

# R&D and Challenges for CO<sub>2</sub> Cooling Systems

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Viren Bhanot  
(on behalf of EP-DT-FS)

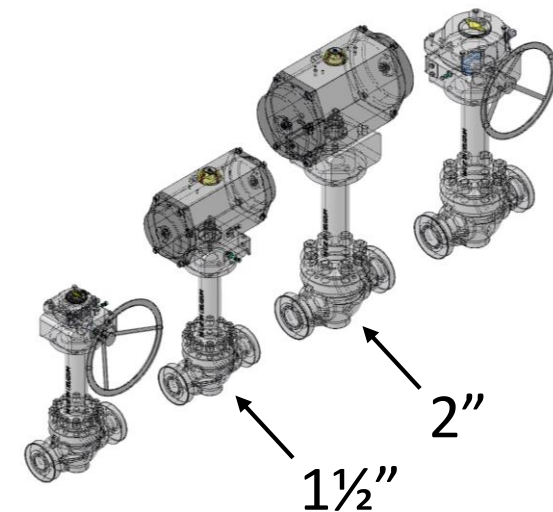
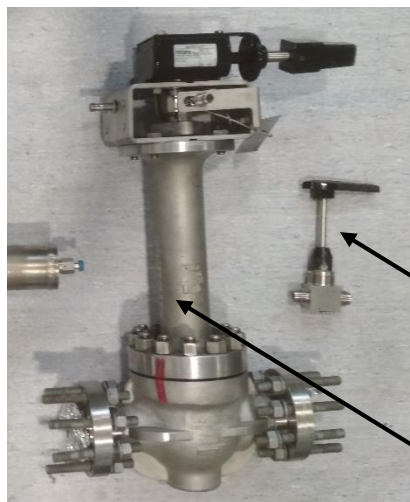
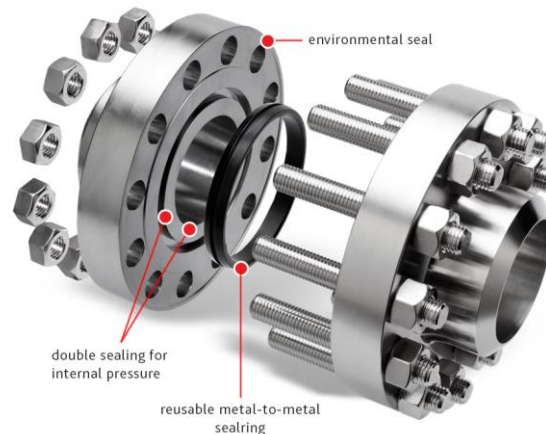
# Challenges for Future CO2 Systems

(all-new Tracker cooling systems in LS3)

- Larger cooling loads (order of  $\sim 0.5$  MW)
- Much lower evaporating temperatures:  $\sim -40^{\circ}\text{C}$ 
  - CO2 freezing point:  $-56.6^{\circ}\text{C}$
- Much larger number of cooling tubes in parallel (order of magnitude increase)
- Parallel operation of multiple plants
  - Redundancy requirements
- Higher luminosity (more radiation damage)

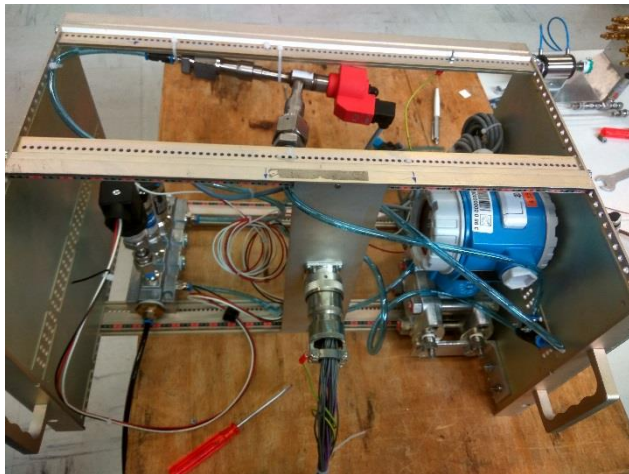
# Large Sizing

- Larger thermal loads require larger components
- Larger piping
  - 1.5" and 2" outer diameters
- Larger flanges to connect piping
- Larger control valves



