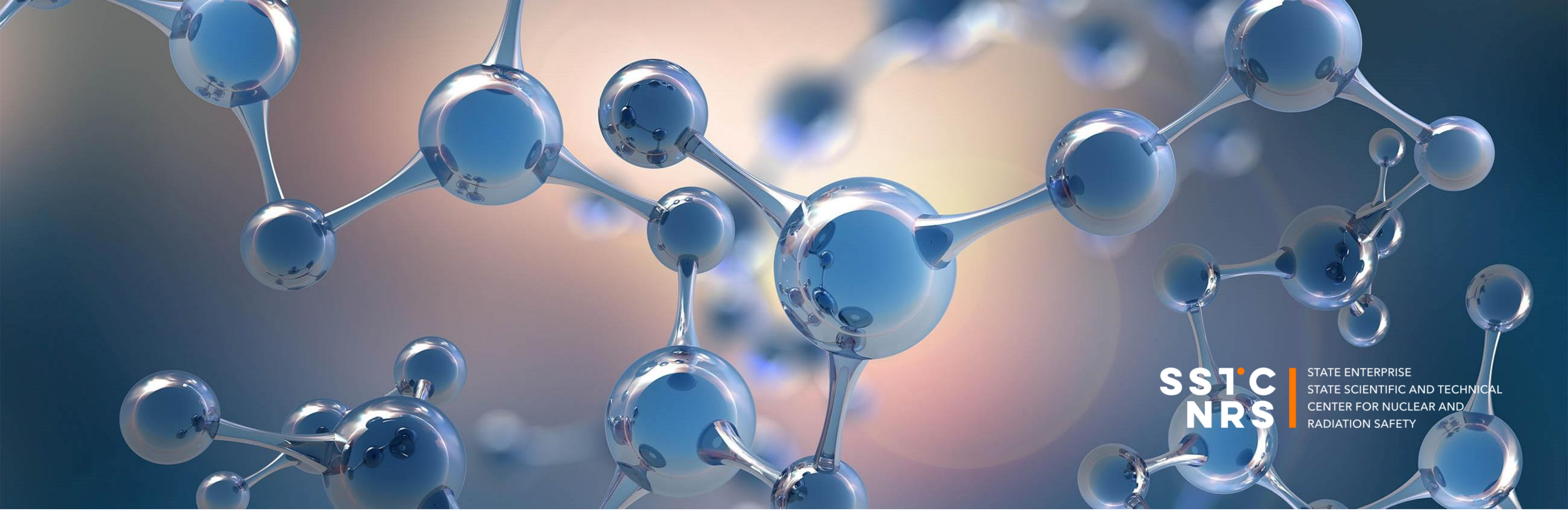


# MELCOR code use for uncertainty and sensitivity analysis of severe accident with operator actions

## EMUG meeting

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EMUG Meeting
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# VVER-1000 Uncertainty Analysis Overview

## Overview

- Part of the work is performed in the frames of MUSA project

## MUSA


- This project has received funding from the Euratom research and training programme 2014-2018 under grant agreement No 847441


## Results

- This presentation reflects only the author’s view, and the European Comission is not responsible for any use that may be made of the information it contains

# MELCOR model

## Approach

- Simple fast running model

## RCS

- Single + triple loop

## Reactor

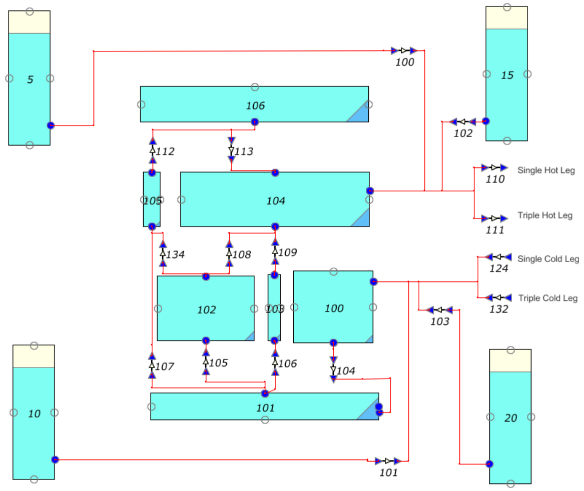
- Simple + 6 CV core

## Secondary

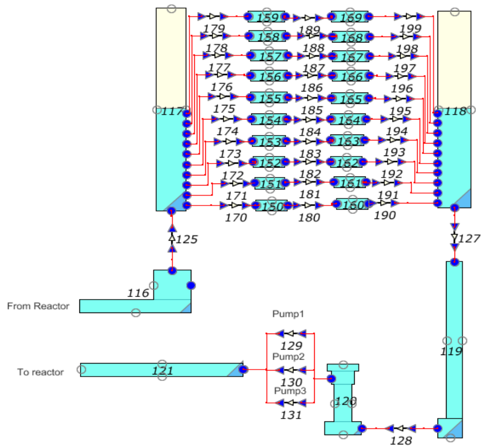
- Simple SGs

## Containment

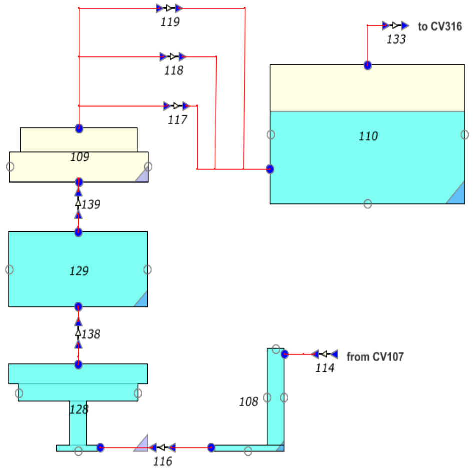
- All compartments + cavity



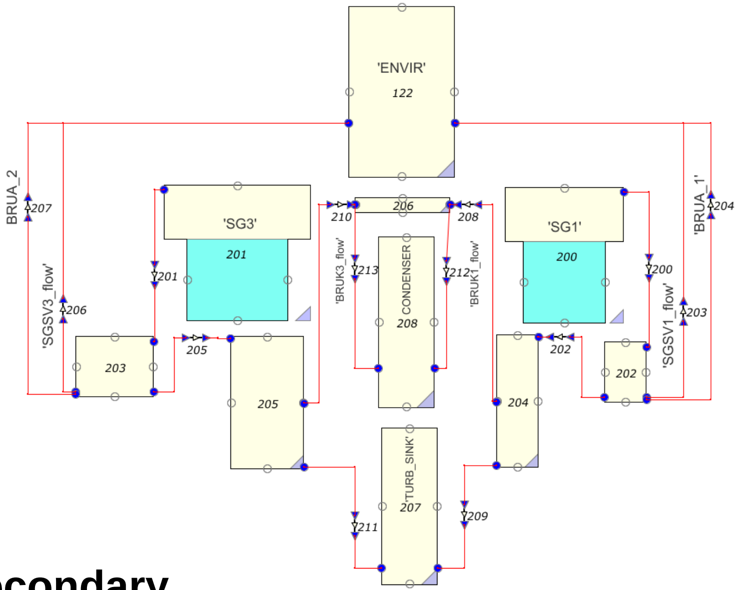

Reactor + HAs




Loop1 + SG1 primary




PRZR + bubbler




Secondary



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# MELCOR model

## Cavities

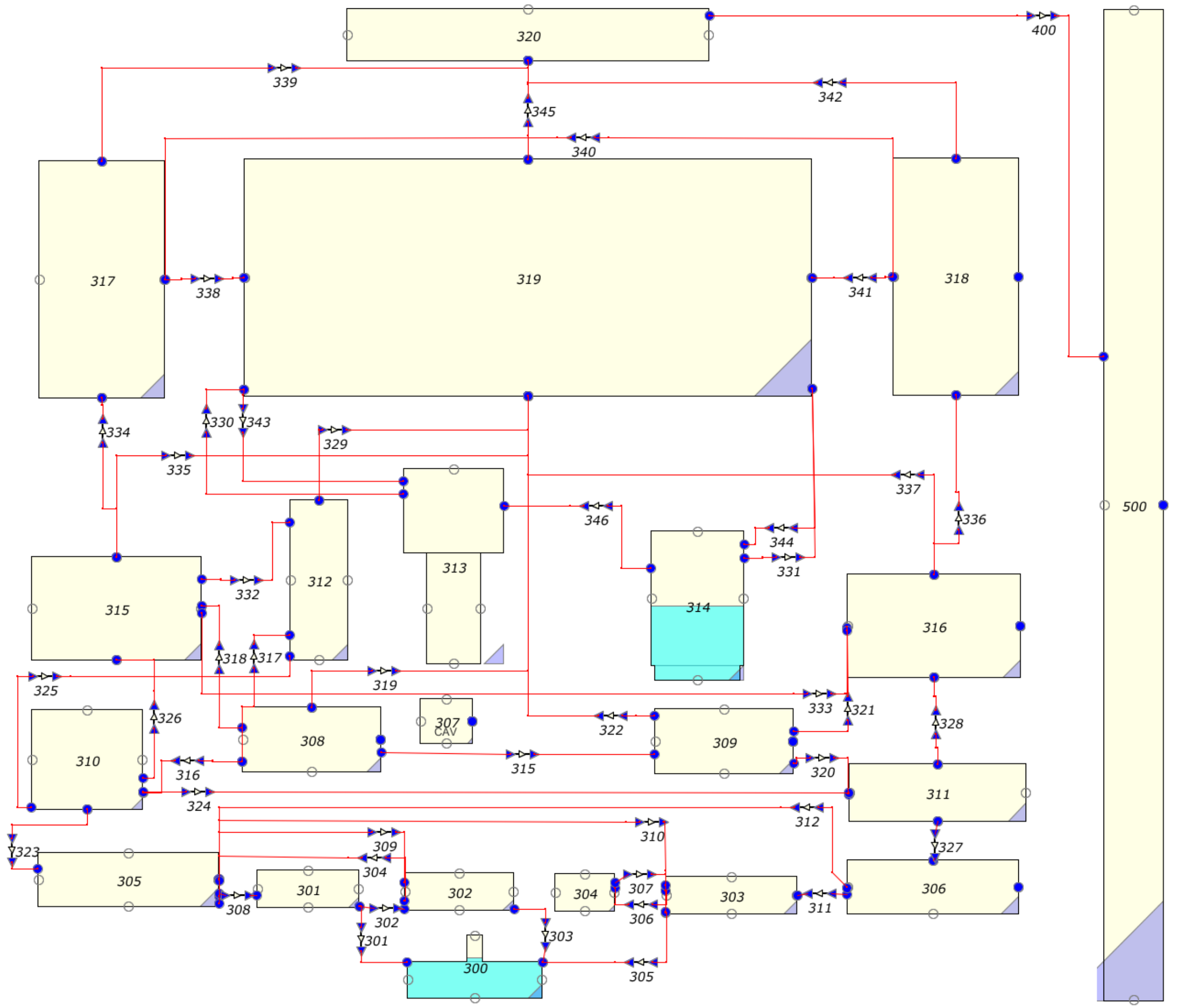
- CAV1 under reactor
- CAV2 on containment floor

## Containment venting

- FL with filter

## Model preliminary testing

- LOOP
- LB LOCA
- SB LOCA



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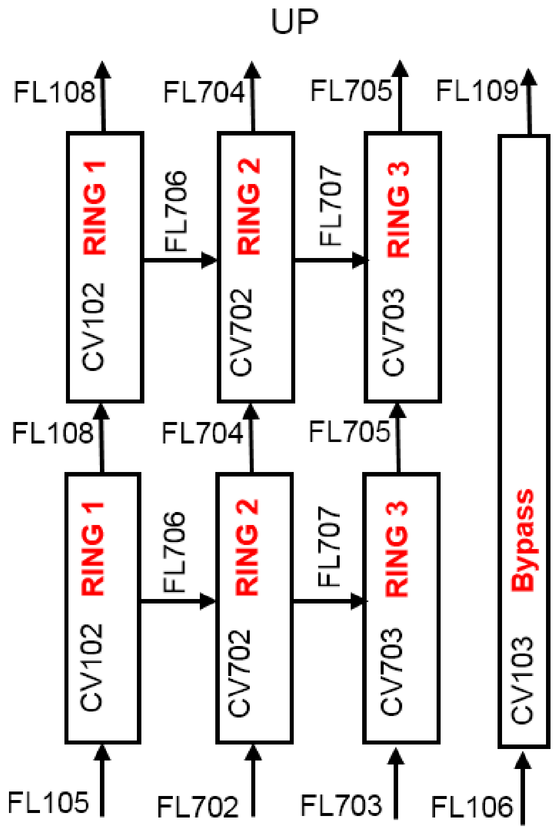
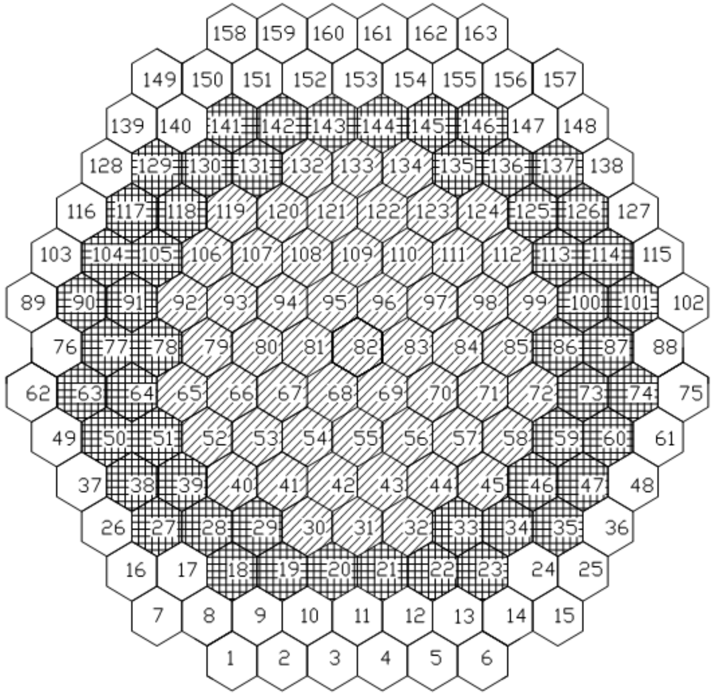
# MELCOR model

