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# Users' Expectations

## Simulator Specification

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# Introduction

The ASSAS project aims at developing a proof-of-concept for a severe accident simulator (SAS), from a reference severe accident evaluation code, whose performance and robustness will be increased using both state of the art acceleration techniques and artificial intelligence (AI).

The project will develop a proof-of-concept (TRL 3) simulator based on ASTEC and TEAM_SUITE® (Westinghouse Application for Modelling, Westinghouse's simulation environment). It will consist of a basic principles' simulator developed with non-sensitive plant data. It will feature a 4-loop 1,300 MWe PWR. This prototype could be used to provide general training about SA phenomenology to students, operators, TSOs, nuclear regulatory bodies or emergency responders. It is intended to prove the capability of ASTEC to run in real time with a high level of accuracy and to interact synchronously with a commercial simulation environment (TEAM_SUITE®). It will also show the potential of SASs to different stakeholders that will be able to make use of a user-friendly interface to interact with the accident sequences and use the learning and analytical features included in it. It is hoped that the results achieved during the project will give confidence to potential industrial customers to include SA capabilities into their own industry-level simulators, like analytical or full-replica simulators.

The proposed simulator will be based on PWR design but can be extend to other designs since TEAM_SUITE® and ASTEC technologies allow it.

The aim of this document is to define the main characteristics of the ASSAS simulator including simulator scope, human machine interface and interface between ASTEC and TEAM_SUITE® simulation environment.

The simulator will enable the user to visualize the main physical phenomena (like core degradation) and to understand the actions, delays and information available during a real crisis. The list of systems and possible operator actions has been limited for two reasons:

- Resources of the project have been saved to address scientific challenges but future users can easily add new systems,
- Limiting the number of degrees of freedom makes the development of AI-based surrogate models easier.

The document has been reviewed by ASSAS partners and the members of its advisory board and end-user group.

The plant model in the simulator will focus on the reactor building with simplified emergency systems, like safety injection, containment sprays, passive air recombiners or filtered venting.

Energy producing systems like the condenser and the turbine will not be modelled, because they do not participate in severe accident mitigation. Venting systems will be drastically simplified (except for the emergency filtered venting system). Many plant systems (as well as instrumentation and control) will be modelled directly by ASTEC, but a few will be modelled directly by TEAM_SUITE®, Westinghouse's simulation environment. Modelling systems with TEAM_SUITE® will show the possibility for simulator owners to extend the capabilities of their existing simulator to severe accident conditions, without coding the characteristics of all engineering systems in ASTEC.

For a realistic training, the simulator must have the capability to run in real time at any moment of the simulation. Users have expressed the wish to be able to perform a training on the in-vessel and ex-vessel phase of the accident in one or two days. So, an acceleration factor of 15 would be desired for the ex-vessel phase of the accident, at least.

# List of acronyms

- AC Alternating Current
- ACI Accumulator Injection System
- AFW Auxiliar Feed Water
- AI Artificial Intelligence
- BOL Beginning Of Life
- CCS Containment Cooling Sprays
- CET Core Exit Temperature
- CIS Containment Isolation Systems
- DBA Design Basis Accident
- EOL End Of Life
- EOP Emergency Operation Procedure
- FP Fission Product
- FW Feed Water System
- GUI Graphical User Interface
- HMI Human Machine Interface
- HP High Pressure
- HPSI High Pressure Safety Injection
- IC Initial Condition
- IS Instructor Console
- LOCA Loss of Coolant Accident
- LOOP Loss of Offsite Power
- LP Low Pressure
- LPSI Low Pressure Safety Injection

- MCR Main Control Room
- MDP Motor Driven Pump
- MF Malfunction
- MFG Malfunction Generic
- MFW Main Feed Water
- MSS Main Steam Supply
- NA Not Applicable
- NPP Nuclear Power Plant
- NR Narrow Range
- PCT Peak Cladding Temperature
- PES Portable Equipment System
- PORV Pressure Operated Relief Valve
- PRZ Pressurizer
- RCP Reactor Coolant Pump
- RCS Reactor Coolant System
- RPV Reactor Pressure Level
- SA Severe Accident
- SAMG Severe Accident Management Guideline
- SAS Severe Accident Simulator
- SBO Station Black Out
- SG Steam Generator
- SI System Injection
- SRV Safety Relief Valve
- RWST Refueling Water Storage Tank
- TDP Turbine Driven Pump
- VR Virtual Reality
- WD Wide Range

# ASSAS Simulator Scenarios

Two scenarios have been considered to define the ASTEC and Team_SUITE® models scope, the surrogate models and to validate the simulator.