# Instrumentation qualification

Test setup to qualify pressure transmitters and a control valve

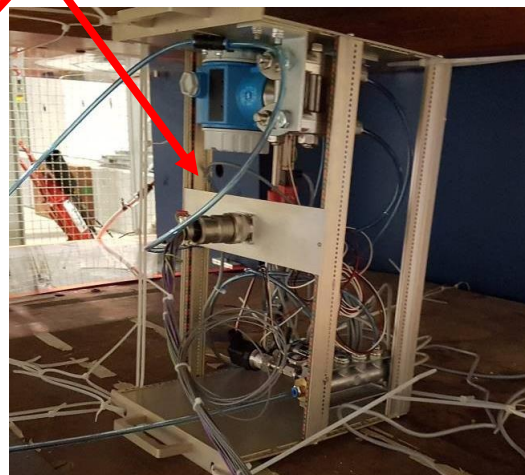


← Magnetic field test  
(~ 650 mT)

(normal and 90°  
rotated positions)

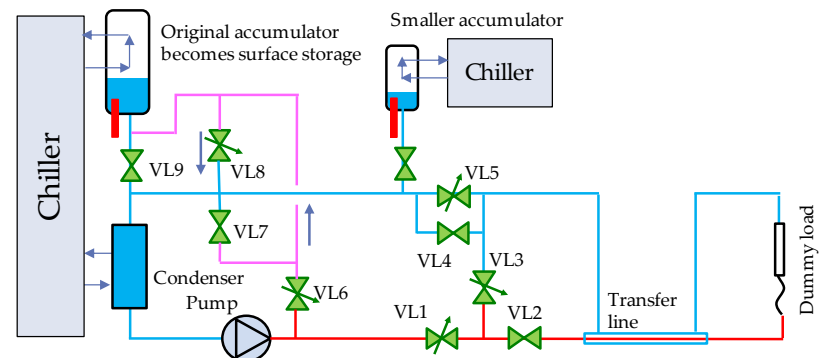
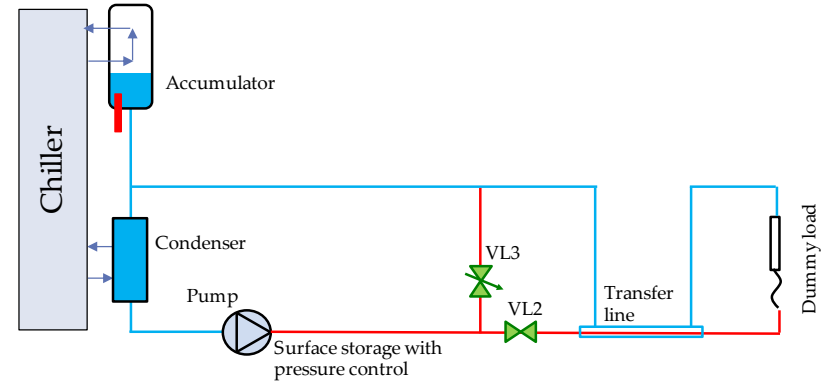


↑ Irradiation test @ CHARM  
(~ 212 Gy)



