EUROfusion

# Simulation of transients of DONES lithium loop with MELCOR fusion 1.8.6

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# Introduction

- According to the 2014 European Fusion Roadmap, an early construction of DEMO is expected by 2030

- A **DEMO-Oriented Neutron Source** (**DONES**) has been proposed to create a fusion material database required in a fusion reactor (based on “IFMIF” concept)

- The objective of the **Early Neutron Source** (**ENS**) project (EUROfusion/ WPENS) is to carry out activities for the engineering design development of DONES

- A safety analysis is required for DONES licensing and construction

# CIEMAT activities on DONES SA

- ❑ DONES deterministic safety analysis performed on selected reference scenarios (identified by FMEAs)

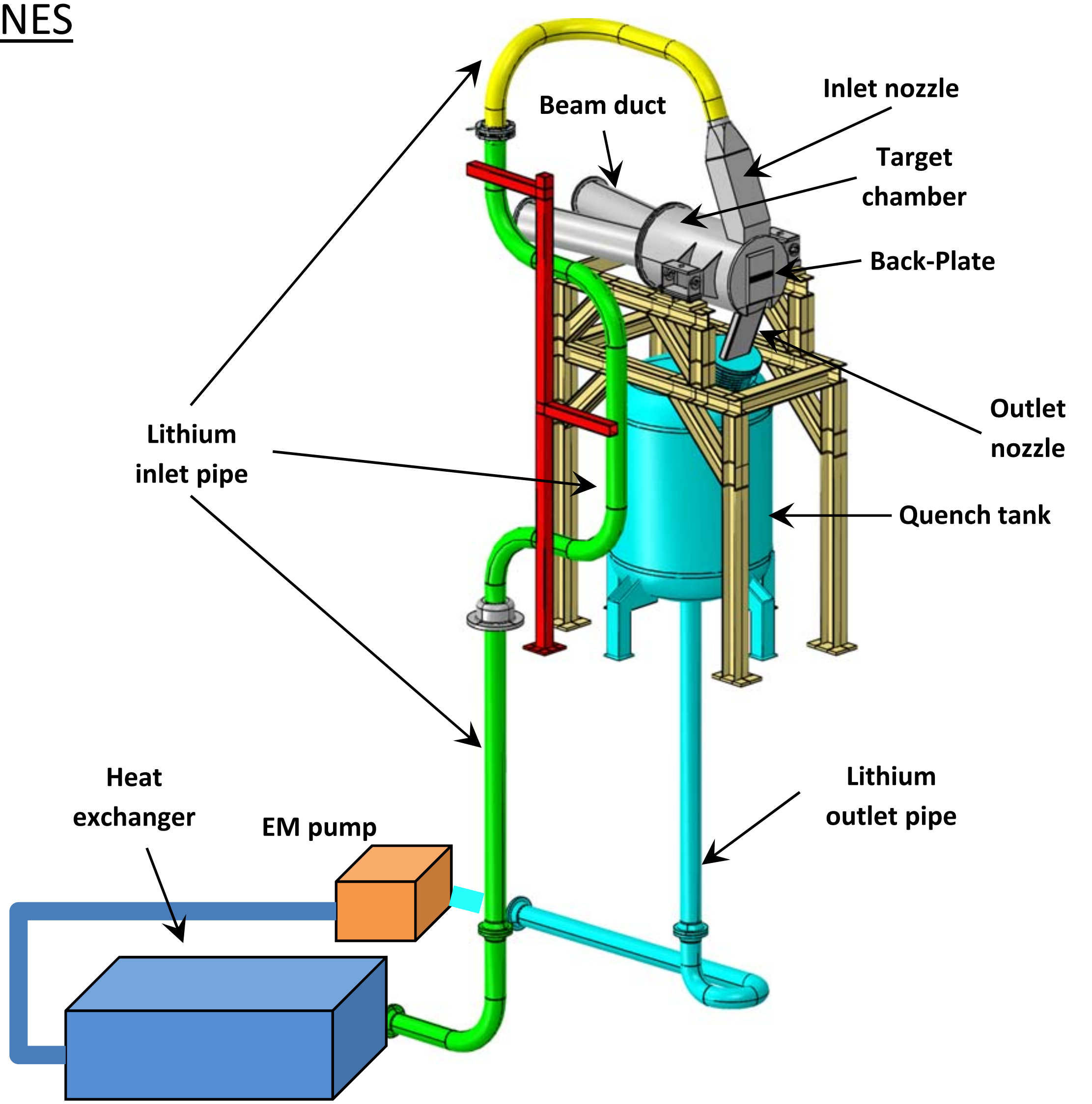
- ❑ Preliminary assessment of consequences to public and workers in support of DONES licensing

- ❑ In this presentation**:**

- Operational transient sequence and **LOFA scenario** (with/without beam shutdown) of **DONES lithium loop**

# DONES main Li Loop

3D Sketch of DONES main Li Loop

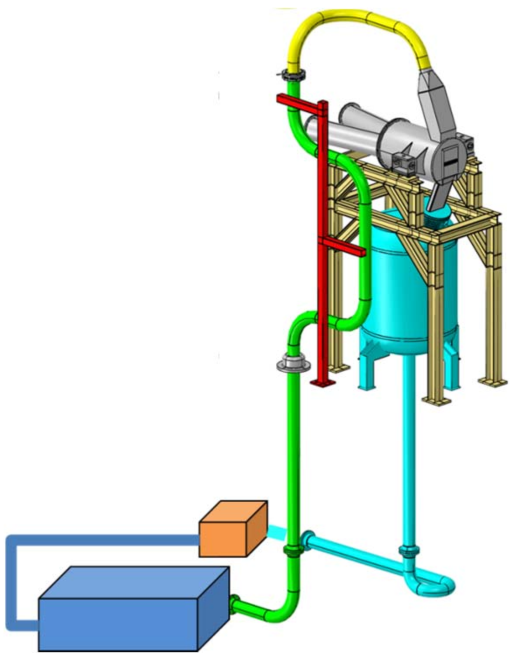


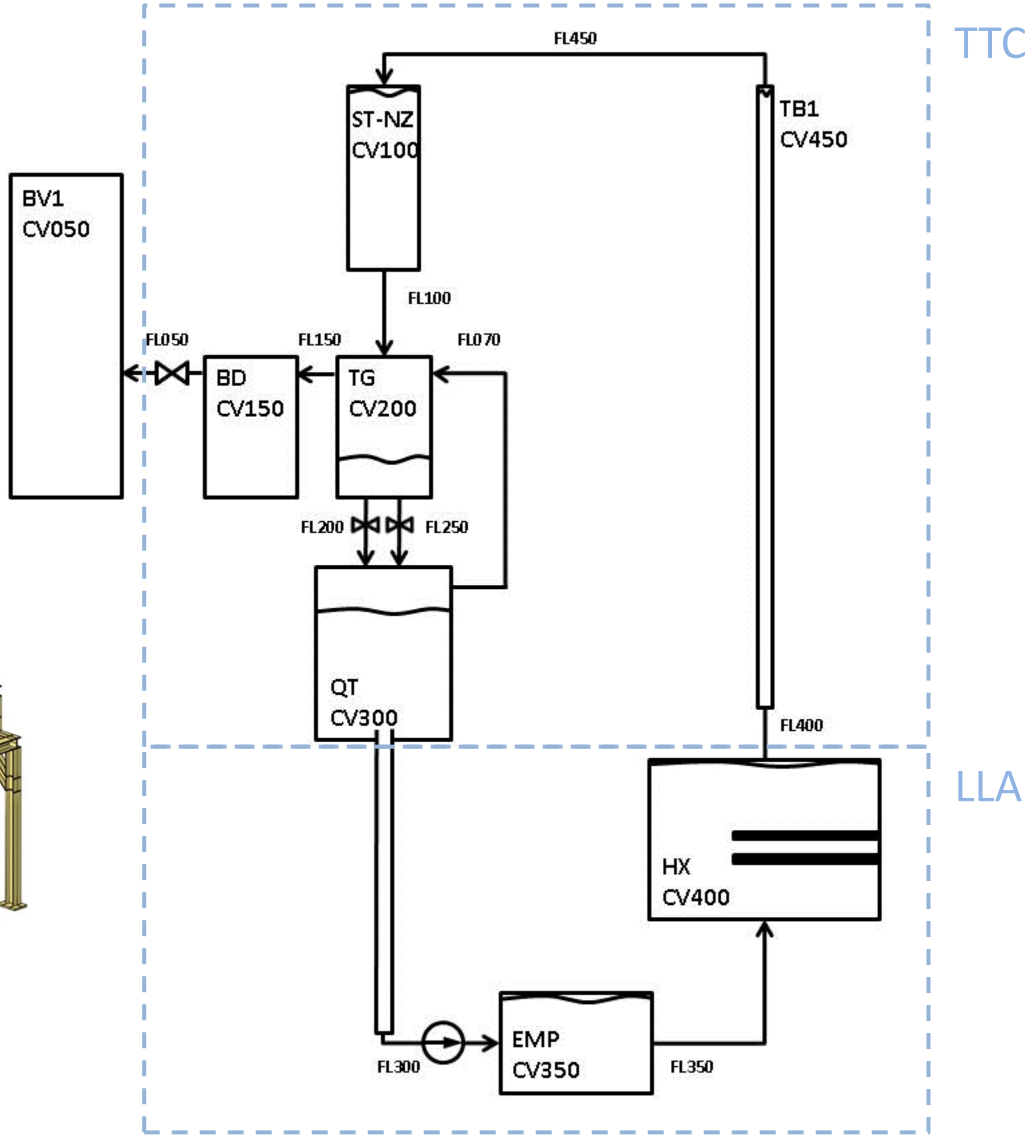

*D. Bernardi. IFMIF-DONES Target System Design Description Document. EFDA_D_2N74W4 (2017).*