## Core model

- 3 rings
- 6 CV COR
- 10 axial for fuel part




**Core TH nodalization**




**Core COR rings**

| Bottom elevation, m | Top elevation, m | Section height, m | HS10201 | HS10203 | HS10205 | HS10205 | | |
|---|---|---|---|---|---|---|---|---|
| 22.301 | 23.018 | 0.717 | 125 | 225 | 325 | 425 | HS10224 | Upper unheated part of the reactor core |
| 21.946 | 22.301 | 0.355 | 124 | 224 | 324 | 424 | HS10222 | Fuel part of the reactor core |
| 21.591 | 21.946 | 0.355 | 123 | 223 | 323 | 423 | HS10220 | |
| 21.236 | 21.591 | 0.355 | 122 | 222 | 322 | 422 | HS10218 | |
| 20.881 | 21.236 | 0.355 | 121 | 221 | 321 | 421 | HS10216 | |
| 20.526 | 20.881 | 0.355 | 120 | 220 | 320 | 420 | HS10214 | |
| 20.171 | 20.526 | 0.355 | 119 | 219 | 319 | 419 | HS10212 | |
| 19.816 | 20.171 | 0.355 | 118 | 218 | 318 | 418 | HS10210 | |
| 19.461 | 19.816 | 0.355 | 117 | 217 | 317 | 417 | HS10208 | |
| 19.106 | 19.461 | 0.355 | 116 | 216 | 316 | 416 | HS10206 | |
| 18.751 | 19.106 | 0.355 | 115 | 215 | 315 | 415 | HS10204 | |
| 18.525 | 18.751 | 0.226 | 114 | 214 | 314 | 414 | HS10202 | Bottom unheated part of the reactor core above support structures |
| 18.348 | 18.525 | 0.177 | 113 | 213 | 313 | 413 | HS10108 | Elements of reactor barrel bottom and support structures |
| 18.219 | 18.348 | 0.129 | 112 | 212 | 312 | 412 | - | |
| 18.099 | 18.219 | 0.120 | 111 | 211 | 311 | 411 | - | |
| 17.979 | 18.099 | 0.120 | 110 | 210 | 310 | 410 | - | |
| 17.878 | 17.979 | 0.101000 | 109 | 209 | 309 | 409 | - | |
| 17.787053 | 17.878 | 0.090947 | 108 | 208 | 308 | 408 | - | |
| 17.691573 | 17.78705 | 0.095480 | 107 | 207 | 307 | 407 | - | |
| 17.595671 | 17.69157 | 0.095902 | 106 | 206 | 306 | 406 | - | |
| 17.509051 | 17.59567 | 0.086620 | 105 | 205 | 305 | 405 | - | |
| 17.417259 | 17.50905 | 0.091792 | 104 | 204 | 304 | 404 | - | |
| 17.226125 | 17.41726 | 0.191134 | 103 | 203 | 303 | 403 | - | |
| 17.061902 | 17.22612 | 0.164222 | 102 | 202 | 302 | 402 | - | |
| 16.899 | 17.0619 | 0.162902 | 101 | 201 | 301 | 401 | - | |
| | | | 1 | 2 Reactor bottom | 3 | 4 | | |

**COR axial elevations**



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# Uncertainty Analysis Set-up

**Unit**

- VVER-1000

**Initial Event**

- Station Blackout

**Operator actions**

- Open 3, 2 or 1 PORVs after enter SAMG (450C CET + delay)

**Features/Failures**

- CNT venting operable (setpoints 5-3kgf/cm2, Decontamination Factor 1000)
- No ECCS
- No CNT sprays
- 1 day sequence time

**Code**

- MELCOR 2.2.21402

**Uncertainty tool**

- SUSA 4.0

**Number of runs**

- 100 for mixed PORVs number (additional 100 for 3 PORVs open, 100 for 2 PORVs open, 100 for 1 PORV open)

**Method**

- Uncertainty propagation approach
- Wilks 2$^{nd}$ order (93 runs min)
- Latin Hypercube sampling
- Failed cases are restarted with Dtmax change or small other params change

# Uncertainty Analysis Set-up

## Uncertainty parameters categories analyzed

- Source term phenomena
- Core heat-up
- Core degradation
- In-core thermal-hydraulics
- Corium downward motion / Corium slumping
- Corium/debris transfer to cavity
- MCCI
- Containment thermal-hydraulics
- Containment leak
- Hydrogen combustion
- Containment venting
- Equipment setpoints
- SAM (PORV opening)
- Numerics

## Methods and references

- State-of-art NUREGs
- Experiment reports
- MUSA project experience
- MELCOR code manuals
- Engineering judgment (EJ)

## Uncertainty parameters

- 43 total
- All independent

# Uncertainty Analysis Set-up

## Uncertainty parameters

- 43 total

| Note* Par. # | Name | Short description | Reference value | Range of Variation | PDF Type |
|---|---|---|---|---|---|
| 1 | RN1_GAP00_CLFAIL | Gap Release Temperature | 1173 | CLFAIL = 1173 +/-100 K | Uniform |
| 2 | RN_CHI | Dynamic shape factor | 1.5 | CHI = 1.0 - 2.0 | Uniform |
| 3 | RN_RHONOM | Aerosol density | 2560 | RHONOM = 1000-4120 kg/m$^3$ | Uniform |
| 4 | RN_FSLIP | Slip factor | 1.257 | FSLIP = 1.257 +/- 20% | Uniform |
| 5 | RN_STICK | Sticking coefficient | 0.75 | STICK = 0.5-1.0 | Uniform |
| 6 | RN_FTHERM | Thermal accommodation coefficient | 2.25 | FTHERM = 2.25 +/-20% | Uniform |
| 7 | RN2_FLT_DFG | Global decontamination factor | 1000 | DFG= default +/- 20% | Uniform |
| 8 | COR_FCELR | Radial radiation exchange factor | 0.1 | FCELR = 0.1 +/- 0.05 | Uniform |
| 9 | COR_FCELA | Axial radiation exchange factor | 0.1 | FCELA = 0.1 +/- 0.05 | Uniform |
| 10 | COR_SC1104_3 | Cladding emissivity | 0.81 | SC1104(3) = 0.81 +/-20% | Uniform |
| 11 | COR_SC1104_5 | Cladding emissivity | 0.76 | SC1104(5) = 0.76 +/-20% | Uniform |
| 12 | COR_SC1104_1 | Cladding emissivity | 0.325 | SC1104(1) = 0.325 +/-20% | Uniform |
| 13 | **DCH_TFSCAL** | **Thermal decay heat multiplier** | **1** | **TFSCAL = 1.0 +/- 0.1** | Uniform |
| 14 | COR_OX_SC1001(1,2) | Metallic Cladding Oxidation Rate Constant Coefficient, steam | 26.7 | SC1001(1,2) = 26.7 +/- 20% | Uniform |
| 15 | COR_OX_SC1001(3,2) | Metallic Cladding Oxidation Rate Constant Coefficient, oxygen | 26.7 | SC1001(3,2) = 26.7 +/- 20% | Uniform |
| 16 | COR_OX_SC1001(3,1) | Metallic Cladding Oxidation Rate Constant Coefficient, oxygen | 87.9 | SC1001(3,1) = 87.9 +/- 20% | Uniform |
| 17 | COR_OX_SC1001(1,1) | Metallic Cladding Oxidation Rate Constant Coefficient, steam | 29.6 | SC1001(1,1) = 29.6 +/- 20% | Uniform |
| 18 | **COR_EUT_TM** | **UO2-ZrO2 eutectics** | **2500** | **COR_EUT, TM = 2500 K +/- 100 K** | Uniform |

# Uncertainty Analysis Set-up

## Uncertainty parameters

- 43 total

| Note* Par. # | Name | Short description | Reference value | Range of Variation | PDF Type |
|---|---|---|---|---|---|
| 19 | COR_SC1131(2) | Maximum ZrO2 temperature permitted to hold up molten Zr in CL | 2400 | SC1131(2) = 2400 K +/- 100 K | Uniform |
| 20 | COR_SC1132(1) | Temperature to which oxidized fuel rods can stand in the absence of unoxidized Zr in the cladding | 2600 | SC1132(1) = 2600 K +/- 100 K (UNIFORM) | Uniform |
| 21 | COR_TSSFAI | Supporting structure failure temperature | 1273 | TSSFAI = 1273 K +/- 100 K | Uniform |
| 22 | COR_CMT_FUOZR | Transport parameter for UO2 in molten Zircaloy | 0.2 | FUOZR = 0.2 +/- 0.1 | Uniform |
| 23 | COR_CHT_HFRZZR | Refreezing heat transfer coefficient for Zircaloy | 7500 | HFRZZR = 7500 +/- 5000 W/m$^2$/K | Uniform |
| 24 | COR_CHT_HFRZZX | Refreezing heat transfer coefficient for ZrO2 | 7500 | HFRZZX = 7500 +/- 5000 W/m$^2$/K | Uniform |
| 25 | COR_CHT_HFRZUO | Refreezing heat transfer coefficient for UO2 | 7500 | HFRZUO = 7500 +/- 5000 W/m$^2$/K | Uniform |
| 26 | COR_EDR_DHYPD_CORE | Particulate Debris Equivalent Diameter (Core Region) | 0.01 | For core region DHYPD = 0.01m +/- 0.005m | Uniform |
| 27 | COR_EDR_DHYPD_LP | Particulate Debris Equivalent Diameter | 0.002 | DHYPD = 0.002m +/- 0.001m | Uniform |
| 28 | COR_ZP_PORDP | Porosity of particulate debris | 0.4 | PORDP = 0.4 +/- 0.1 | Uniform |
| 29 | COR_LP_HDBH2O | HTC from in-vessel falling debris to pool | 2000 | HDBH2O = 2000 +/- 1000 W/m$^2$/K | Uniform |
| 30 | COR_LP_VFALL | Velocity of falling debris | 0.01 | VFALL = 0.01 +/- 0.005 | Uniform |
| 31 | CVH_SC4407(1) | Pool bubble rise velocity | 0.3 | SC4407(1) = 0.3 m/s +/- 0.1 m/s | Uniform |
| 32 | CVH_SC4407(11) | Pool maximum void fraction | 0.4 | CVH, SC4407(11) = 0.4 +/- 0.1 | Uniform |
| 33 | **CAV_RT_NCFREL** | **Overflow height from CAV1 to CAV2** | **0.325** | **NCFREL = 0.15-0.5 m** | Uniform |
| 34 | CONT_LEAK_AREA_MUL | Containment leak area multiplier | 1 | Area VALUE +/- 50% | Uniform |
| 35 | PAR_EFF_FACTOR | PARs model efficiency multiplier | 1 | PAR, VALUE +/- 20% | Uniform |

# Uncertainty Analysis Set-up

## Uncertainty parameters

- 43 total

| Note* Par. # | Name | Short description | Reference value | Range of Variation | PDF Type |
|---|---|---|---|---|---|
| 36 | CFVS_Open_P | CFVS opening pressure setpoint | 5 | nominal setpoint of 5 bar +/-10% | Uniform |
| 37 | **DTMAX** | **Maximum timestep** | **0.105** | **DTMAX = 0.01 ... 0.2 s** | Uniform |
| 38 | **PORV1_AVAIL** | **PRZ PORV availability** | **3** | **PORV amount operable** | Discrete |
| 39 | **PORV_OP_DELAY** | **Time delay for manual RCS depressurization via PRZ PORV after CET increase above 450 C** | **1350** | **delay 0-2700s** | Uniform |
| 40 | COR_SC1020(1) | Radial debris relocation time constant (solid debris) | 360 | TSPRS = 180-540 | Uniform |
| 41 | COR_SC1020(2) | Radial debris relocation time constant (molten debris) | 60 | TSPRM = 30-90 | Uniform |
| 42 | CDISPN | Discharge coefficient for ejection of debris | 1 | CDISPN = 0.5-1.5 | Uniform |
| 43 | **GAMMA** | **Agglomeration shape factor** | **2** | **RN, GAMMA = 1.0 3.0** | Uniform |

**Maximum calculation Timestep**

**Number of PRZ SVs open with probability:**

**3 PORVs open 0.729**
**2 PORVs open 0.243**
**1 PORV open 0.027**
**0 PORVs open 0.001**

**PRZ SVs open delay (operator action)**

# Uncertainty Analysis FOMs

## Variables of interest (Figures of Merits, FOMs)

- Xe release to environment (MUSA)
- Cs release to environment (MUSA)
- Cs airborn in containment
- Gap release time
- $H_2$ generation in core
- $H_2$ generation in cavities
- CFVS open time
- LH failure time
- Cavity ablation depth
- CFVS filter thermal load (aerosols)

# MELCOR Runs

## Sampled number PORVs open

### “Mixed” PORVs set

- 3, 2 or 1 PORV open (sampled)
- Other UPs sampled
- Total 100 runs

### “Mixed” PORVs set

- 3 PORVs – 72 sequences
- 2 PORVs – 25 sequences
- 1 PORV – 3 sequences

## Fixed number PORVs open

### 3 PORVs set

- Fixed 3 PORVs open
- Other UPs sampled
- Total 100 runs

### 2 PORVs set

- Fixed 2 PORVs open
- Other UPs sampled
- Total 100 runs

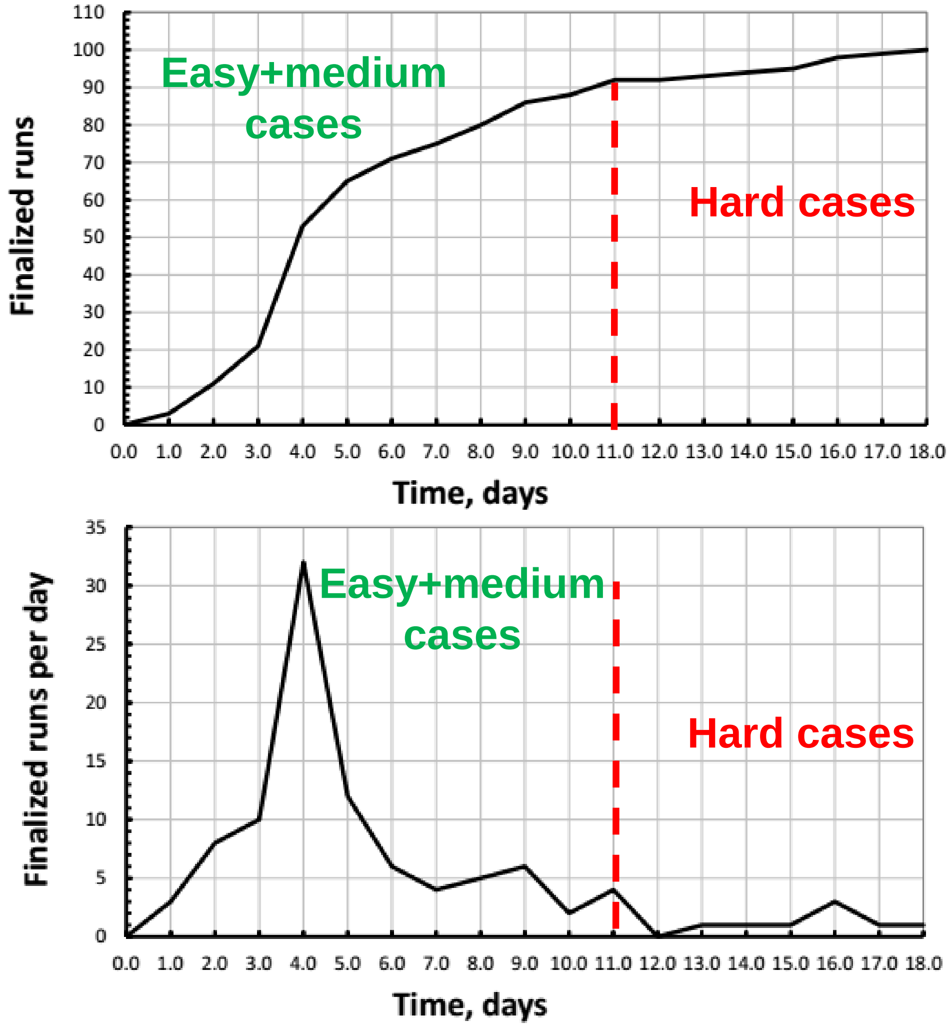
### 1 PORV set

- Fixed 3 PORVs open
- Other UPs sampled
- Total 100 runs

# MELCOR Runs

**MELCOR 100 runs statistics (“mixed” PORVs)**

| | |
|---|---|
| without restarts (easy cases) | 9 |
| with restarts (DT change) (medium cases) | 83 |
| with restarts (DT + param. change) (hard cases) | 8 |




