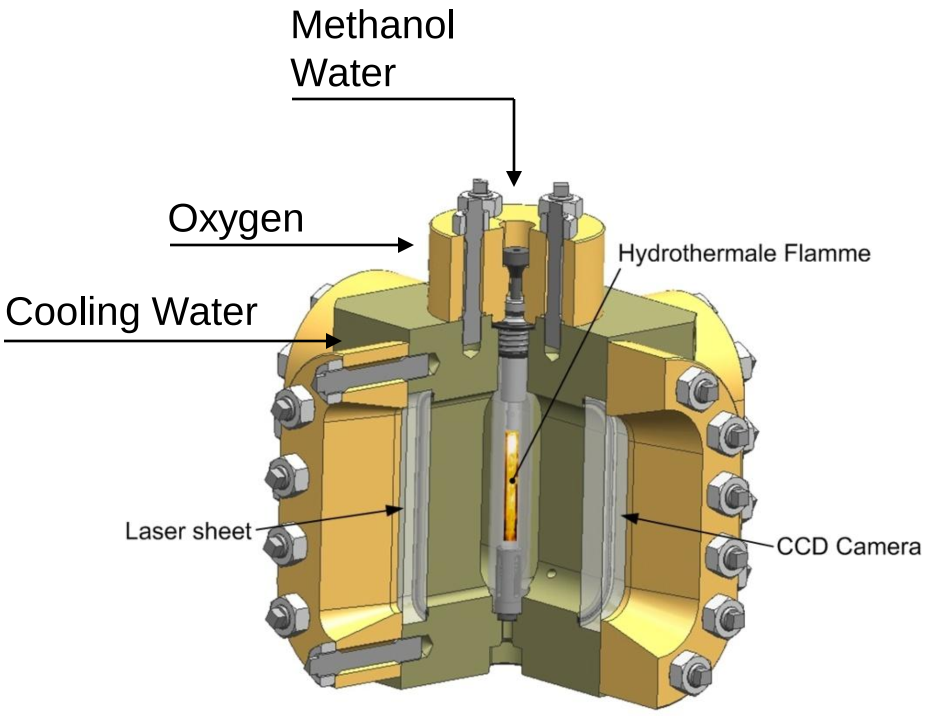


Water-filled hole

H > 2.3 km

p > 221 bar

Our SCWO-reactor



Methanol
Water

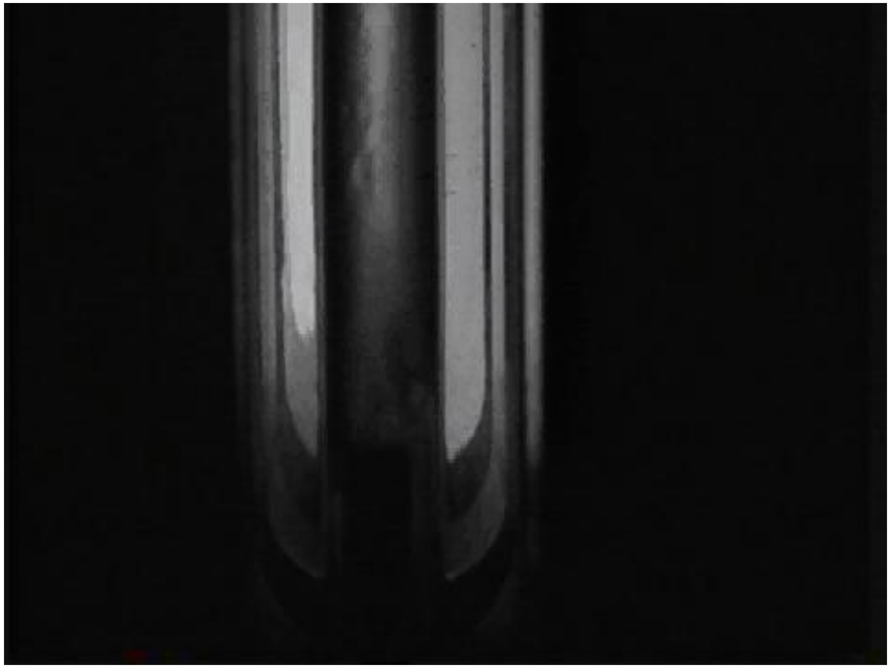
Oxygen

Cooling Water

T_{flame} ≈ 1200 C
p = 250 bar

SCWO

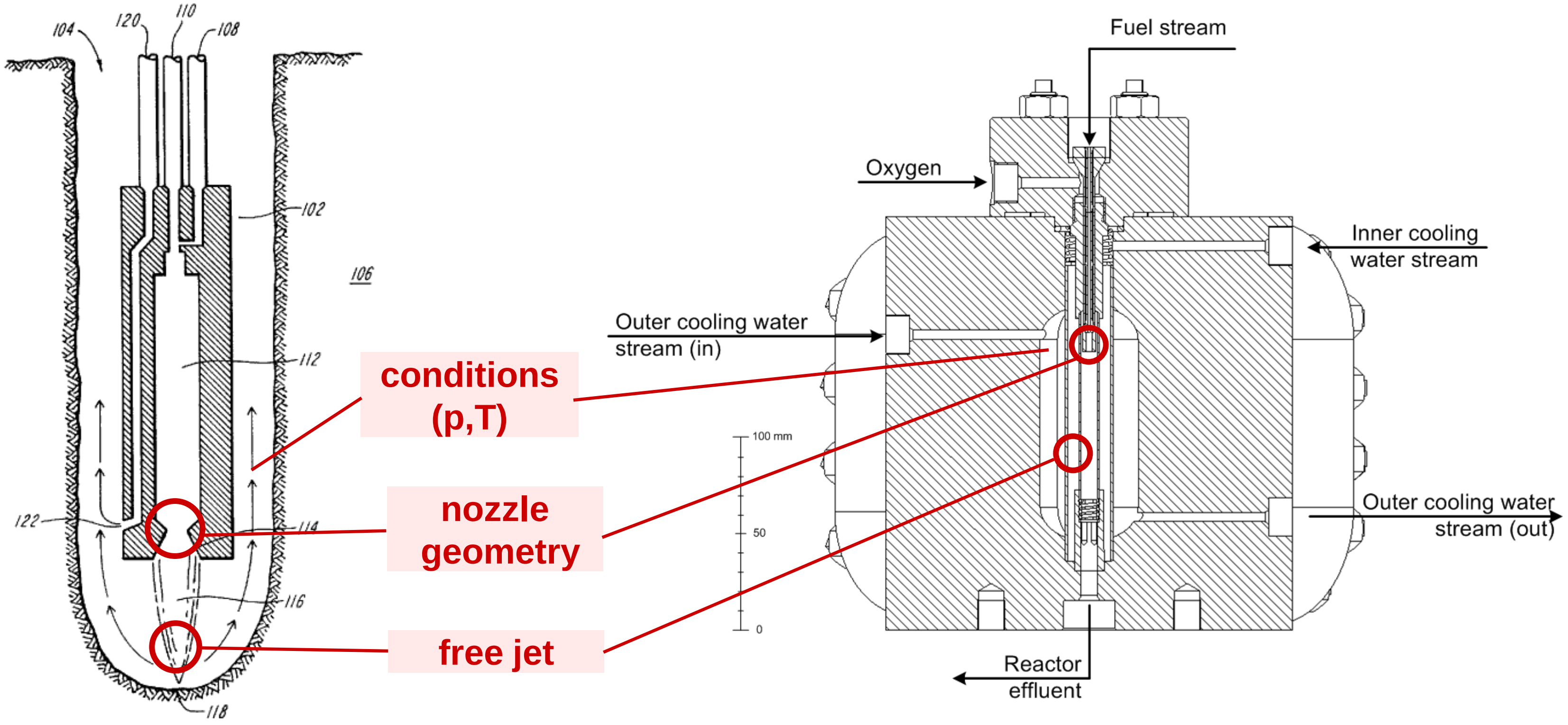
