# Assessment of the Post-Fukushima Improvement of SAM of German PWRs by Severe Accident Analyses

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# Introduction

- GRS is using the MELCOR Code since 1992. The application of MELCOR started with code version 1.8.3. Currently, MELCOR 1.8.6 and 2.1 are used.
- Current applications of MELCOR at GRS are:
  - Assessment of accident management measures realized at German NPPs after Fukushima, like
    - mobile emergency diesel generators, and
    - mitigative procedures of the new SAMG concept.
  - SA analyses of shutdown modes and spent fuel pool behavior for a German PWR and BWR reference plants,
  - Evaluation of source terms.
- Usage of MELCOR 2.1 has been started at GRS for SAM assessment and source term evaluation.

# Extension of Severe Accident Management for German NPPs

- From the national and European stress test a need of improvement and extension of SAM of PWRs has been identified by the German Reactor Safety Commission and summarized in the German Action Plan concerning:
  - long-term energy supply (e.g. mobile generator (realized in the plants), bunkered supply connections (realized in the plants))*,
  - long-term heat removal from reactor core and spent fuel pool (second ultimate heat sink ⇨ diverse heat sink like e.g. water/air heat exchanger, shortened mobile cooling chain, additional feeding line for the SFP (realized in the plants)),
  - safe release of the off-gas containing combustible gas species by the filtered containment venting system (under examination),
  - availability of the measures under conditions of long-term Station Blackout,
  - identification of available safety margins,
  - optimization of existing measures, and
  - need of a SAMG Concept ⇨ On behalf of the utilities, AREVA has done the development of the SAMG Concept for the German NPPs. The concept has been realized in the PWRs and BWRs*.

* treated in the SA analyses presented here

# Extension of Severe Accident Management for German NPPs
# SAMG Concept (1)

- SAMG concepts has been realized for both PWR and BWR nuclear power plants.
- "Handbook of Mitigative Severe Accident Measures" consists of two volumes:
  - first volume gives the general strategy and the procedures to mitigate SA scenarios.
  - The second volume contains additional information regarding severe accidents and decision support for the crisis team, e. g. due to computational results.
- In the German plants are now available: Operational Manual, Emergency Operating Manual (preventive and mitigative EOPs), and the new "Handbook of Severe Accident Mitigative Measures (HMN)" (SAMG)
- Criteria for the transition into the PWR SAMG:

| Operational Mode | Criteria |
|---|---|
| RPV closed | Temperature fuel assembly outlet > 650 °C<br>**or**<br>Dose rate containment > 30 Gy/h |
| RPV opened | Temperature reactor circuit > 95 °C<br>**or**<br>Water level RPV < Mid-loop level for at least 30 minutes |
| Spent Fuel Pool | Water level below 5.2 m<br>**or**<br>Water temperature inside SFP > 120 °C |

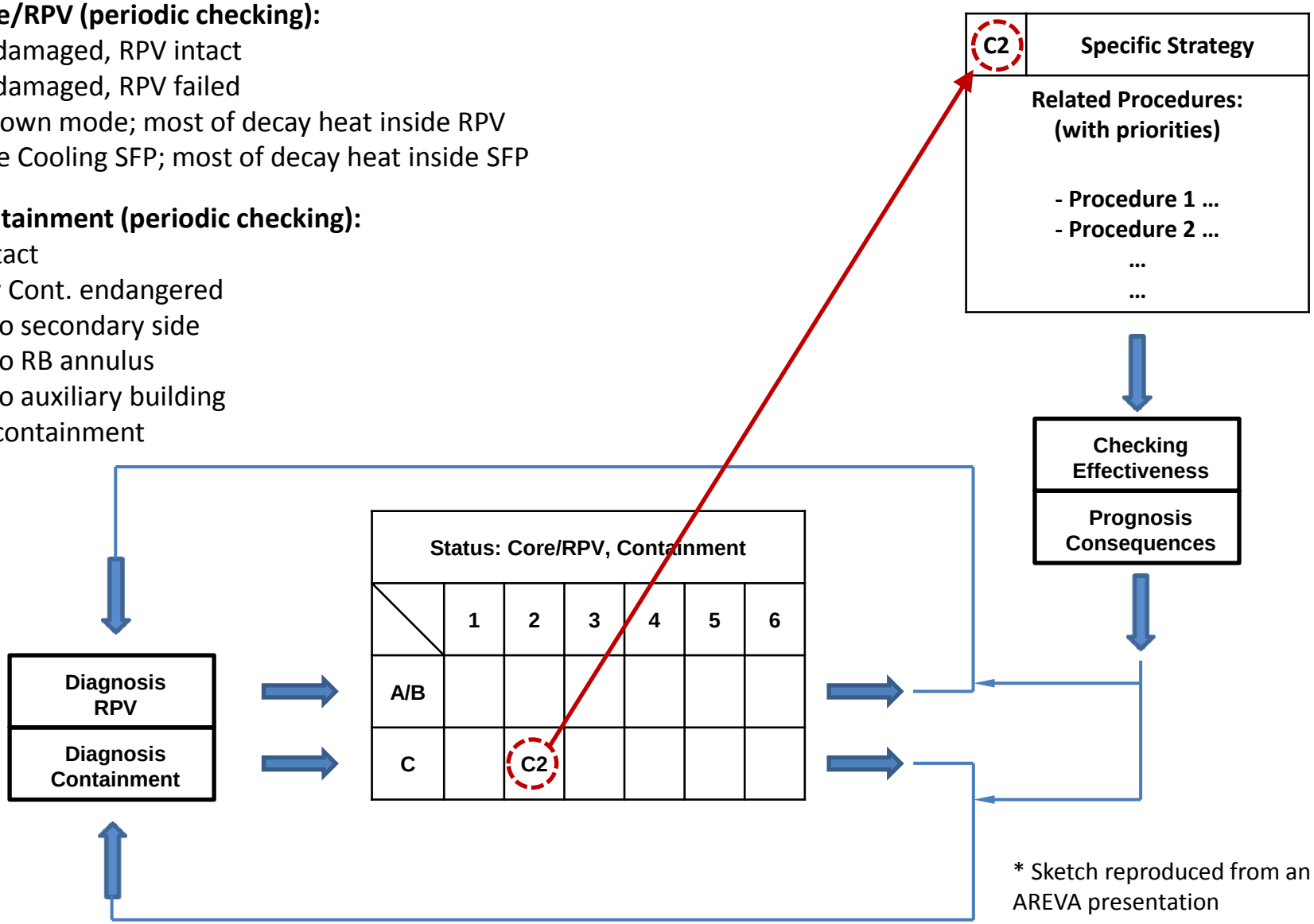
# Extension of Severe Accident Management for German NPPs
# SAMG Concept (2)

