

DE LA RECHERCHE À L'INDUSTRIE

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Dynamic simulations of a tokamak cryogenic system

R Cirillo, C Hoa, F Michel, J M Poncet
and B Rousset

OUTLINE

Introduction – Context

The experimental set-up HELIOS

Validation of the modeling tool via HELIOS results

JT-60SA & HELIOS - A numerical comparison

JT60-SA Auxiliary Cold Box

Comments & Conclusions

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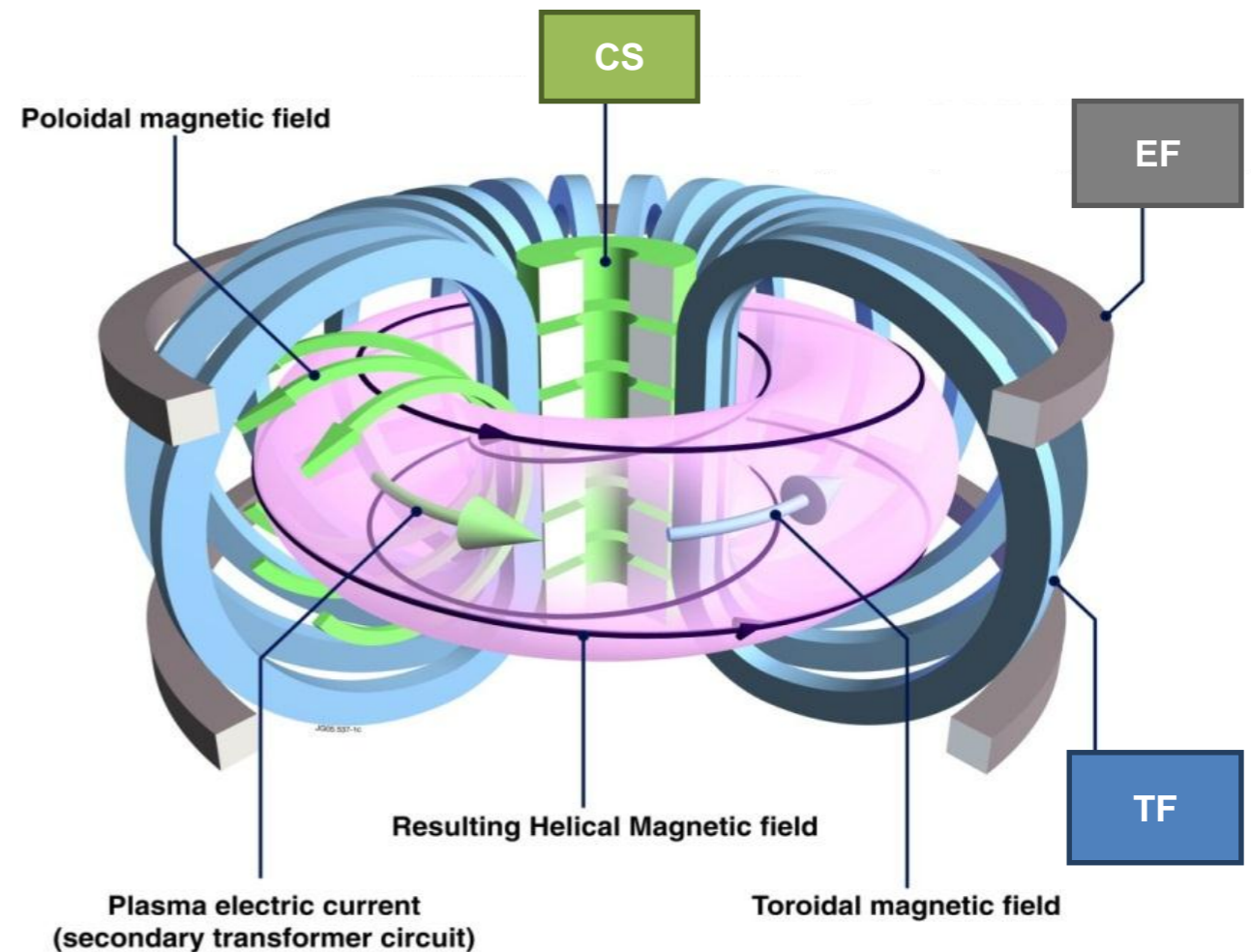
JT60-SA Auxiliary Cold Box

Comments & Conclusions

Nuclear **FUSION** Experimental Reactors

The **aim** is to **confine** a dense **plasma**
long enough to convert
the released fusion power into electrical power

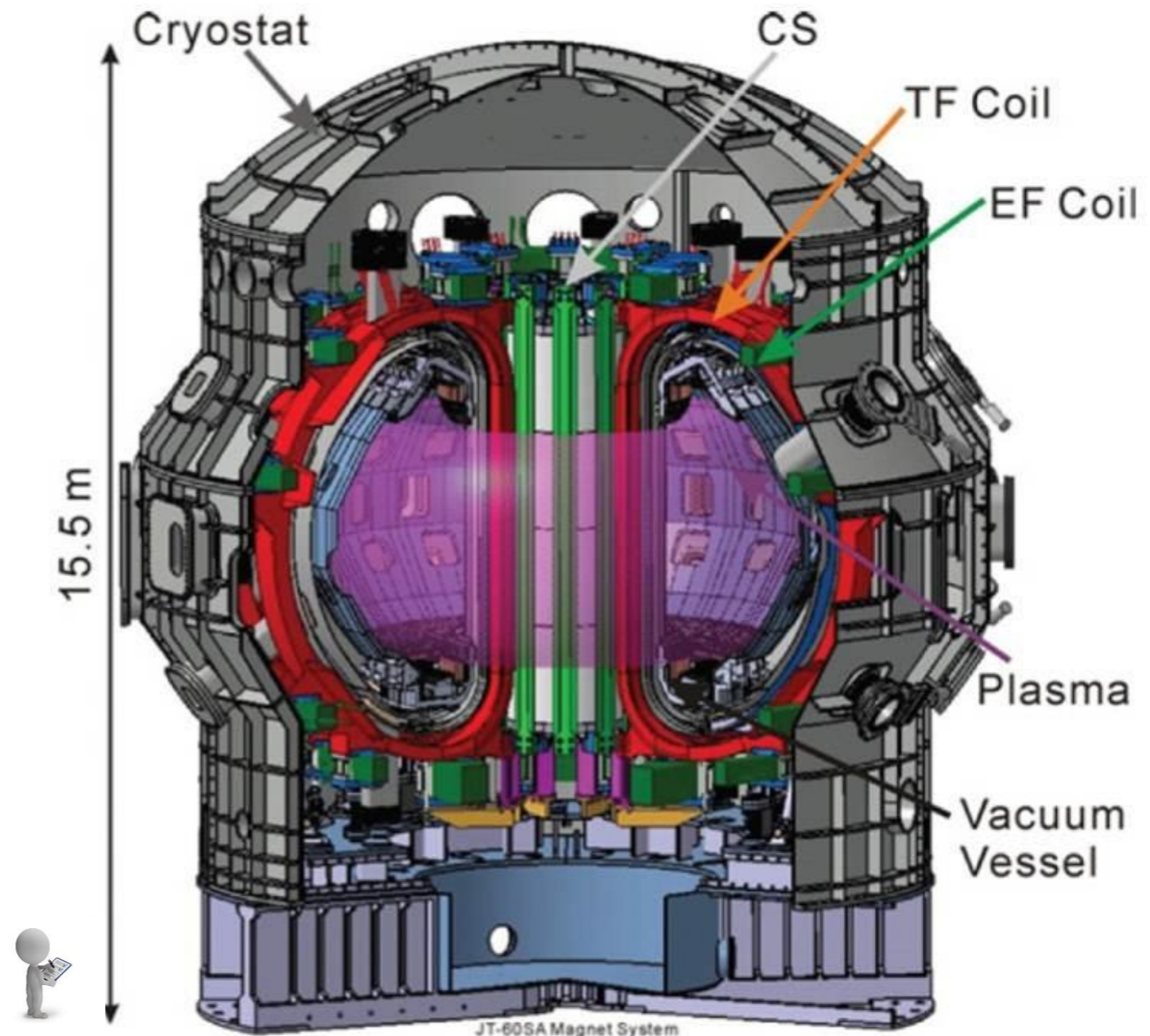
Superconductive coils
cooled down to **4,4K**



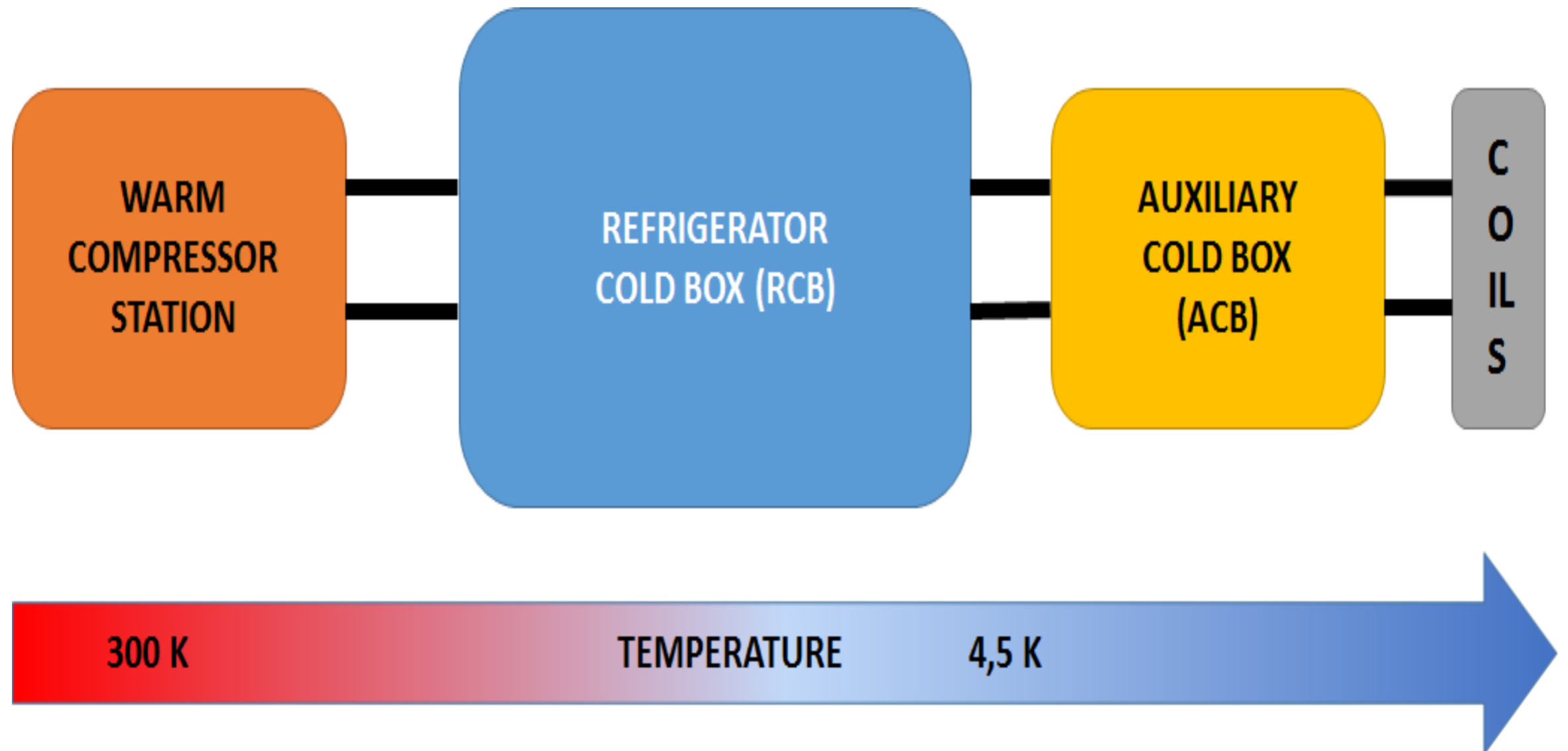
Japan Torus - 60 Super Advanced

CEA is in charge of providing the **cryogenic system**

ITER
Broader Approach



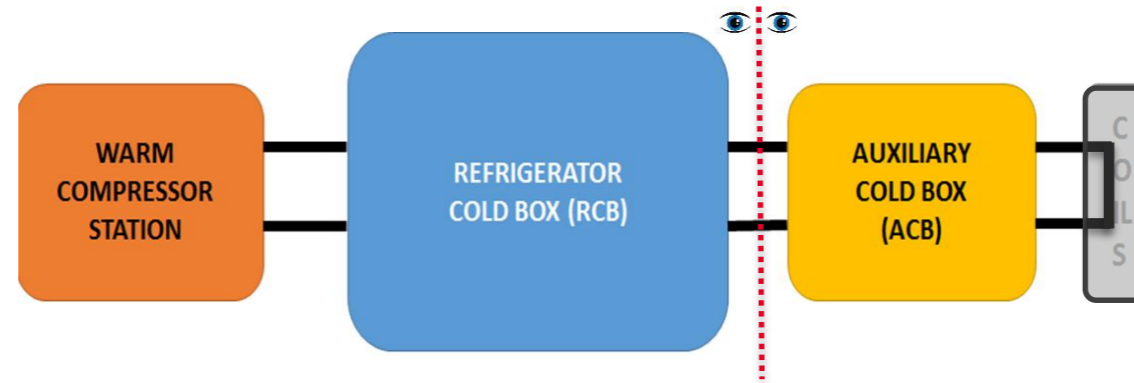
CRYOGENIC SYSTEM



ACCEPTANCE TEST

FUNCTIONAL AND CAPACITY TEST

have to be performed and **passed to LICENCE the refrigerator**



Check the fulfillment of the “performance requirements”