# Li Loop Modeling

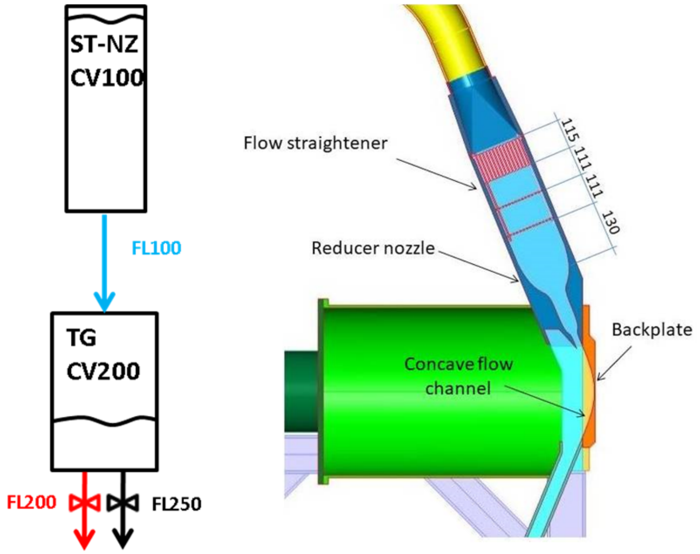
Basic model

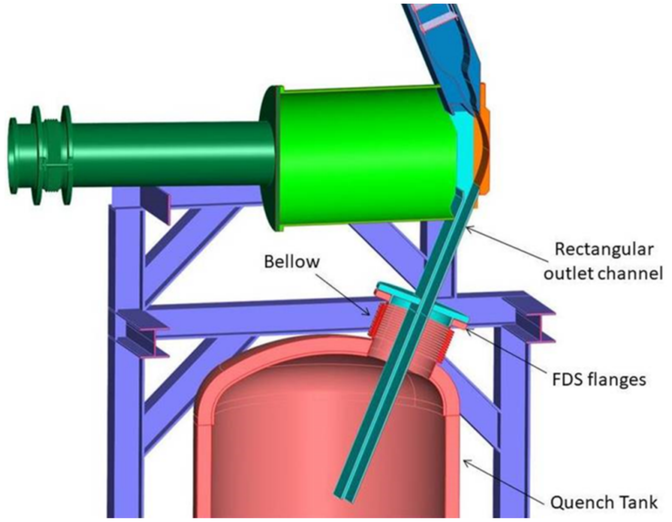
for Melcor-fusion





# Li target modeling




Key phenomenology: Li flows at high velocity in a small thickness layer (25 mm) to remove the high local power (5MW)

- A specific CVH/FL model is considered ("Momentum flux" option has been first explored without success)

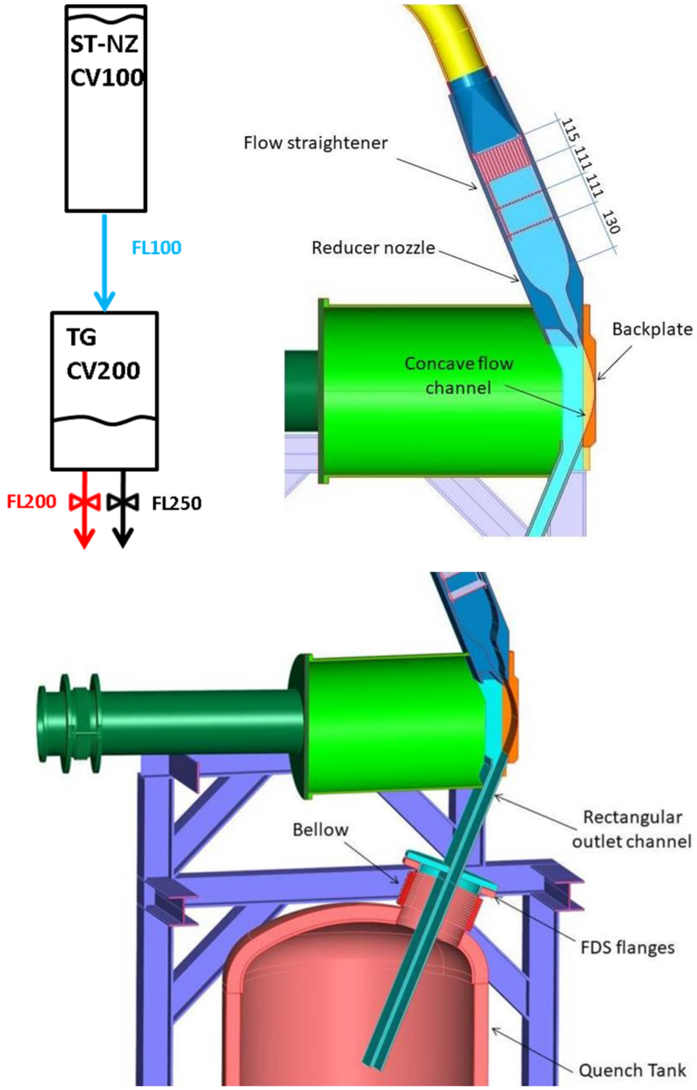
Mass flow rates of FL100 & FL200 are coupled by CF420 (same flow path area):

```
FL200T1   2   420
*
CF42000   VELFLOW    multiply    3    1.0    0.0
CF42010   1.0   0.0     FL-VELLIQ.100
CF42011   1.0   0.0     CVH-RHOP.100
CF42012   1.0   0.0     CFVALU.419
*
CF41900   INVRHO     DIVIDE      2    1.0    0.0
CF41910   1.0   0.0     CVH-RHOP.200
CF41911   0.0   1.0     TIME
```

$$\frac{(\rho * v)_{fl100}}{\rho_{fl200}} = v_{fl200}$$

*D. Bernardi. IFMIF-DONES Target System Design Description Document. EFDA_D_2N74W4 (2017)*

# Li target modeling




## But…

- When CV100 runs out of Li (FL-VELLIQ.100 = FL-VELLIQ.200 = 0 m/s), there is still a little amount of Li mass in CV200

**<u>CV200 must be empty!</u>**

**How to solve this issue?**

- We created another flow path **FL250** (identical to **FL200**), which opens when velocity in **FL100** becomes zero, and
- We imposed a constant velocity for **FL250** equal to the last non-zero value of **FL-VELLIQ.200** until CV200 empties *(conservative assumption)*

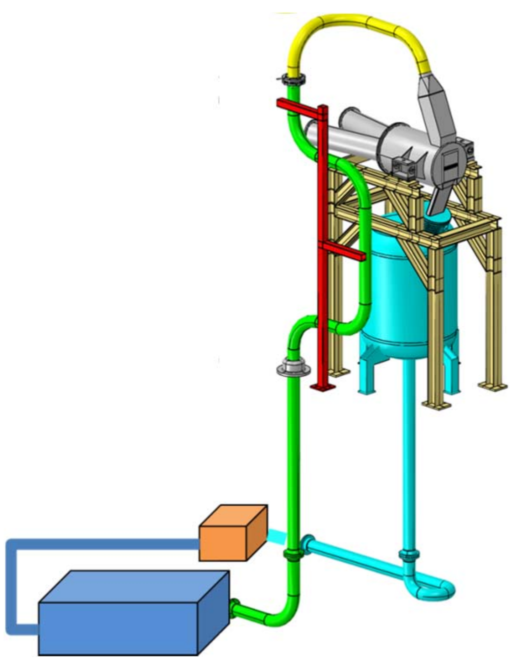
*D. Bernardi. IFMIF-DONES Target System Design Description Document. EFDA_D_2N74W4 (2017)*