**Status Core/RPV (periodic checking):**

A/B: Core damaged, RPV intact
C: Core damaged, RPV failed
S1: Shutdown mode; most of decay heat inside RPV
S2: Failure Cooling SFP; most of decay heat inside SFP

**Status Containment (periodic checking):**

1. Cont. intact
2. Integrity Cont. endangered
3. Bypass to secondary side
4. Bypass to RB annulus
5. Bypass to auxiliary building
6. Leak at containment




* Sketch reproduced from an AREVA presentation

# Severe Accident Analyses for Assessment of New SAM Procedures – Overview

- A project on behalf of the Federal Ministry BMUB has been finished recently at GRS regarding the assessment of the improvement of existing SAM and the new SAMG for PWR by deterministic analyses using MELCOR.
  - Analyses of two events “Station Blackout (SBO)” and “Small break LOCA with multiple failures” (significant contribution to core damage states or release categories of PSA Level 2). Postulated boundary conditions:
    - SBO: Secondary and primary side Bleed & Feed available, passive injection of feedwater from FW lines and FW tank available, mobile pump available/unavailable,
    - SB LOCA: 20 $cm^2$ leak at hot leg, feedwater system and emergency feedwater system failed, failure of switching to sump suction mode, failure of HP sump suction.
  - Calculation of the SBO event with both the status of the EOPs up to Fukushima (**base case**) and the improved EOPs (e.g. increased capacity of batteries, mobile diesel generators, etc.) ⇨ comparable assessment of the analyses to show the benefit.
  - Severe accident analyses of the SB LOCA under consideration of selected procedures of the SAMG concept developed by AREVA and implemented in the PWR plants.

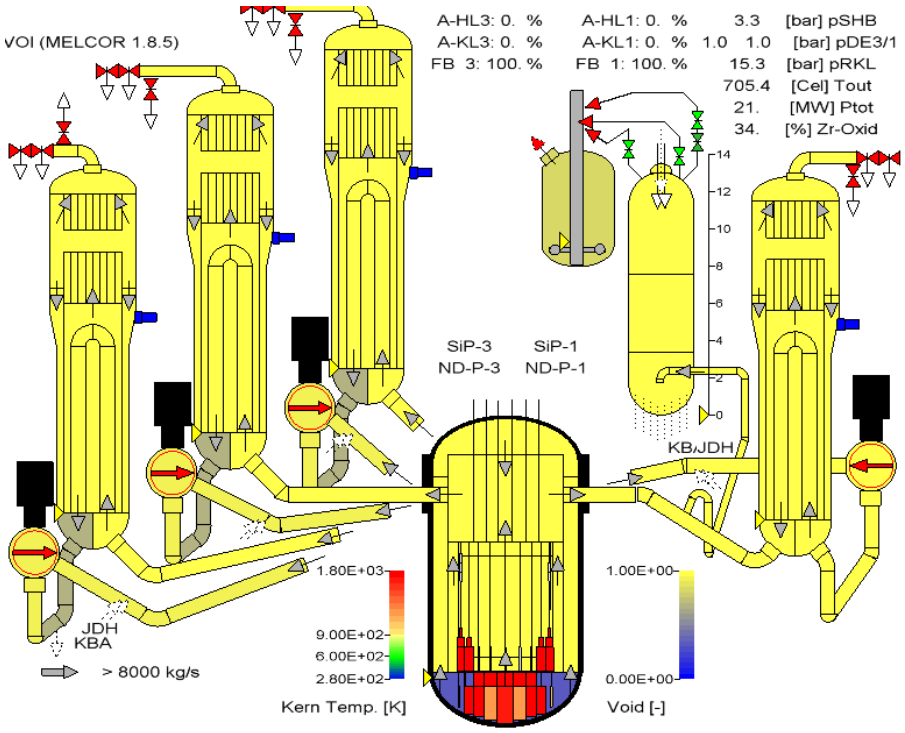
⇨ **Quantification and assessment of the benefit due to the improvement of SAM strategy of PWR.**

# Severe Accident Analyses for Assessment of New SAM Procedures – Selected SAM Measures

- **SBO**:
  - Connecting of two mobile diesel generators 10 hours after SBO initiation:
    - **Mobile EDG1**: Recovery of electrical supply for instrumentation and extra borating system ⇨ Injection of 4 x 2 kg/s available.
    - **Mobile EDG2**: Recovery of electrical supply for one bunkered train of the ECC System ⇨ RHR of reactor circuit and SFP (≈ 20 MW, alternating operation) available.
- **SB-LOCA**:
  - Different plant states under examination (A/B1, C1, and C2). Measures under consideration:
    - **A/B1**: Injection into RPV to avoid RPV failure (by volume control system, accumulators and/or from SFP), maximizing heat removal from reactor building by ventilation system, filtered containment venting.
    - **C1-C2**: Injection into RPV to terminate/mitigate MCCI inside the reactor cavity (by volume control system, accumulators and/or from SFP), maximizing heat removal from reactor building by ventilation system, filtered containment venting (order of measures is dependent on the plant state).

# Severe Accident Analyses for Assessment of New SAM Procedures – Modelling of Reactor Circuit

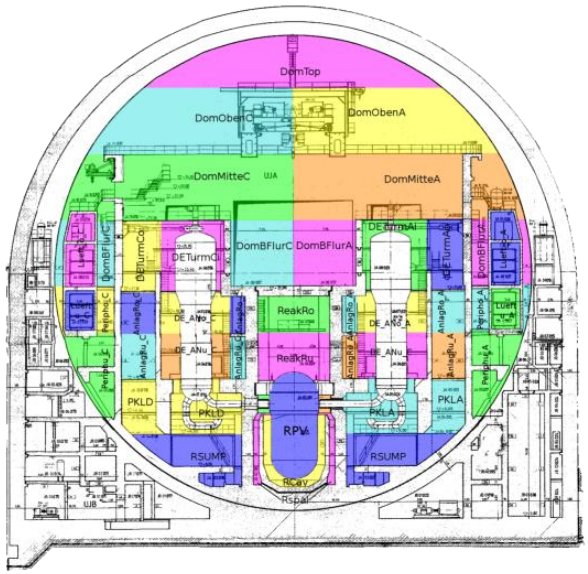
- 2-Loop-Modelling (represents one single and one triple loop)
- RPV: 6 CVs, 17 FLs, 40 HSs, 5 radial rings, 15 axial meshes
- Each Loop: 6 CVs and heat structures
- Surge Line: 1 CV and heat structures
- Pressurizer: 3 CVs, 3 HSs, 1 PORV and 2 safety valves
- Relief tank: 1 CV, heat structures and bust disks
- Inventory of radionuclides are considered by using real core data from ORIGEN calculations.