**MELCOR runs performance**

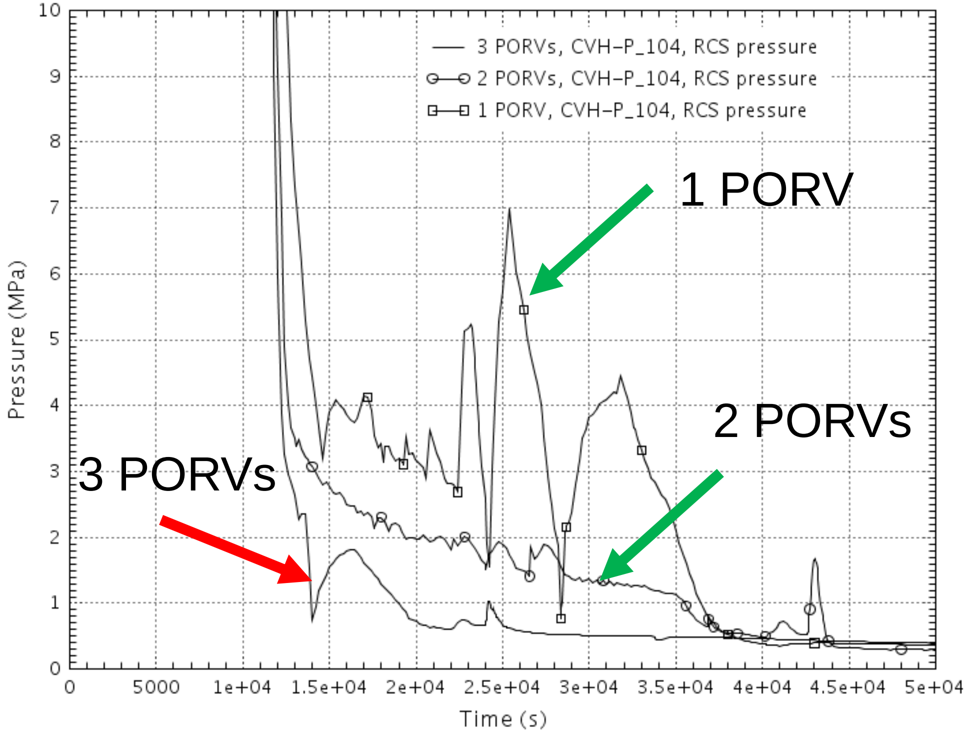
# MELCOR Runs

**TH typical behavior**

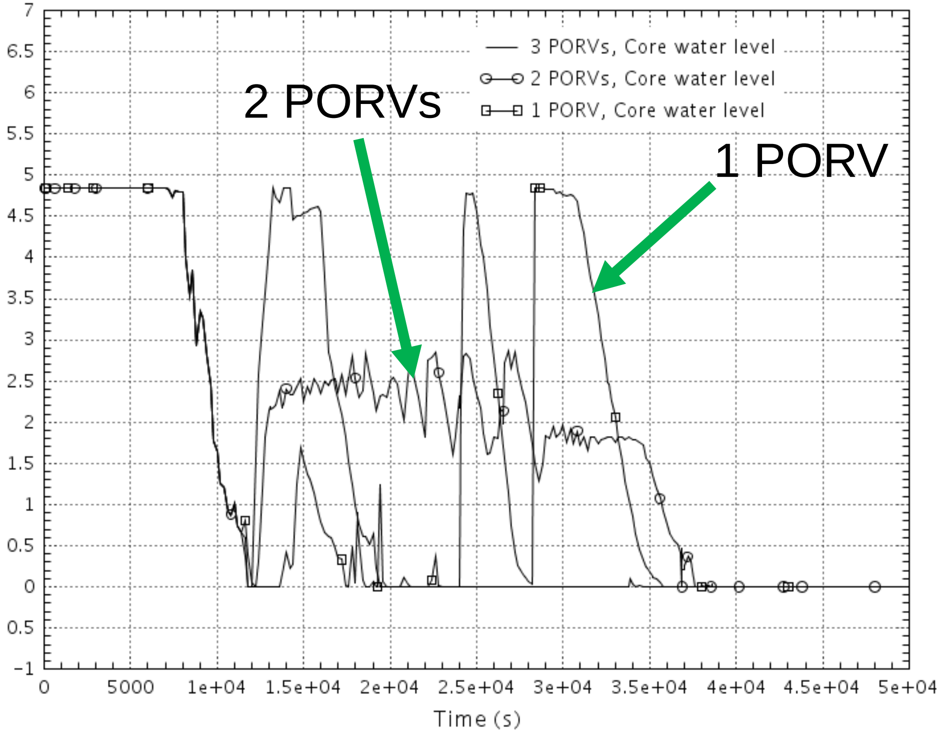
- Main difference for 3, 2 and 1 PORVs open
- Below cases with central UPs
- HAs are injecting (P<60kgf/cm2)

**RCS pressure**

- 3 PORVS – faster decrease
- 2 PORVS – smooth decrease
- 1 PORV – periodical decrease-increase (long periods)




**RCS pressure**




**Level in the core**

**Core level**

- 3 PORVS – low
- 2 PORVS – long half-core
- 1 PORV – periodic full and dry core

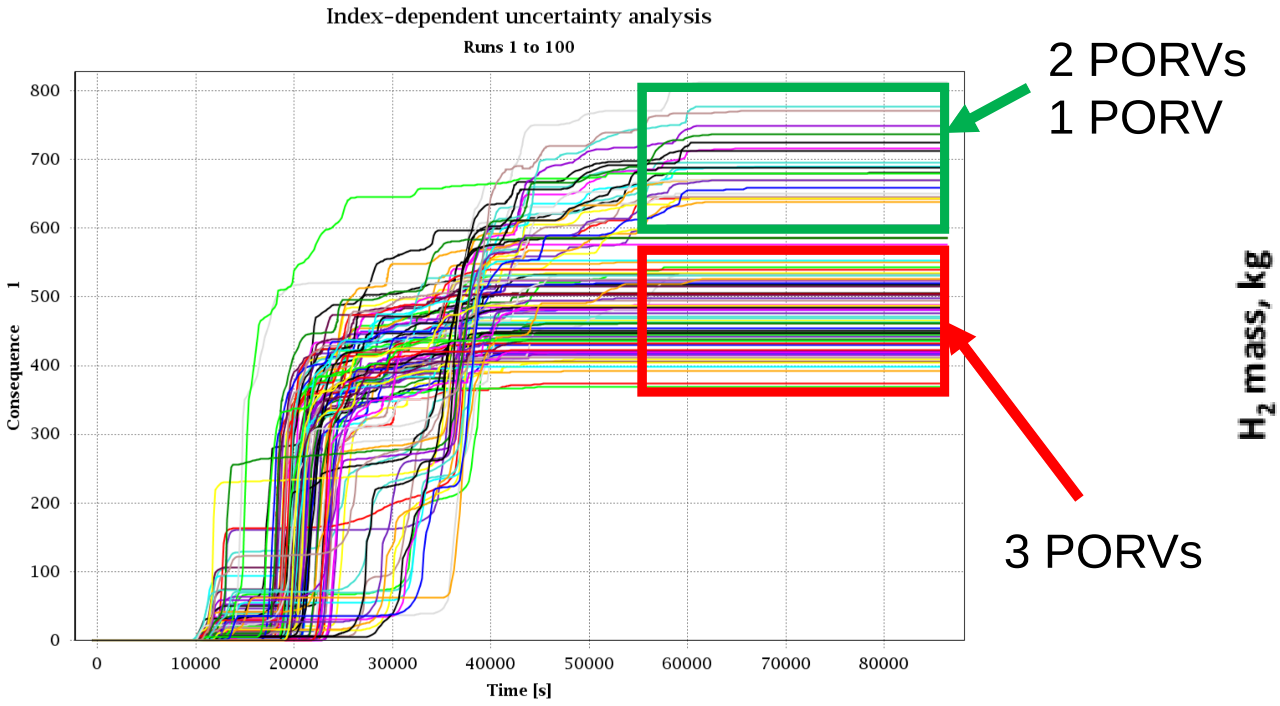
# Uncertainty Analysis Results Example

## Uncertainty analysis results example (H2 generation in reactor)

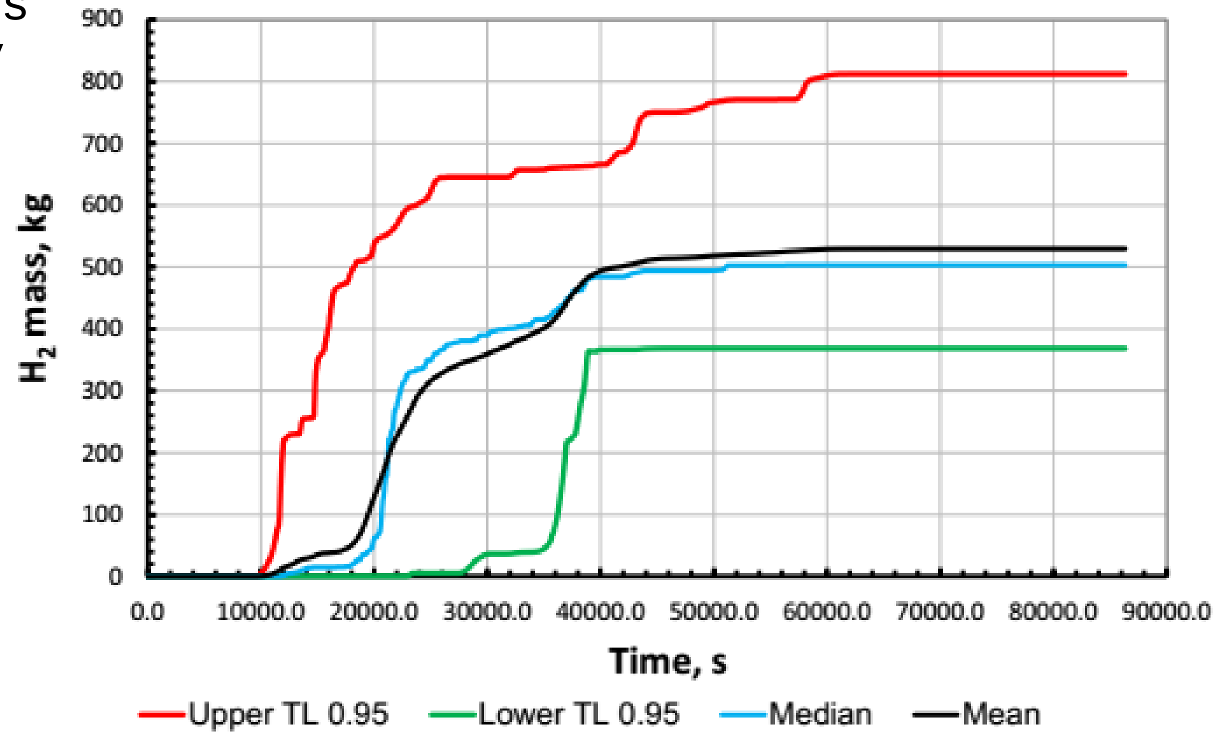
- Can be given as mean with tolerance limits (0.95, 0.95)

**"Mixed" PORVs set**

- Mean 529kg
- Median 503kg
- TL 369kg, 812kg
- Std. dev. 106kg




**Hydrogen generated in the core, kg (runs)**




**Hydrogen generated in the core**



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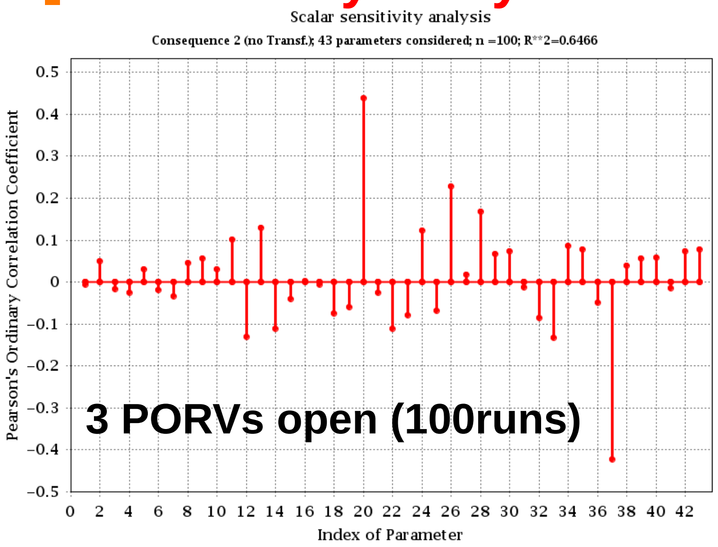
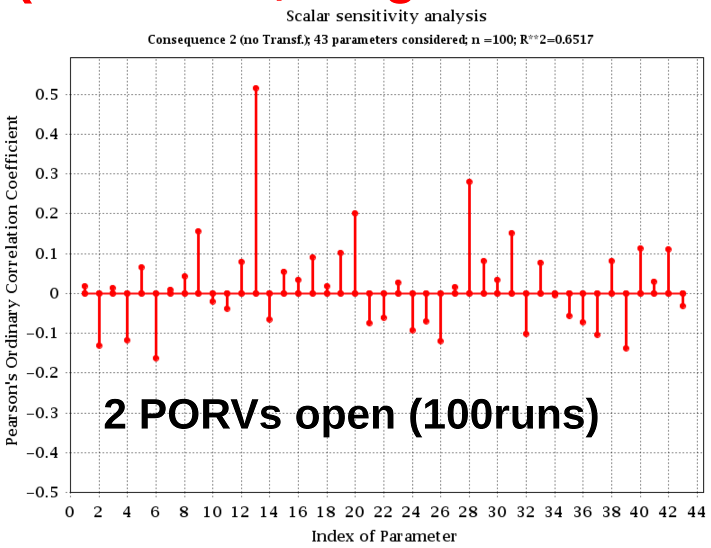
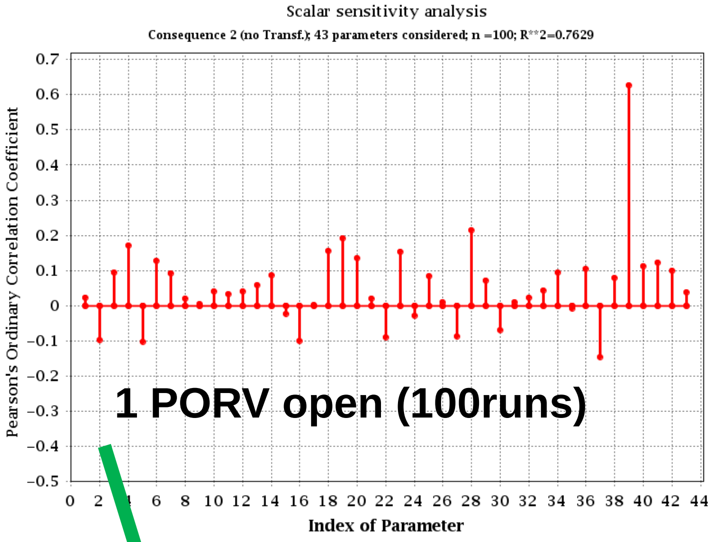
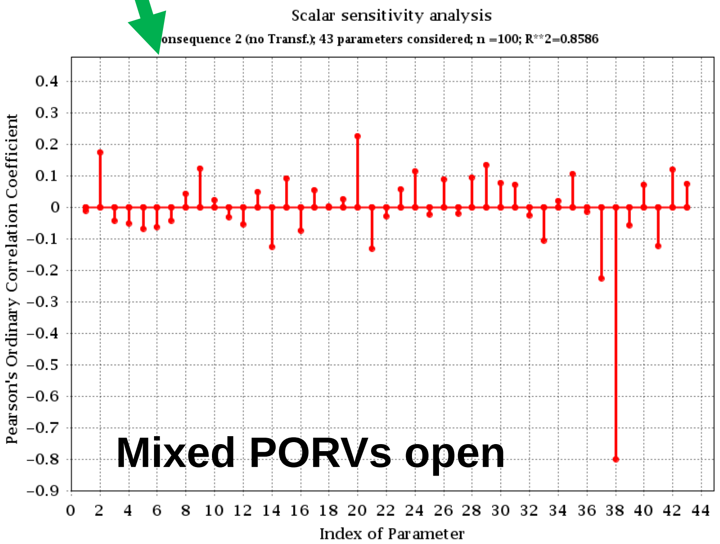
# Sensitivity Analysis Results Example