All along the **time-related cycle**

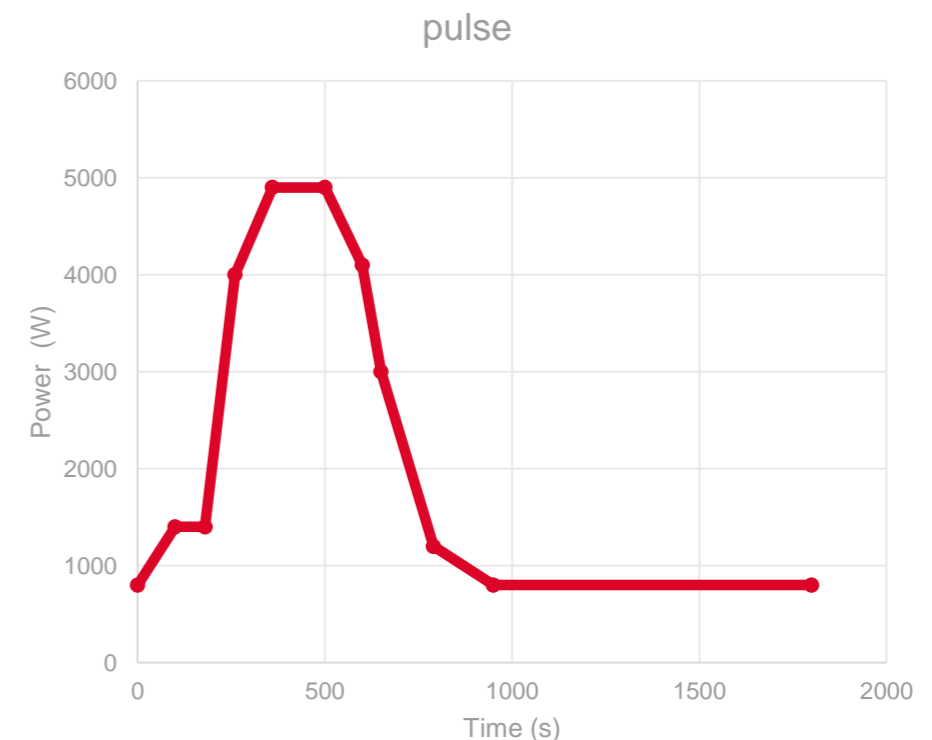
MASS FLOW

PRESSURE HEAD

TEMPERATURE

At the beginning of the cycle

Pump PRESSURE INLET



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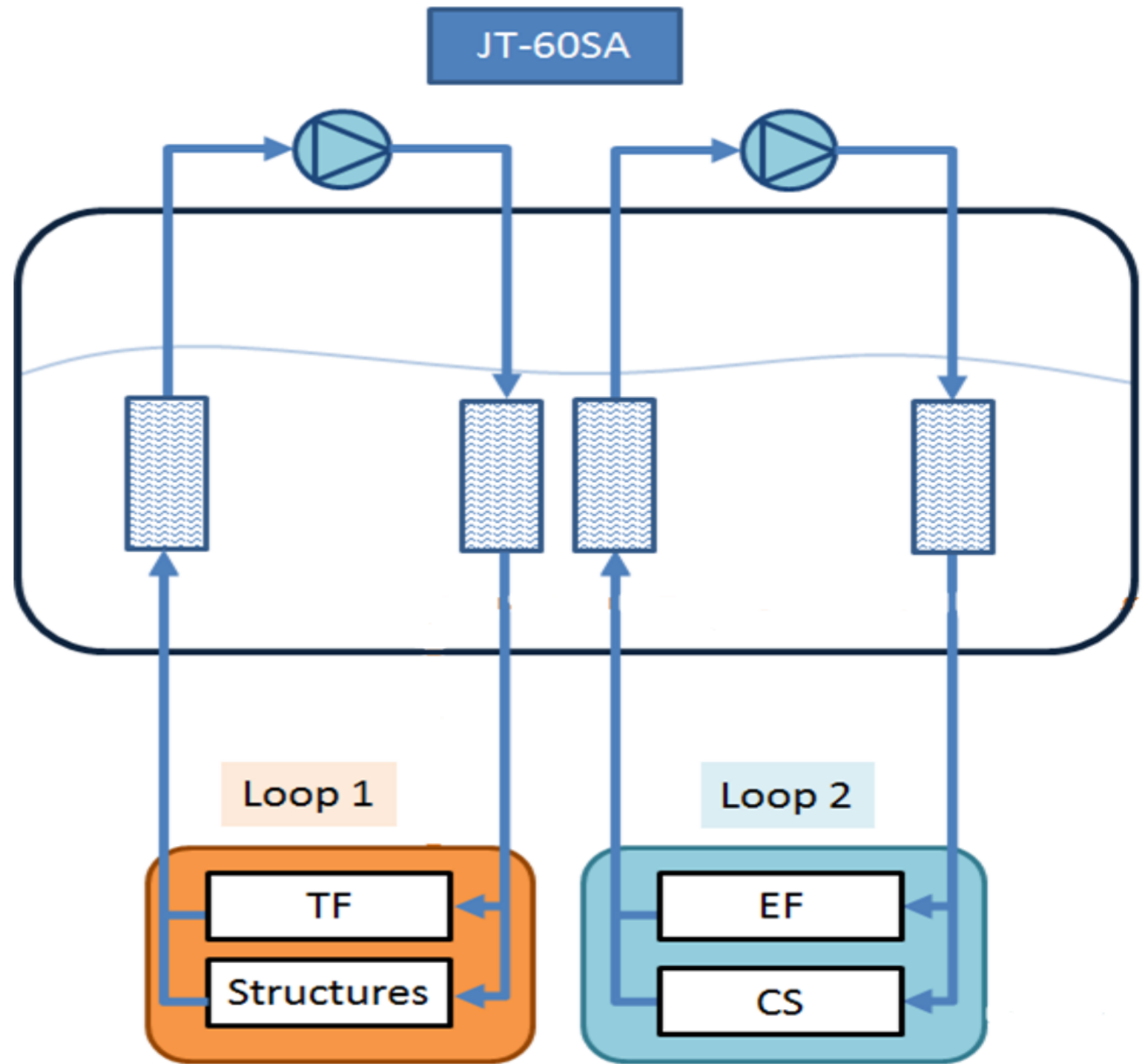
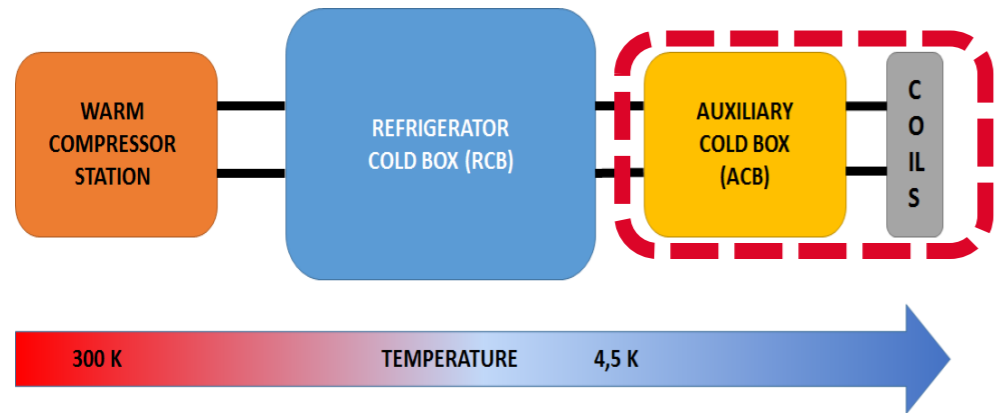
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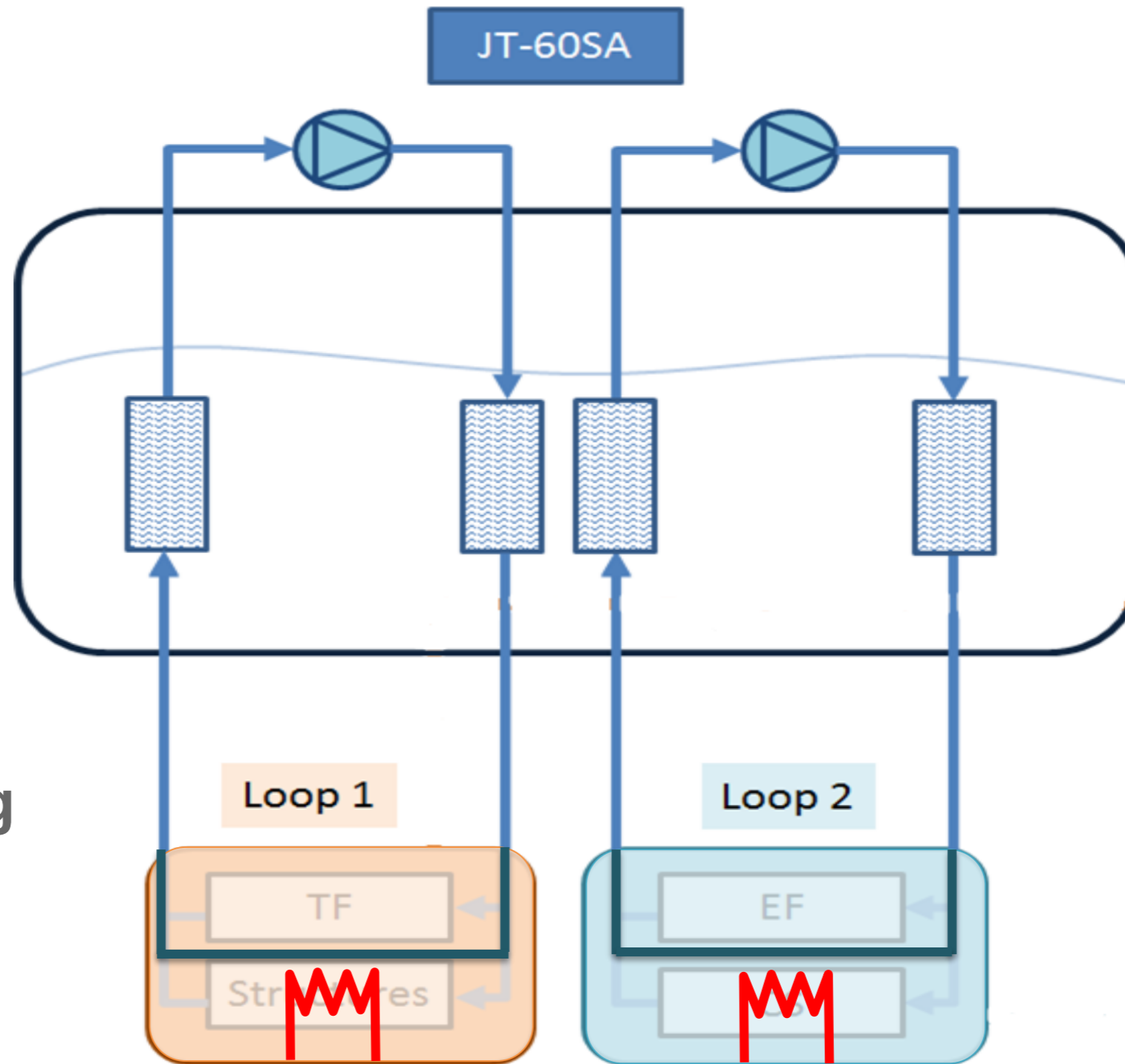
JT60-SA Auxiliary Cold Box