Autoignition of flame



Project Ideas I

Situation downhole

Modifications on reactor

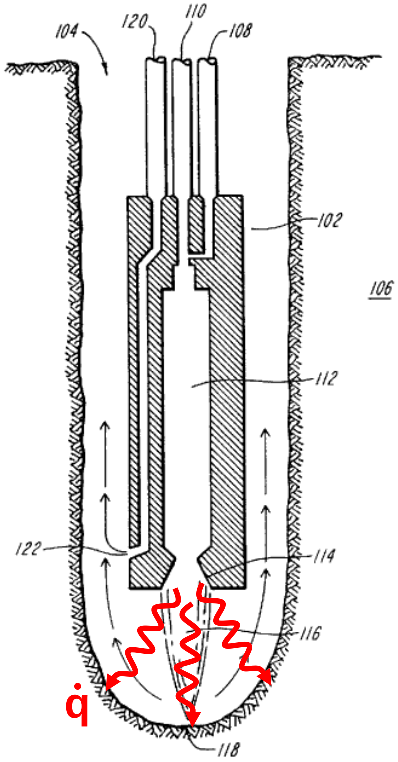


conditions (p,T)

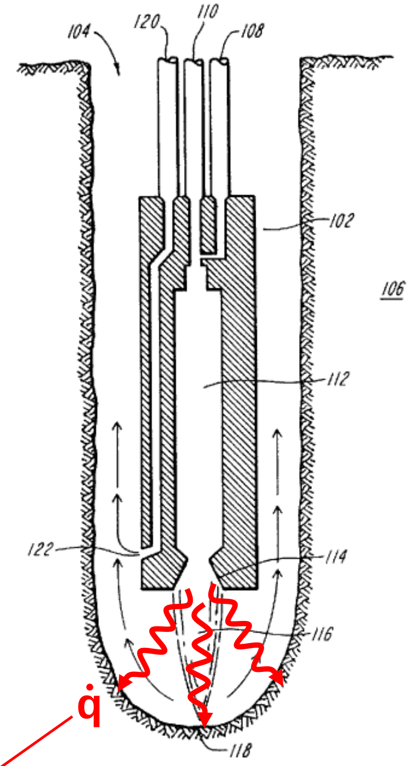
nozzle geometry

free jet

Project Ideas II



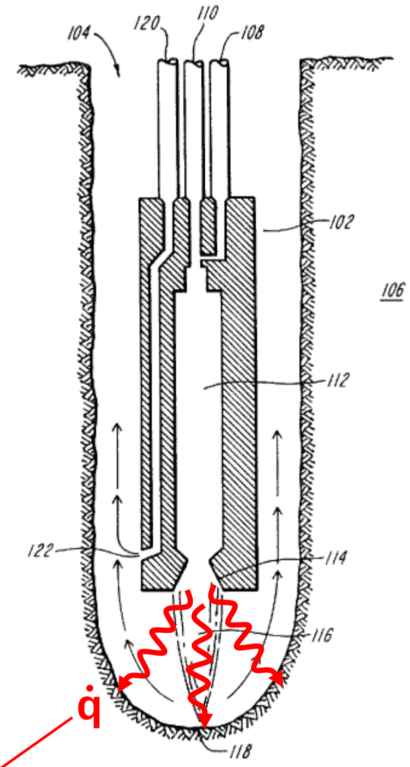
Project Ideas II



$$\Delta T_S = \left[\left(\frac{\dot{q}}{\rho \cdot c_p} \right)^3 \cdot \left(\frac{(1-\nu) \cdot \sigma_o}{\beta \cdot E} \right)^m \cdot \left(\frac{2 \cdot (0.693)}{\pi \cdot C_L^{\,2}} \right) \cdot \left(\frac{m}{a_r} \right)^3 \right]^{m+3}$$