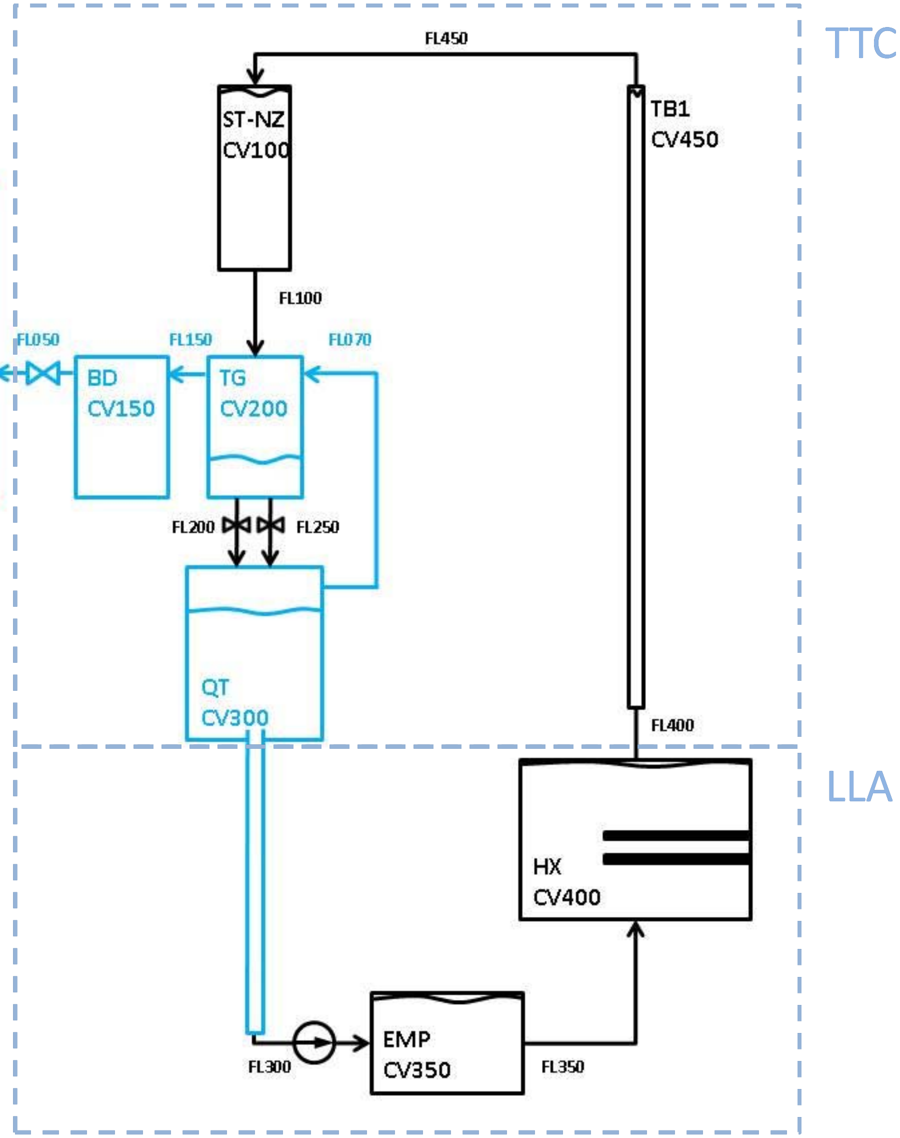
# Li Loop Modeling

Basic model

for Melcor-fusion

“Vacuum pumping “
Low P, 1E-5 Pa
Boundary Volume



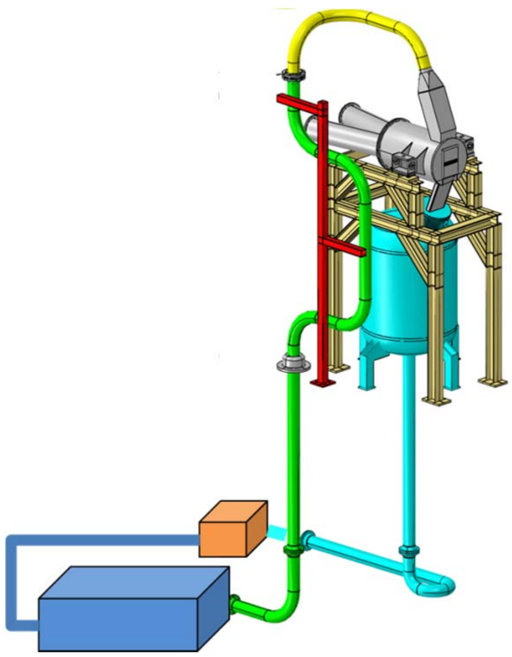


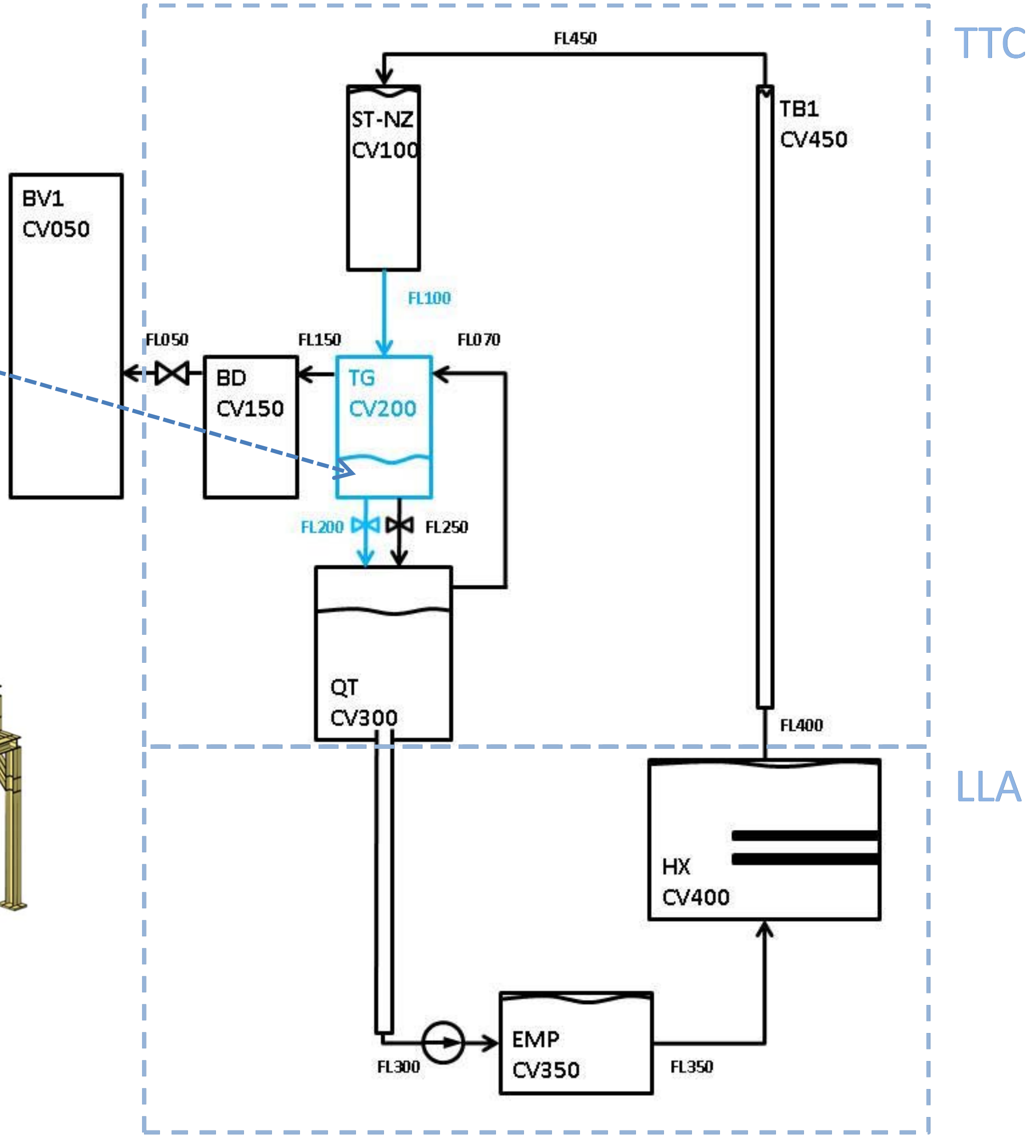
# Li Loop Modeling

Basic model

for Melcor-fusion

- FL100-FL200 coupled
- 5 MW in little mass amount (<10 kg)



