Thermal evaluation of the DN30 PSP without housing

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DN30 package temperature limits

Admissible component temperatures of the DN30 package

- In current SAR, complete 30B cylinder and its contents listed with the same covering maximum temperature of 131 °C (267.8 °F). This limit is based solely on the possible pressure build-up of melted UF_6 contents and therefore actually is just a limit for the average UF_6 temperature.

In new revision, a more differentiated approach is planned

- Admissible temperature of the 30B cylinder and its components defined like in the French SAR based on the lowest admissible temperature of its components: 183 °C (361.4 °F) (solidus temperature of the tin lead solder of the valve and plug)
- Admissible temperature of the UF_6 content based on the possible pressure build-up of melted UF_6 contents of 131 °C (267.8 °F).

No significant influence of the removal of the housing expected for the temperature of the UF_6

- Area of housing very small in comparison to surface area of the 30B cylinder

Evolution of the thermal protection

Safety requirement

maximum temperature at valve/plug < 183 °C (361.4 °F), for UF_6 < 131 °C (267.8 °F)

History of the experimental fire tests

Fire test		Max. temp. at valve	Max. temp. at plug	Improvements
1st	March 2016	394 °C (741 °F)	245 °C (473 °F)	-
2nd	September 2016	234 °C (453 °F)	207 °C (405 °F)	Relocation of thermal plugs and addition of intumescent material (incl. housing) to prevent ingress of hot gases
3rd	November 2017	131 °C (268 °F)	144 °C (291 °F)	Improvements from 2nd fire test and addition of microporous thermal insulation

Evolution of the thermal protection

1st fire test

2nd fire test

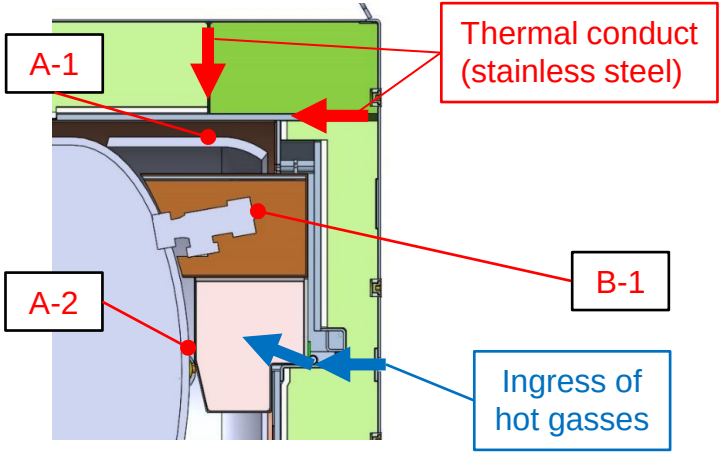
3rd fire test

Evaluation based on fire tests

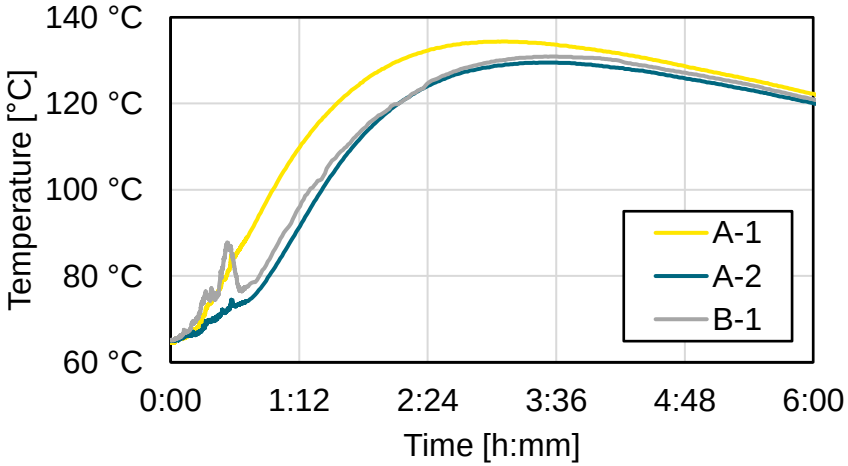
Thermal analysis based on 3rd fire test (November 2017)