## Sensitivity analysis results (Pearsons, $H_2$ generated in reactor)



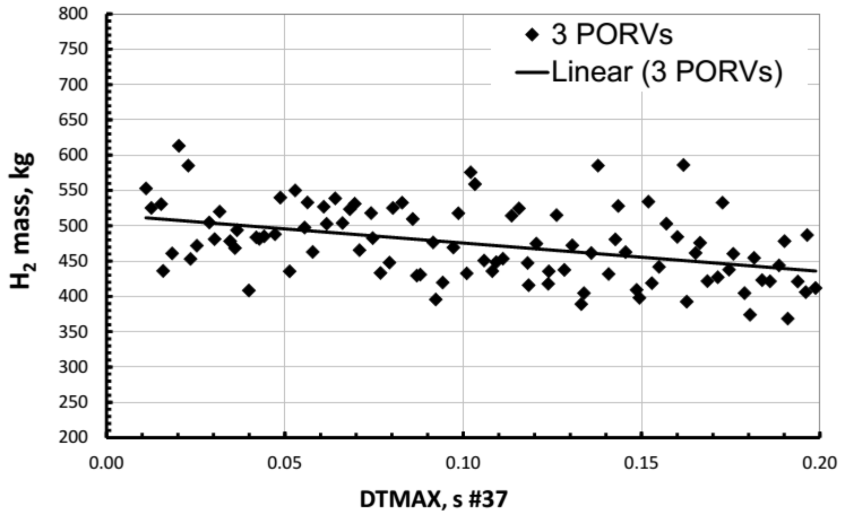




**Outcomes:**

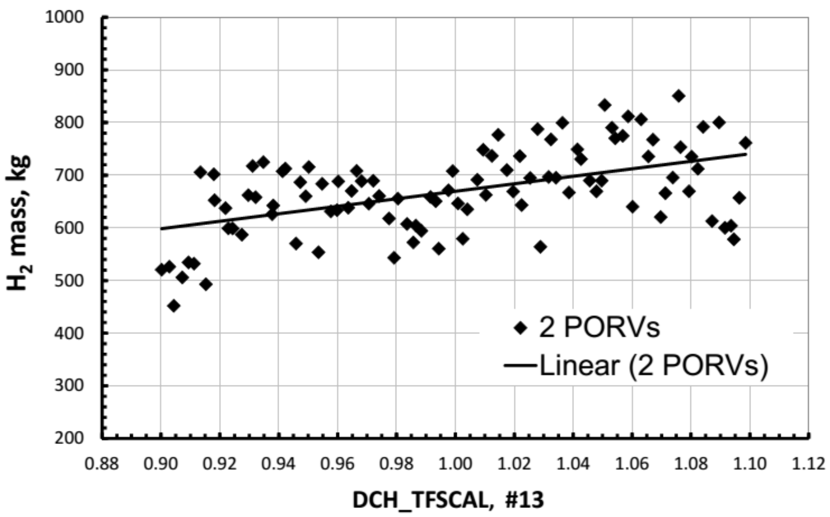
- Each equipment configuration has its own **main** sensitivities
- Mixed analysis sensitivities are VERY different

# Sensitivity Analysis Results Example

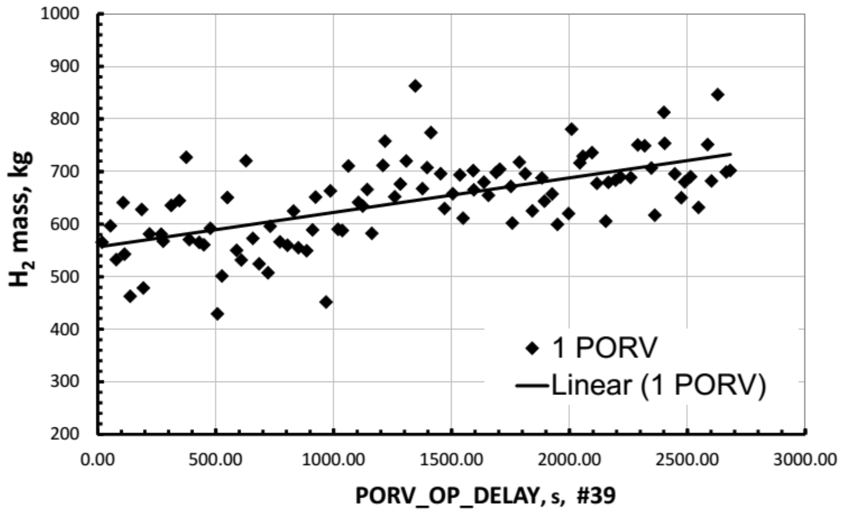
## H2 generated in reactor, scatter plots




**3 PORVs open (100runs)**
**DTMAX**




**2 PORVs open (100runs)**
**Decay heat**




**1 PORV open (100runs)**
**Actions delay**

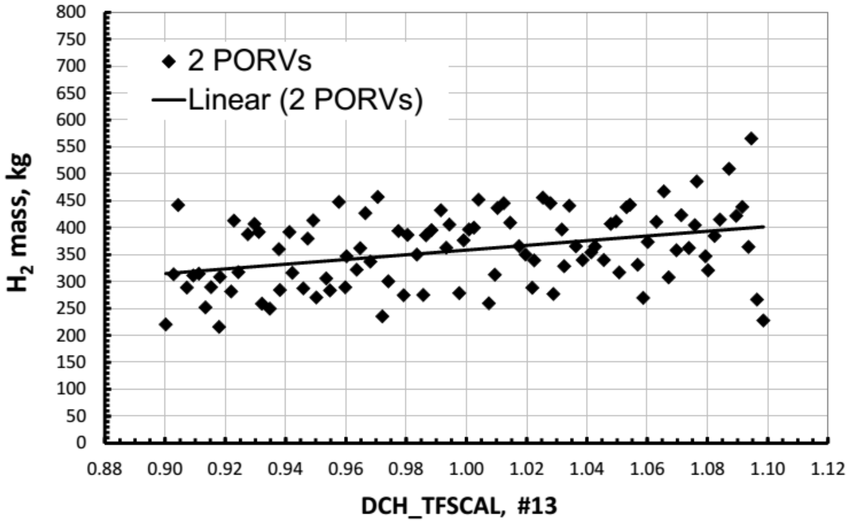
**Outcomes:**

- MELCOR results scatter
- H2 depends on DTmax for 3 PORVs
- Scatter plots are useful

# Sensitivity Analysis Results Example

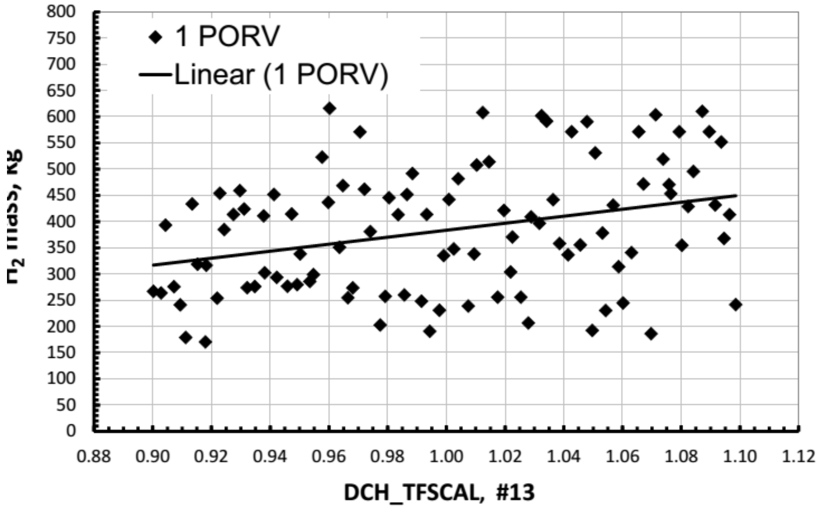
## Example scatter plots (high VS low scatter results)

### moderate scatter



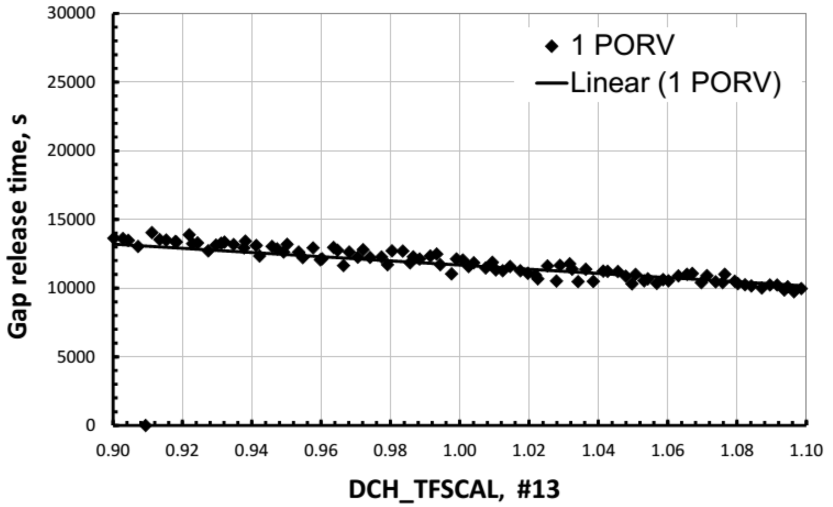

**2 PORVs open (100runs)**
**H2 in cavities from**
**Decay heat**

### high scatter




**1 PORV open (100runs)**
**H2 in cavities from**
**Decay heat**

### low scatter




**1 PORV open (100runs)**
**Gap release time from**
**Decay heat**

## Outcomes:

- MELCOR results scatter depends on parameters and time
- Sequence-dependent sensitivities

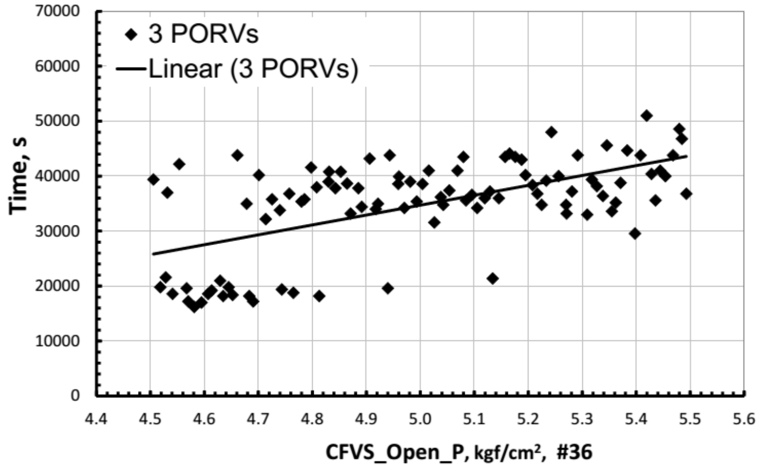
# Sensitivity Analysis Results Example

## CFVS open time, scatter plots (dep. on Open setpoint and Decay heat)

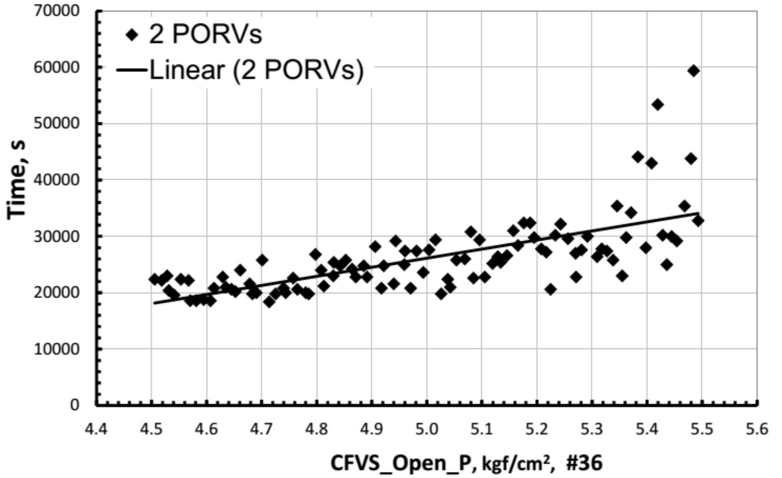
**Outcomes:**

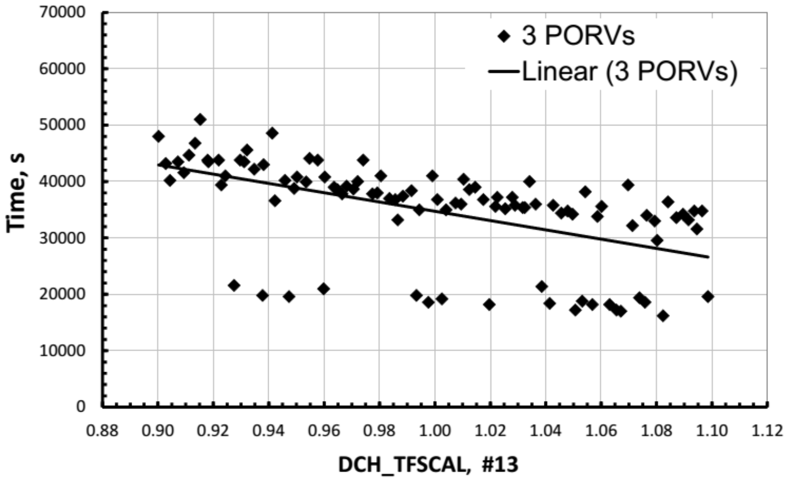
- CFVS can open early and later
- With increase of decay heat open time decreases

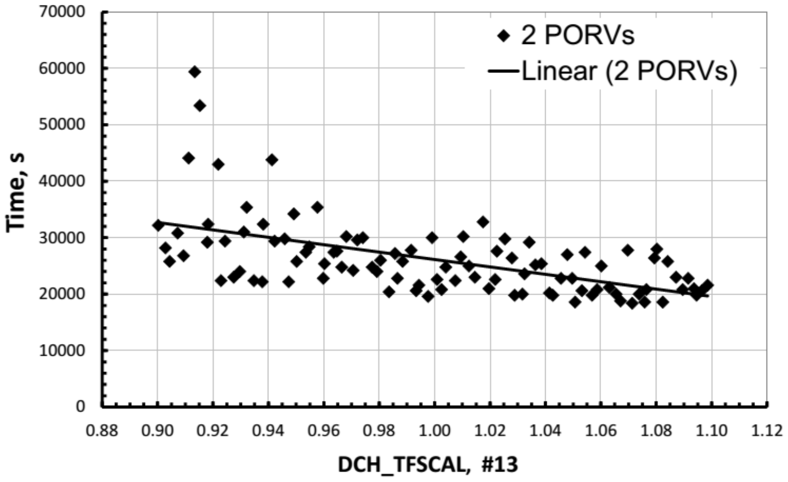
### 3 PORVs open (100runs)