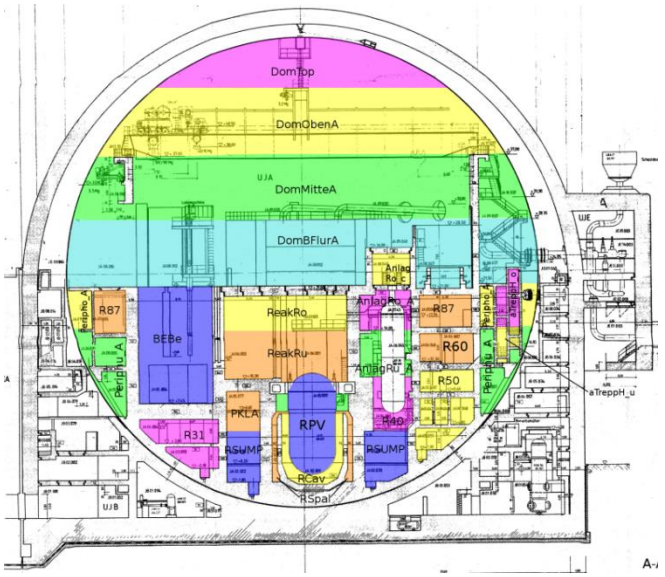


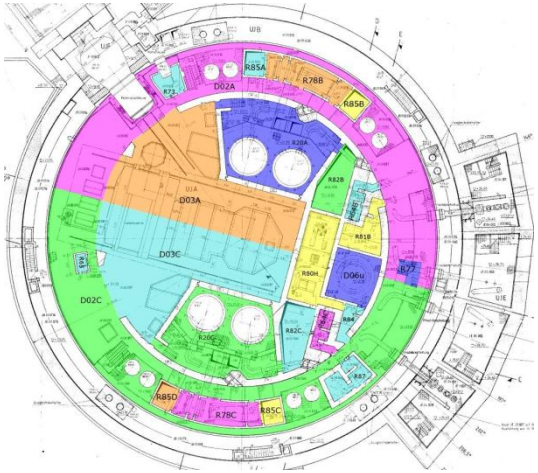

- Preventive EOPs considered:
  - Secondary side bleed and feed (bleeding by opening of MS relief valves, passive injection from FW lines and FW tank, sec. side feeding by mobile pump) **and** primary side bleed by opening all pressurizer valves after reaching initiation criteria.
- SAMG modelling:
  - Transition criteria, injection of operational systems or from SFP by mass sources.

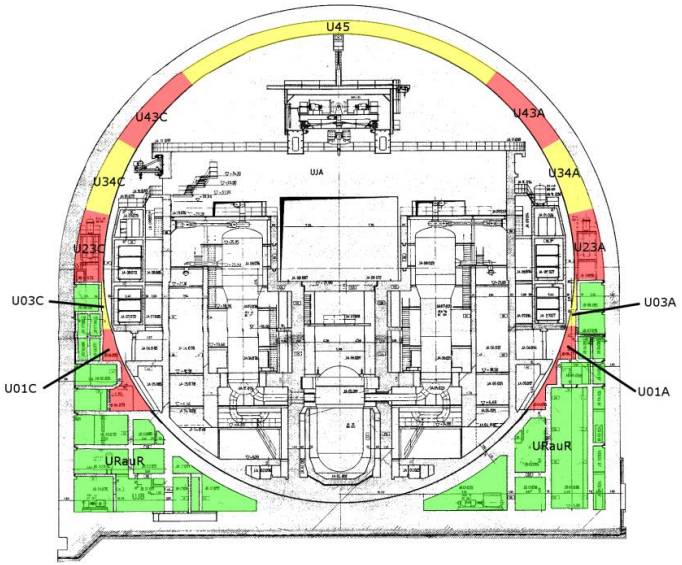
# Severe Accident Analyses for Assessment of New SAM Procedures – Overview of Containment Modelling

- Containment:
  - 77 control Volumes
  - 217 internal HS,
  - 11 external HS,
  - 256 internal FLs,
  - 7 external FLs (FCVS, design leakage, potential break location, locks etc.).
- RB annulus:
  - 12 control volumes,
  - 20 internal heat structures,
  - 23 external heat structures,
  - 19 internal FLs,
  - 7 external FLs.
- Auxiliary Building:
  - 1 control volume,
  - 7 internal HS,
  - 3 external FLs (environment, lock to containment, door to RB annulus).