Temperature at the valve without housing evaluated using sensors near the valve not covered by the housing (A-1 and A-2)

Geometry at the valve side



Temperature profile of A-1, A-2, and B-1



Evaluation based on fire tests

In general: maximum temperatures are reached during cooldown, when heat transfer likely dominated by conduction through the 30B cylinder

Temperature at the valve without housing will be between the temperatures recorded for sensors A-1 and A-2

- **Sensor A-2 is located near the valve and not covered by the housing**
  → good indication for influx of hot gases between top and bottom half of DN30 PSP during fire phase
- **Sensor A-1 is located at the top of the skirt and closer to the steel reinforcements**
  → good indication for heat influx by conduction through these reinforcements during fire
- **Sensors A-1 and A-2 are directly mounted to the cylinder shell, upstream of the heat conduction through the cylinder compared to valve during cooldown period**
- **Maximum temperatures: A-1: 134 °C (274 °F), A-2: 130 °C (265 °F), B-1: 131 °C (268 °F)**

→ Still high safety margin with maximum temperature ~ 49 °C (87 °F) below limit of 183 °C (361 °F) for the 30B cylinder

Evaluation based on fire tests

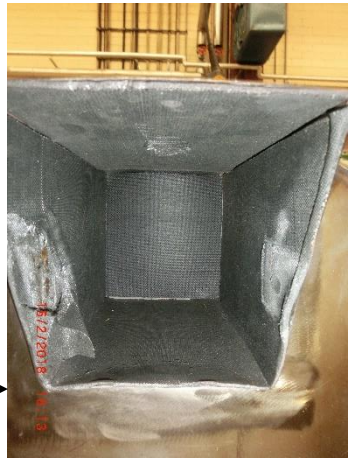
Additional confirmation based on 2nd & 3rd fire test

- During 2nd fire test, expansion of intumescent material clearly visible
- During 3rd fire test, no expansion of the intumescent material due to lower temperatures with added microporous insulation layer

→ maximum temperatures at the housing can be expected to be below the onset temperature of the expansion of the intumescent material of ~ 150 °C (302 °F)

2nd Fire test
$T_{max,Valve}$ = 234 °C (453 °F)

3rd Fire test
$T_{max,Valve}$ = 131 °C (268 °F)



Evaluation based on fire tests

Further confirmation by comparison of valve and plug

→ **Conservatively, maximum temperature at the plug during this 3rd fire test of 144 °C (291 °F) can be assumed at the valve as well:**

- **Gap between PSP and 30B cylinder closer at plug side**
- **Higher damage to PSP at plug side (cracks at inner and outer shell)**
- **In general, thickness of steel sheets, foam, and insulation material is same for the valve and plug side**

→ **Still high safety margin with maximum temperature ~ 39 °C (70 °F) below limit of 183 °C (361.4 °F) for 30B cylinder**

Evaluation using FEM simulations

FEM model in SAR benchmarked using fire tests No. 2 & 3 with housing

- **In current model in SAR, housing not explicitly modelled due to the constraints of the axisymmetric two-dimensional model; instead, housing taken into account in benchmarked heat transfer mechanisms on valve side**

SAR model modified to simulate removal of the housing

- **For the new simulation without housing, the heat transfer mechanisms on the valve side are increased to match the plug side for conduction, convection, and radiation; all other parameters unchanged**

Evaluation using FEM simulations

Results *

Model (see previous slide)	Max. temp. at valve	Max. temp. at plug	Max. avg. temp. of UF_6
SAR model	120.5 °C (249 °F)	119.0 °C (246 °F)	115.3 °C (239 °F)
Modified model without housing	121.6 °C (251 °F)	119.0 °C (246 °F)	115.8 °C (240 °F)

* Temperatures are lower compared to 3rd fire test as regulatory conditions were exceeded during fire test

Increase without housing only ~ 1 °C / 2 °F

- **Heat transfer mechanisms at valve side in part already high (e.g., radiation coefficient for gap 1.0)**
- **Heat transfer in air gaps at valve and plug side dominated by radiation**
- **Heat transfer to 30B cylinder in general dominated by conduction through mantle side during the cooldown phase, when the maximum temperatures are reached**

→ Still large safety margin based on numerical simulations

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