# Baby DEMO Upgrade

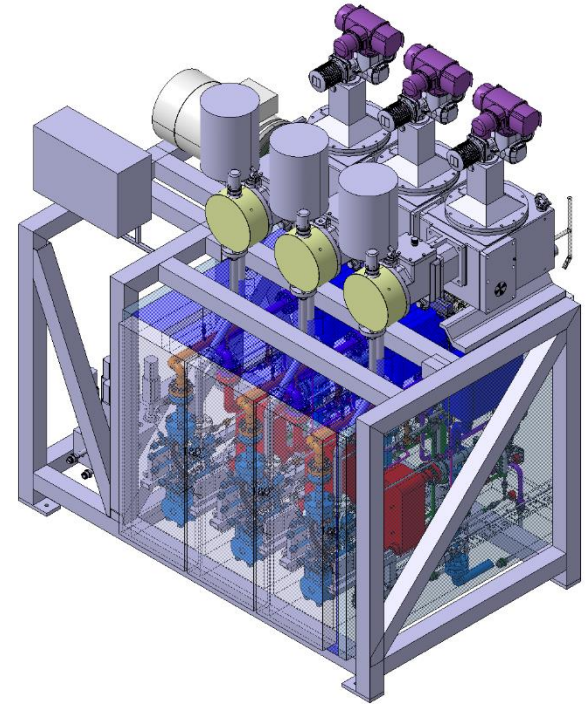
- Check low-temperature limits with CO2 as refrigerant
- Investigate surface storage performance
  - Existing accumulator converted to surface storage concept
  - New (smaller) accumulator installed
- Check impact of elevation change on two-phase return lines





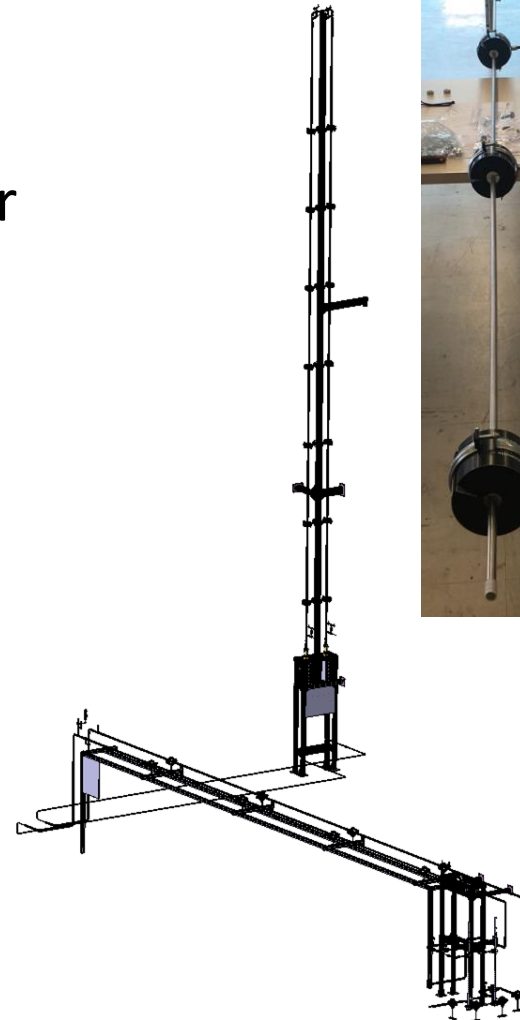
# DEMO

- Full-sized prototype test plant
- Fully operational in 2020
- Investigate working of new concepts
  - High thermal loads
  - Redundancy approach
  - New control strategies
  - Surface storage of excess CO<sub>2</sub>
- Development of a new CO<sub>2</sub> transcritical primary cooling system
  - fully CO<sub>2</sub>-based Tracker cooling system (no HFCs)