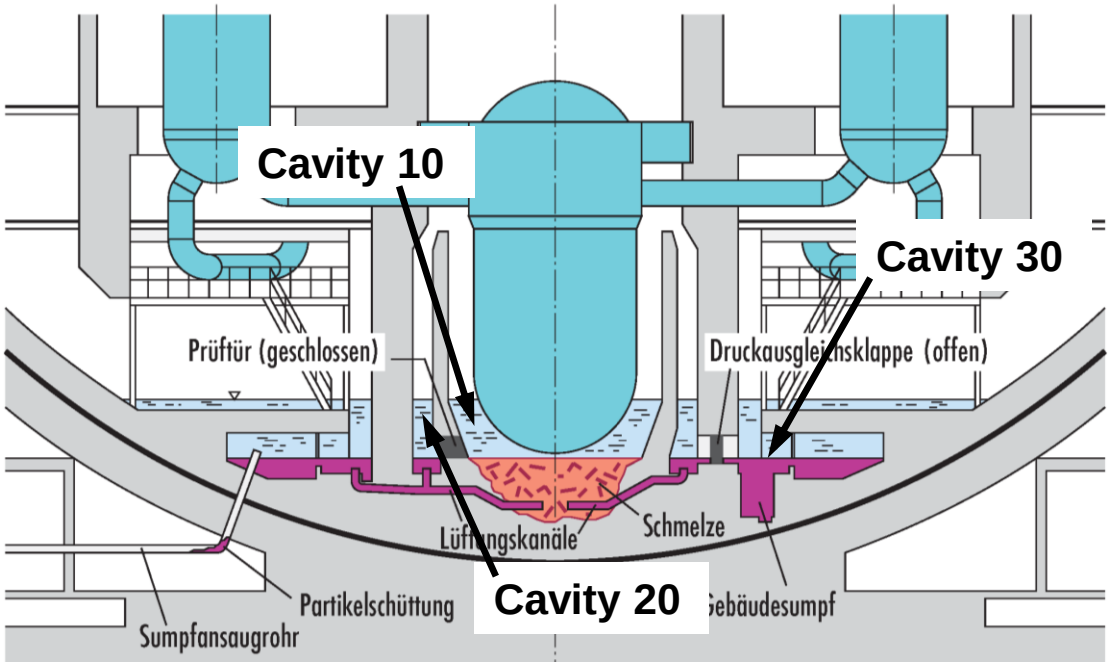



# Severe Accident Analyses for Assessment of New SAM Procedures – Overview of Containment Sump Modelling

## MCCI Modelling:

- Three relevant compartments:
  - Reactor cavity,
  - Annulus,
  - Containment sump,
- Three cavities used:
  - Radial failure criterion for cavity 10 ⇨ relocation of corium into annulus,
  - Instantaneously failure of the pressure flaps after relocation into annulus ⇨ relocation of corium into sump.
- Concrete composition of the reference plant used (e.g. silica based concrete)




**Lower containment compartments reference plant**

```
CAV_G1    100    1.6
CAV_G2    -1.0   3.62   3.0        2.0
CAV_G3    VALUE  4.17   6.0        20      50
CAV_RR    CAVITY 'Spalt' 'Hmin or max' 'cav00-Hoehe'

CF_ID     'Hmin or max'  612  L-OR
CF_LIV        FALSE
CF_CLS        'LATCH'
CF_ARG    2
      1  CF-VALU('Hmin > 1.368m')
      2  CF-VALU('Rmax > 4.10m')

CF_ID     'Hmin > 1.368m'  610  L-GT
CF_LIV        FALSE
CF_CLS        'LATCH'
CF_MSG    FULL-OUTPUT        ''
CF_ARG    2
      1 CAV-MINALT('R.-Grube')  1.0
      2 EXEC-TIME               0.0    2.968
!
CF_ID     'Rmax > 4.10m'  611  L-GT
CF_LIV        FALSE
CF_CLS        'LATCH'
CF_MSG    FULL-OUTPUT        ''
CF_ARG    2
      1 CAV-MAXRAD('R.-Grube')  1.0
      2 EXEC-TIME               0.0    4.1
```

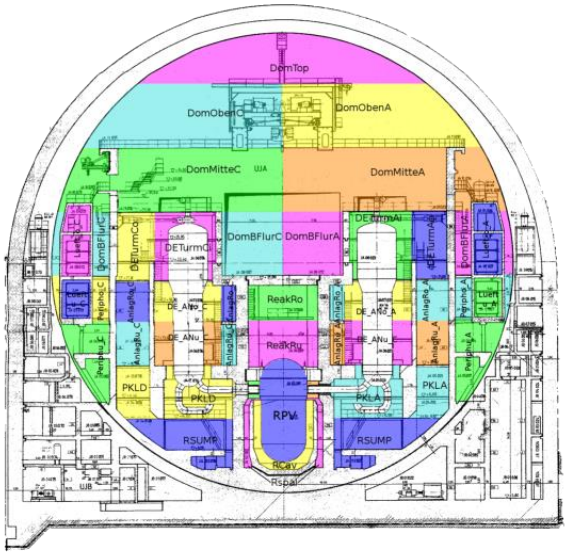
# Severe Accident Analyses for Assessment of New SAM Procedures – Modelling of PARs

Three different types of passive autocatalytic recombiners are modelled by mass sinks ($H_2$, CO and $O_2$) and mass sources ($H_2O$, $CO_2$) and are allocated to the relevant control volumes (CVs). In total 58 PARs are available in the reference plant.

```
CV_ID       'AnlagRu_C'          74
CV_TYP        'CTYP-36'
CV_THR     NONEQUIL         FOG       ACTIVE
CV_PAS     SEPARATE      ONLYATM   SUPERHEATED
CV_PTD         PVOL       1.0E5
CV_AAD         TATM       303.15
CV_NCG            2         RHUM         0.5
        1        'O2'       0.206
        2        'N2'       0.794
CV_VAT   2 !n         cvz        cvvol
        1        12.0         0.0
        2        17.9       1485.6
! Types of Rekos:
!                          FR_90-380T
!                          FR_90-1500 (2.0x)
CV_SOU   6
        1 MASS   RATE    CF  H2-ABBAU-GES_7     'H2'          ! H2 consumption rate
        2 MASS   RATE    CF  CO-ABBAU-GES_7     'CO'          ! CO consumption rate
        3 MASS   RATE    CF O2-KONSUM-GES_7     'O2'          ! O2 consumption rate
        4 MASS   RATE    CF H2O-GENER-GES_7     'H2O-VAP'     ! Steam generation
        5 MASS   RATE    CF CO2-GENER-GES_7     'CO2'         ! CO2 generation
        6   AE   RATE    CF      'Enth.=.'
```

Rate equations (kg/s) for the consumption of $H_2$, CO, and $O_2$ as well as for the generation of $H_2O$ and $CO_2$ have to be coded by sets of control functions for each recombiner.

These sets of CFs are linked with the control volumes of the containment nodalisation.