Comments & Conclusions

JT-60 SA's ACB



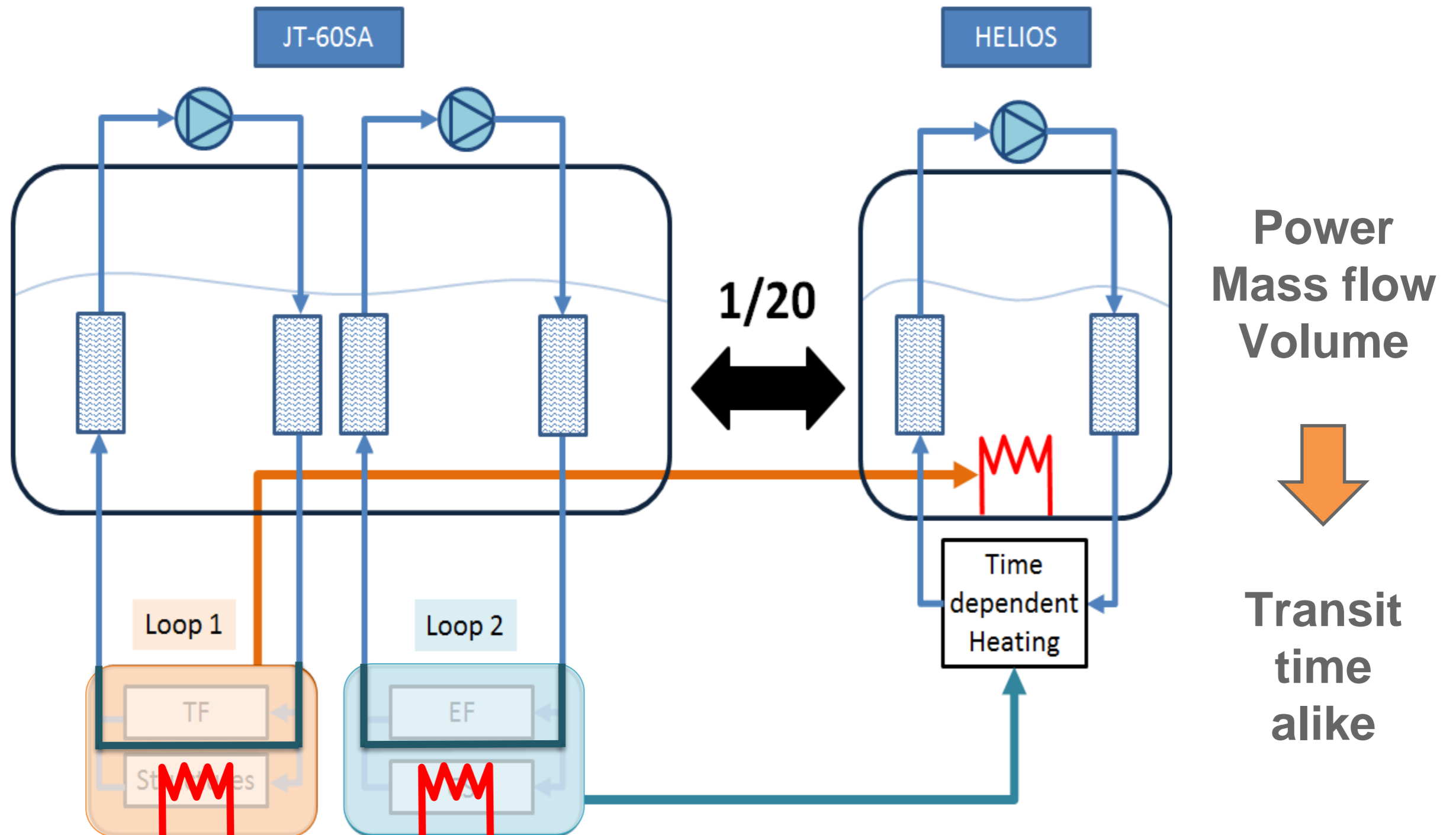
ACCEPTANCE TEST Configuration



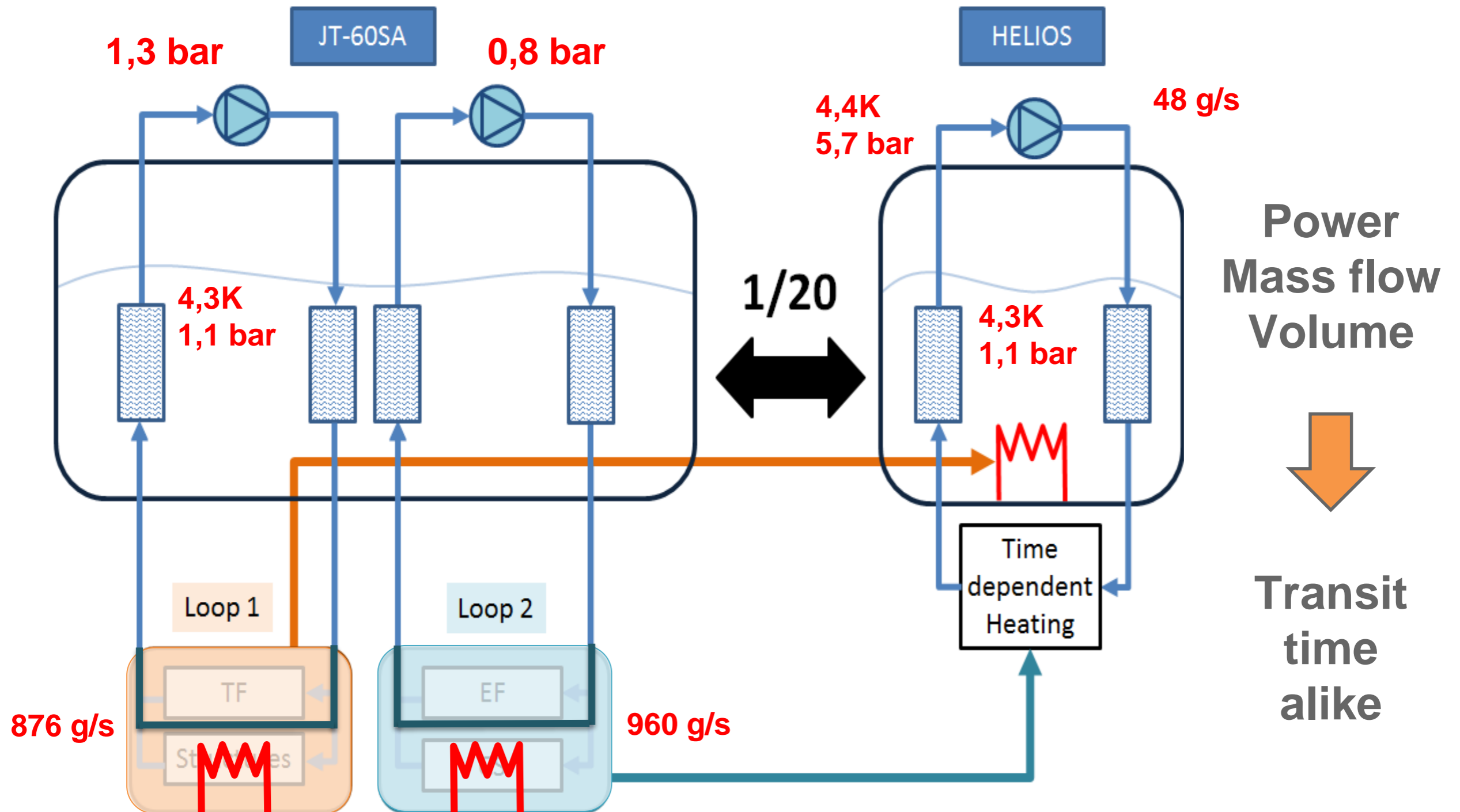
Bypass line +
thermal heating

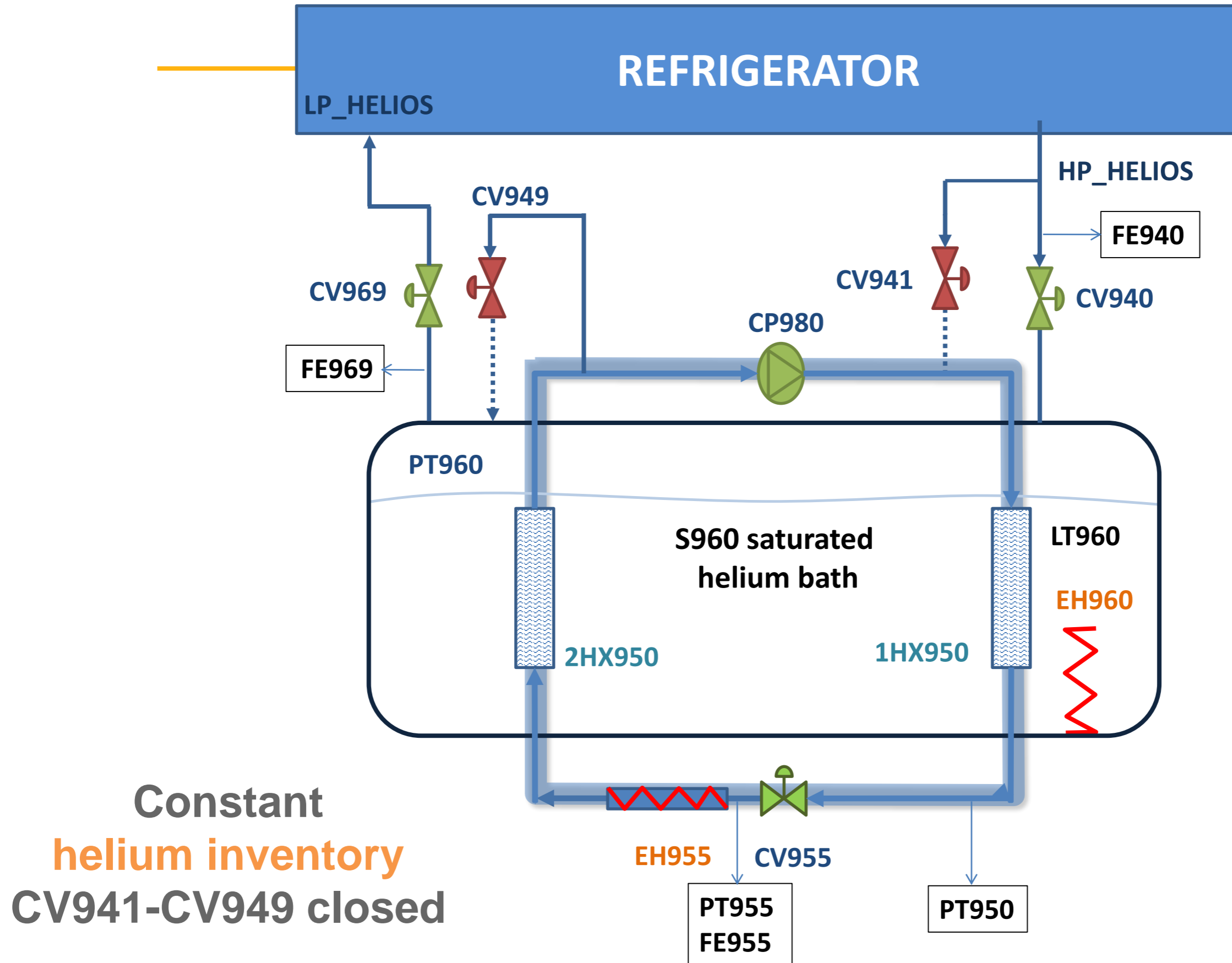
NO MAGNET
CONNECTED

HElium Loop for high IOad SMOOTHing

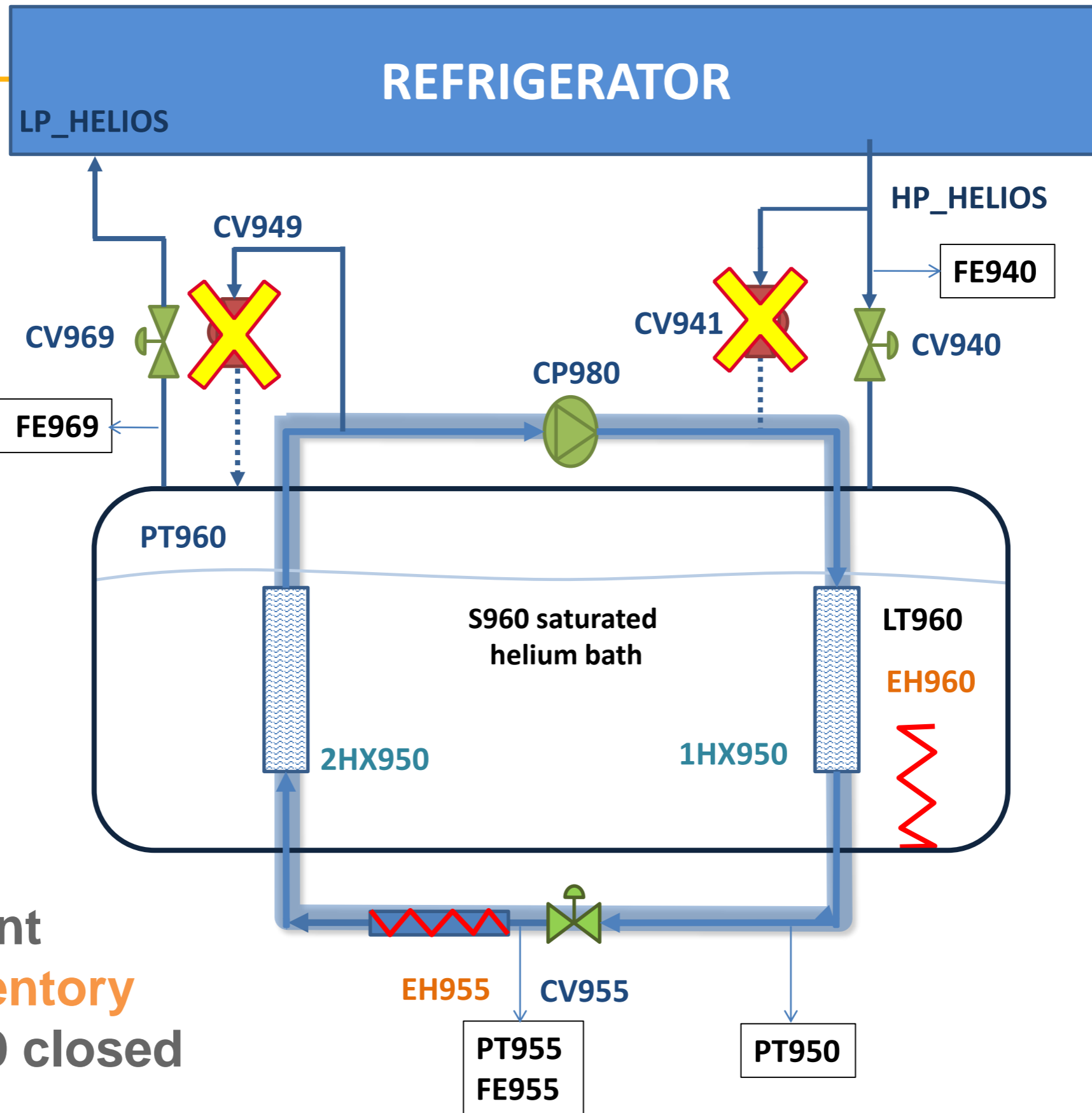


HElium Loop for high IOad Smoothing

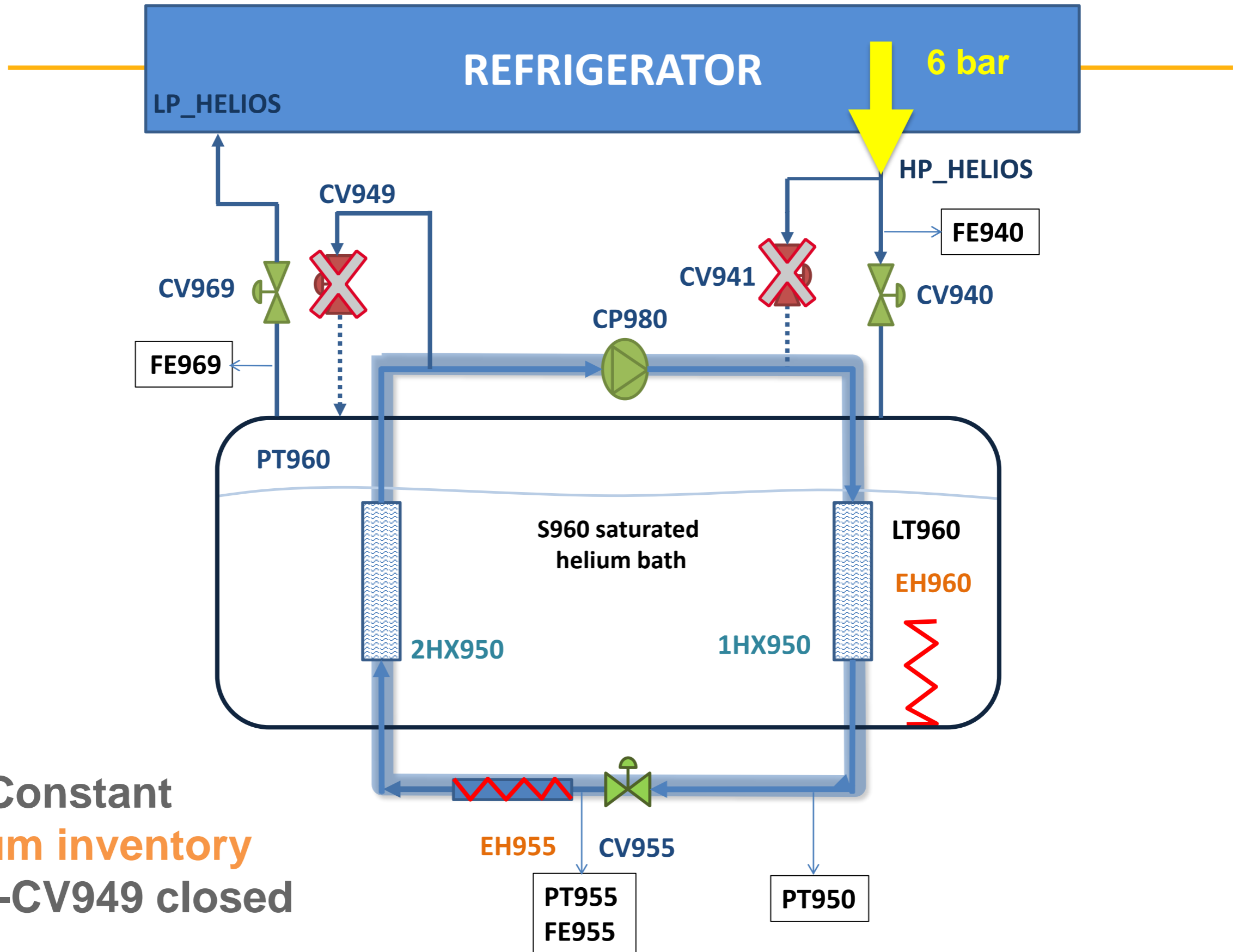




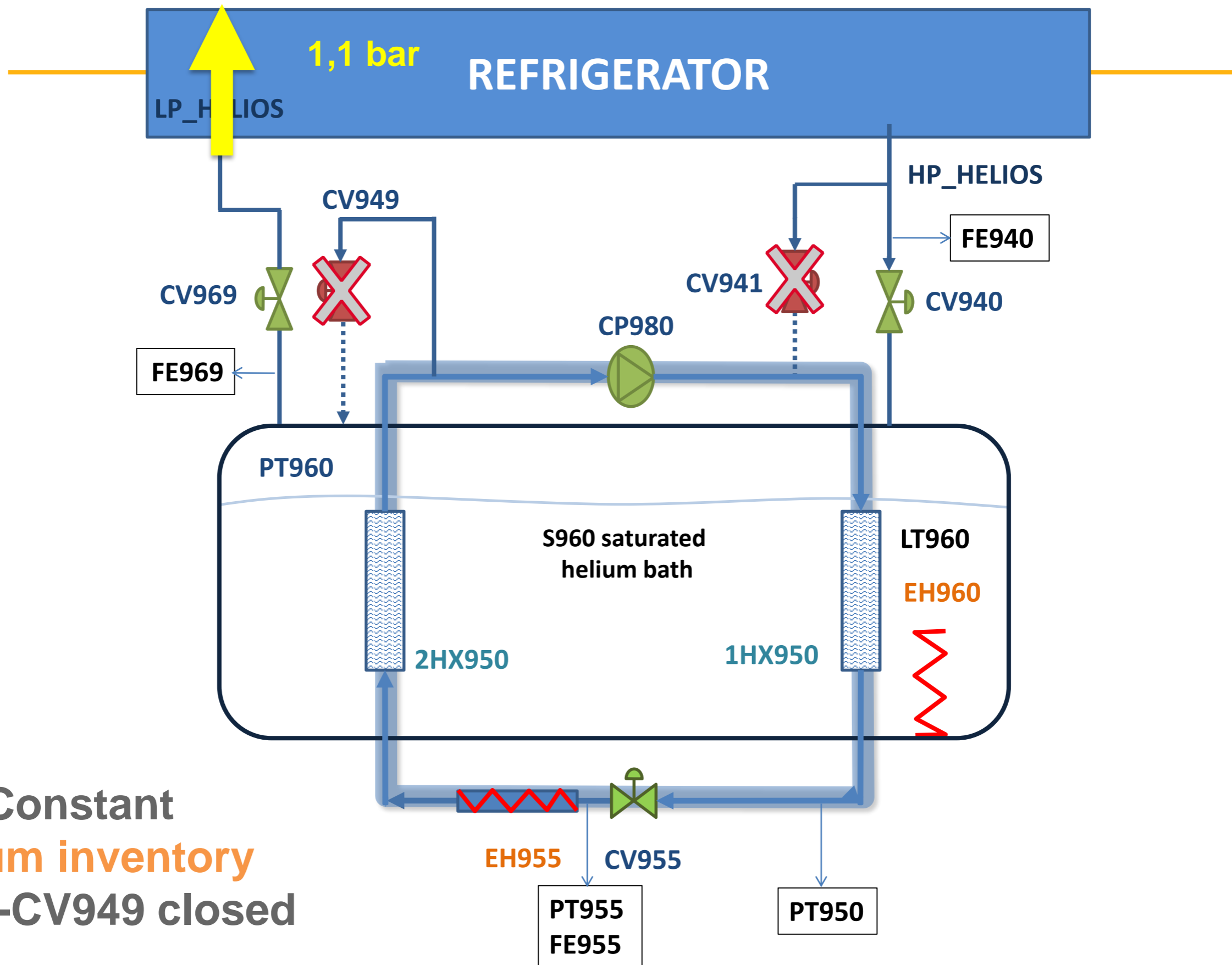
Constant
helium inventory
CV941-CV949 closed



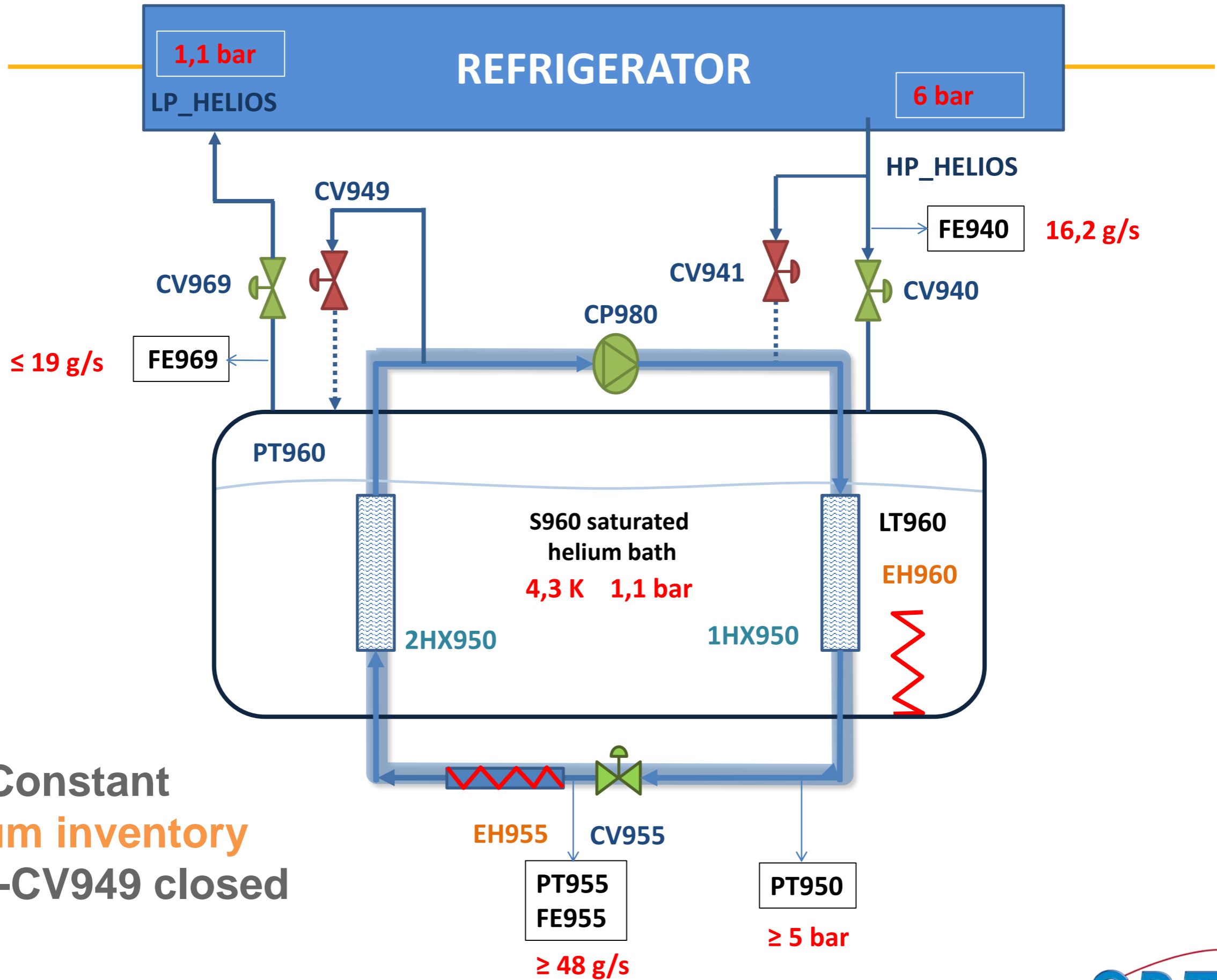
Constant
helium inventory
CV941-CV949 closed