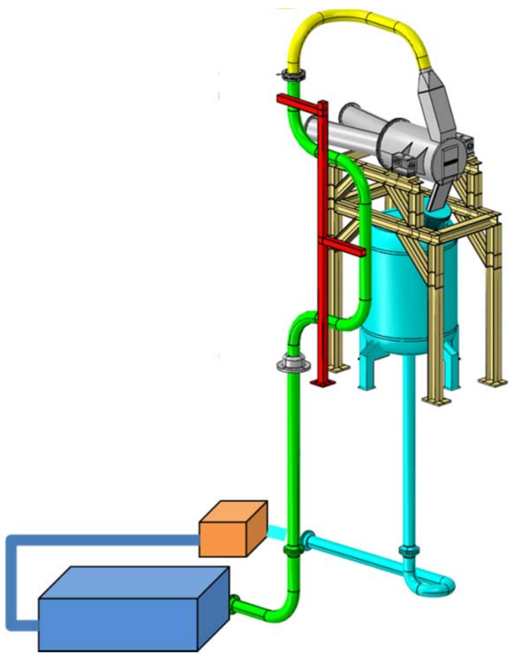


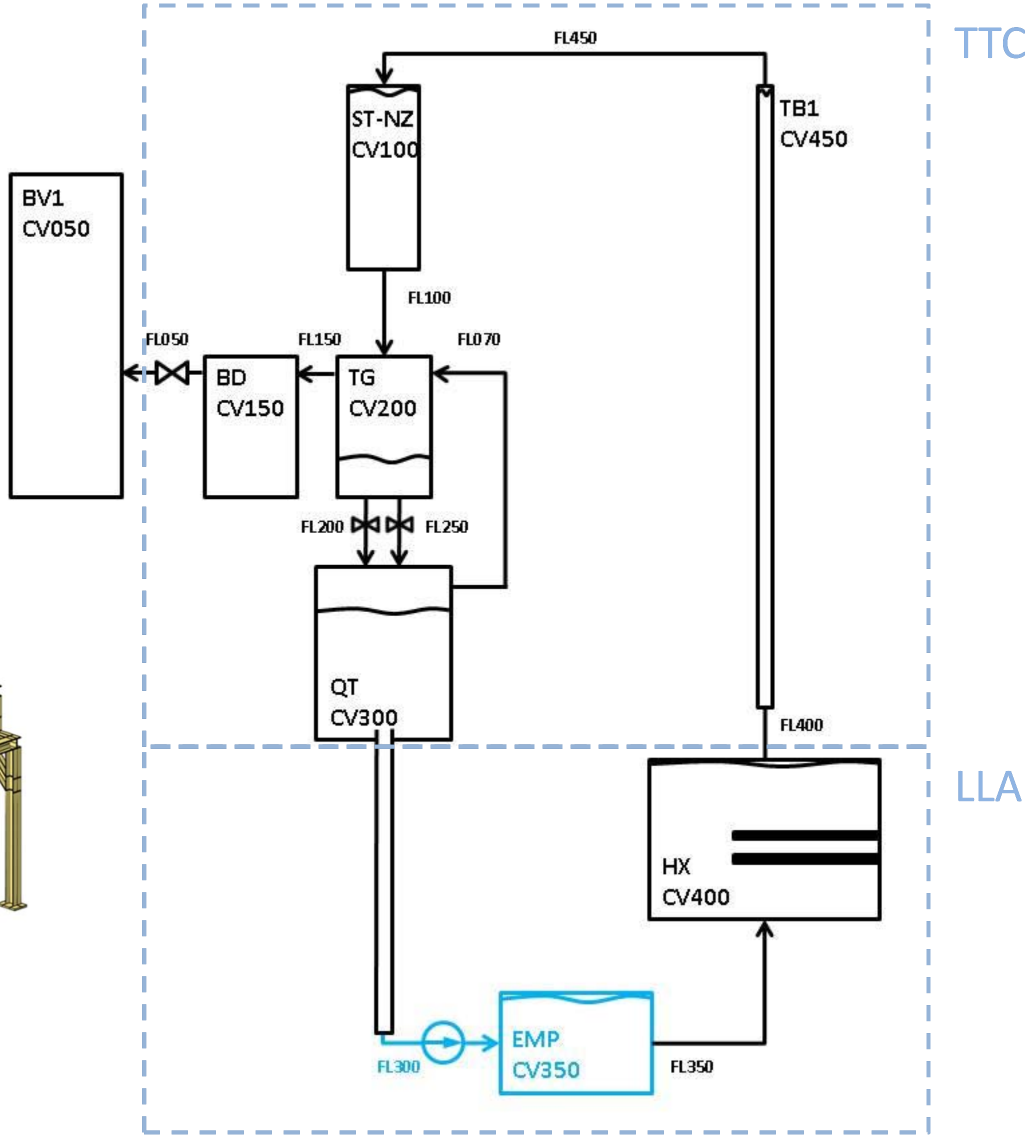
# Li Loop Modeling

Basic model

for Melcor-fusion

Pump homologous model





# Pump model

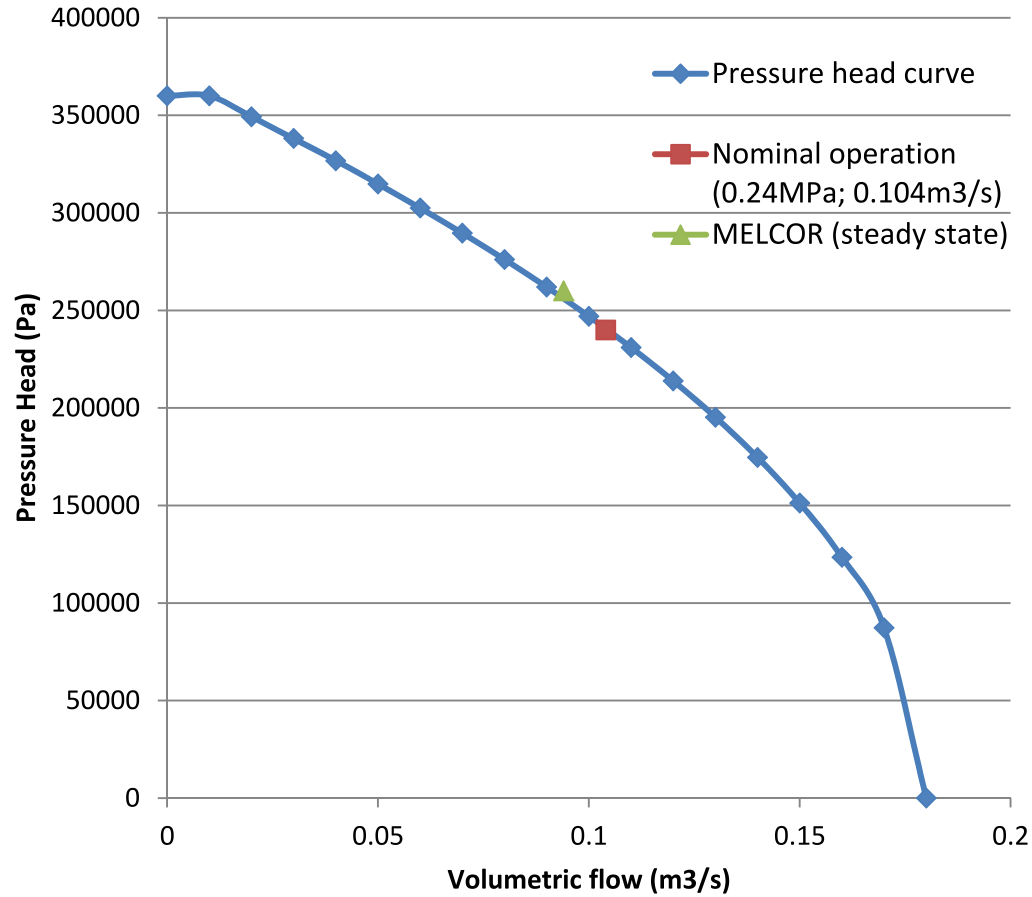
MELCOR "FANA" model (constant-speed coolant pump)

```
*MELGEN input

FL300P1   FANA   360000.0   0.18   0.01   550
*
*
CF55000  pump    TAB-FUN   1   1.0
CF55003  300
CF55010  1.0  0.0   time
*
TF30000   TAB300   3  1.0  0.0
*
*      TIME   Pressure head (Pa)
*
TF30010   0.0          1.0
TF30011  1500.00   1.0
TF30012  1510.0     0.0
```