### 2 PORVs open (100runs)



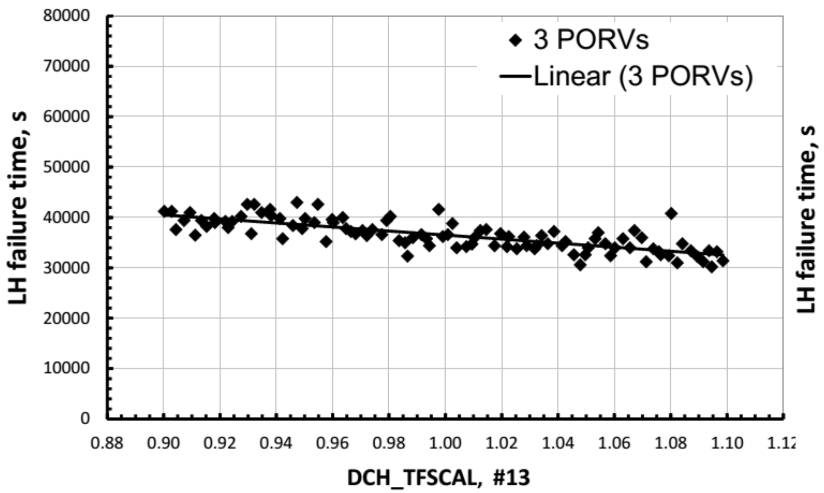



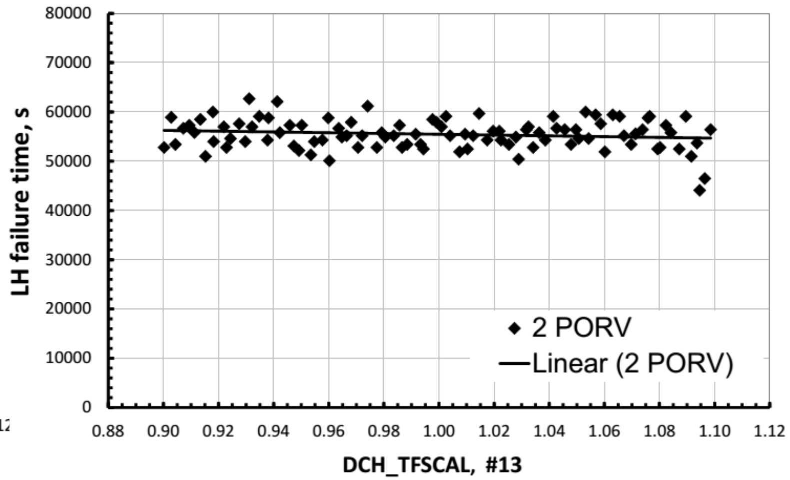

**CFVS open time**

# Sensitivity Analysis Results Example

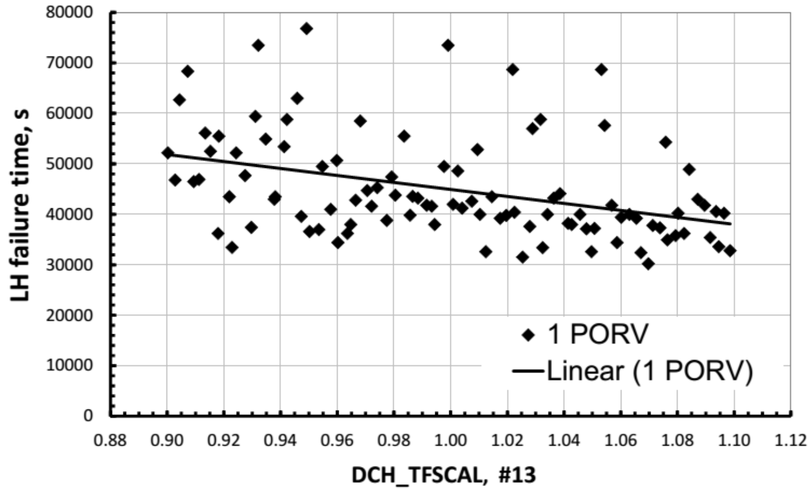
## RV failure time, scatter plots (from Decay heat)




**3 PORVs open (100runs)**



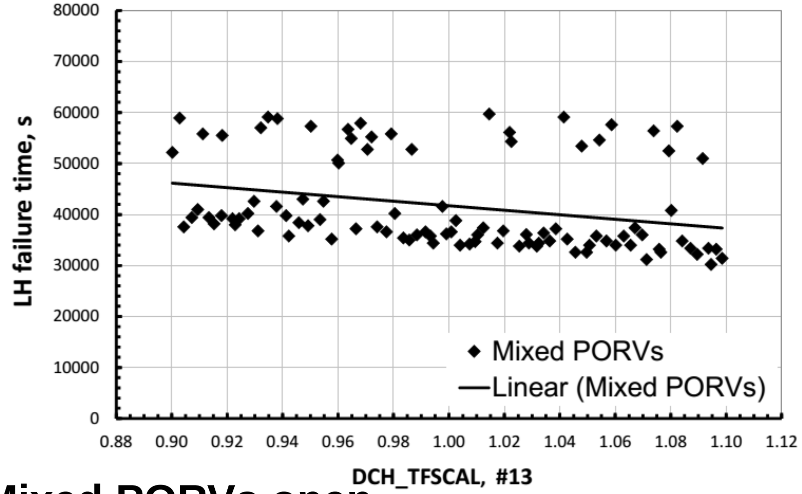

**2 PORVs open (100runs)**




**1 PORV open (100runs)**

## Outcomes:

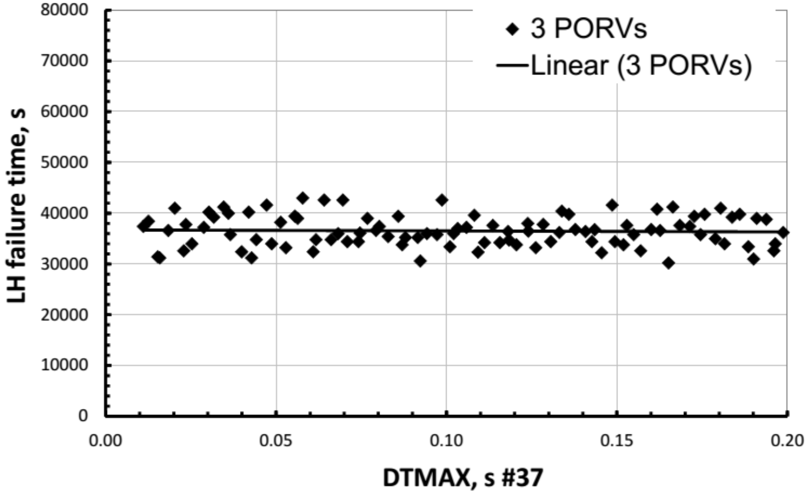
- RV vessel failure time is very scattered for 1 PORV
- RV vessel failure time is low dependent on decay heat for 2 PORVs



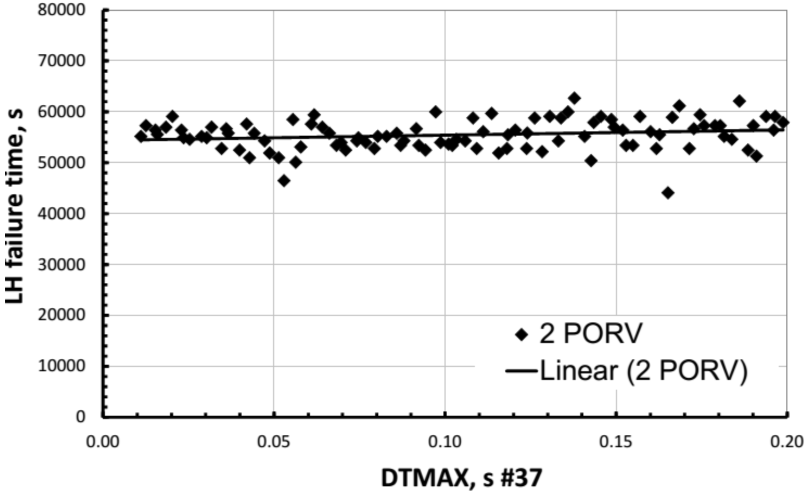

**Mixed PORVs open**

# Sensitivity Analysis Results Example

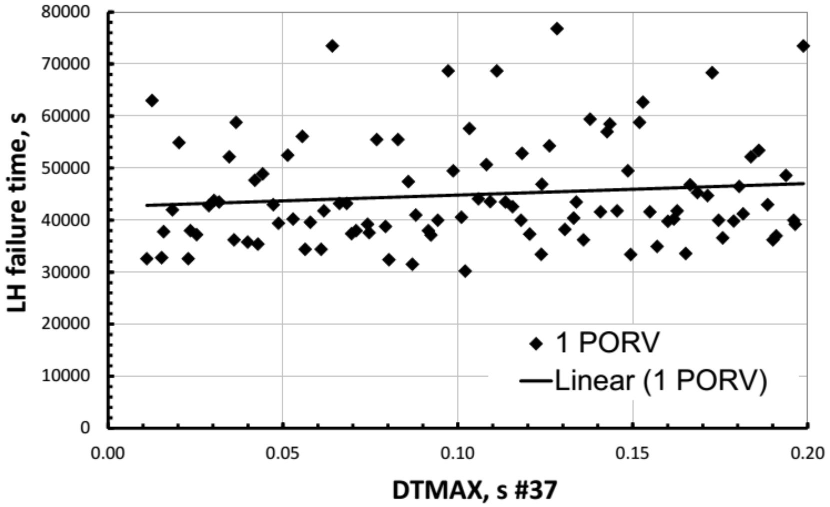
## RV failure time, scatter plots (from DTMAX - timestep)



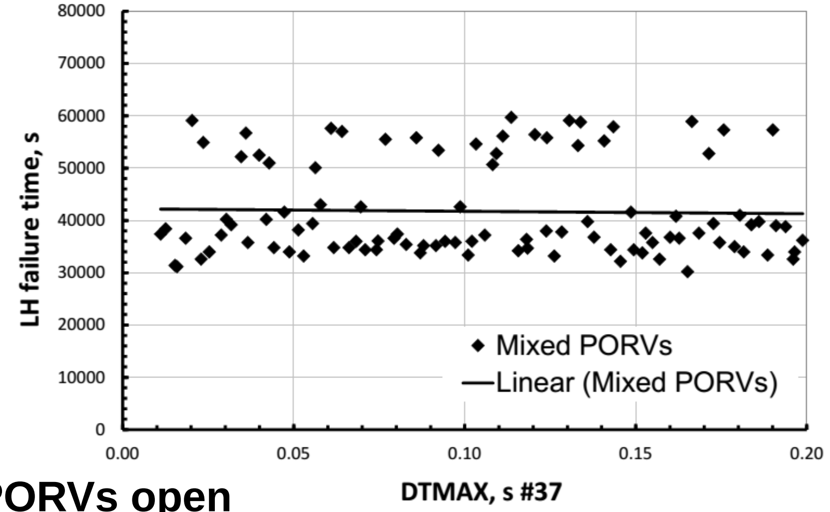

**3 PORVs open (100runs)**




**2 PORVs open (100runs)**




**1 PORV open (100runs)**




**Mixed PORVs open**

**Outcomes:**

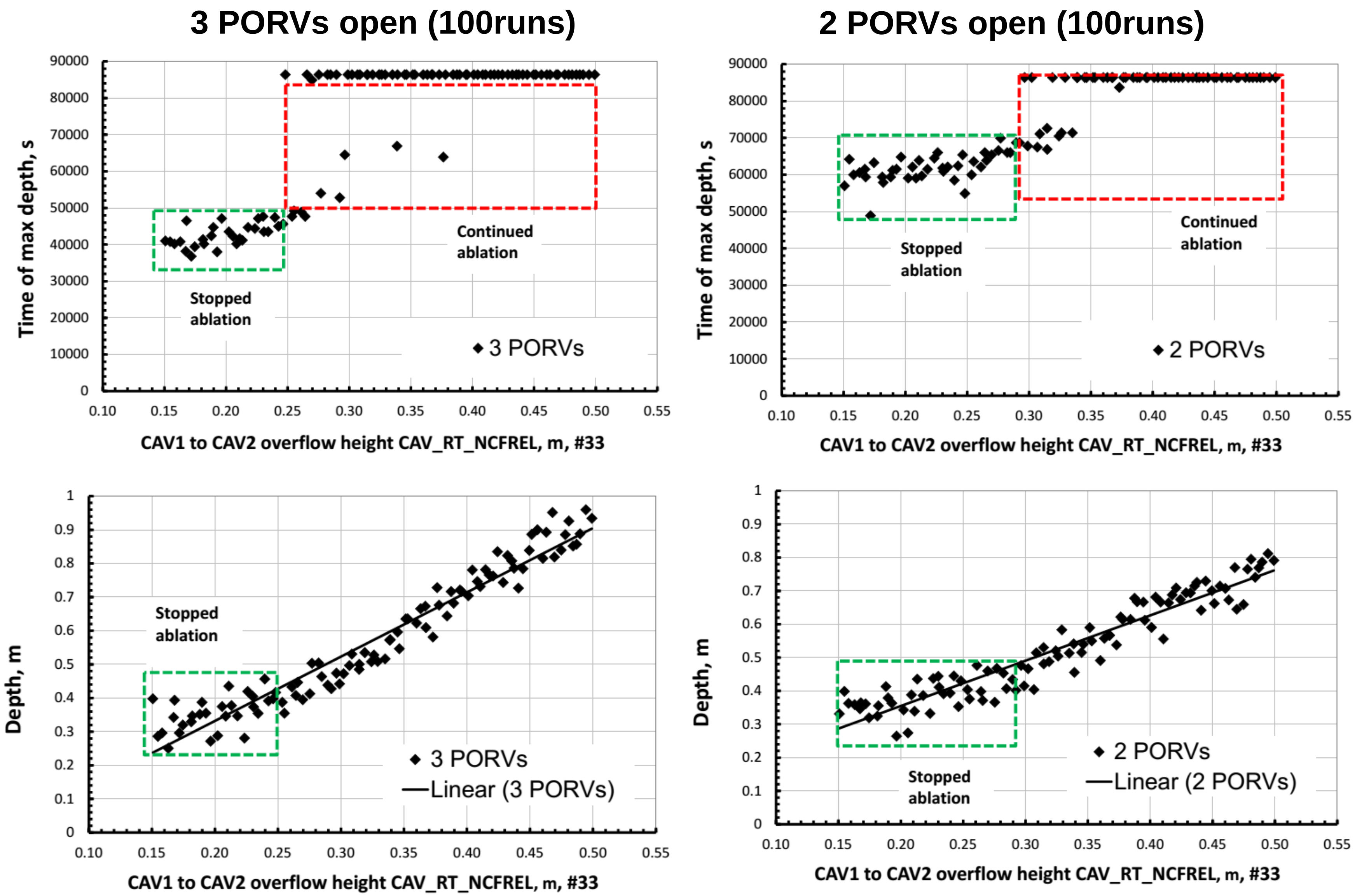
- No DTmax dependence
- Large scatter for 1 PORV

# Sensitivity Analysis Results Example

## CAV1 ablation depth, scatter plots (from Overflow height)

**Outcomes:**

- For 3 PORVs statistically ablation in CAV1 is stopped for overflow height less than 0.25m with maximal ablation depth 0.46m
- For 2 PORVs cases statistically ablation in CAV1 is stopped for overflow height less than 0.29m with max ablation depth 0.48m