Constant
helium inventory
CV941-CV949 closed



Constant
helium inventory
CV941-CV949 closed



Constant
helium inventory
CV941-CV949 closed

OPERABILITY of the TOKAMAK

2 AIMS : Protect the coils and optimize the cost

2 kinds of constraints

PERFORMANCE → **ACCEPTANCE TESTS** (mechanical and capacity ; safety requirements; process control system)

ECONOMY → size and cost of the CRYO SYSTEM → **PULSE SMOOTHING STRATEGY**

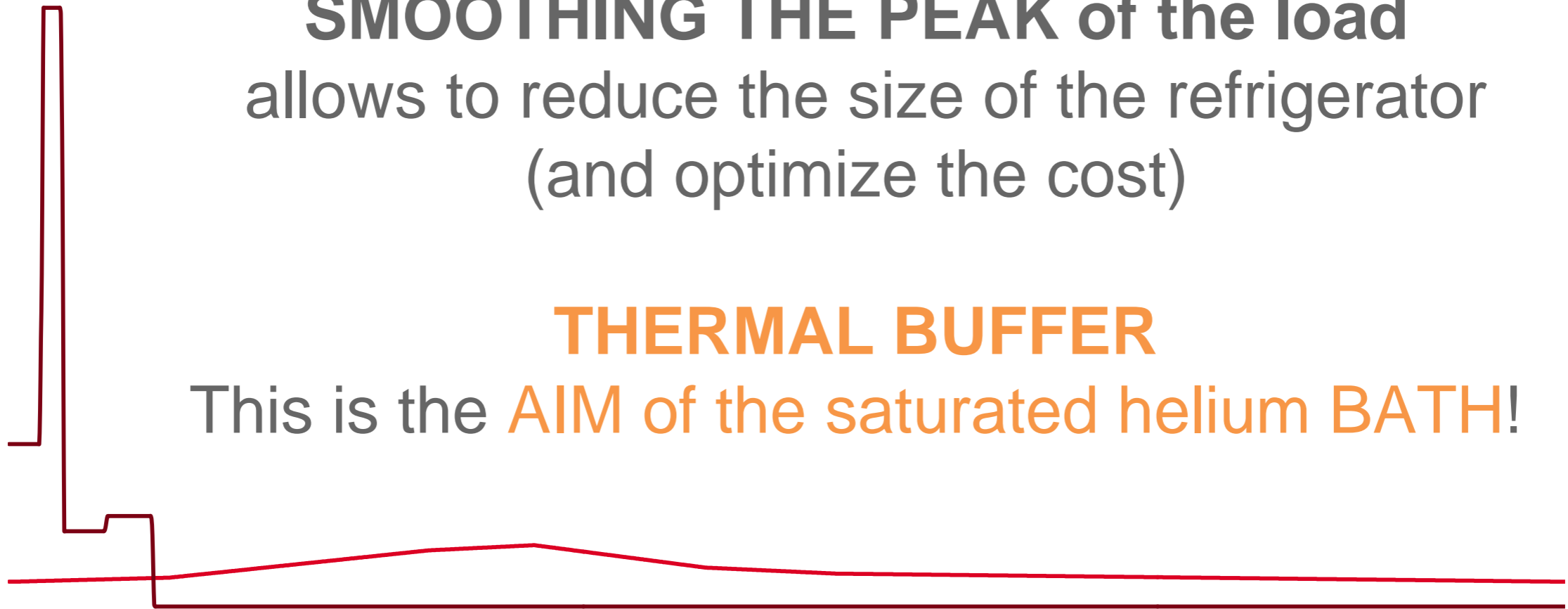
PULSE SMOOTHING STRATEGY

A TOKAMAK works cyclically
the heat **LOAD** seen by the magnets is **VARIABLE**

SMOOTHING THE PEAK of the load
allows to reduce the size of the refrigerator
(and optimize the cost)

THERMAL BUFFER

This is the **AIM** of the saturated helium **BATH**!



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Recap INPUTS

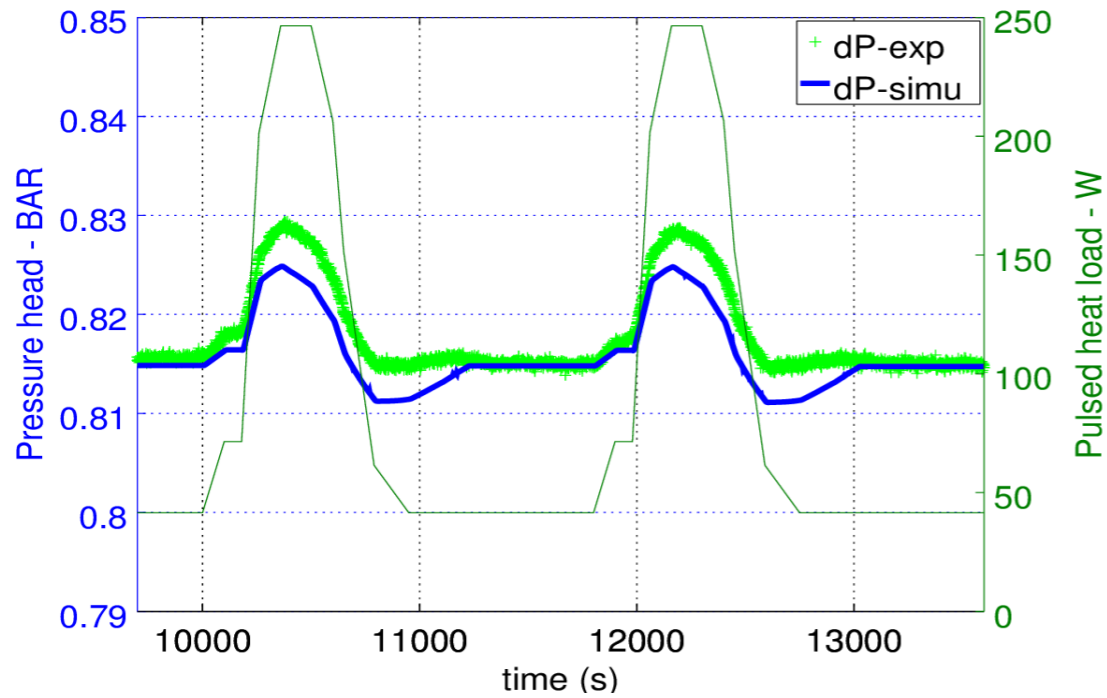
HEAT LOAD PROFILE



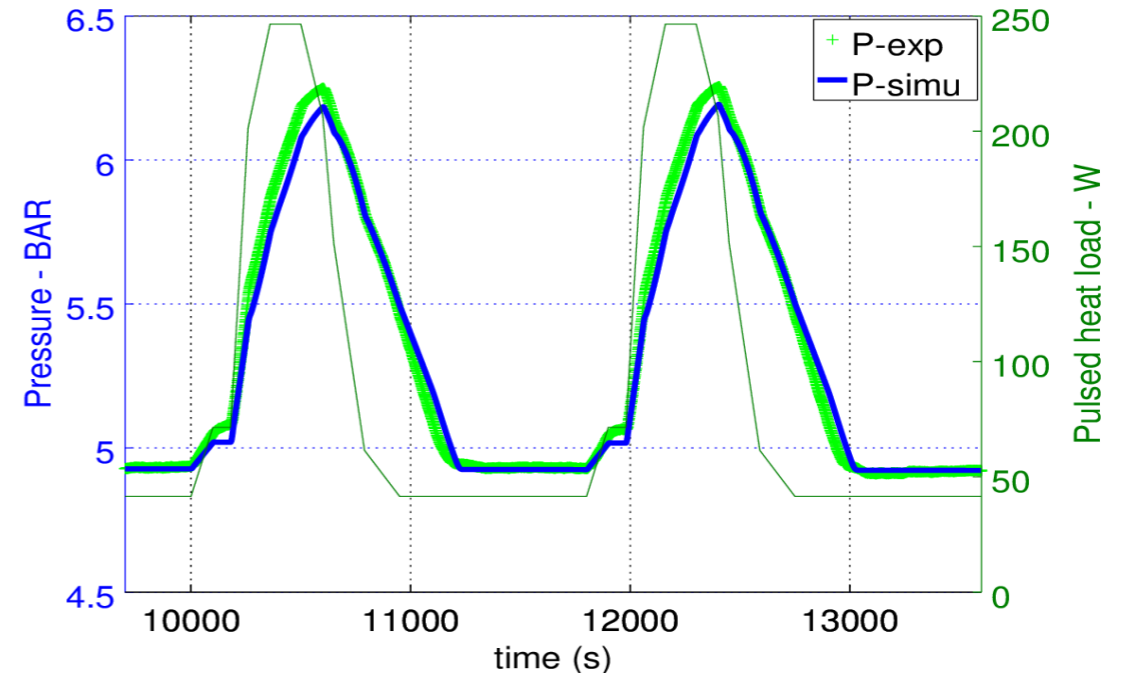
INITIAL CONDITIONS	
Loop	4.4 K , 5.7 bar (coils interface) 4.4 K , 4.9 bar (pump inlet)
Bath	4.3 K , 71 % liquid level
High Pressure Line – HP	4.7 K , 6 bar
Low Pressure Line – LP	4.3 K , 1.16 bar
BOUNDARY CONDITIONS	
Bath mass flow control	16.2 g/s inlet – FE940 19.0 g/s outlet – FE969
Loop fixed settings	14.9 W (Static Losses – A posteriori estimation) Time dependent power applied to the loop – pulse like Circulator speed: 134 Hz
Dead Volumes (NON circulating Helium + plugs and connections)	10 liters