# Severe Accident Analyses for Assessment of New SAM Procedures – Modelling of Doors and Burst Elements

- **Doors:**
  - 82 doors has been considered for a German PWR.
  - Closed at the beginning of simulation.
  - Small gap at the doors in closed state are considered.
  - Two failure modes (in and against swing direction), two different pressure differences for the failure,
  - Modelled by flow path with valve:
    - two pressure differences for failure (e. g. 100 mbar in swing direction and 555 mbar against swing direction),
    - after failure in swing direction partial re-closure is modelled,
    - after failure against swing direction 100% opening of the door.
- **Burst elements:**
  - 56 burst elements (rupture discs and foils) has been modelled.
  - E. g. burst elements on the ceiling of SG chambers, doors with burst membranes.
  - Modelled by flow path with valve
    - failure at dedicated pressure difference (between 20 mbar and 200 mbar), e. g. foils at the ceiling of SG chambers 28 mbar and 80 mbar

# Severe Accident Analyses for Assessment of New SAM Procedures – SBO, Boundary Conditions

- **Analyses Station Blackout (SBO):**
  - Analysis with state of preventive and mitigative SAM measures up to Fukushima **(base case)**:
    - Secondary side bleed + passive injection from FW lines and FW tank available,
    - injection of eight accumulators available,
    - with/without mobile pump,
    - primary bleed available,
    - capacity of batteries = 9 hours, and
    - PARs and filtered containment venting.
  - Consideration of post-Fukushima improvement of preventive SAM (two mobile diesel generators); available 10 hours after event initiation. Objective is reaching RHR with closed circuit cooling mode.
    - **Case 1:** Base case + Injection by 4 JDH pumps (plunger pumps, 4 x 2 kg/s) and one FAK pump (58 kg/s at 12 bar up to 210 kg/s at 1 bar).
    - **Case 2:** Base case + Injection by one FAK pump (58 kg/s at 12 bar up to 210 kg/s at 1 bar).

# Severe Accident Analyses for Assessment of New SAM Procedures SBO, Results

| | Base case (M21) | Case 1 (M186) | Case 2 (M186) |
|---|---|---|---|
| Phenomena of the SA Progression | SBO Without mobile Pump | SBO EDG1+EDG2+FB | SBO EDG2+FB |
| | Time [hh:mm:ss] | | |
| Station Blackout | 00:00:00 | 00:00:00 | 00:00:00 |
| ⋮ | ⋮ | ⋮ | ⋮ |
| Water Level RPV < MIN3 | 07:55:09 | 08:17:40 | 08:17:40 |
| Primary Bleed | 07:55:09 | 08:17:40 | 08:17:40 |
| Start of Uncovering of the Core | 07:57:52 | 08:20:37 | 08:20:37 |
| Uncovering Active Core | 08:04:53 | 08:27:27 | 08:27:27 |
| Start Cladding Failure | 08:14:56 | 08:38:02 | 08:38:02 |
| Loss of Batteries | 09:00:00 | 09:00:00 | 09:00:00 |
| Mobile Diesel Generators Available | - | 10:00:00 | 10:00:00 |
| Start of Injection by JDH Pumps | - | 10:00:50 | Not Available |
| Start of Injection by FAK Pump | - | - | 11:05:11 |
| Available Time for the Transition to RHR | - | - | 11:35:11 – 16:08:45 |
| Start of Failure of Lower Supporting Grid | 12:33:58 | - | - |
| Complete Evaporation of Lower RPV Plenum | 12:44:50 | - | - |
| Failure RPV | 13:54:36 | - | - |
| Start of MCCI Reactor Cavity | 13:54:36 | - | - |
| Termination of Injection by FAK Pump | - | - | 15:15:00 |
| Start MCCI Annulus | 17:03:28 | - | - |
| Start MCCI Containment Sump | 17:03:28 | - | - |
| Start of Failure of Lower Supporting Grid | - | - | 20:39:16 |
| Complete Evaporation of Lower RPV Plenum | - | - | 21:07:42 |
| Failure RPV | - | - | 22:20:04 |
| Start of MCCI Reactor Cavity | - | - | 22:20:04 |
| Start 1st Filtered Containment Venting | 40:16:46 | - | - |
| Start Boiling of SFP Water | 46:46:15 | | - |
| Start 1st Filtered Containment Venting | - | 53:21:34 | - |
| Start Boiling of SFP Water | - | 61:50:50 | - |
| Termination of Injection by JDH Pumps | - | 69:44:09 | Not Available |
| Drying-out Containment Sump | 71:09:35 | - | - |
| Start of Failure of Lower Supporting Grid | - | 74:22:12 | - |
| Complete Evaporation of Lower RPV Plenum | - | 74:54:44 | - |
| Failure RPV | - | 75:49:47 | - |
| Start of MCCI Reactor Cavity | - | 75:49:47 | - |
| Available Time for the Transition to RHR | - | Not Possible | - |
| Start MCCI Annulus | | 83:35:50 | - |
| Start MCCI Containment Sump | | 83:35:52 | - |
| Start Boiling of Sump Water | - | 85:28:00 | - |
| End of Analysis | 97:13:20 | 97:13:20 | 25:46:31 (Abortion of MELCOR) |

Closed circuit RHR cooling possible

Delay in failure of RPV

Delay in FCV

Boiling of SFP water

Dried-out sump

# Severe Accident Analyses for Assessment of New SAM Procedures – SB LOCA, Boundary Conditions

- **Analyses Small Break LOCA (SB LOCA):**
  - Analysis with state of preventive and mitigative SAM measures up to Fukushima **(base case)**:
    - "20 $cm^2$" LOCA at hot leg,
    - feedwater systems and emergency feedwater system failed,
    - no passive injection of secondary side,
    - injection of safety injection pumps from flooding tanks available,
    - failure of switching to sump suction mode,
    - failure of HP sump suction, and
    - injection of four accumulators (four were isolated before as designed) available, and
    - PARs and filtered containment venting.
  - Consideration of post-Fukushima improvement of mitigative SAM (from HMN).
    - **Case 1:** Base case + Injection KBA system from coolant storage system + Injection FAK pump from spent fuel pool + cooling containment atmosphere by coolers (initiation before RPV failure) **(KBA+FAK+KLA_A/B1)**.
    - **Case 2:** Case 1 + Injection four isolated accumulators (initiation before RPV failure) **(JNG+KBA+FAK+KLA_A/B1)**.
    - **Case 3:** Case 2 but initiation after RPV failure **(JNG+KBA+FAK+KLA_C1)**.