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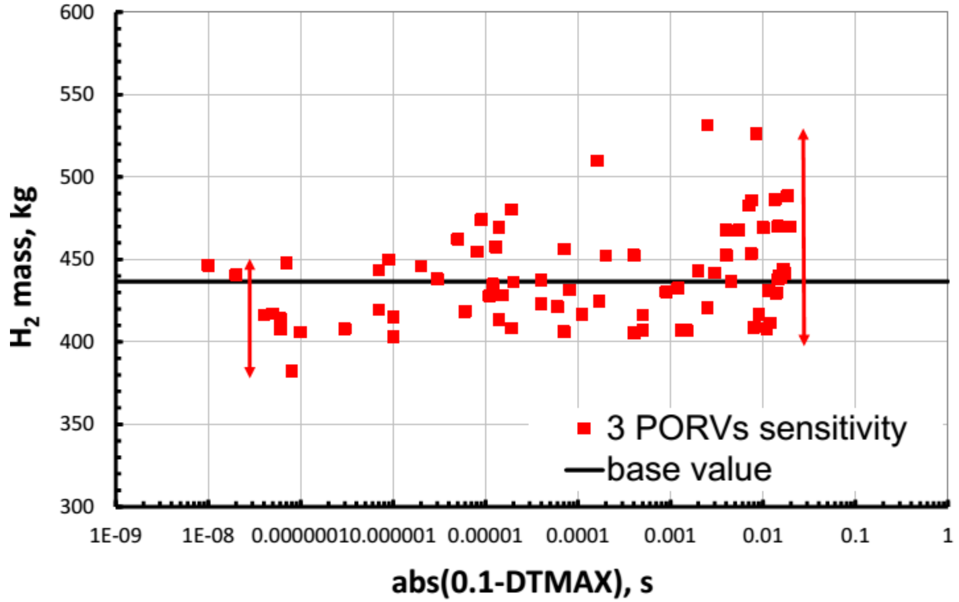
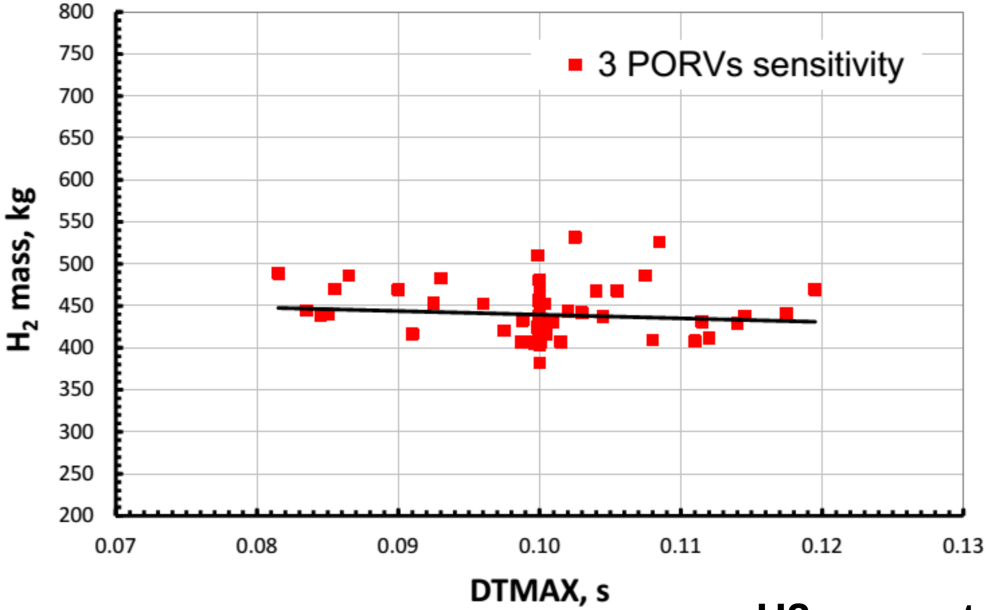
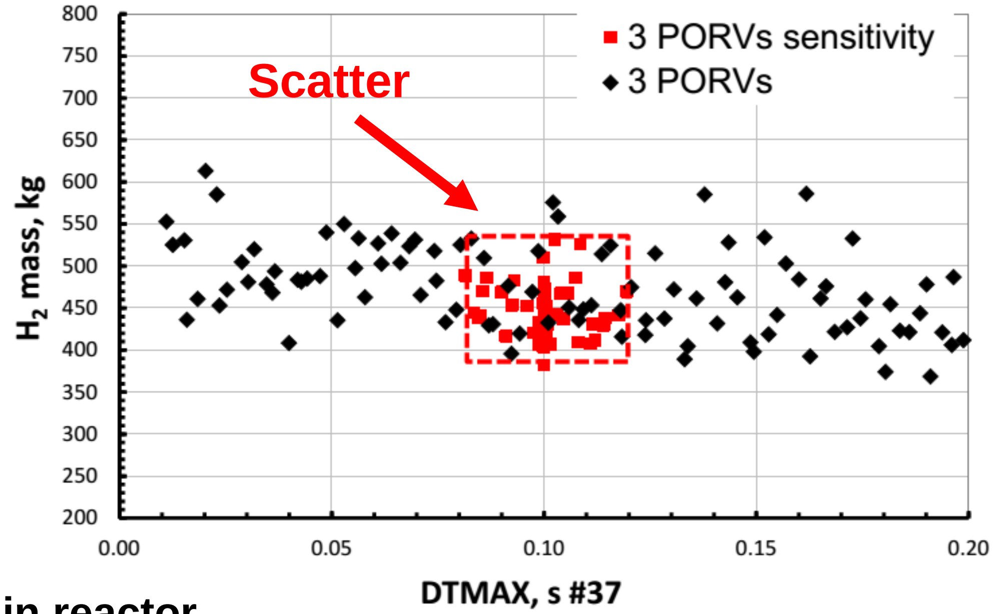
# Code-model numerical noise/scatter

## Code/model numerical noise/scatter estimation

- Performed for 3 PORVs with 0.1s base DTmax
- DTmax is changed by 1e-8s … 0.02s both ways
- Analyzed only calcs without code stop (one-through)




**H2 generated in reactor**



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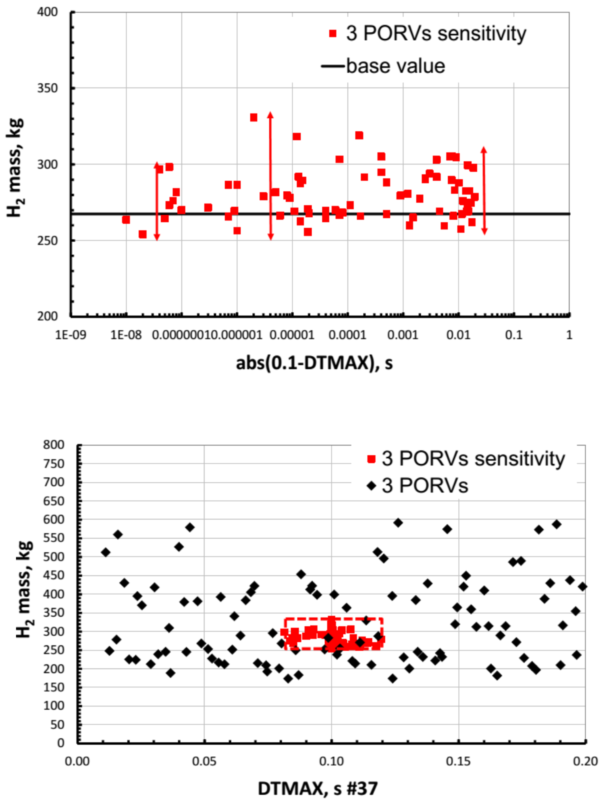
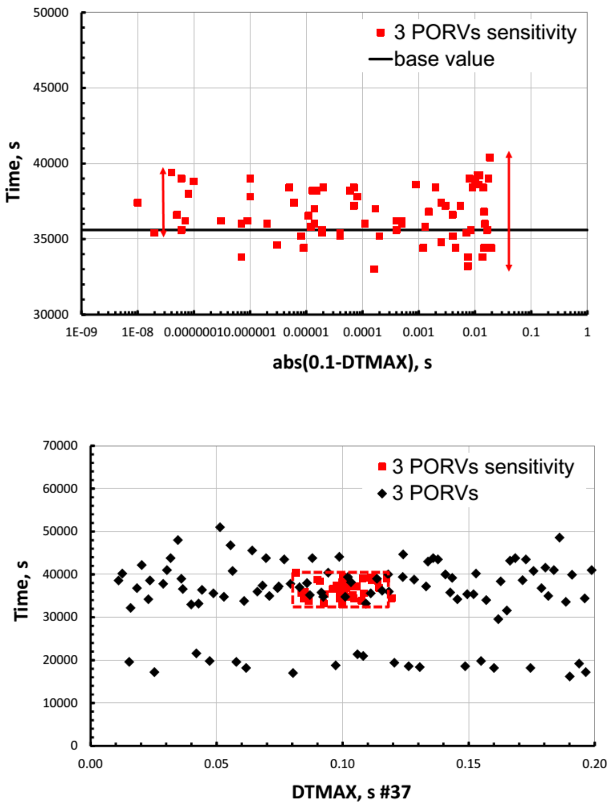
# Code-model numerical noise/scatter

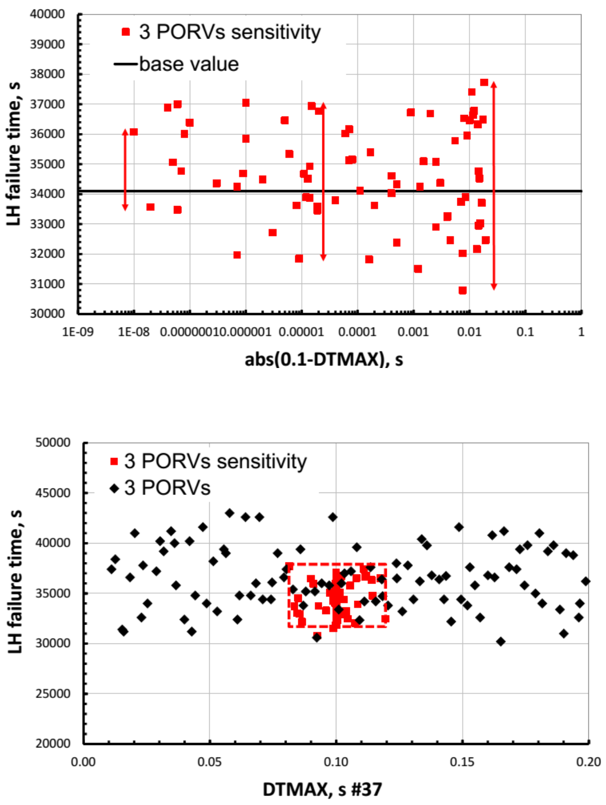
## Code/model numerical noise/scatter estimation



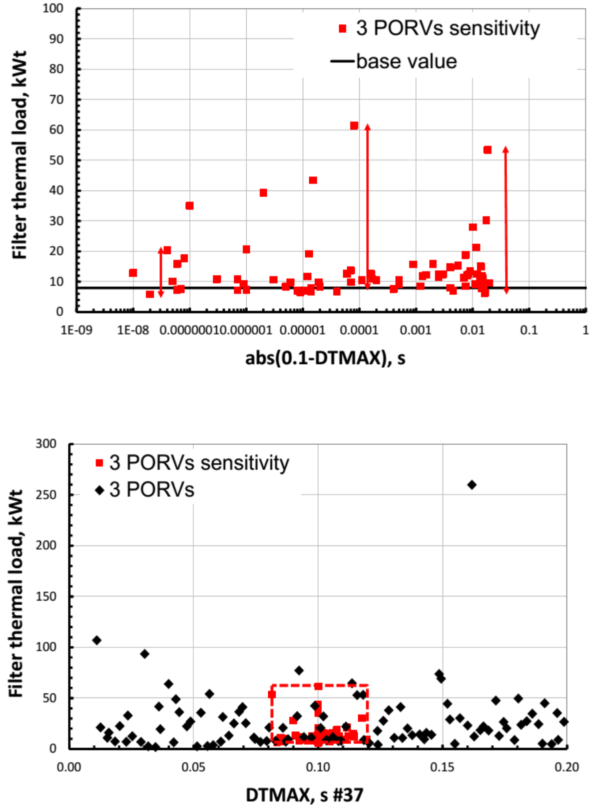

H2 generated in cavities




CFVS open time




RV failure time



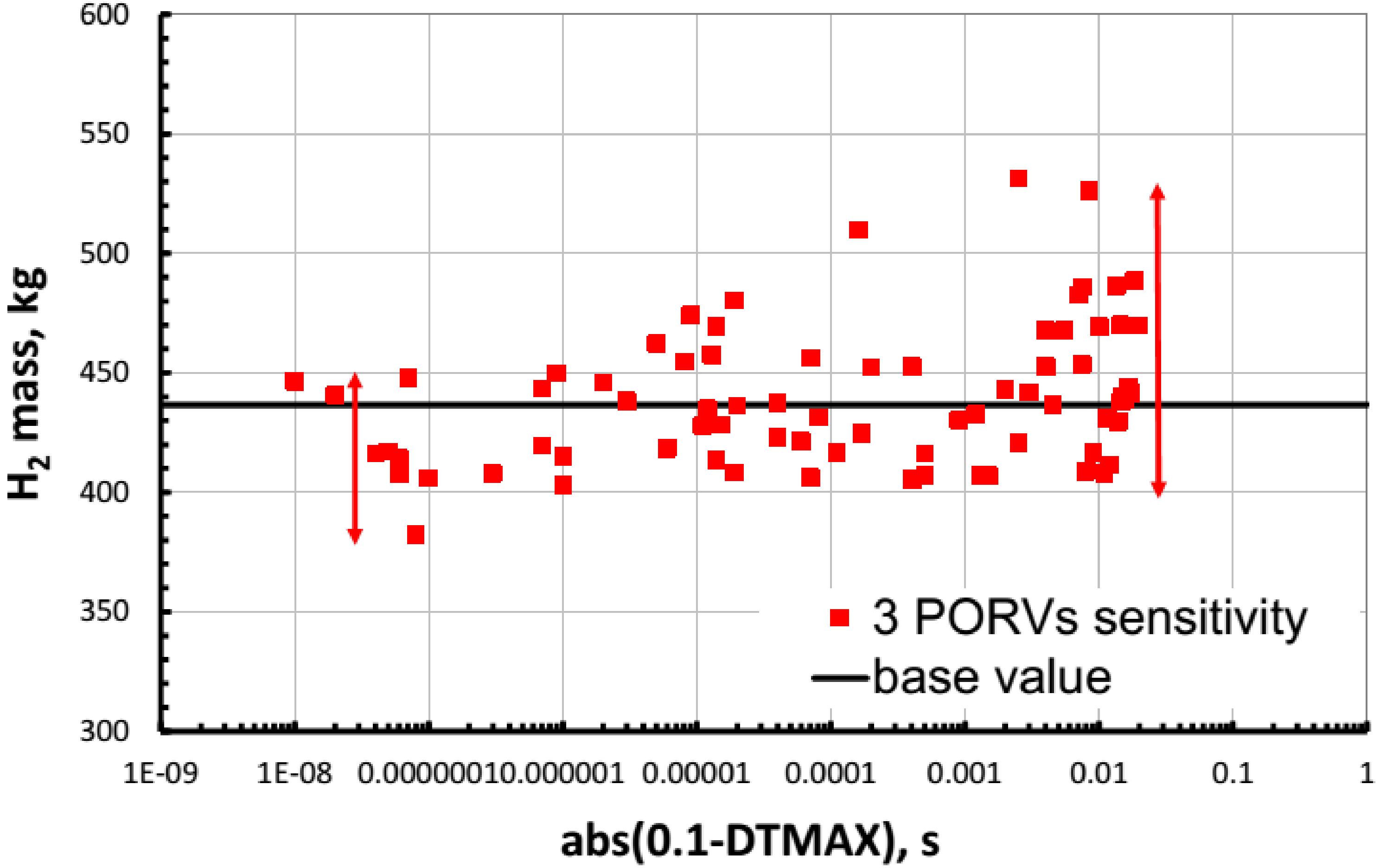

CFVS filter load

# Code-model numerical noise/scatter

## Code/model numerical noise/scatter estimation

**Outcomes:**

- The code result **does NOT converge** to base value (always scattered, tends to decrease)
- This scatter is **anavoidable**
- Scatter of MELCOR results CAN NOT be LESS than code/model noise
- Scatter **can mask** the correlation