Experimental campaign **MAY 2015**

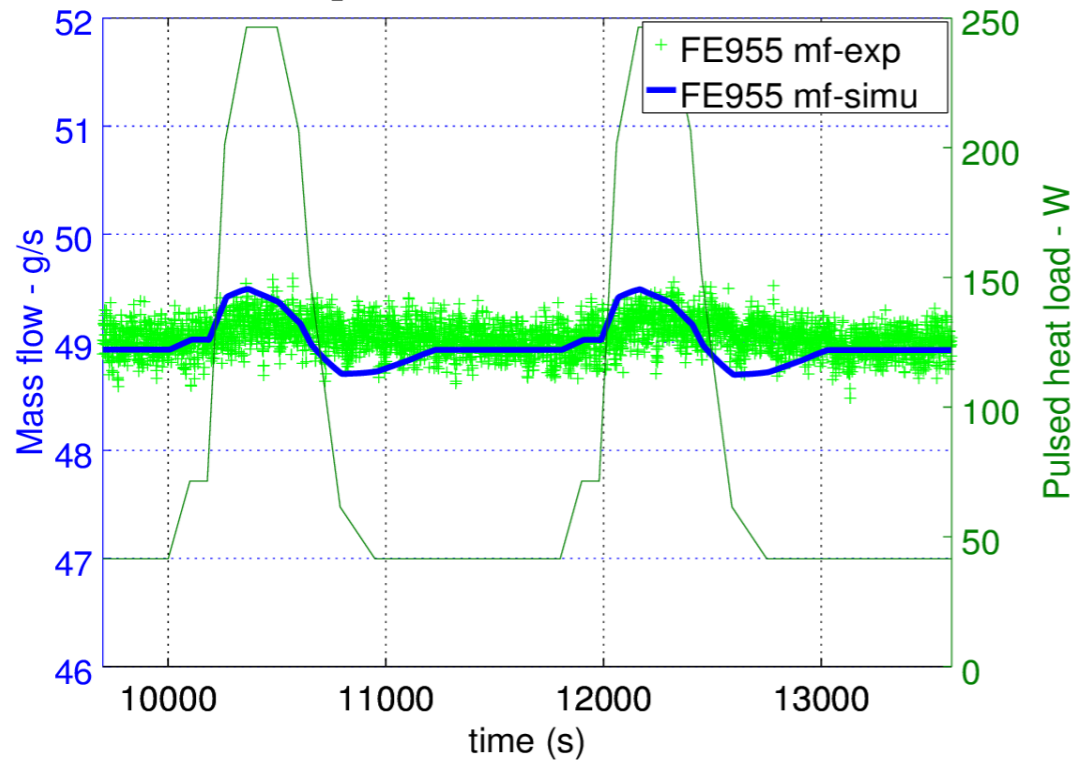
Pressure head



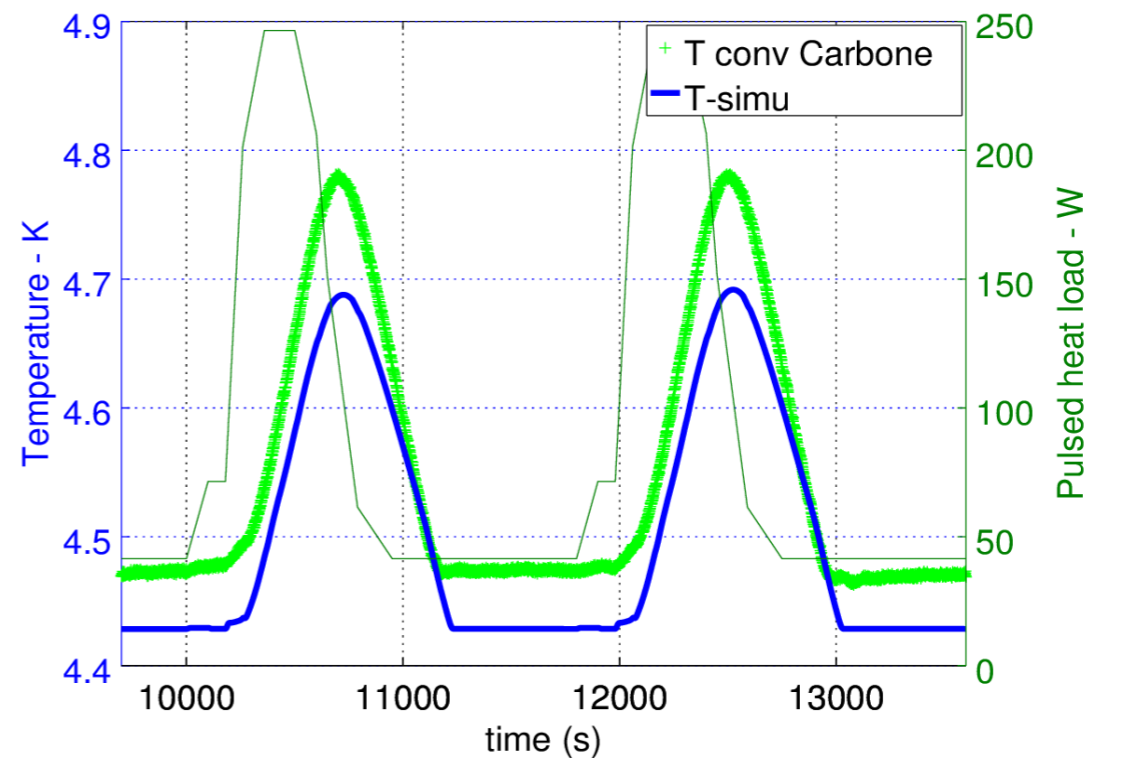
Pump Inlet Pressure



Loop mass flow

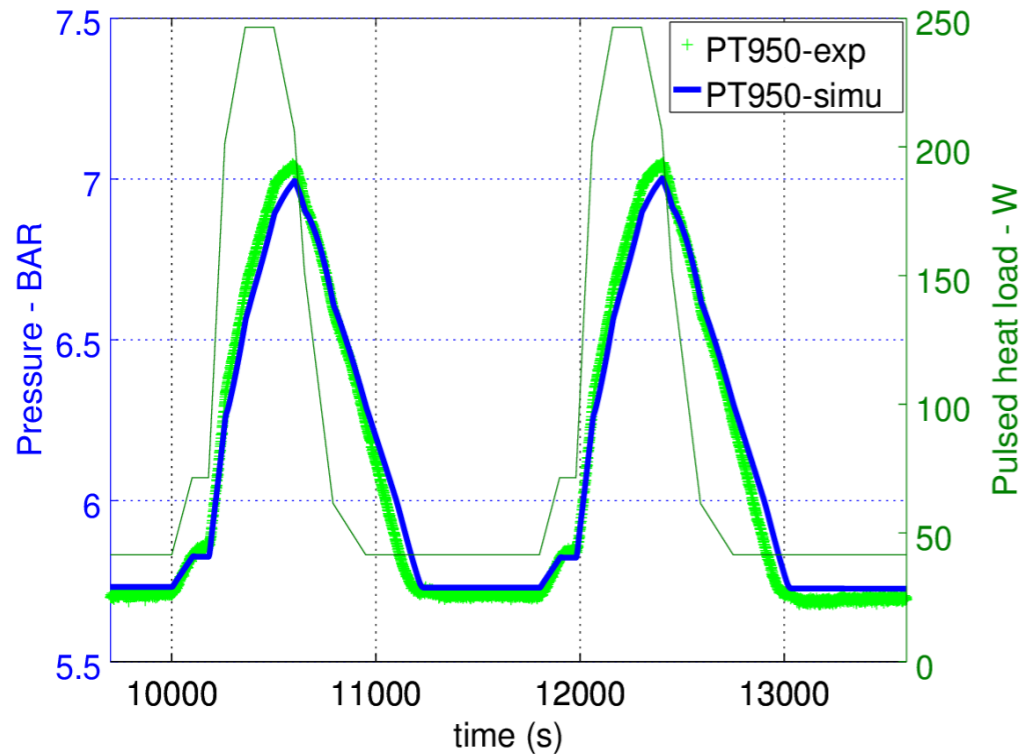


Pump Inlet Temperature

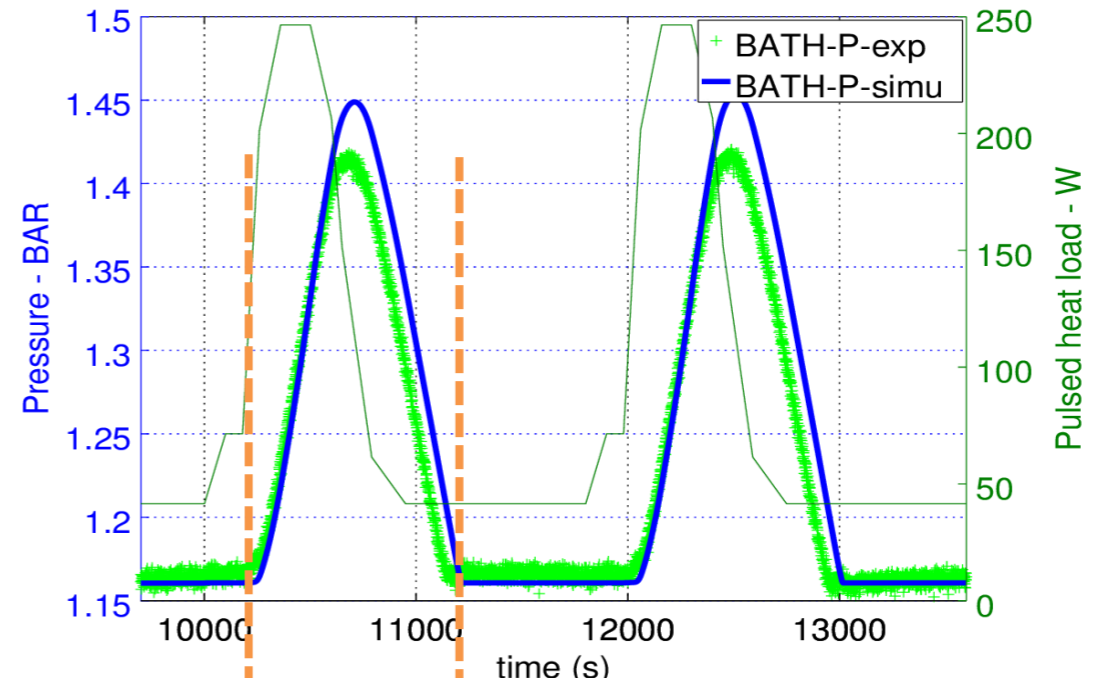


Experimental campaign **MAY 2015**

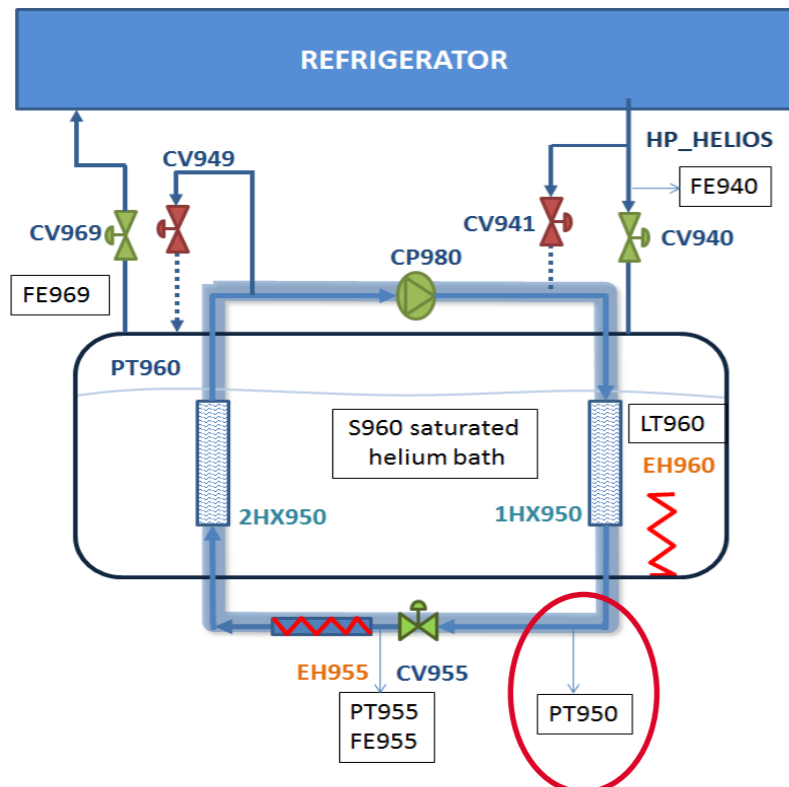
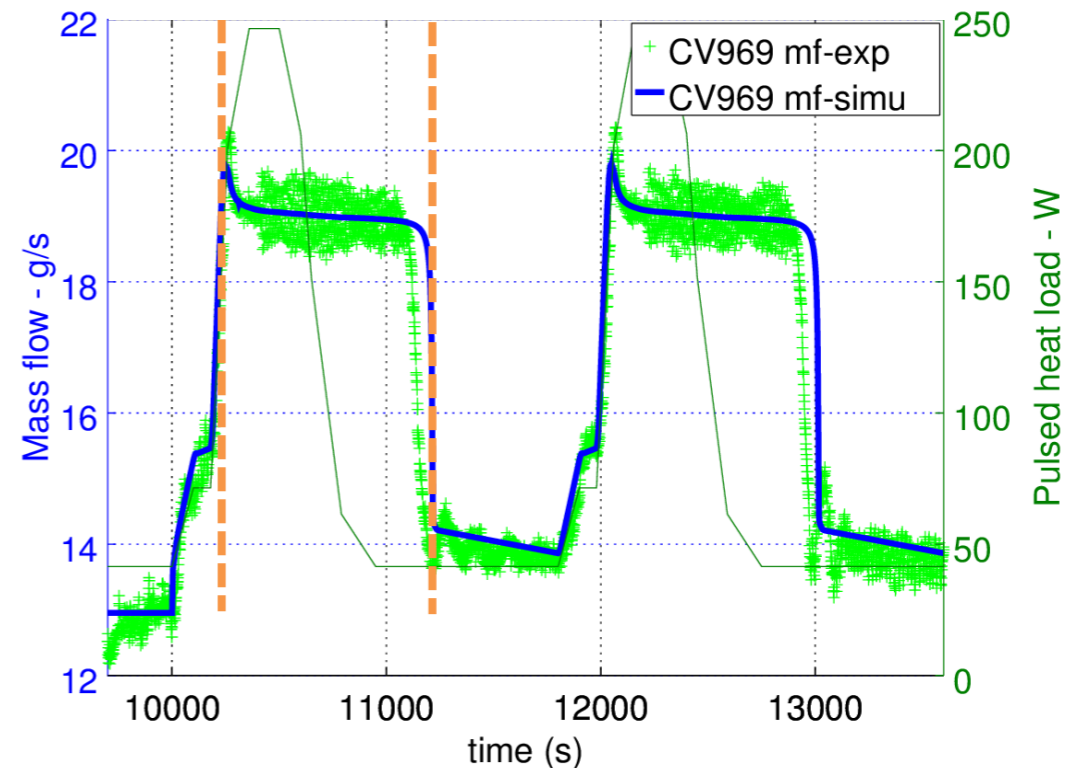
Loop Pressure



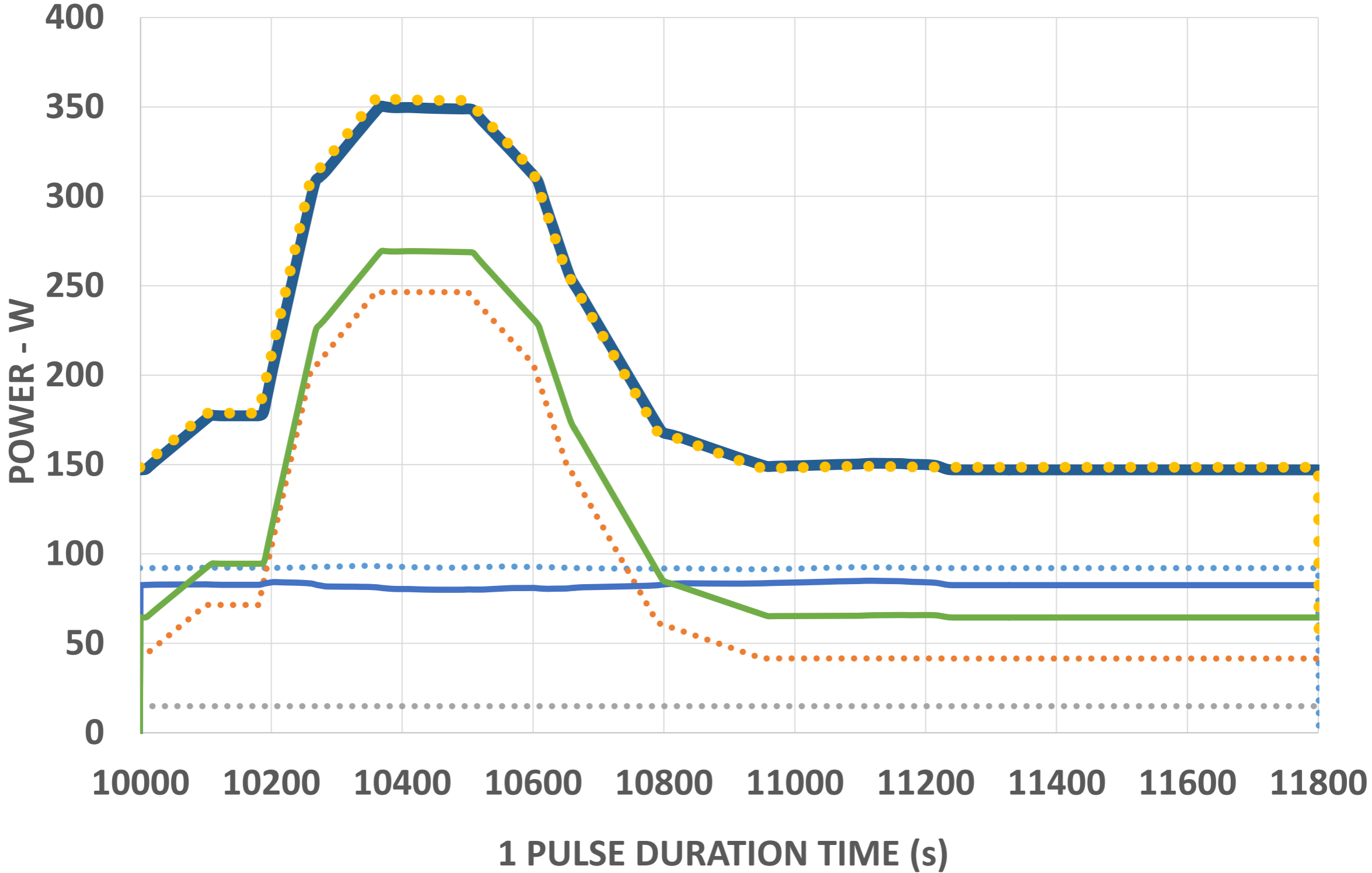
Bath Pressure



Bath outlet mass-flow

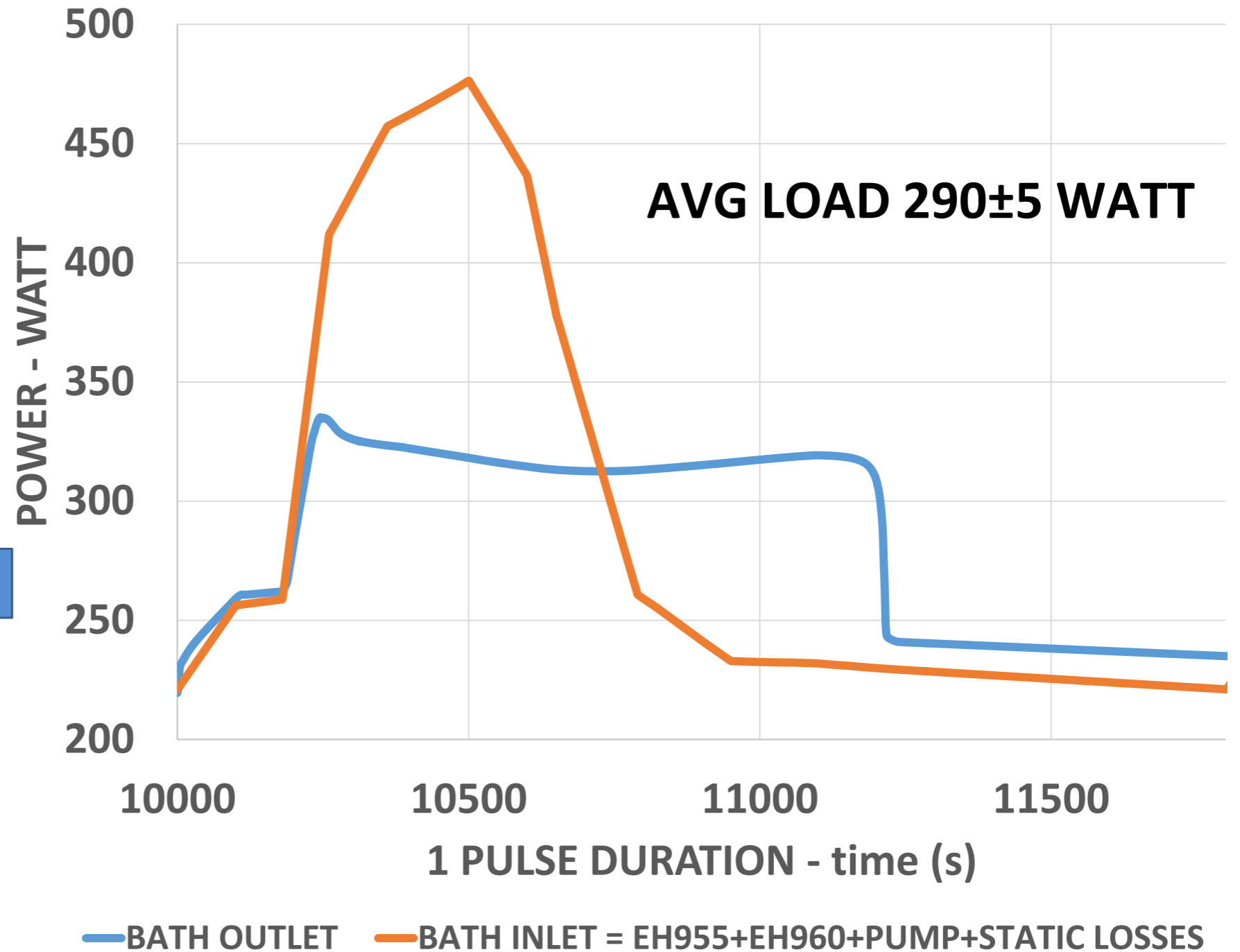
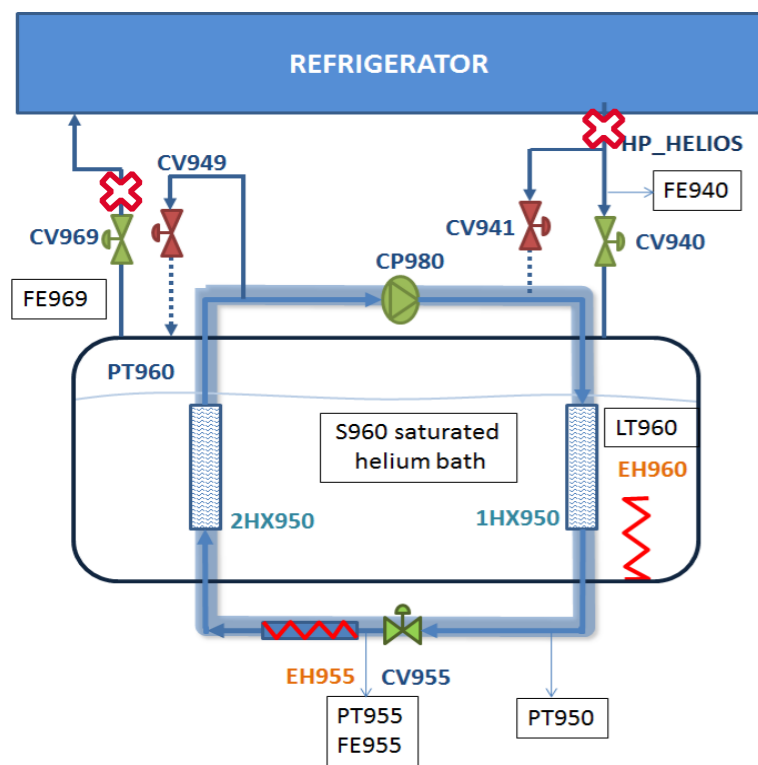