# Severe Accident Analyses for Assessment of New SAM Procedures – SB LOCA, Results

| | | State of RPV/Cont | | |
|---|---|---|---|---|
| | Base case | A/B1 | | C1 |
| Phenomena of the SA Progression | SBLOCA | KBA + FAK + KLA | JNG+KBA+FAK+KLA_A/B1 | JNG+KBA+FAK+KLA_C1 |
| | Time [hh:mm:ss] | | | |
| "20 cm²" SB LOCA | 00:00:00 | 00:00:00 | 00:00:00 | 00:00:00 |
| ⋮ | ⋮ | ⋮ | ⋮ | ⋮ |
| Initiation Criterion SAMG | 06:52:20 | 06:52:20 | 06:52:20 | 06:52:20 |
| Start of Cladding Failure | 06:56:50 | 06:56:50 | 06:56:50 | 06:56:50 |
| Start of Injection by JNG | - | - | 07:11:58 | - |
| Start of Injection by KBA | - | 07:22:20 | 07:22:20 | - |
| 1st Full Uncovering of Reactor Core | 07:31:30 | 07:23:24 | 07:12:50 | 07:31:30 |
| Termination of Injection by KBA | - | 13:12:30 | 13:12:30 | - |
| Start of Injection by FAK10 | - | 16:43:20 | | |
| Start of Failure of Lower Supporting Grid | 08:25:16 | 19:28:22 | 19:05:20 | 08:25:16 |
| Complete Evaporation of Lower RPV Plenum | 08:43:44 | 20:10:52 | 19:25:07 | 08:43:44 |
| Start of Injection by FAK10 | - | - | 19:55:50 | - |
| Termination of Injection by JNG | - | - | 23:36:20 | - |
| Start of Injection by JNG | - | - | - | 10:44:00 |
| Failure of RPV | 10:47:43 | 20:53:50 | 25:23:46 | 10:47:43 |
| Start of MCCI | 10:47:43 | 20:53:50 | 25:23:46 | 10:47:43 |
| Termination of Injection by FAK10 | - | 21:31:40 | 25:54:10 | - |
| Termination of Injection by JNG | - | - | - | 10:47:43 |
| Start of Injection by KBA | - | - | - | 11:08:20 |
| Termination of Injection by KBA | - | - | - | 16:56:40 |
| Failure of Biological Shield due to MCCI | 14:59:13 | 28:29:04 | 32:03:30 | 16:59:17 |
| Relocation of Corium into Annulus | 14:59:14 | 28:29:05 | 32:03:31 | 16:59:18 |
| Failure of Pressure Flaps | 14:59:14 | 28:29:06 | 32:03:31 | 16:59:19 |
| Relocation of Corium into Sump | 14:59:15 | 28:29:07 | 32:03:31 | 16:59:20 |
| Start of Injection by FAK10 | - | - | - | 17:02:30 |
| Termination of Injection by FAK10 | - | - | - | 17:41:40 |
| Start of Evaporation of Sump Water | 18:55:50 | 35:03:20 | 38:23:20 | 21:10:00 |
| Start of 1st filtered Containment Venting | 49:07:16 | 97:10:44 | 94:03:43 | 60:29:57 |
| Termination of 1st filtered Containment Venting | 153:13:22 | 125:13:10 | 132:18:05 | - |
| Start of 2nd filtered Containment Venting | 177:23:10 | 170:56:27 | 190:11:00 | - |
| Drying-out of Annulus | 191:15:21 | - | - | - |
| Drying-out of Reactor Cavity | 191:27:51 | - | - | - |
| Termination of 2nd filtered Containment Venting | 198:48:53 | 198:17:10 | - | - |
| Drying-out Containment Sump | 199:22:51 | - | - | - |
| End of Analysis | 208:20:00 | 208:20:00 | 208:20:00 | 208:20:00 |

## Severe Accident Analyses for Assessment of New SAM Procedures – General Findings

- Extension of the SAM concept (EOPs and SAMG) is a major step regarding the further optimization of the handling of severe accident scenarios.
- Implementation follows the recommendations of the Reactor Safety Commission and the German Action Plan.
- Regarding the handling of some SAMG procedures some weak points could be identified, which can be avoided by a more clear description of the procedures.
- The extension of the emergency operating procedures and the usage of SAMGs is very effective and results in a significant gain in time (SBO at least 8 hours and SB LOCA at least 10 hours) for getting the plant under control during severe accident scenarios.
- The gain in time can be used in addition for recovery actions and transfer of the plant in a secured state.
- MCCI inside reactor cavity cannot be stopped.
- The analyses highlighted several scenario specific characteristics, which could be used for the development of dedicated strategies for the application of the extended measures of both the “Emergency Operating Manual” and the “Handbook of Mitigative Measures (SAMGs)”.

# Open Questions regarding MELCOR 1.8.6 and 2.1

## Application of MELCOR 1.8.6 and 2.1:

- Error Message CORRDB:

**“extDIAG” file at calculation abort:**

*WARNING FROM CORE PACKAGE*
*INTERNAL ENERGIES DID NOT CONVERGE IN CELL 301,* ***COMPONENT 0***
*DECOR=0.6657E+05, SUMMCP=0.1030E+06, TNEW=1699.43,*
*ENEW=0.9786E+06*
*ISTAT==1,CORMP;ISTAT==2,CORSTF;ISTAT==3,CORLHD;ISTAT==4/5,*
*CORfzs;ISTAT==6,CORPOW ISTAT = 3*
*MESSAGE FROM SUBROUTINE CORDBD*
*CORRN1 (or routine called by it) requested an INTERNAL fallback*
*ERROR IN SUBROUTINE CORDBD*
*SUBCYCLE TIME STEP HAS BEEN REDUCED BELOW MINIMUM*
*CORRN1 (or routine called by it) requested a SYSTEM fallback*

- Measures tried out to solve the ‘CORDBD’-Problem:
  - variation of the minimum and maximum time steps
  - Variation of sensitivity coefficients (SC1001, SC1002, SC1003, SC1104, and SC1007)
  - change of support rules for intact components and debris
  - Change in COR modelling
  - use of older MELCOR 1.8.6 versions

  ⇨ no impact on CORDBD problem or only little change in time of abort
  - MELCOR 2.1 ⇨ Error messages occurred but no insolvable ‘CORDBD’ problems up to now

# Open Questions regarding MELCOR 1.8.6 and 2.1

## Application of MELCOR 1.8.6 and 2.1:

- Warning from CAV package usually but not always shortly before a calculation abort :

*Warning message for cavity 2, Kabelkanal, Gang*
** * * CCMLTR * * *, DISCARDING 1.877E-06 MOLES OF C*
*Warning message for cavity 2, Kabelkanal, Gang*
** * * CCMLTR * * *, DISCARDING 2.025E-06 MOLES OF H*

  - What does it mean? And how can it be avoided?