**Pump coastdown (linear ramp)**

**Pump curves to be explored!**

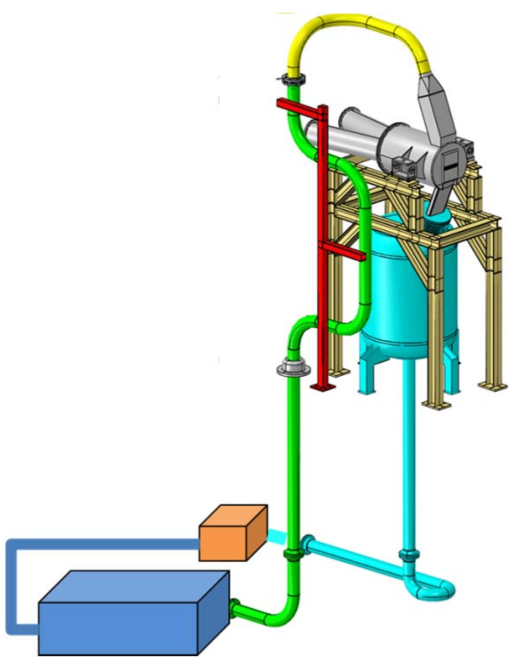


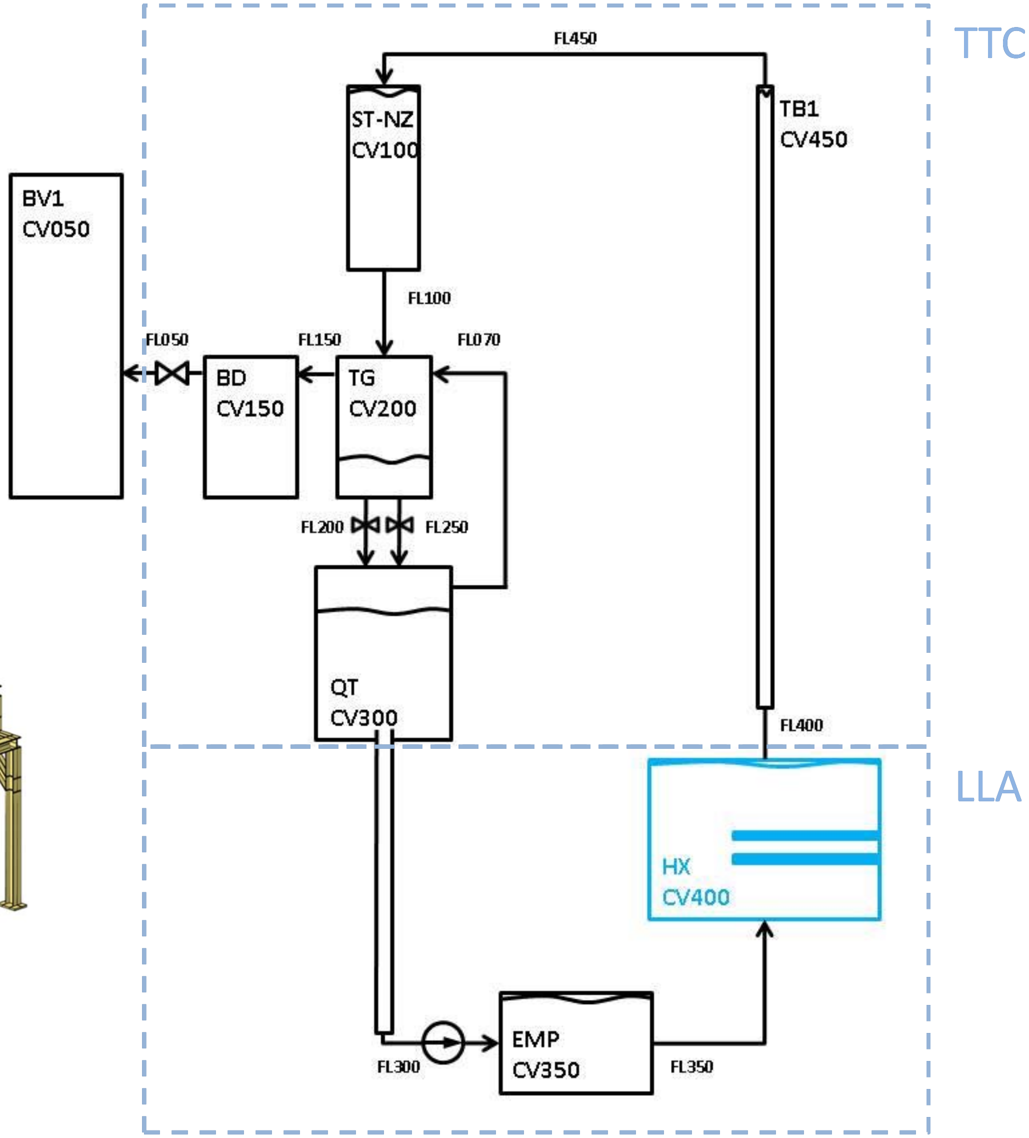
# Li Loop Modeling

Basic model

for Melcor-fusion

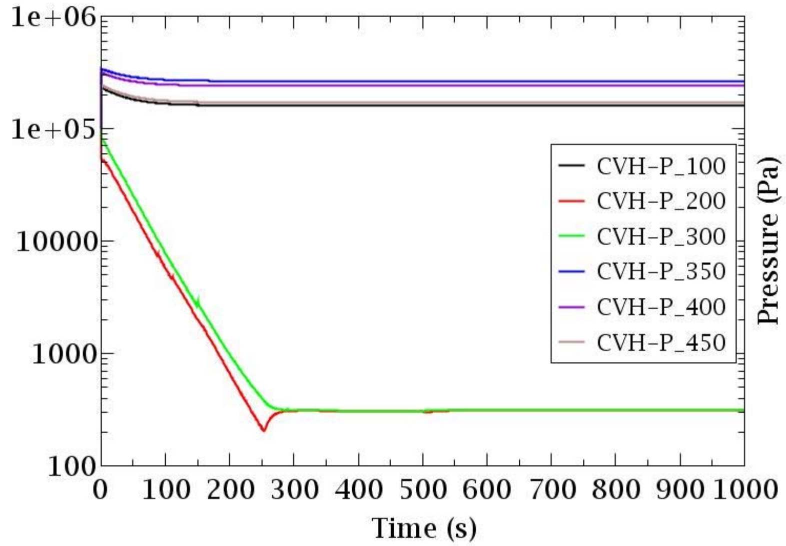
HS at 245.5 °C

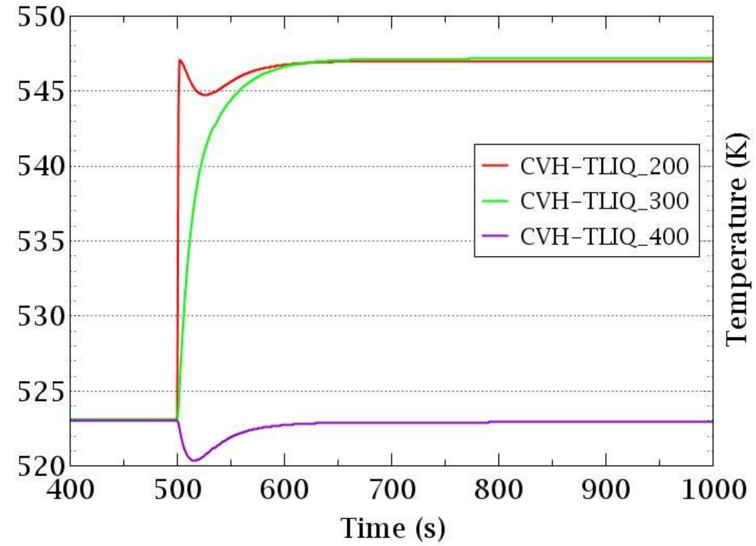




# Start-up transient sequence

A steady state is achieved by means of an operational start-up transient




Steady state results (t = 1000 s) with power injection at t=500 s

| Parameter | Calculation | Reference | Comments |
|---|---|---|---|
| Pressure target | 300 Pa | 1E-3 Pa | *Not allowed below 200 -100 Pa range due to problems with Li EOS extrapolation* |
| Total circuit pressure loss | 2.6E5 Pa | 2.4E5 Pa | Curve pump is unknown; here is fitted for desired point |
| Total Li mass flow rate | 49.7 kg/s | 49.7 kg/s | Same comment |
| Velocity at nozzle exit | 15 m/s | 15 m/s | Li target flow velocity between 10-15 m/s (in operation) |
| Li temperature in HX | 250 °C | 250 °C | |
| Li temperature in QT | 274 °C | 274 °C | |
| Total Li volume in the loop | 8.45 m3 | 8.44 m3 | Li volume of the impurity reduction system is not considered |

# LOFA simulation

Potential consequences of a LOFA scenario:

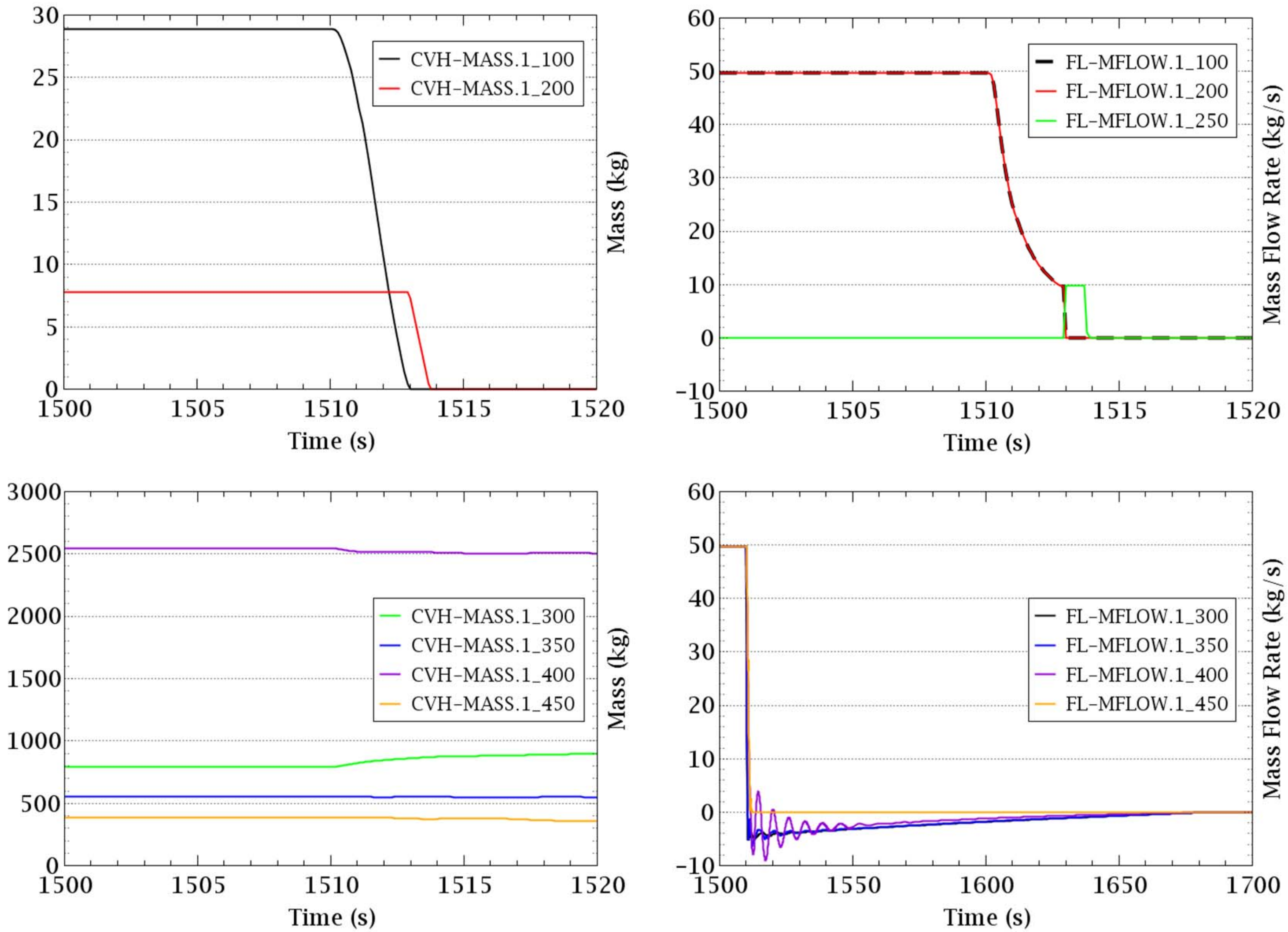
- **Backplate** thermal overload and **rupture** (if beam is not promptly stopped)
- **Release of Li and its radioactive impurities** into Target Test Cell (TTC) or Li Loop Area (LLA) with direct increase of ORE
- Possible **Li-air and/or Li-vapor reactions** (if inert atmosphere is not guaranteed inside TTC or LLA)

Main events of MELCOR transient sequence:

| **Event** | **Time (s)** | **Quantity** |
|---|---|---|
| Start of calculation (pump on) | 0 | |
| Power injection into target (→Li mass) | 500 | 5 MW |
| Pump trip (pump head linear ramp to zero) | 1500-1510 | *assumed* |
| Li mass flow rate reaches 70% of its nominal value in the target (*assumed*) | 1510.7 | ~ 35 kg/s |
| Beam shutdown (5 → 0 MW in 1s) | 1510.7 – 1511.7 | *assumed* |
| Target completely empties | 1513.9 | - |
| End of calculation | 3000 | - |

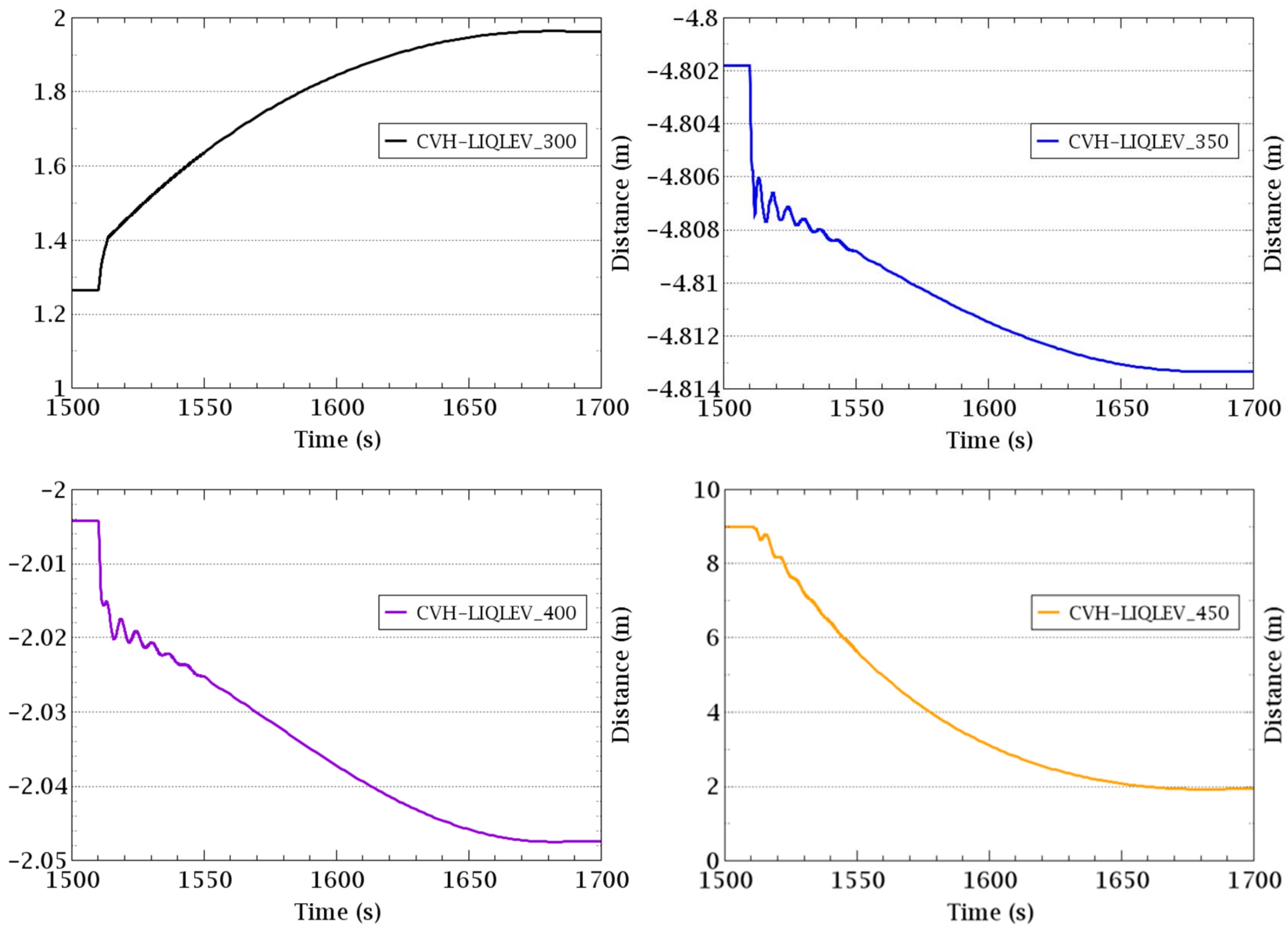
# LOFA simulation with beam shutdown

MELCOR results (Li mass flow rates and Li mass inventories)



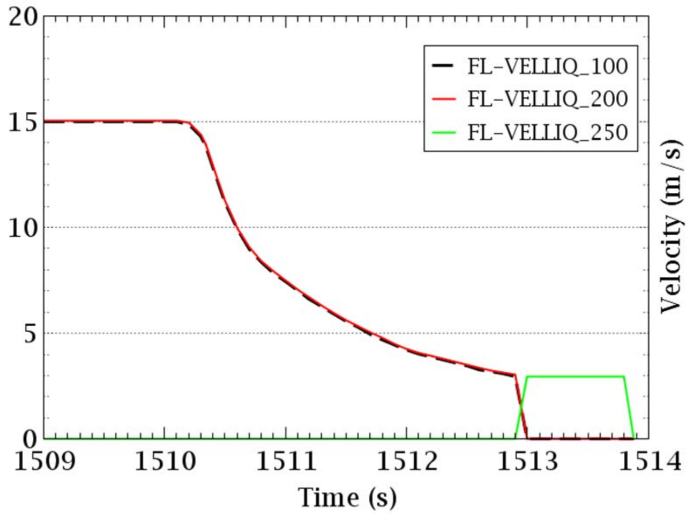
# LOFA simulation with beam shutdown

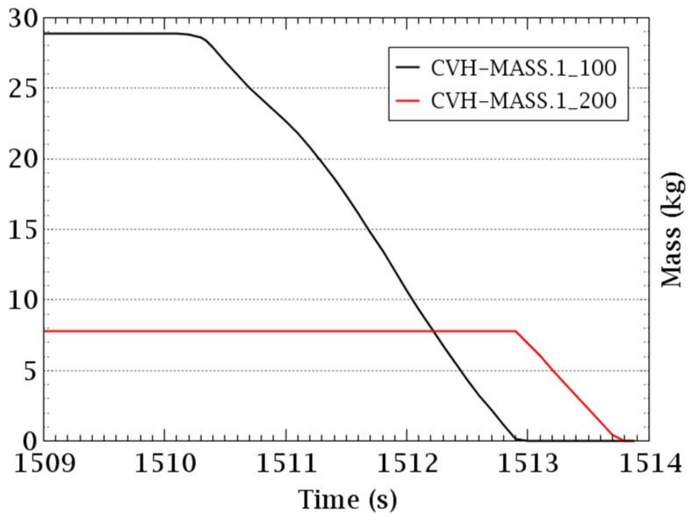
MELCOR results (Li mass elevations in CVs)