THERMAL BALANCE



●●● PUMP
 ●●● EH955 Loop 2 HEATING
 ●●● HEAT LEAKS
 — HX 1
 — HX 2
 — TOT IN THE BATH
 ●● TOT IN THE LOOP

BUFFER EFFECT



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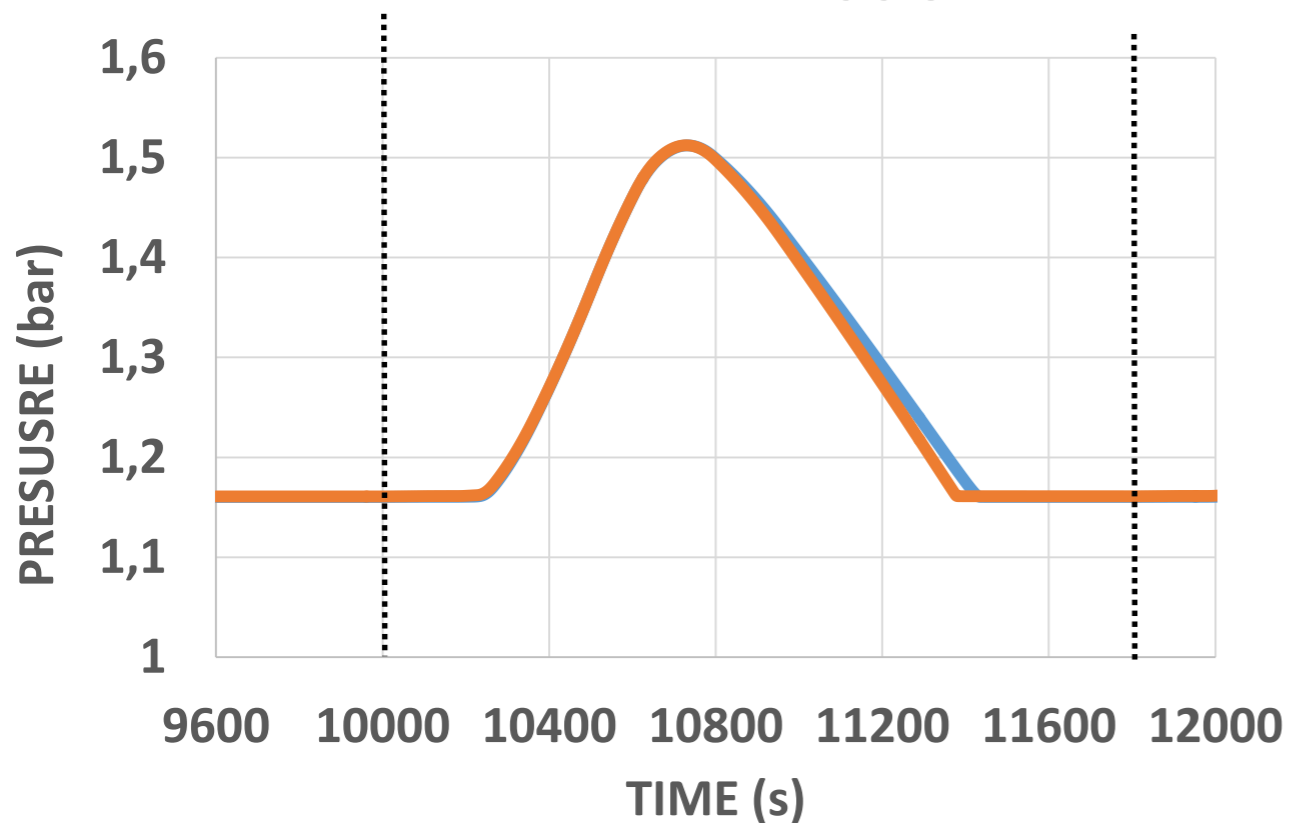
JT-60SA & HELIOS - A numerical comparison

JT60-SA Auxiliary Cold Box

Comments & Conclusions

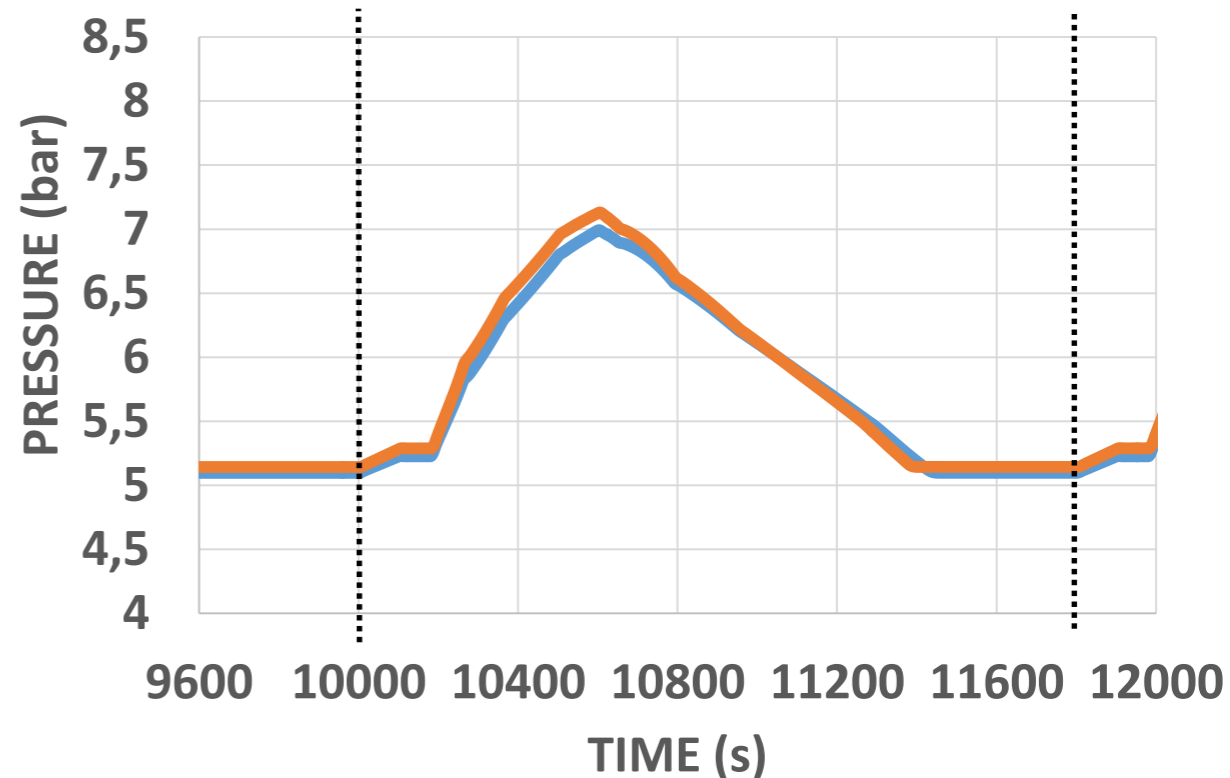
JT-60 Vs HELIOS: a numerical example

BATH PRESSURE



— HELIOS — JT-60SA

PUMP PRESSURE



— HELIOS inlet — JT-60SA inlet

OPERATIONAL POINT @ PULSE START - LOOP 2

HELIOS	49,2 g/s	0,819 bar	(977/20=48,85)
JT-60SA	977 g/s	0,814 bar	

NO dead volumes
NO static heat losses
SAME initial conditions

SAME buffer effect
SAME P rising at the pump inlet
COHERENT mass flow & pressure head

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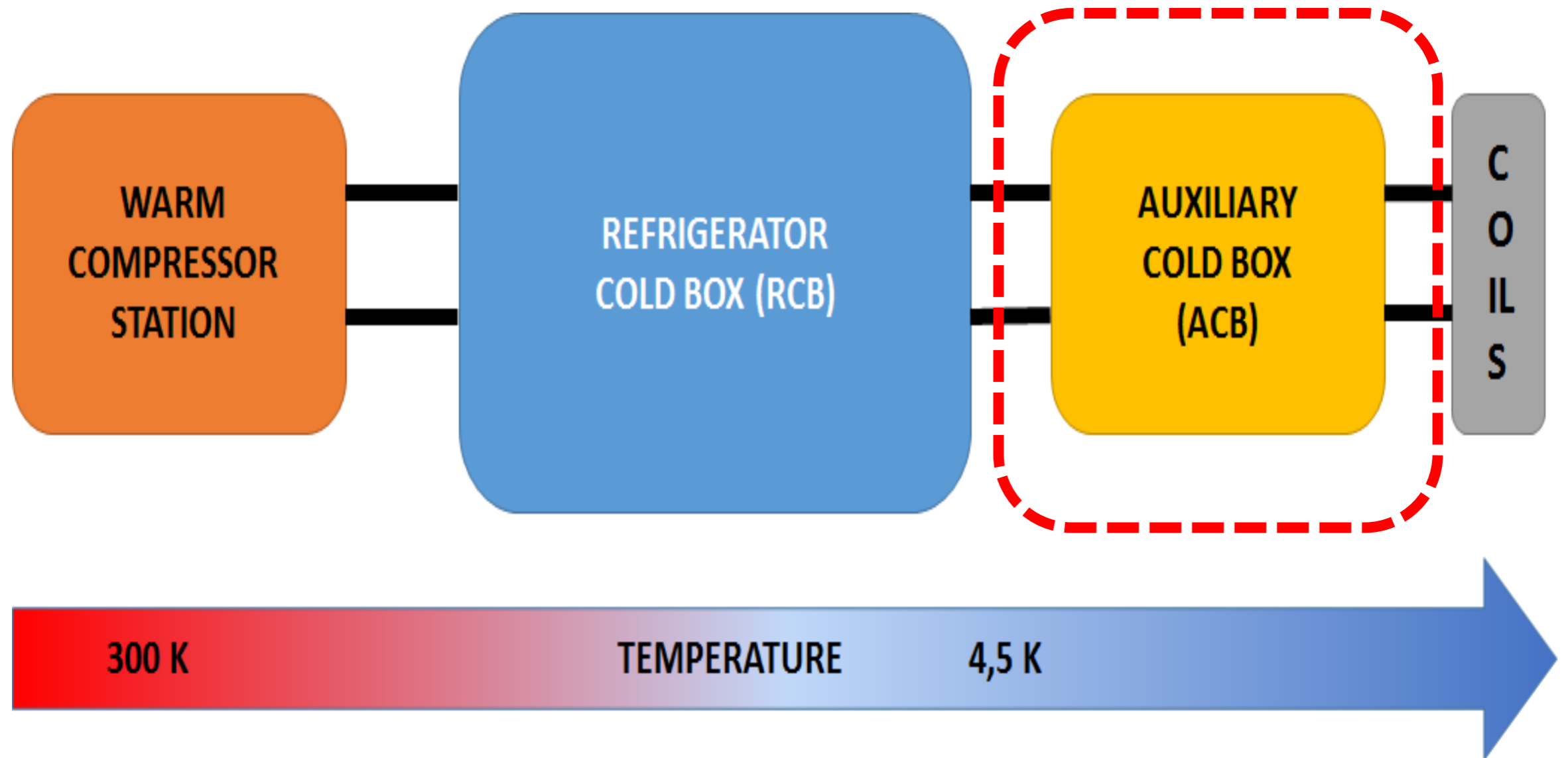
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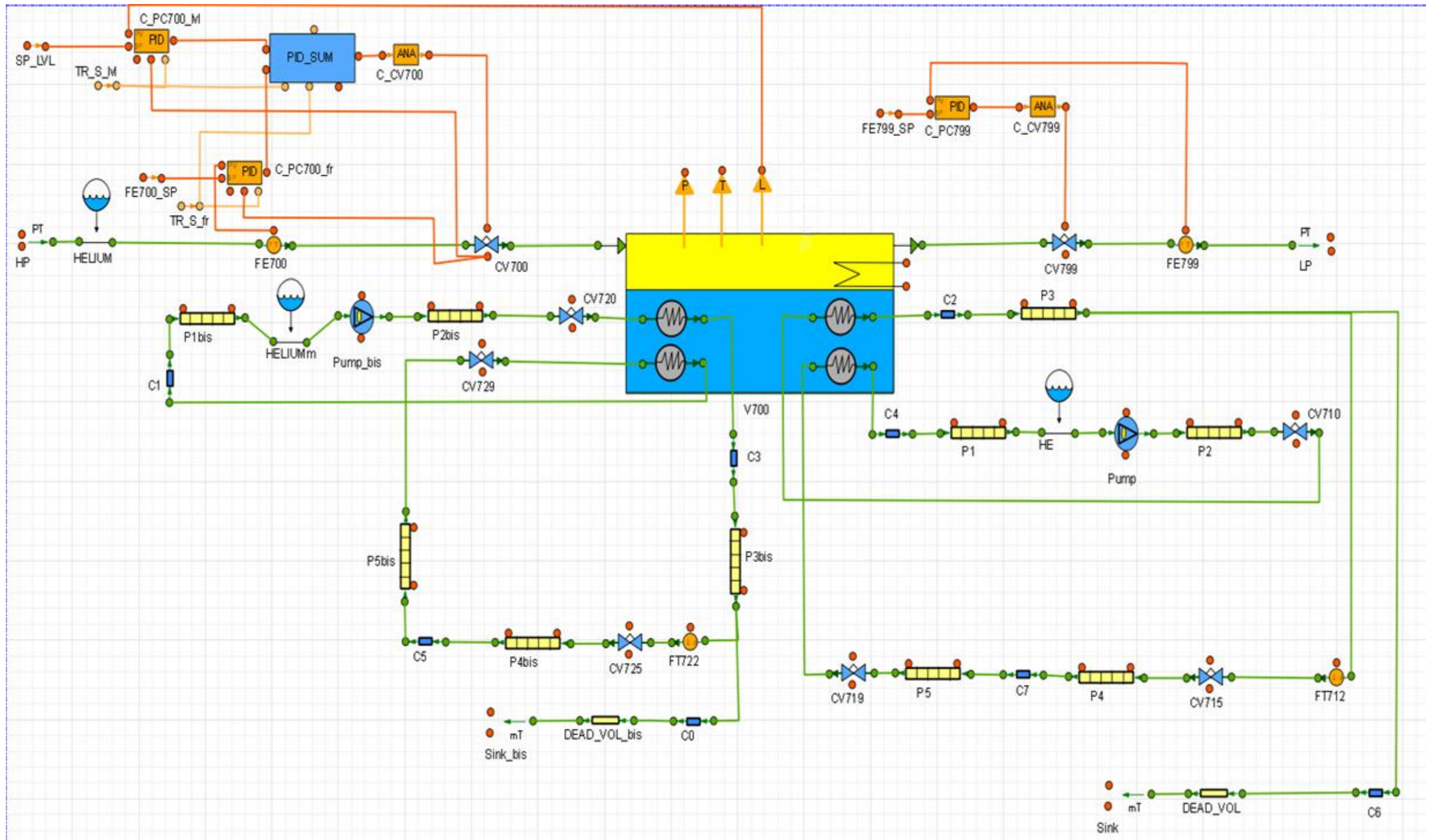
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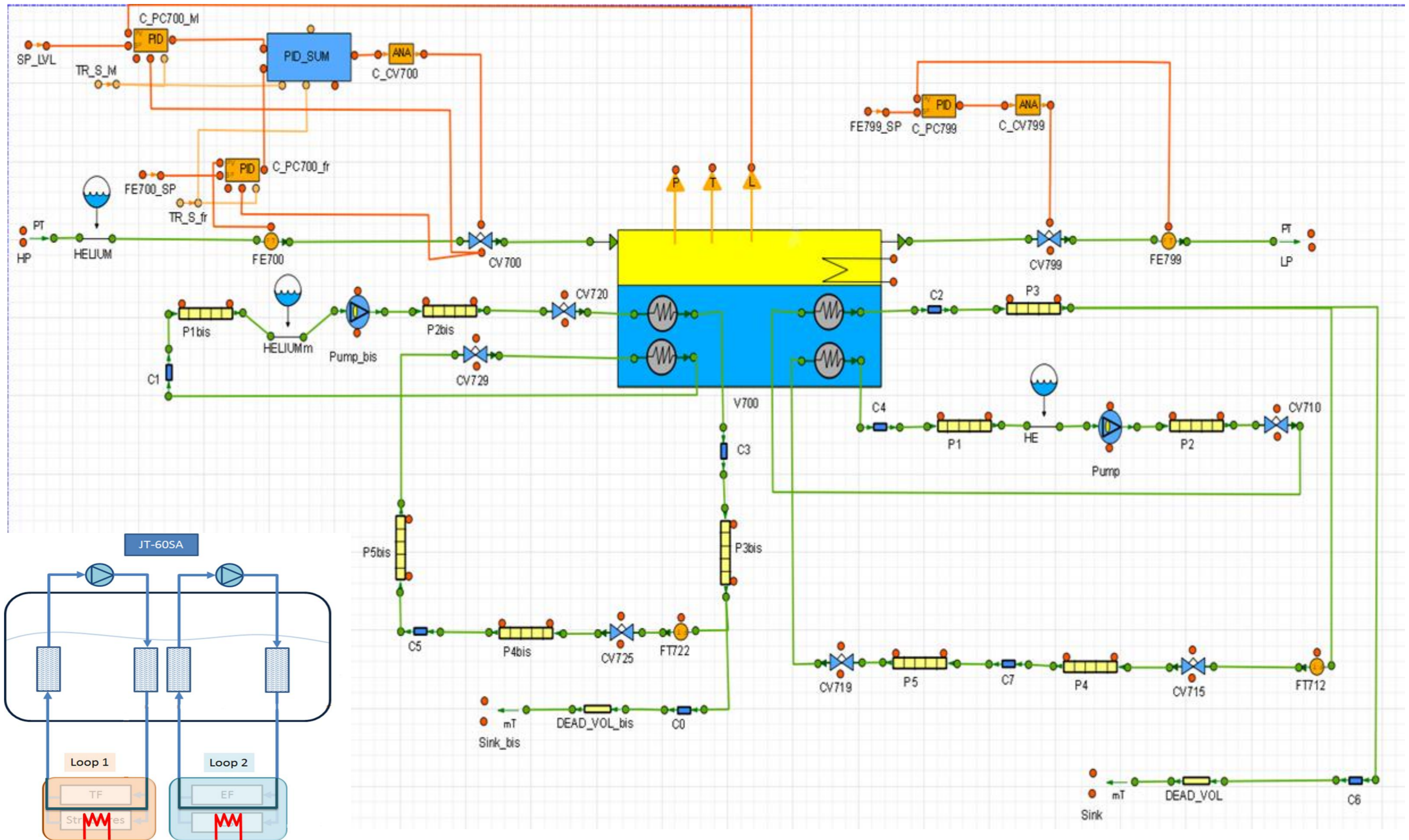
JT60 – SA's ACB MODEL