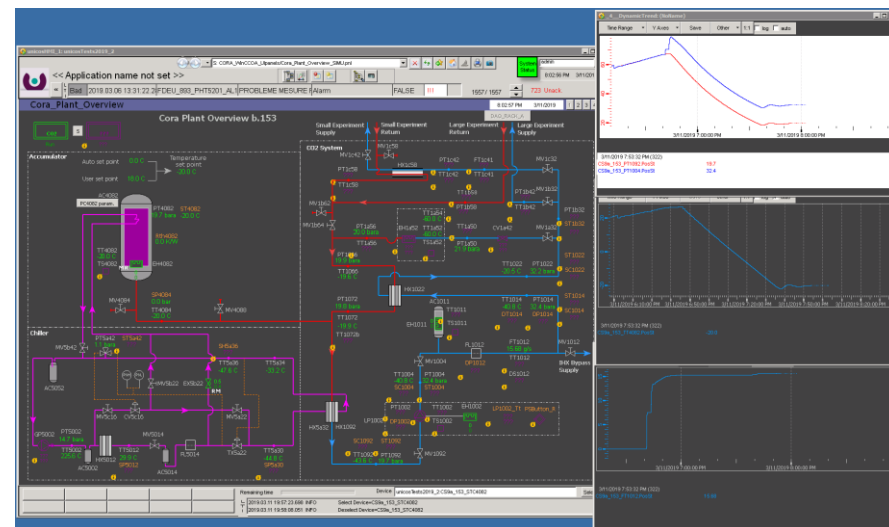
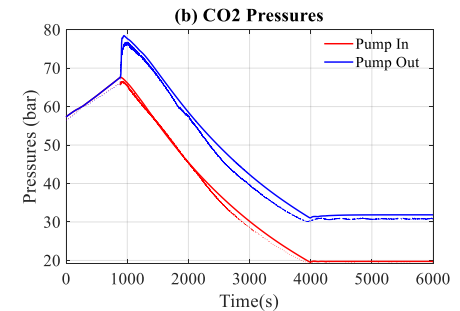
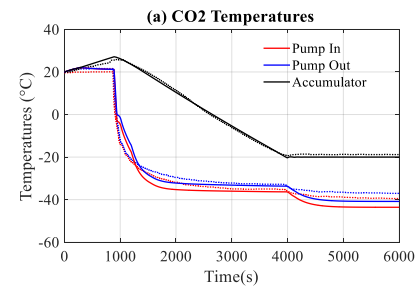
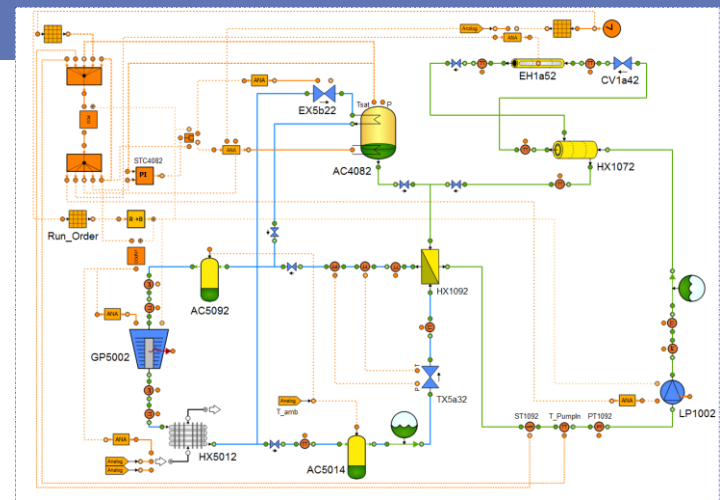
# Vertical Flow Setup

- Test setup created in Building 153 (part of the DEMO project)
- Future systems → vertical transfer lines
- Investigate impact of elevation change (20 m) in two-phase flow
  - Flow/temperature oscillations
  - Pressure drop
- High-speed camera with transparent glass sections
- Highly accurate instrumentation
- Small-scale and full-scale tests