# LOFA simulation without beam shutdown

MELCOR results (Li flow velocities and mass inventories)



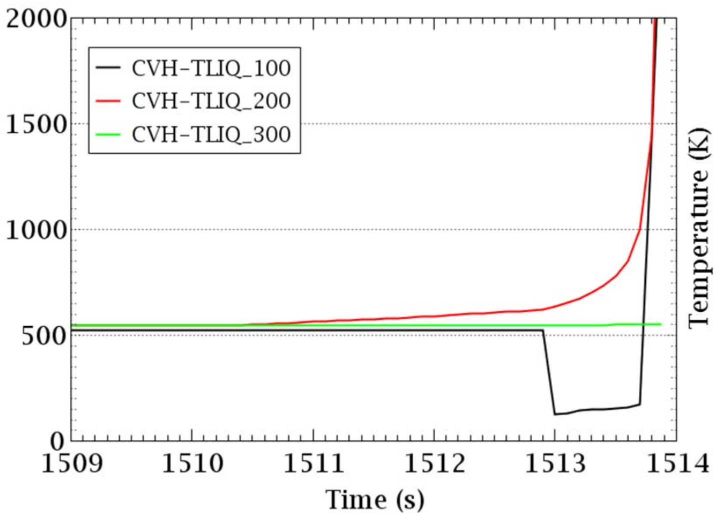

- Li flow velocities and mass inventory evolutions inside CV100 & CV200 show a very similar tendency with their respective quantities of the previous scenario

- CV200 empties at t = 1513.9 s

- Time range available to shut down the beam and to prevent damages to the backplate and surrounding structures is ~14 s from the beginning of the pump trip

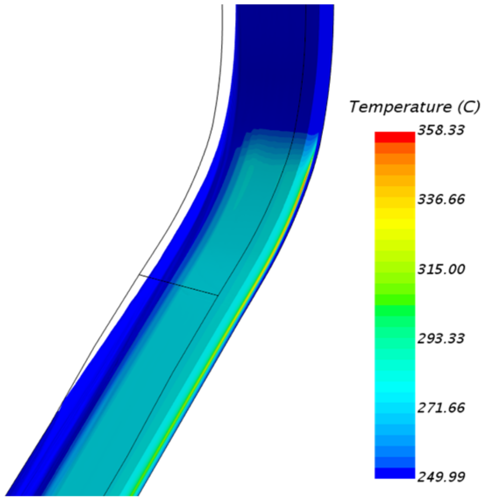
# LOFA simulation without beam shutdown

## MELCOR results (Li temperature in CV100, CV200 & CV300)




- Temperature in CV200 (Li target) raises from 547 to 2000 K in less than 4 seconds from t = 1510 s (when pump head becomes zero)!

## CFD simulation of Li jet temperature distribution (DONES: 5 MW, 15 m/s)




Tmax = 358°C (631 K) (in the Li bulk)
Tboil ~ 1030°C (1303K)
ΔT ~ 672°C

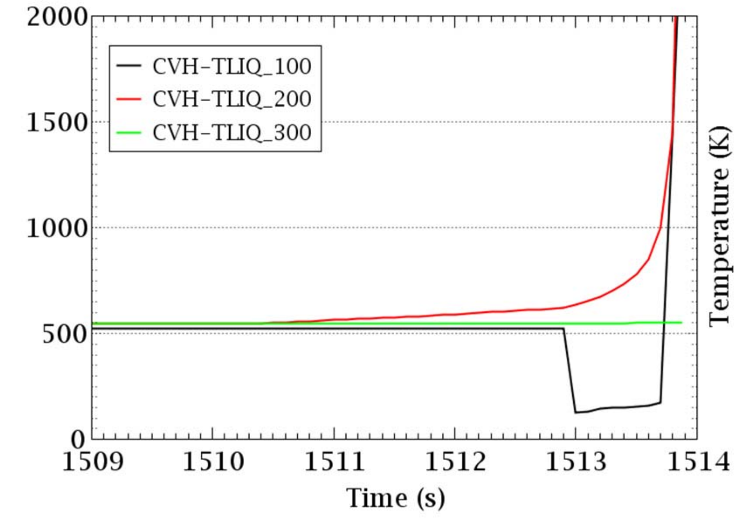
*S. Gordeev. Preliminary Numerical Analysis of Li jet, BP Discharge Line and QT, with power deposition. EFDA_D_2N4NNF v1.1 (2017).*

Tsurf = 278°C (551 K) (at Li-free surface)
Tboil ~ 342°C (615 K)
ΔT ~ 65°C

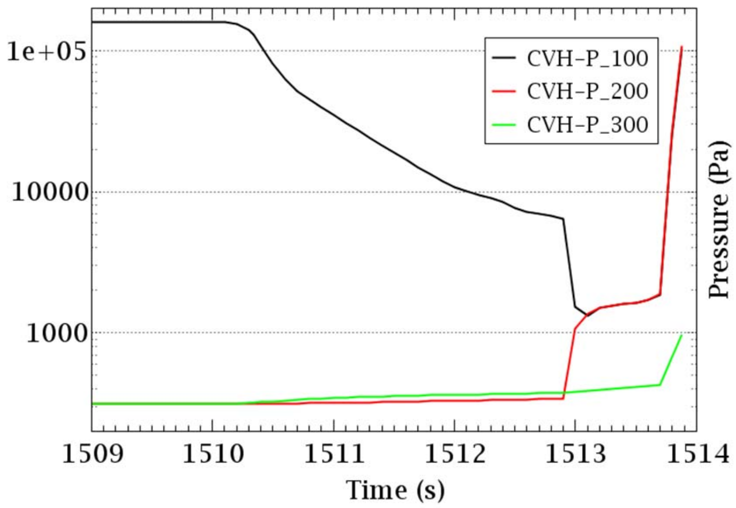
*S. Gordeev. Evaluation of Li Vaporization in the TA. EFDA_D_2MNNTD v1.1 (2017).*

# LOFA simulation without beam shutdown

MELCOR results (Li temperature and pressure evolution in CV100, CV200 & CV300)




- Temperature in CV200 (Li target) raises from 547 to 2000 K in less than 4 seconds from t = 1510 s (when pump head becomes zero)!




- Atmospheric pressure is reached inside CV100 & CV200 at the end of the calculation

# Final remarks

## ❑ A preliminary model for DONES Li loop is available

- Good agreement between MELCOR predictions (steady state) and reference design requirements has been achieved
- First simulations of LOFA scenario have been performed

## ❑ Not straightforward modeling

- High sensitivity to adopted nodalization
- Numerical problems experienced:
  - Dependence on timestep
  - EOS impact when extrapolation at low pressures