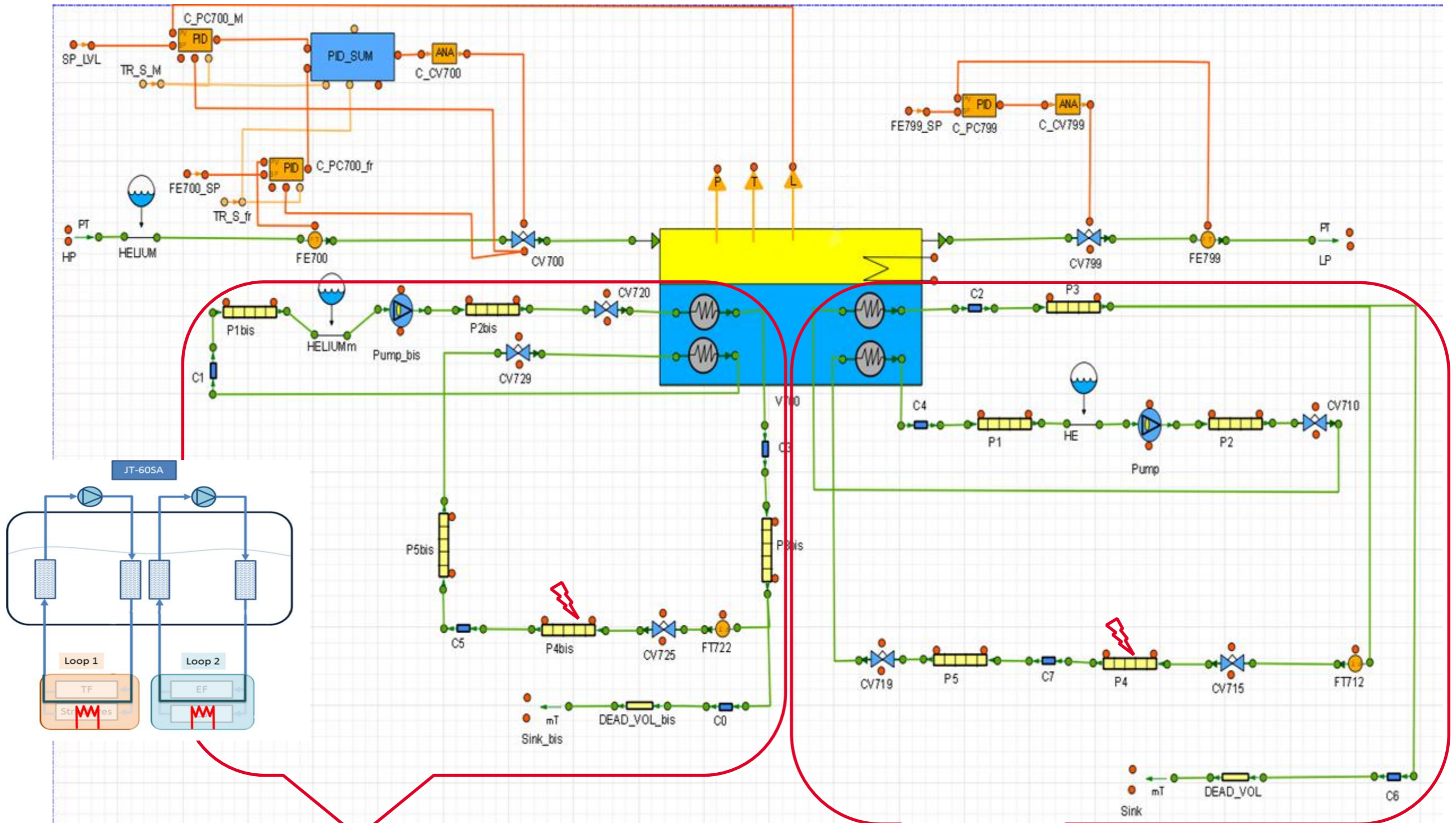
JT60 – SA's ACB MODEL



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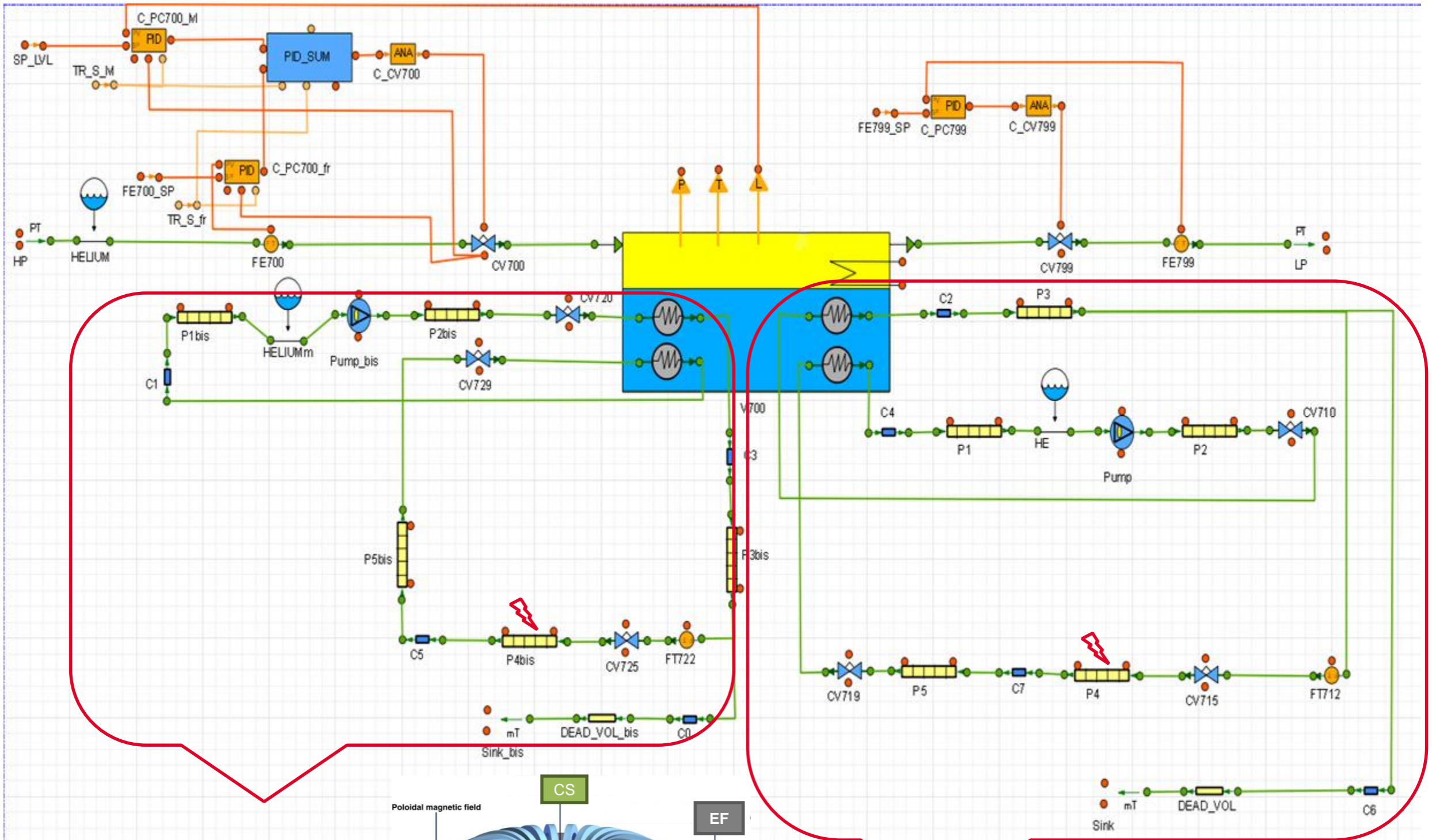
JT60 – SA's ACB MODEL