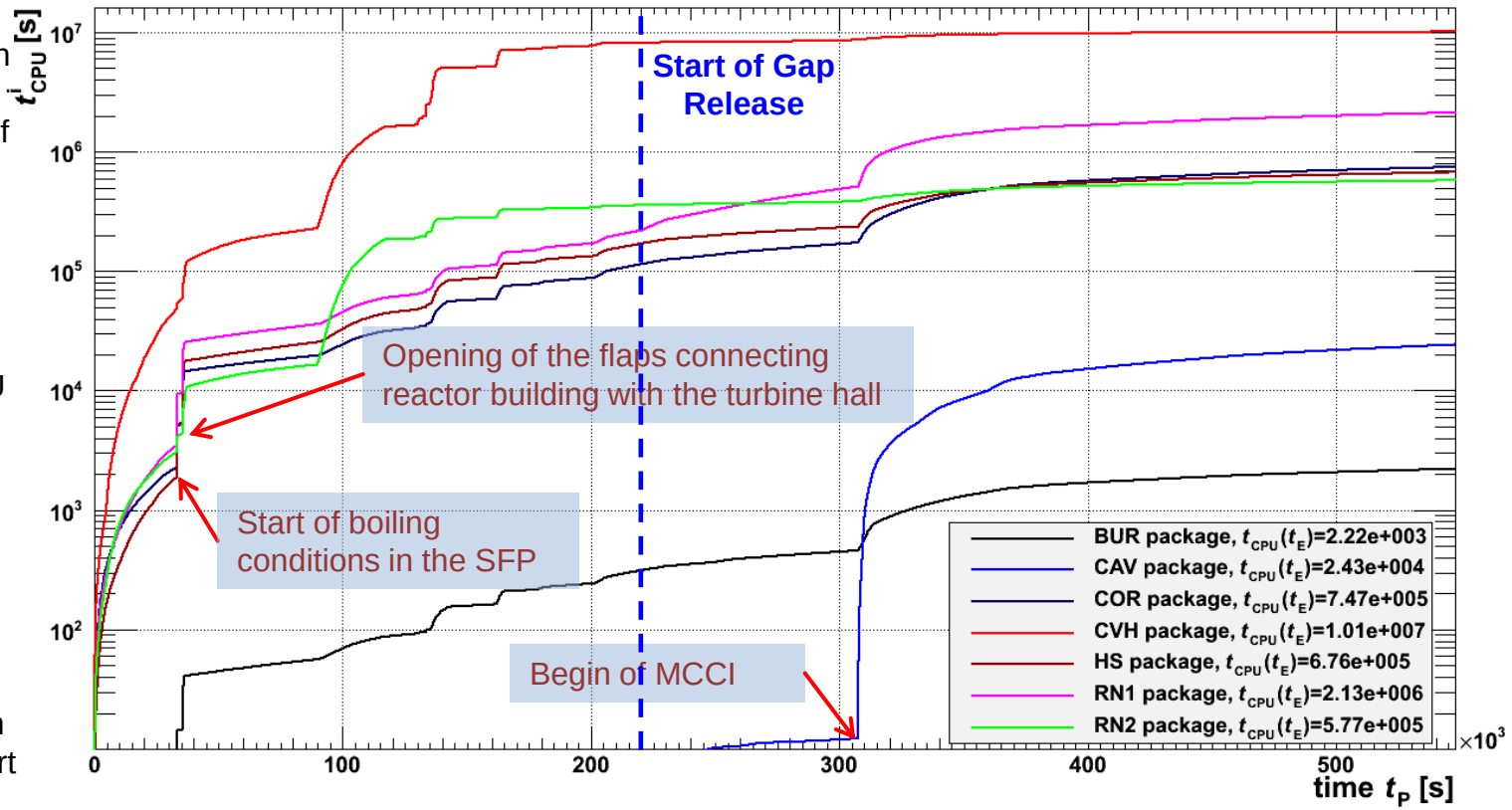
- Defining of new RN classes has been tried out for SFP analyses in order to consider the different radionuclides inventory of both FAs from core and very “old” FAs. Worked well up to start of transfer to Cavity Package ⇨ After that, wrong results regarding decay heat (loss of decay heat).

# Open Questions regarding MELCOR 1.8.6 and 2.1

## Application of MELCOR 1.8.6 and 2.1:

- Hugh CPU times in case of long-lasting evaporation and condensation phases in a SFP (especially for the BWR):

  - Significant increase of the CPU consumption is observable since beginning of producing steam.
  - CVH package is dominant in CPU consumption.
  - Escalation of CPU consumption correlate sometimes with the transition of the water level over the vertical boundary of CVs.
  - CPU consumption of RN2 before start of gap release questionable



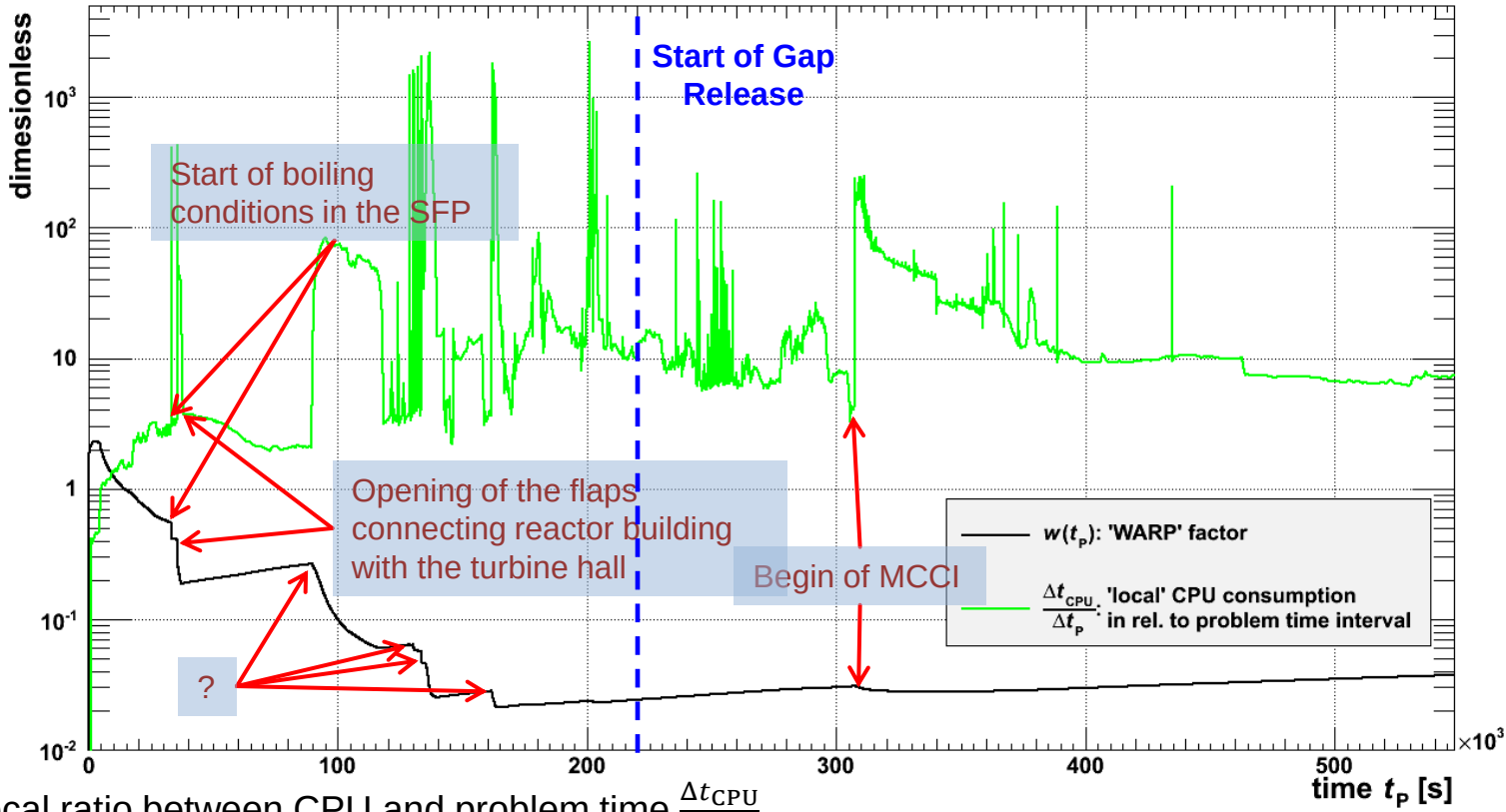
# Open Questions regarding MELCOR 1.8.6 and 2.1