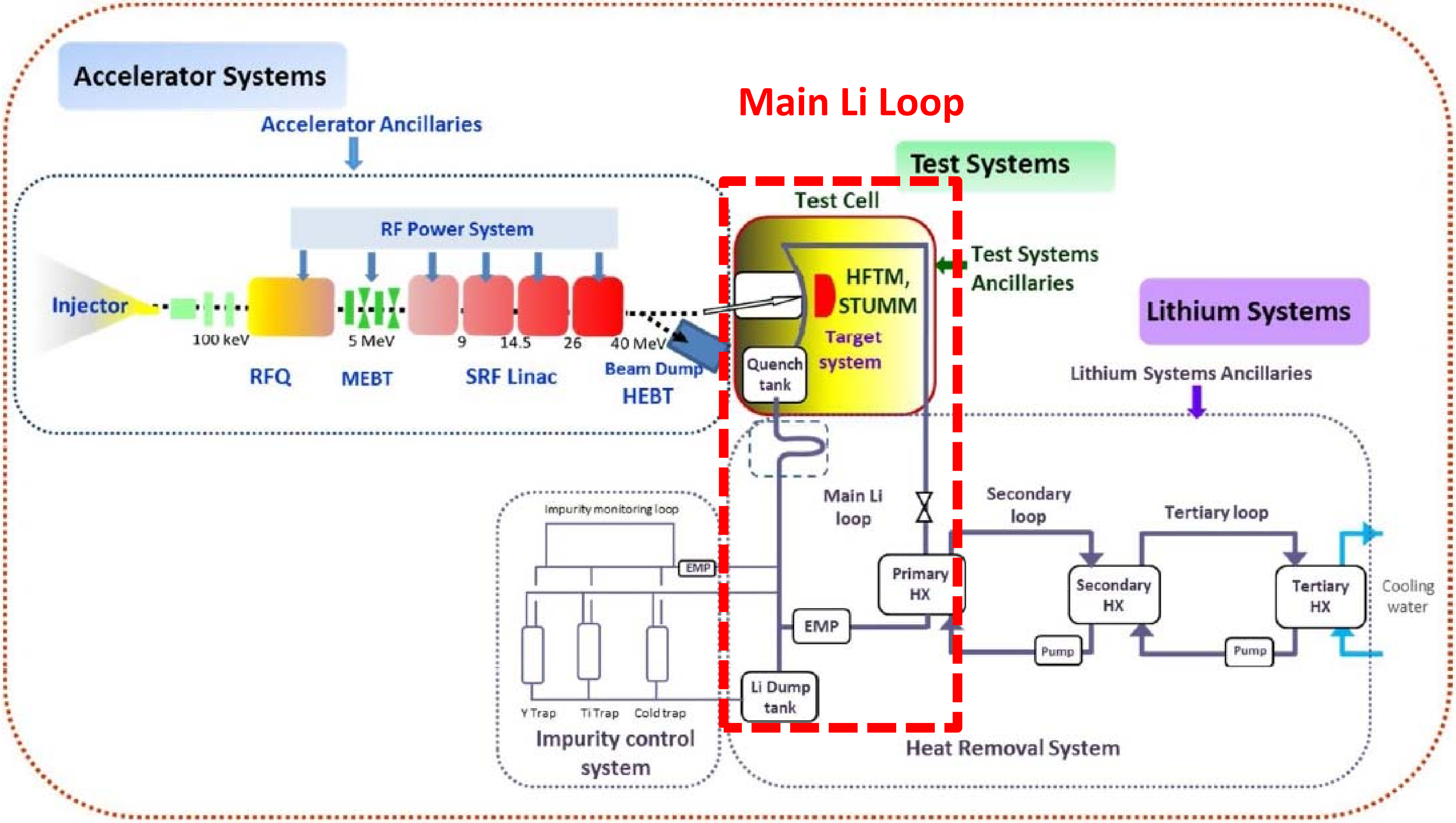
## ❑ Future developments and exploratory calculations

- Modeling upgrade based on future design documents
- Sensitivity to
  - HS implementation for all control volumes
  - Pump coastdown curve for design improvement (coastdown tail)
  - New model for Li target
  - …
- Simulation of LOCA scenarios in TTC and LLA (candidates for DONES “RAS”) with release of Li radioactive impurities (tritium, activation products)

# Thank you for your attention

**Questions? Comments? Suggestions?**

# DONES Plant Configuration



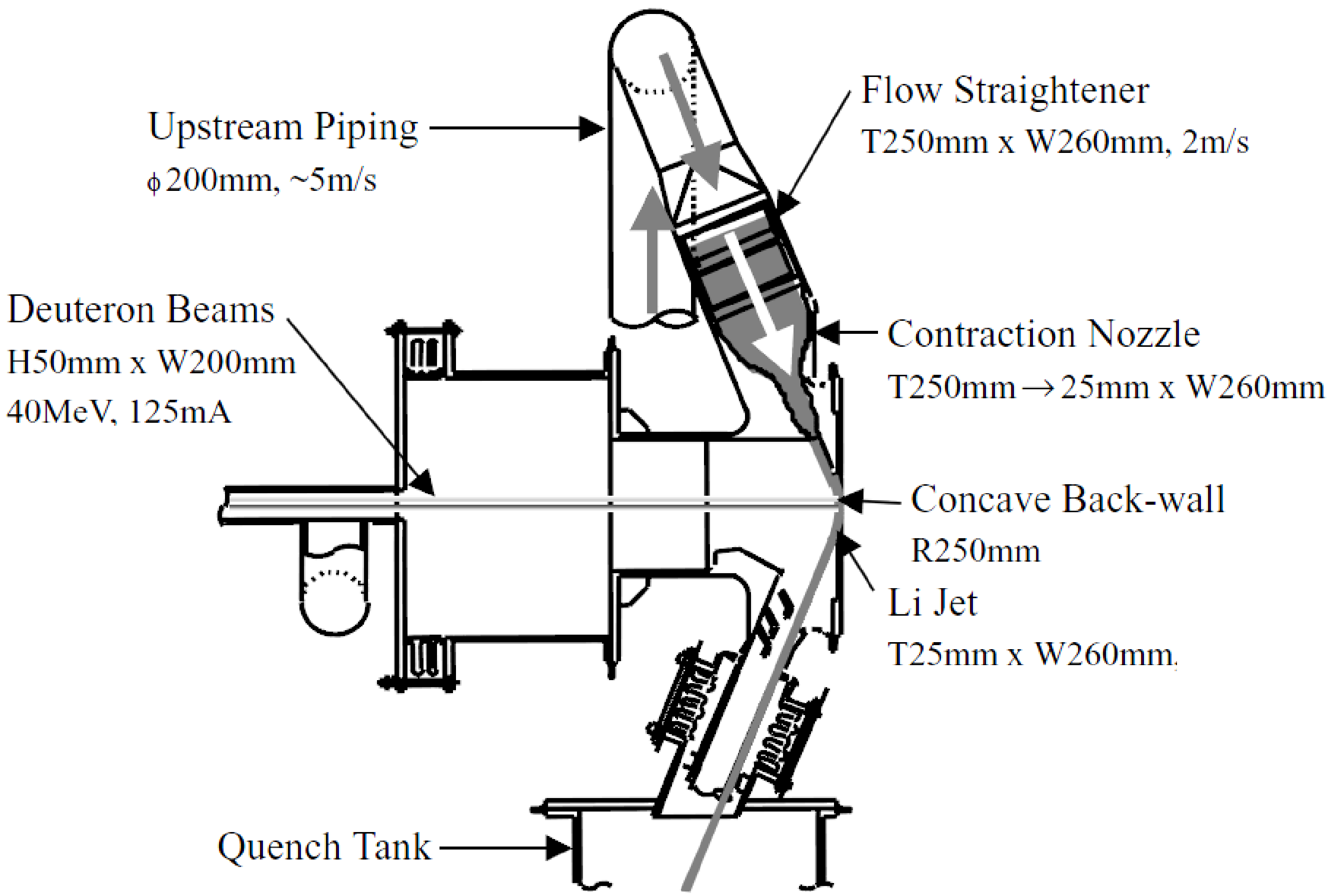

**Site, Buildings & Plant Systems**

- Layout & Site Infrastructures
- Buildings
- HVAC, Electrical Power Supply, HRS, etc.
- Remote Handling System
- Central Control Systems and Integrated Instrumentation

*DONES Plant Description Document 2017*

# Backup slides

Cross-sectional schematic of DONES target assembly




*M. Ida et al. Fusion Engineering & Design 70 (2004) 95-106*

# Backup slides

## Li Loop total pressure loss (estimated)

| Element | No. | Specification | Pressure loss [kPa] |
|---|---|---|---|
| Pipe, in TC | 1 | 6B, Sch40, 13.24 m | 11.16 |
| Pipe, EMP - LLA ceiling | 1 | 8B, Sch20, 36.48 m | 6.88 |
| Pipe, QT - EMP | 1 | 10B, Sch20, 17.89 m | 1.15 |
| Bend, in TC | 2 | 6B, 90°, R228.6 mm | 3.60 |
| Bend, EMP - LLA ceiling | 17 | 8B, 90°, R304.8 mm | 9.35 |
| Bend, QT - EMP | 6 | 10B, 90°, R381.0 mm | 1.32 |
| Gate valve, under QT | 1 | 10B (loss coefficient: $\zeta$ = 0.05) | 0.05 |
| Globe valve | 1 | CV408 (6B) | 57.66 |
| QT outlet | 1 | ID: 254.4 mm→10B ($\zeta$ = 0. 5) | 0.55 |
| Primary HX | 1 | Li side: L7.15 m, ID1.1 m | 17.00 |
| Reducer, LLA ceiling | 1 | 8B→6B, L152.4 mm | 0.10 |
| **Flow straightener** | 1 | - | 15.7 |
| **Double reducer nozzle** | 1 | L370 mm, W260 mm, T200→62.5→25 mm | 75.1 |
| **Total pressure loss** | | | **199.61** |
| Head, inlet pipe - Li level in QT | | 8.13 m | 40.16 |
| **Pressure loss + head** | | | **239.77** |

~46%

## Li conditions for pressure loss estimation

| Item | Value |
|---|---|
| Li flow rate | 0.104 m3/s (16 m/s at nozzle exit) |
| Li temperature | 250°C |
| Li density | 510 kg/m3 |
| Li kinematic viscosity | 9.83E-7 m2/s |

*M. Ida. Design Description Document for the Lithium Target Facility (IIEDR) 2013*