**LOOP 2
CS+EF**

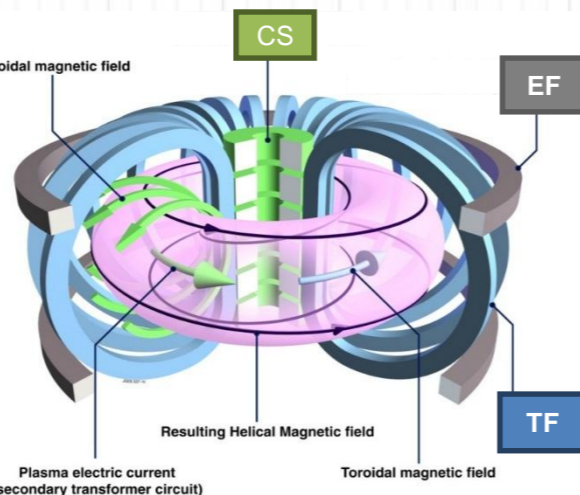
**LOOP 1
TF + Struct**

JT60 – SA's ACB MODEL

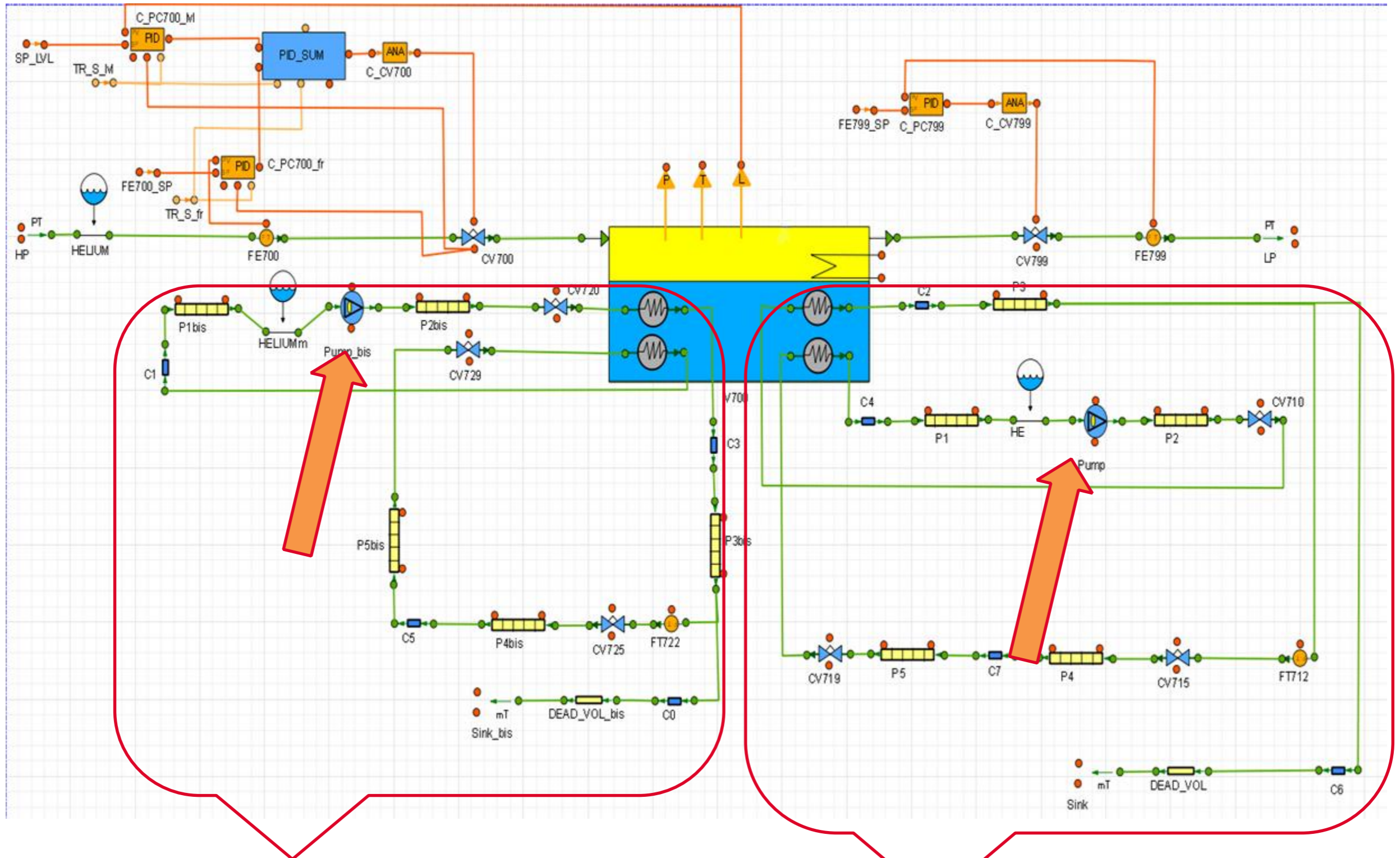


**LOOP 2
CS+EF**

**LOOP 1
TF + Struct**



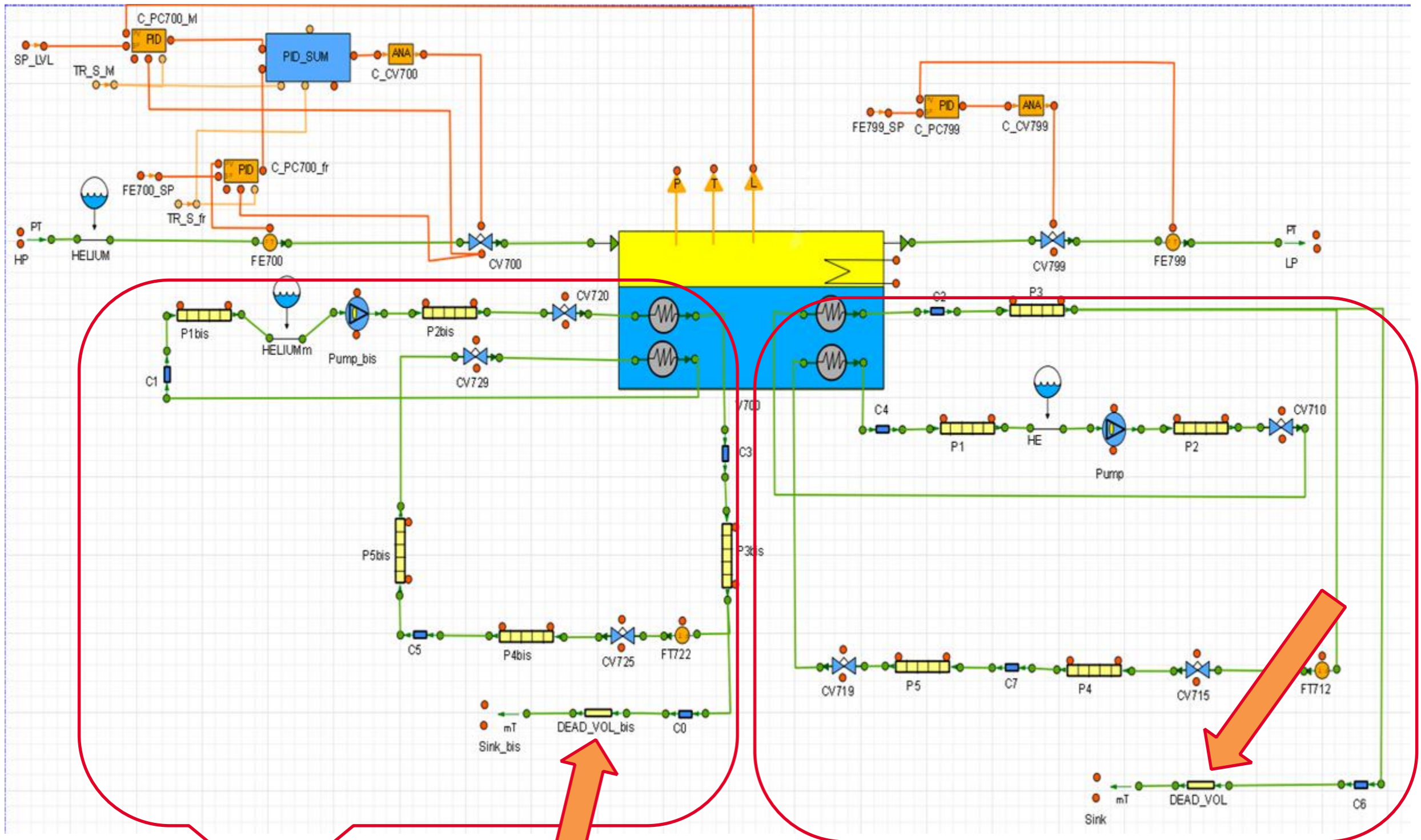
JT60 – SA's ACB MODEL



**LOOP 2
CS+EF**

**LOOP 1
TF + Struct**

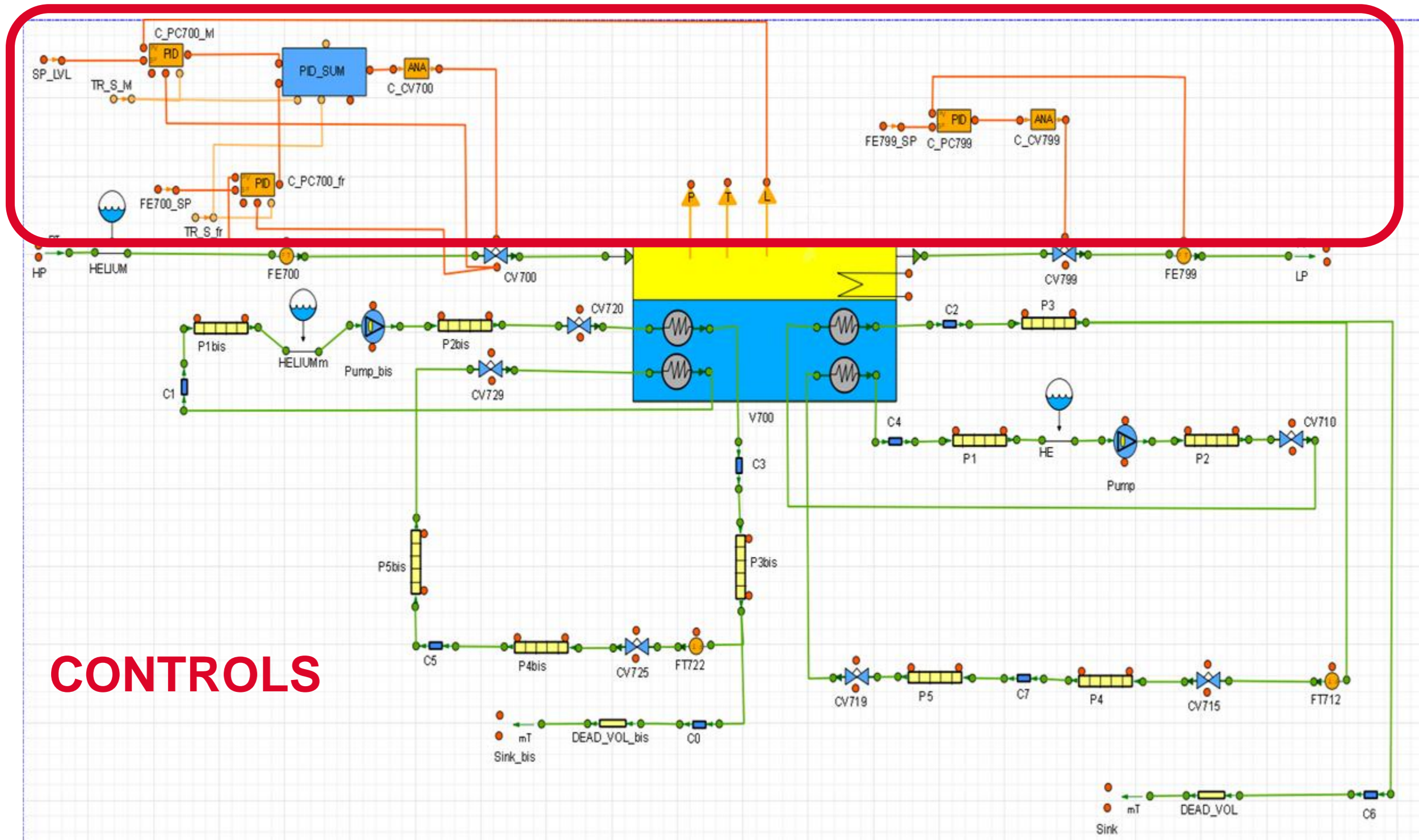
JT60 – SA's ACB MODEL



LOOP 2
CS+EF

LOOP 1
TF + Struct

JT60 – SA's ACB MODEL

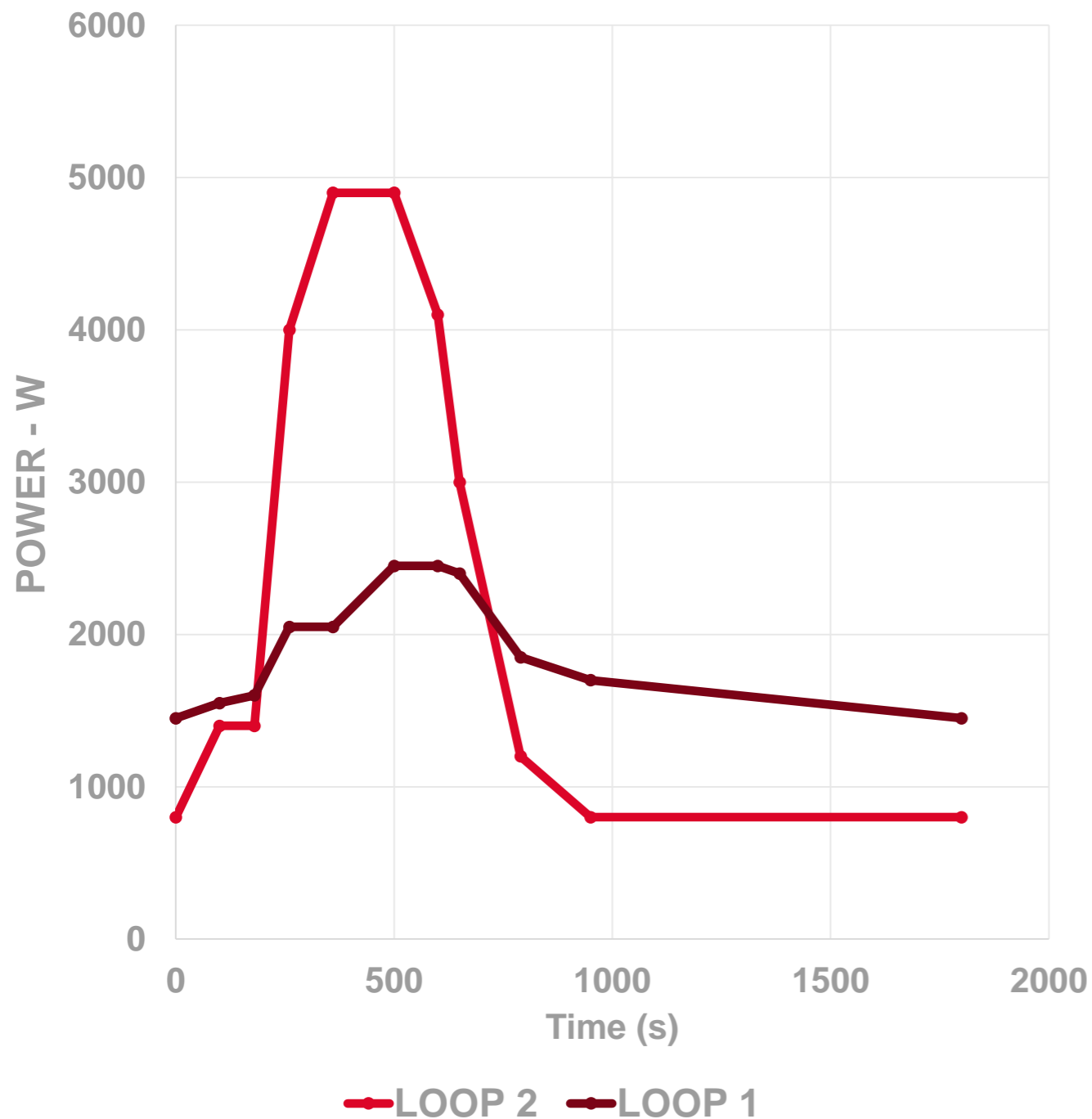


CONTROLS

BEFORE the pulse → LVL control & outlet mass-flow
DURING the pulse → inlet & outlet mass-flow

INPUTS

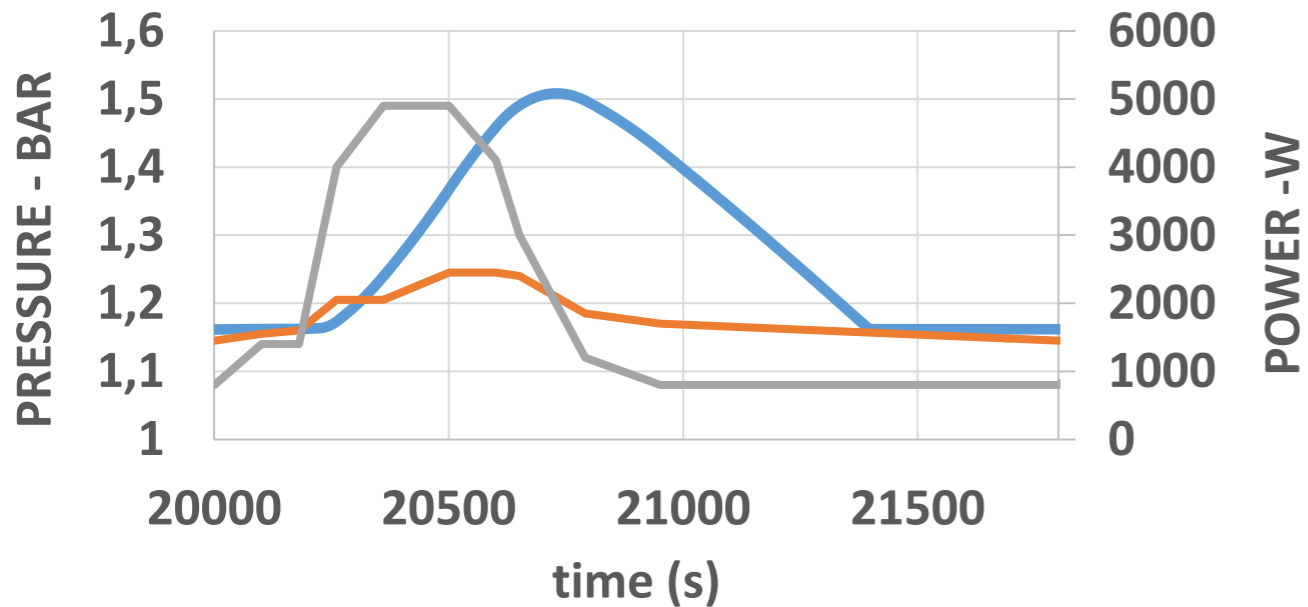
JT-60SA pulses



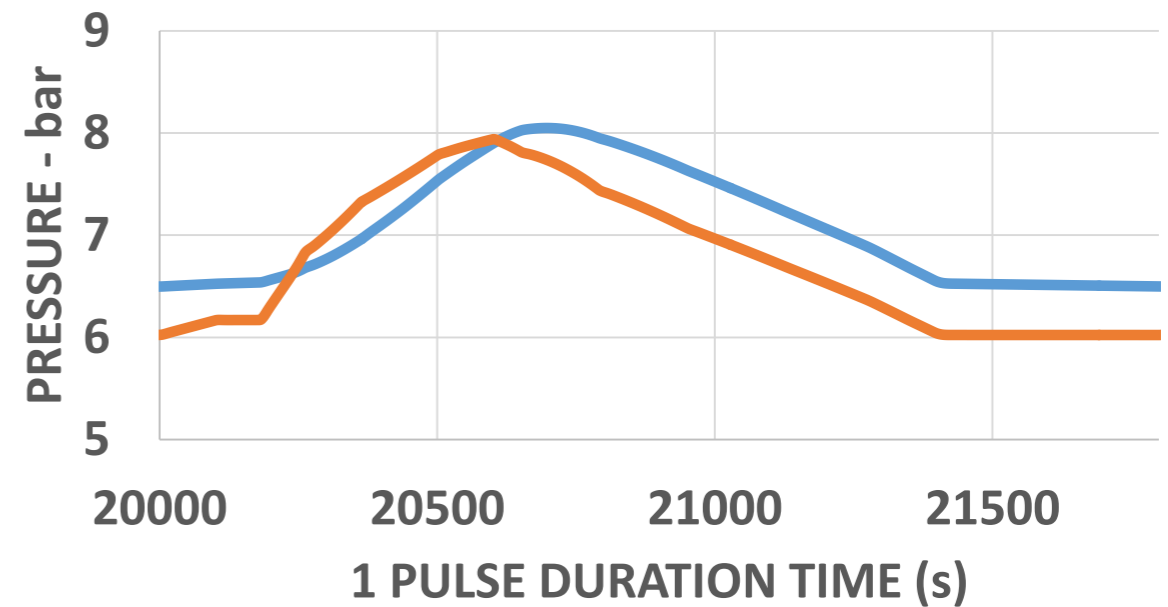
INITIAL CONDITIONS	
Loop 1	4.6 K , 6.5 bar (coils interface) 4.4 K , 5.1 bar (pump inlet)
Loop 2	4.5 K , 6.0 bar (coils interface) 4.4 K , 5.2 bar (pump inlet)
Bath	4.3 K , 71 % liquid level
High Pressure Line – HP	4.7 K , 6 bar
Low Pressure Line – LP	4.3 K , 1.16 bar
BOUNDARY CONDITIONS	
Bath mass flow control	338 g/s inlet – FE700 367 g/s outlet – FE799
Loop fixed settings	164,2 W – heat leaks (49,9 in the bath) 2 Time dependent heat profiles applied to the loops – pulse like
Dead Volumes	24,6 litres in total

SOME RESULTS

Bath Pressure



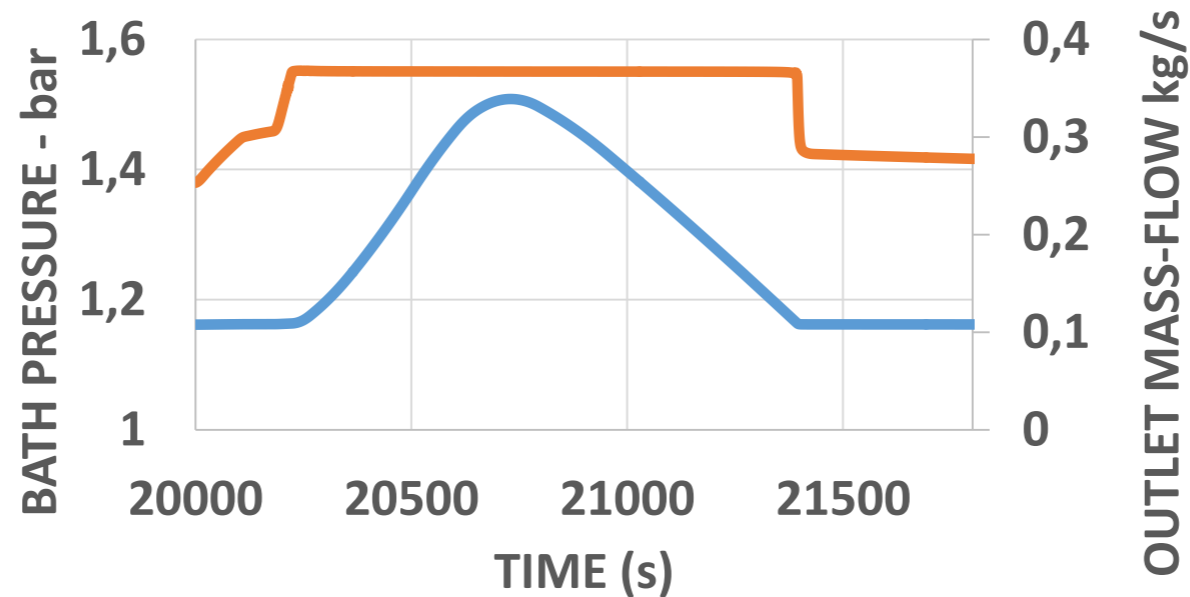
Loop Pressure (Pump Outlet)



— BATH PRESSURE — PULSE Loop 1 — PULSE Loop 2

— LOOP 1 — LOOP 2

Bath Outlet mass-flow control



— BATH PRESSURE — BATH OUTLET MASS-FLOW

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- ✓ **START:** Good results on HELIOS → positive perspective for JT60-SA
- ✓ **GOAL:** The JT-60SA model wants to be a **predictive** tool to reproduce qualitatively the experimental tests
- ✓ **NEXT STEPS:**
 - refining the ABC model (details: CC, 2nd bath...)
 - modelling RCB and WCS

Thank you for
Your kind attention

Contact:

roberta.cirillo@cea.fr

Univ. Grenoble Alpes, CEA INAC-SBT

Service des Basses Températures

17, rue des Martyrs, 38054 Grenoble Cedex 9 - France