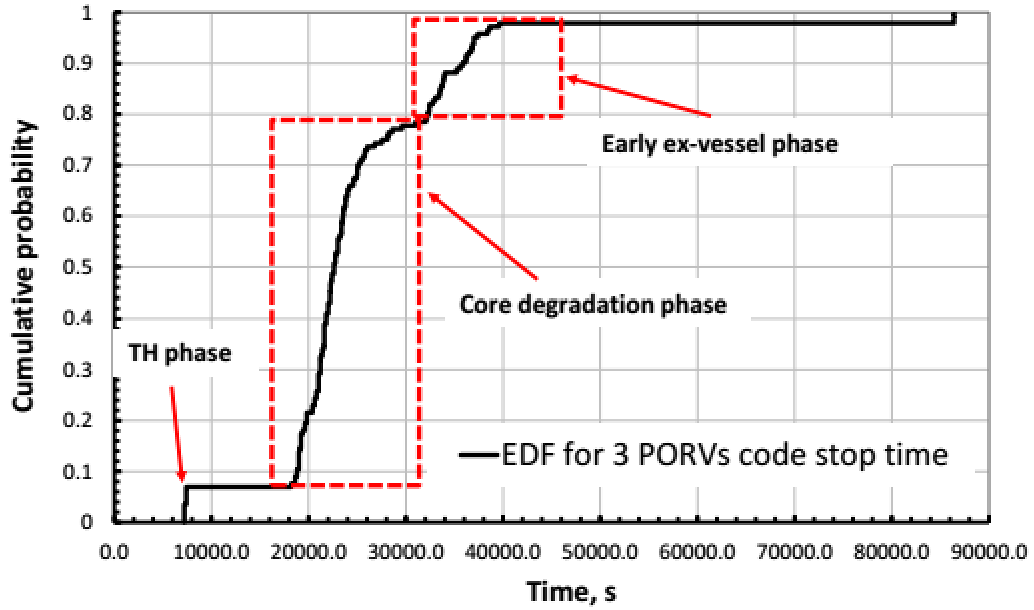



**H2 generated in reactor**

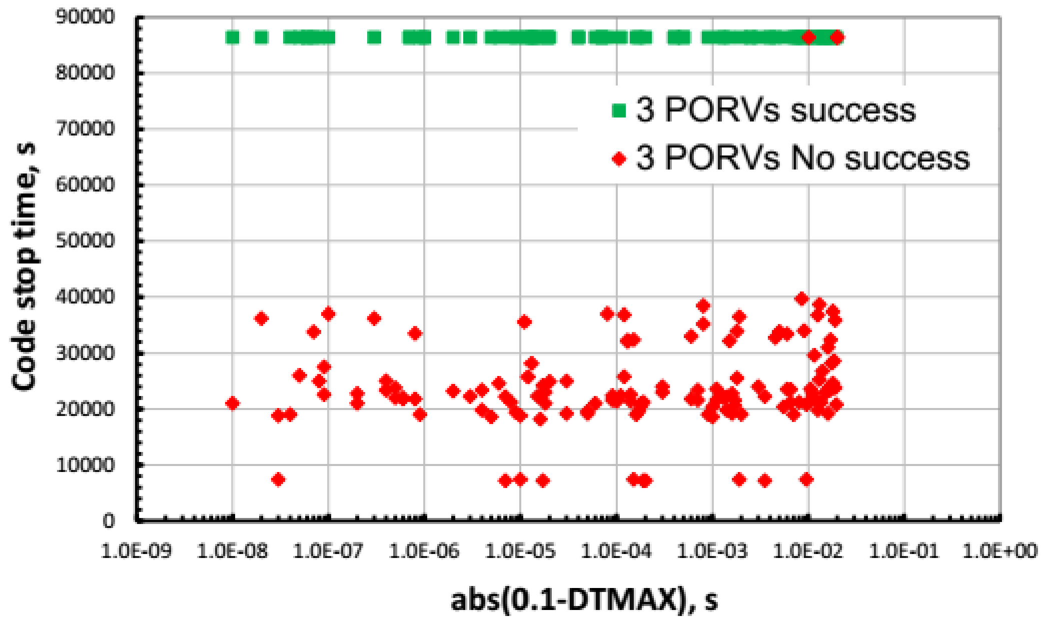
# Code-model failure rate

## Code/model success statistics

- Performed for 3 PORVs noise
- Successful and failed cases statistics




**Code stop time EDF**




**Outcomes:**

- Total 221 cases run, 77 success (**35%**), 144 failed (**65%**)
- Code fails in decreasing order of priority at
  - Core degradation phase
  - Early ex-vessel phase
  - Early TH phase
  - Late ex-vessel phase



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# MELCOR Uncertainty/Sensitivity Analysis Applications

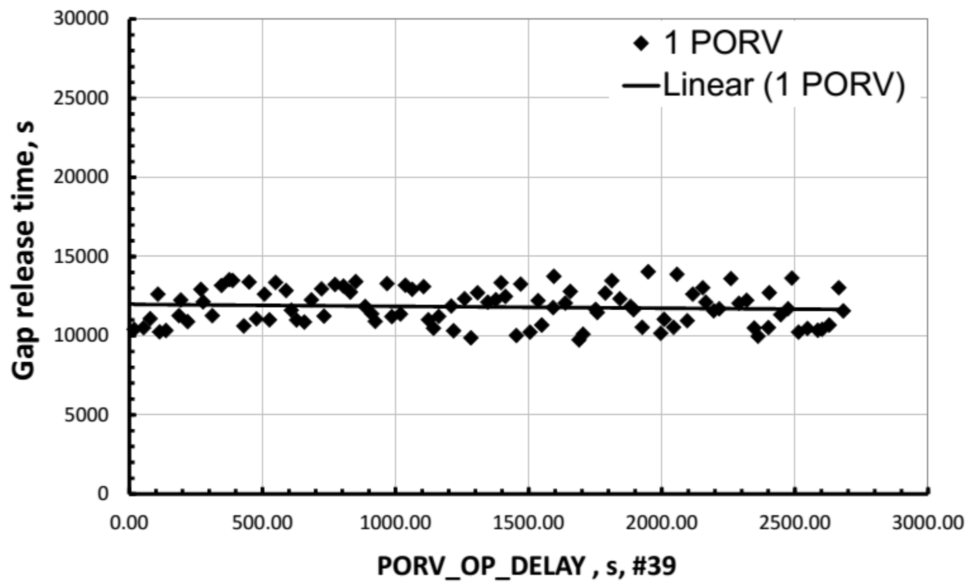
## Importance parameters ranking for FOMs

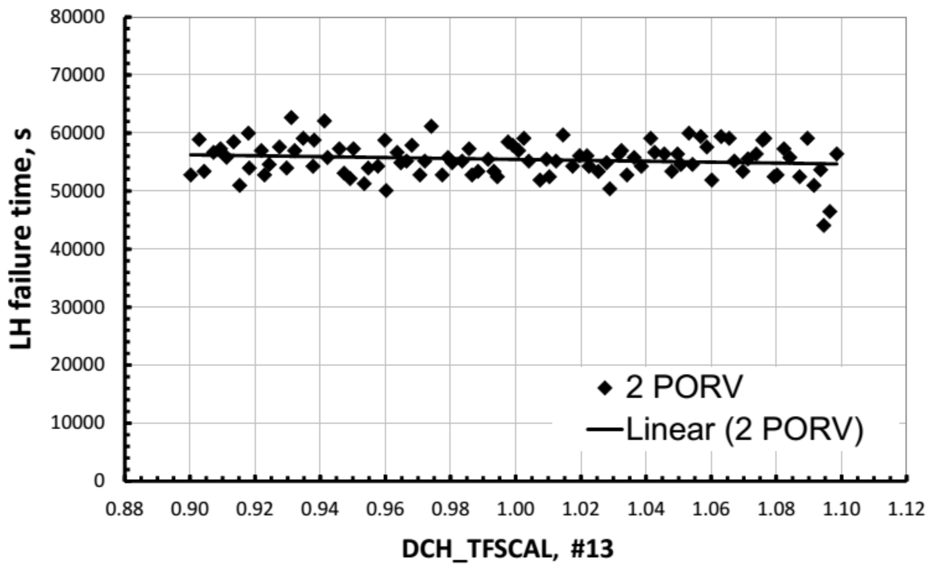
Can be used to estimate:

- Parameter important or not
- Areas of deeper modeling needed
- Areas of simpler modeling

## Examples of LOW sensitivity

- Time of gap release from actions delay (1 PORV)
- LH failure time from decay heat (2 PORVs)



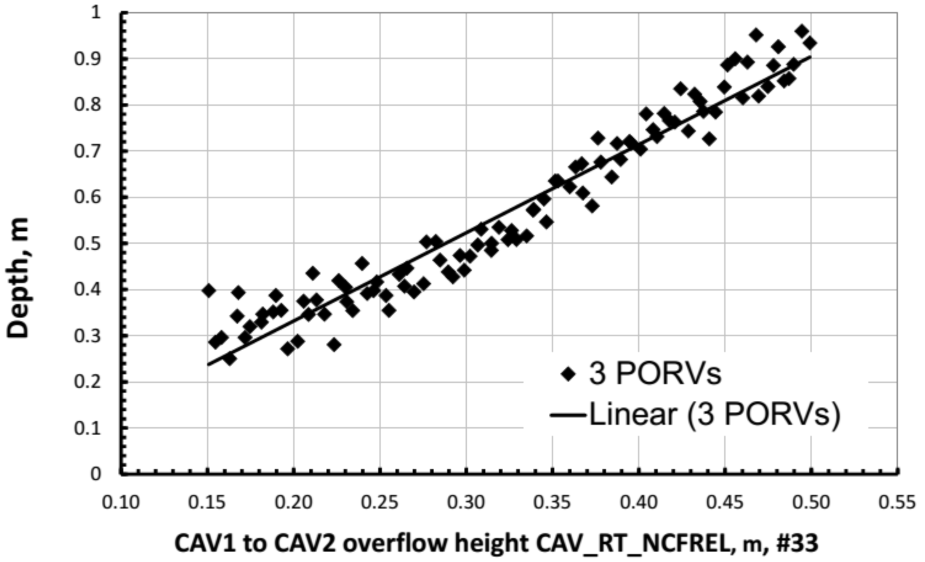



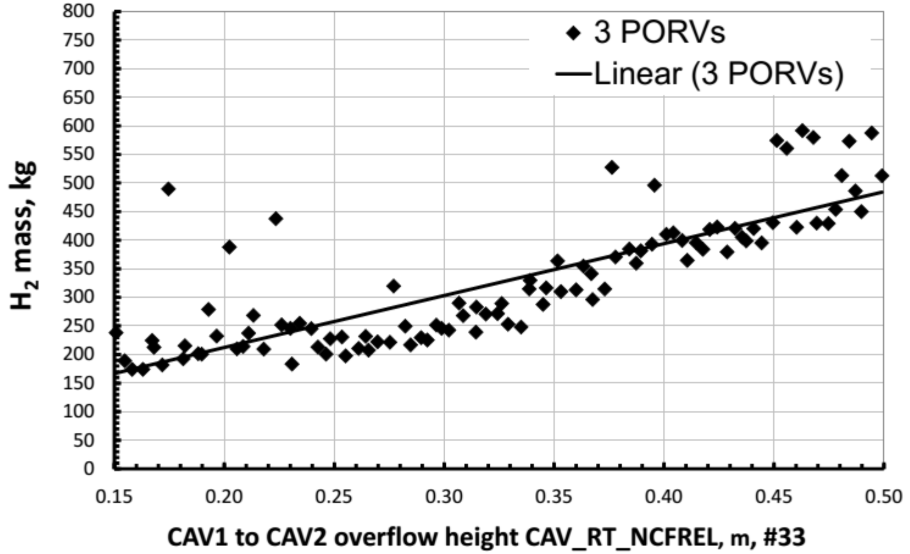
# MELCOR Uncertainty/Sensitivity Analysis Applications

## Importance parameters ranking for FOMs

## Examples of HIGH sensitivity

- Ablation depth in cavity from melt overflow height (3 PORVs)
- H2 generated in cavity from melt overflow height (3 PORVs)



# MELCOR Uncertainty/Sensitivity Analysis Applications

## Important parameters for FOMs (table below)

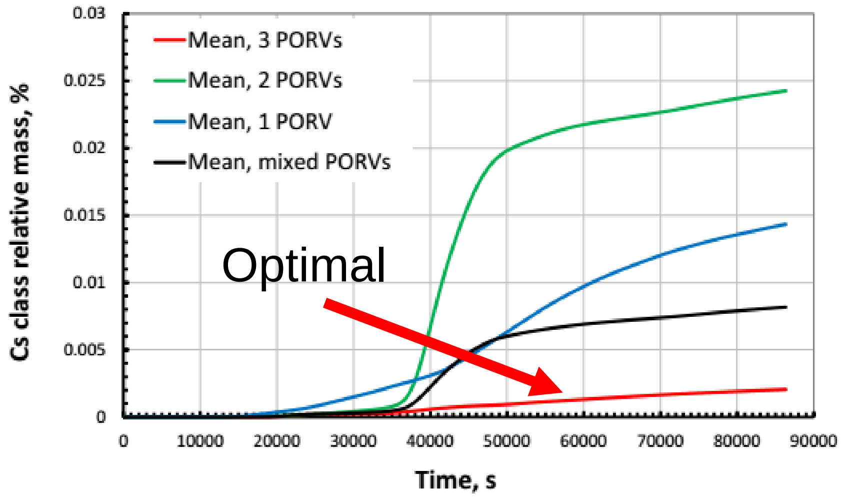
- Detectable high sensitivity in MELCOR calculations
- In table N PORVs for sensitive cases
- Other sensitivities are not detected (<0.2)
- Reasons not detecting – No any OR code-model scatter

| Param. | Xe release | Cs release | Gap time | H2 reactor | H2 cavities | CFVS time | LH time | CAV abl. | CFVS load |
|---|---|---|---|---|---|---|---|---|---|
| #13, Decay heat | 3,2,1 | 2,1 | 3,2,1 | 2 | 3,2,1 | 3,2,1 | 3,1 | | 2,1 |
| #20, Zr upper Temperature | | | | 3 | | | | | |
| #28, COR porosity | | | | 2 | | | | | |
| #33, CAV overflow height | 2 | | | | 3,2,1 | | | 3,2,1 | |
| #36, CFVS open P | | | | | | 3,2,1 | | | |
| #37, DTMAX | | | | 3 | | | | | |
| #39, PORV open delay | | 1 | 3 | 1 | | | | | 1 |