# Dynamic Simulations

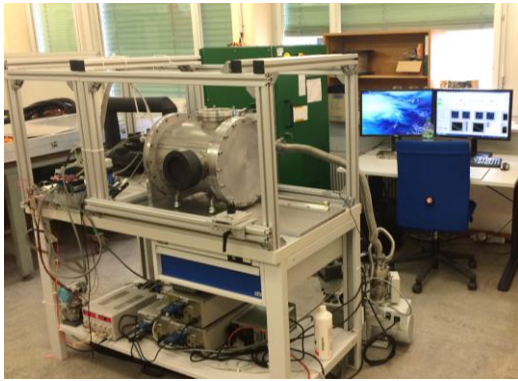
- Many changes forthcoming
  - Surface storage of CO<sub>2</sub>, parallel plants, redundancy, new controls...
- Experimentation is higher risk, more expensive and much more time consuming
- Development of simulation platform to investigate plant behavior
- Validated against 2 existing systems
- Future → Virtual commissioning setup for operator training





# Evaporative CO2 in small-channels

## Test Facility

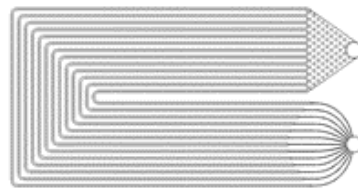
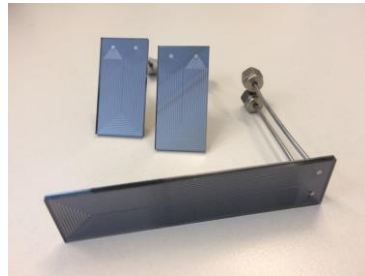


- Stable flows from +20°C to -25°C
- Vacuum vessel for adiabatic test conditions
- High-precision sensors account for pressure drop, heat transfer and mass flow rate

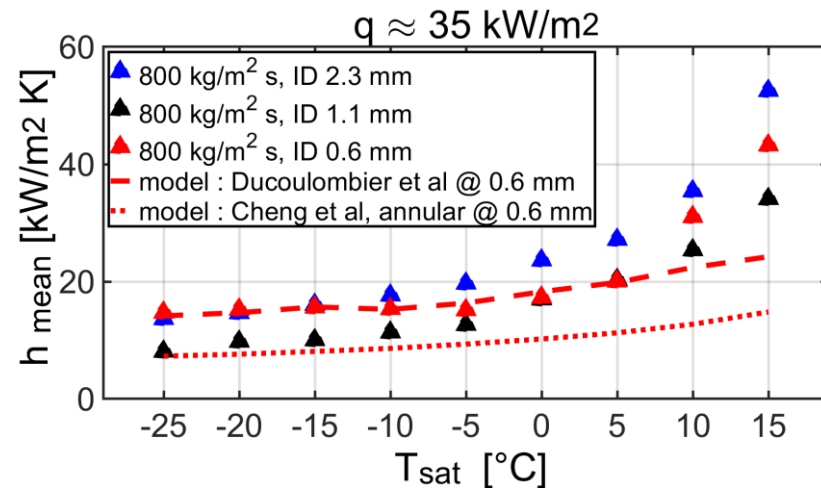
## Tubular evaporators

- Hydraulic diameters: from 0.1 to 2 mm
- Already tested: 0.5, 1, 2 mm (inner diameter)

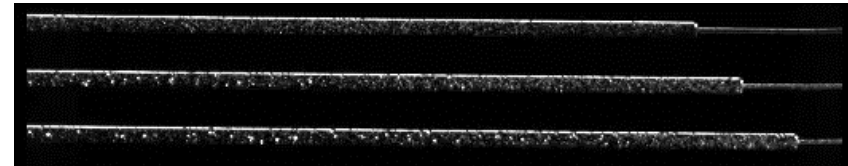
## Multi-micro-channels



## Heat Transfer Coefficient along tubular evaporators



## Bubble dynamics in small channels



# Conclusions

- Several ongoing projects → investigate all major design changes for next generation of cooling systems
- Several test plants developed/being developed to acquire experience
- Much larger components requiring new approach to mechanical design (welding techniques etc.)
- Study of CO<sub>2</sub> performance in long vertical lines
- Simulations incorporated in design/commissioning phases
- Investigate behavior of evaporative CO<sub>2</sub> in a wide range of operating conditions