→ **prediction of spall thickness**

Project Ideas II



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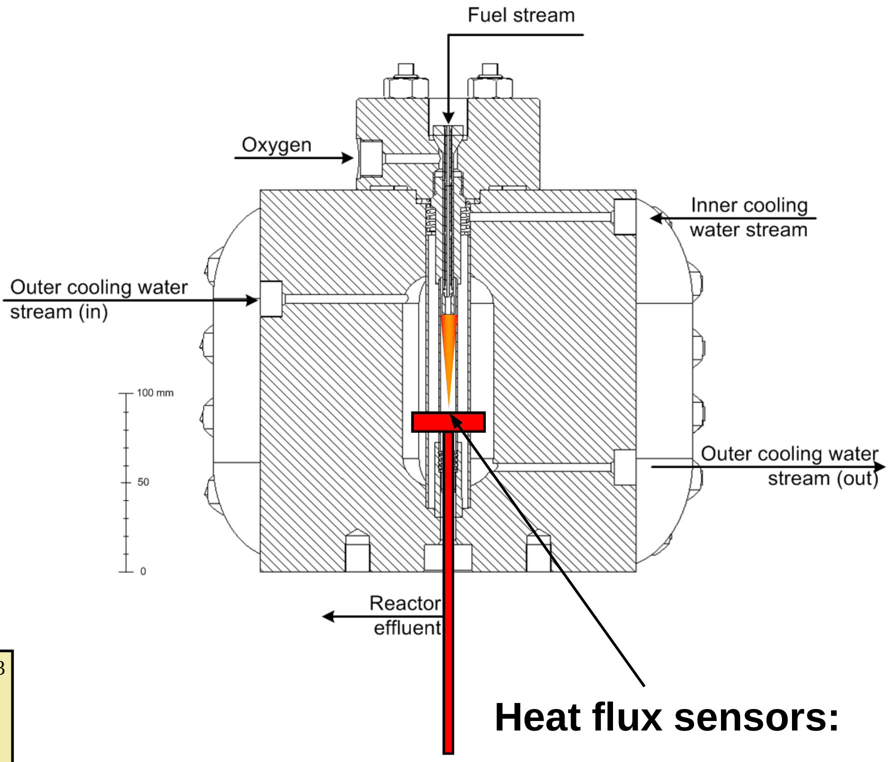
→ **prediction of spall thickness**

Insertion of a flat plate:

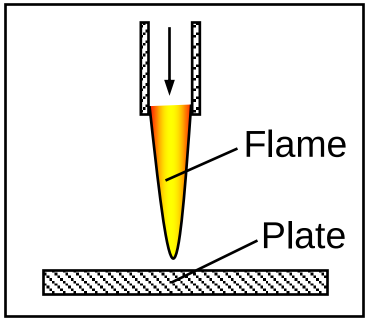


Heat flux sensors:

- **Heat flux**
- **Surface temperature**

Project Ideas II

Impinging flame jets – Heat transfer mechanisms



1. Convective heat transfer
2. Thermochemical heat release (TCHR)
3. Radiative heat transfer
4. Condensation

Research goals:

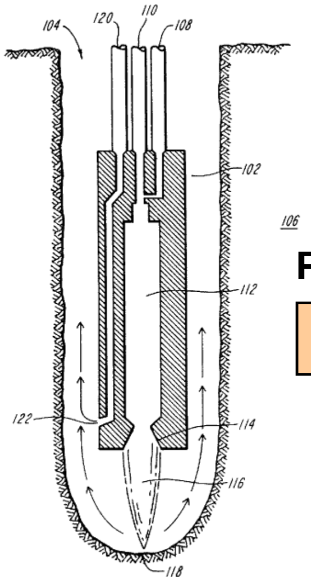
- Comparison of experimental results:
  → Heat Transfer Enhancement/Detereoration
  → Estimation of heat radiation
- Simplified model of overall heat transfer

Project Ideas III

Ignition of Flame (Autoignition)

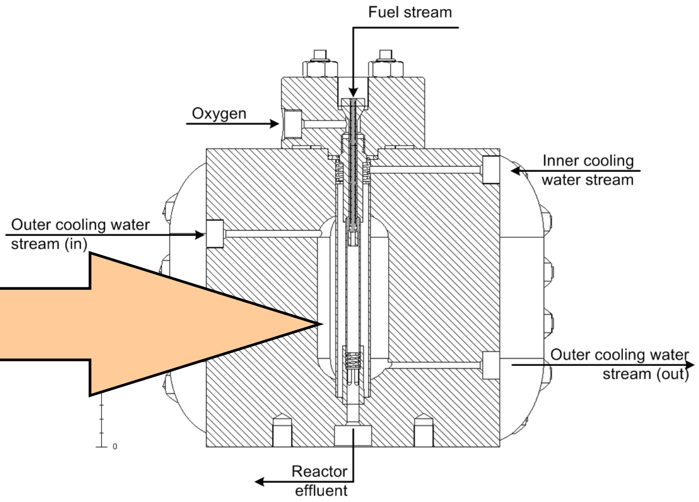
Stability of Flame
- Blowoff-Experiments
- Flashback-Experiments

Process Design



Realistic operation conditions

p, T



Thanks for your attention!