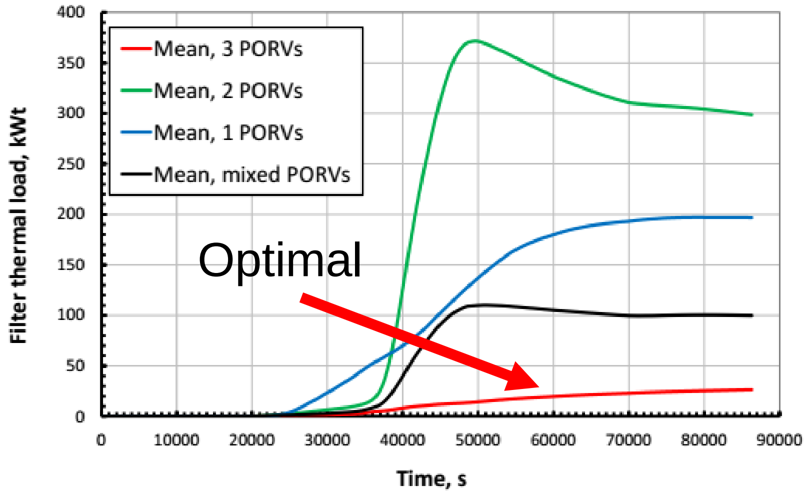
# MELCOR Uncertainty/Sensitivity Analysis Applications

## SAMGs optimization

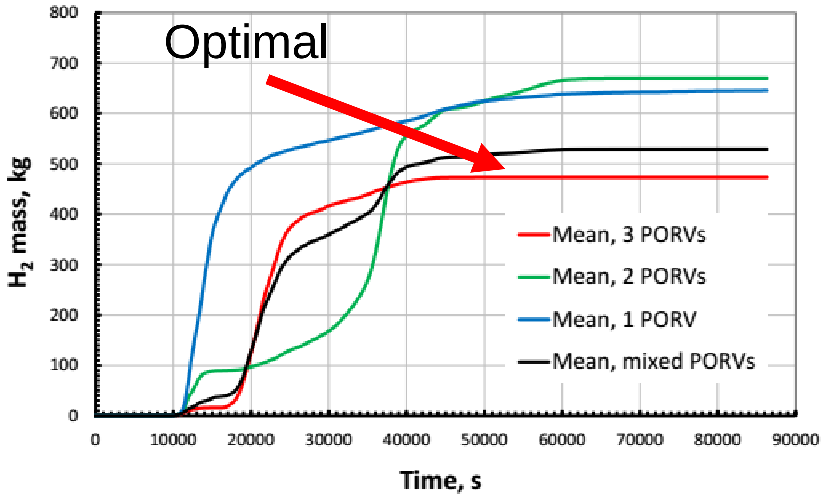
- Use of population MEAN values
- Lowest Cs release to ENV for 3 PORVs (optimal)
- Lowest H2 generation for 3 PORVs (optimal)
- Lowest CFVS filter load for 3 PORVs (optimal)
- But for 3 PORVs the earliest RV failure ! (optimal?)




Cs release to environment, %




CFVS filter thermal load

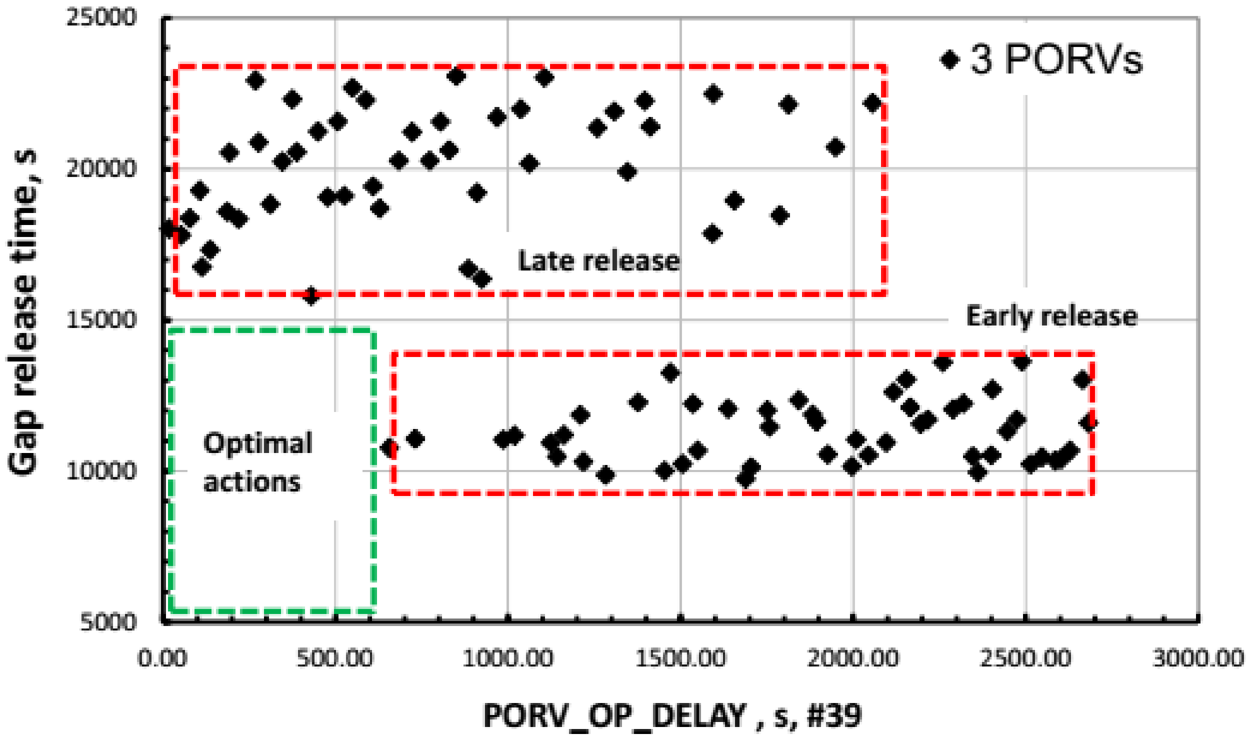



H2 generated in core

# MELCOR Uncertainty/Sensitivity Analysis Applications

## SAMGs optimization

- Scatter plot of analysis can show **optimal** areas of actions
- Example for gap release time
- For operator delay 0…600s the gap release is always later (optimal)
- Strategy choice justification




**Gap release time depending on PORV operator actions delay**



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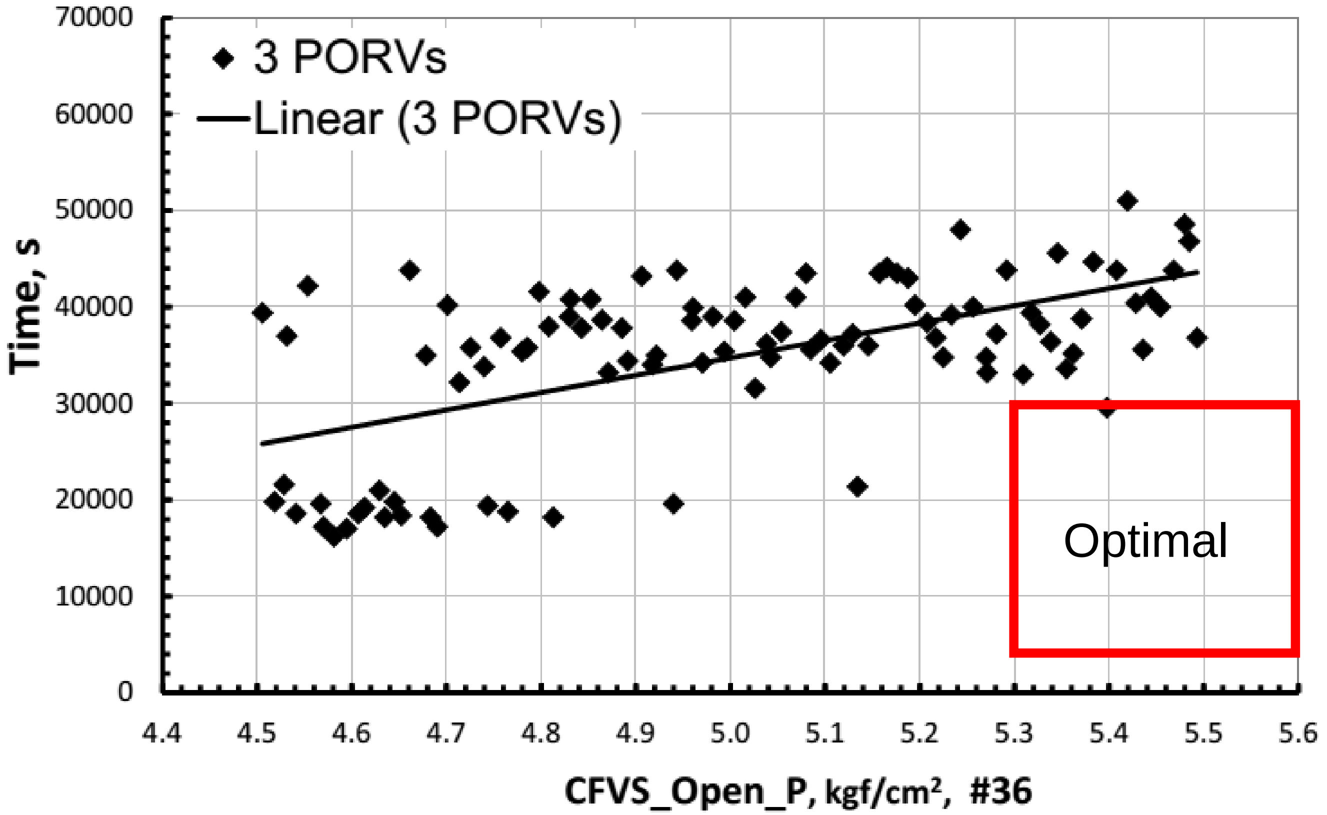
# MELCOR Uncertainty/Sensitivity Analysis Applications

## Setpoints optimization

- Scatter plot of analysis can show **optimal** setpoints
- Example for CFVS open time
- Setpoint >5.3kgf/cm$^2$ would statistically exclude early CFVS opening for 3 PORVs

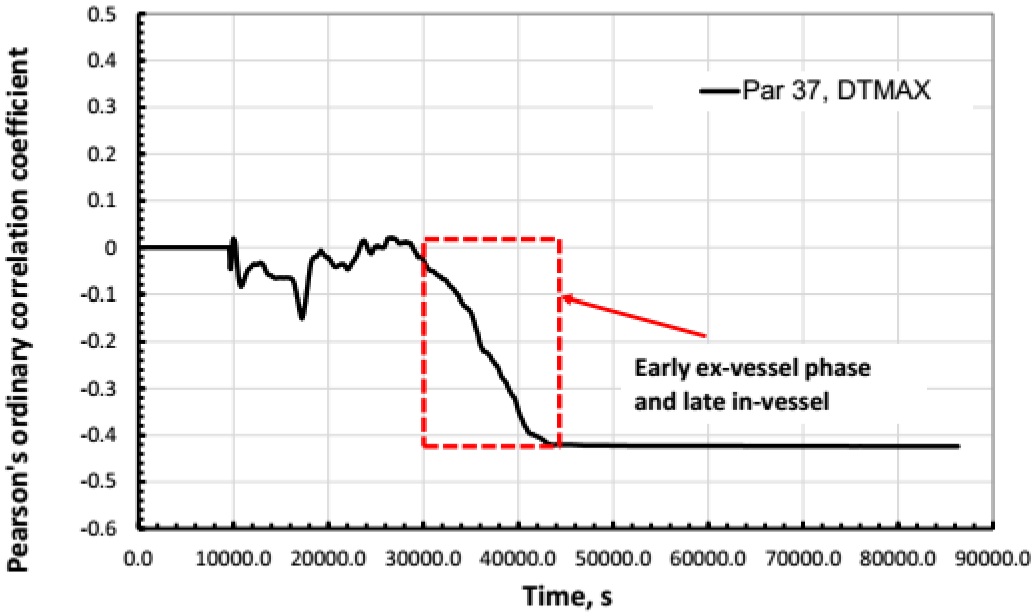



**CFVS open time (FOM7) depending on parameter #36 (CFVS_Open_P - CFVS opening pressure setpoint)**

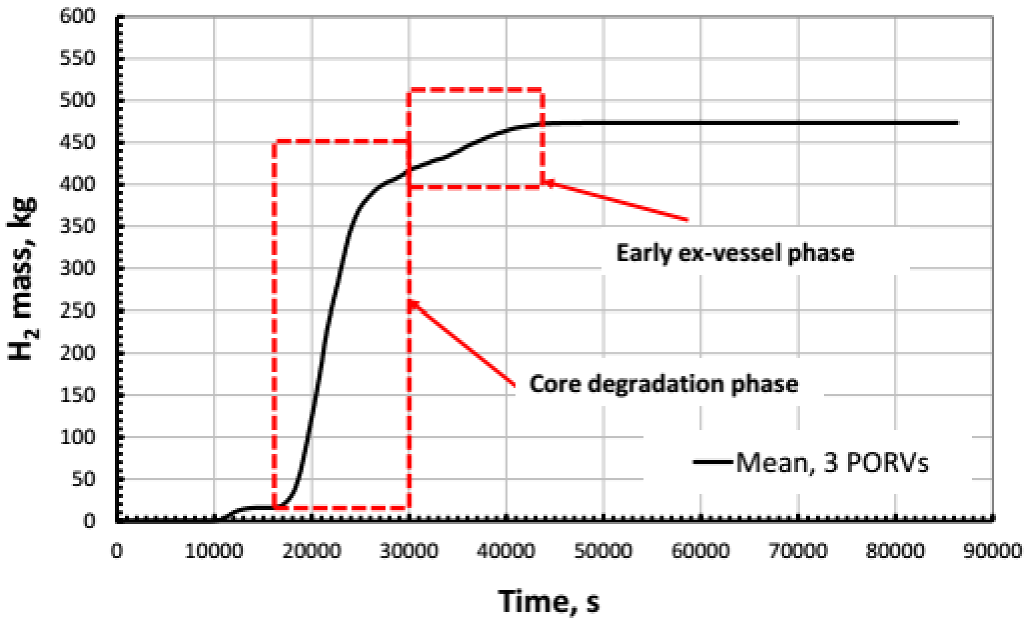
# MELCOR Uncertainty/Sensitivity Analysis Applications

## Sensitivity analysis for code improvement

- Performed for 3 PORVs
- See the time-dependent correlation analysis for H2 generated in core




**PCC for hydrogen generated in the core**




**Outcomes:**

- Correlation to DTmax starts to grow at early ex-vessel phase
- MELCOR code H2 in core generation algorithm should be **checked** at this phase

# Conclusions

## MELCOR concerned conclusions

- MELCOR code is a **powerful** integral tool for uncertainty/sensitivity analysis
- MELCOR results have **anavoidable** scatter (verified)
- MELCOR scatter is **different** for different parameters and can mask the correlations
- MELCOR scatter range **increases** with transient progression (high after core damage)
- MELCOR UA results are powerful for SAMG **optimization** in statistical manner
- MELCOR run failures rate depends on the modeling but still significant
- MELCOR sensitivity analysis can be used for code **improvement**
- MELCOR application results are presented in CSARP in-kind report “Uncertainty and Sensitivity Analysis for VVER-1000 SBO Accident with Personnel Actions by MELCOR code. Methods, Insights and Conclusions”

# Thank you for your time!

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