## Application of MELCOR 1.8.6 and 2.1:

- Analysis of CPU Consumption by MELCOR (MELCOR 2.1):
  - MELCOR provides a value for the ratio between the CPU and the problem time called 'WARP' factor:

$$w(t_\mathrm{P}) = \frac{t_\mathrm{P} - t_\mathrm{P}^\mathrm{ini}}{t_\mathrm{CPU}}$$

  - WARP factor doesn't consider the local ratio between CPU and problem time accurately

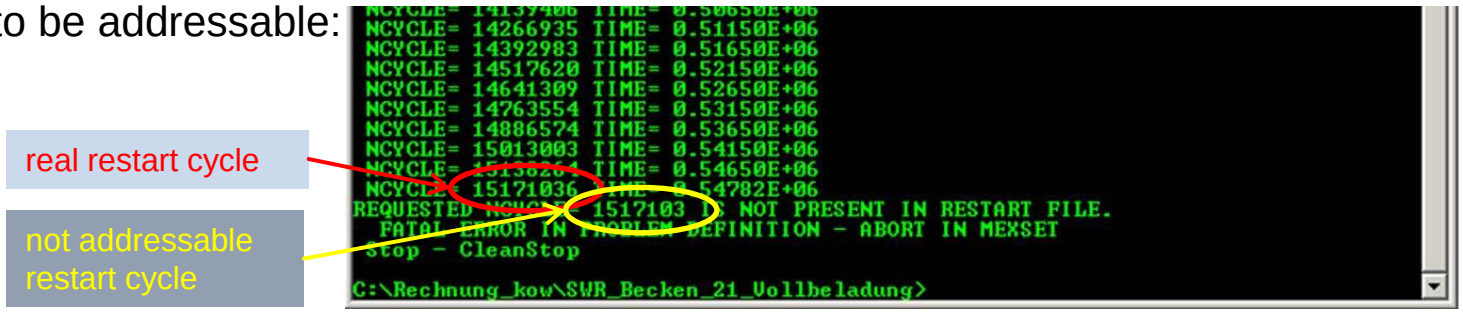



⇨ calculation of the local ratio between CPU and problem time $\frac{\Delta t_\mathrm{CPU}}{\Delta t_\mathrm{P}}$.

- maximum relative 'local' CPU consumption: $\max\left(\frac{\Delta t_\mathrm{CPU}}{\Delta t_\mathrm{P}}\right) \sim 10^3 \ldots 10^4 \frac{\text{CPU sec.}}{\text{problem sec.}}$
- relative CPU consumption at the end of calc.: $w(t_\mathrm{E}) \approx 3{,}7 \cdot 10^{-2} \rightarrow \frac{1}{w(t_\mathrm{E})} = \left\langle \frac{\Delta t_\mathrm{CPU}}{\Delta t_\mathrm{P}} \right\rangle_0^{t_\mathrm{E}} \approx 27 \frac{\text{CPU sec.}}{\text{problem sec.}}$, let $t_\mathrm{E} = 5.5 \cdot 10^5$ s ⇨ $t_\mathrm{CPU}(t_\mathrm{E}) \sim 5.6$ months ⇨ hard to accept for long term calculations

# Open Questions regarding MELCOR 1.8.6 and 2.1

- **Transition from MELCOR 1.8.6 to MELCOR 2.1 input:**
  - Comments are not adopted,
  - control functions for triggering the cavity rupture and determining the rupture elevation are not adopted,
  - SHAPEPLOT option has changed without user request.
- **Application of MELCOR 2.1:**
  - External FORTRAN interface didn't work with external routines of GRS ⇨ Leading in a runtime error ⇨ Finally, coding of recombiner model has been realized by control functions.
  - Message file is not extended when performing a restart, also if the 'ow=e' option in the command line is considered.
  - No plot variable concerning the HTR model showing the exchanged radiation power is available.
  - Trouble with restart numbers for very long calculations. Restart numbers with more than 7 digits seem not to be addressable:



# Conclusions

- Different applications of MELCOR 1.8.6 and 2.1 are running at GRS
- An example for an activity at GRS with the application of MELCOR code versions 1.8.6 and 2.1 has been presented.
- Analyses for an assessment of the improvement of the SAM concept for German PWR have been performed by MELCOR severe accident analyses.
- The MELCOR code is well qualified for performing SA analyses for both PWR and BWR.
- Open questions regarding the application of both MELCOR 1.8.6 and 2.1 have been seen and presented here.

# Thank you for your attention!
# Questions?

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