- SBO with Auxiliary Feedwater (AFW) Turbine Driven Pump (TDP) failure,
- LOCA with Safety injection and Containment spray systems failure.

These scenarios have been chosen, one with high pressure and the other with low pressure, to try to cover as much phenomenology as possible. In real life, these are the scenarios that are used to

validate the severe accident management guidelines because they go through most of the guideline strategies.

These scenarios define:

- The operator actions that must be taken into account in surrogate models.
- The transmitters that the final user must monitor at least.
- The involved phenomena.

The specific evolution will depend on the automatic and operator actions taken by the user.

# SBO with AFW failure

The phenomena involved consist of the following phases.

Design Basis Accident phase:

- Initiating Event: Station Blackout (SBO) with AFW-TDP failure
- RCP coastdown
- Reactor trip on low reactor coolant flow rate
- Turbine bypass unavailable
- Safeguard systems loss
- HP and LP Safety Injection loss (except passive SI accumulators)
- Auxiliary Feedwater loss
- (Note: loss of coolant through RCP seals not considered; shutdown seals assumed)
- Steam Generators drying
- RCS heat sink degradation
- Steam Generators pressure increase up to SG safety/relief valves cycling
- RCS pressurization up to pressurizer PORV/SRV opening
- Loss of RPV subcooling
- RCS natural circulation affected by AFW loss to SGs and steam in SG tubes
- Core uncover and overheating

Severe Accident phase:

- RCS hot gases circulation
- High cladding temperatures promoting metal-water reaction
- Extensive cladding failures

- FP release to RCS
- Generation of H2
- Steam and H2 discharge into containment through PORV valves
- Potential creep failure of SGs tubes (triggered by the instructor)
- H2 (and later in the accident CO) recombination by autocatalytic recombiners assumed available (H2 explosions should be avoided: this point will be checked during the project)
- Core melting and relocation
- (note: steam explosions are out of the scope of the simulator because they require a connection to external models like MC3D, which is out of the scope of the project)
- Potential vessel failure (different criteria considered by ASTEC's models)
- Corium discharge into containment
- Corium-Concrete Interaction
- H2 / CO generation
- Containment basemat ablation
- Containment pressurization
- Potential long term containment failure

The table below describes the different steps of the accidental sequence, assuming a good application of EOPs and SAMGs. The response of the simulator may be different depending on the actions of the trainee.

| **MULFUNCTION:** | IS CODE | **DESCRIPTION:** | SBO with AFW Turbine Driven Pump failure | |
|---|---|---|---|---|
| **STEP ID.** | **PROCEDURE STEPS** | **GUI SHEET** | **EXPECTED RESPONSE** | **STATE** |
| Setup | Reset the Simulator to IC #1 '100% EOL'. | | | |
| Initial Conditions | Check the following variables are stable:<br>1. Neutron power (%).<br>2. Thermal power ($MW_t$).<br>3. Generator load ($MW_e$).<br>4. Steam pressure (MPa).<br>5. FW flow (kg/s).<br>6. FW temperature (ºC).<br>7. Pressurizer pressure (MPa).<br>8. Pressurizer level (%).<br>9. Cold leg temperature | Overview Display | All variables stable at:<br>1. 100 %<br>2. 4.000 MWt<br>3. 1.300 MWe<br>4. 6,45 MPa<br>5. 536 kg/s<br>6. 227 ºC<br>7. 15,5 Mpa<br>8. 41%<br>9. 561,57K | |
| 1 | Check there are no active alarms | Alarm Display | | |
| 2 | Load 'SBO' with 'AFW Turbine Driven Pump failure' malfunctions | System Display | | |
| 3 | Verify malfuntion:<br>1. RCP coastdown | System Display | • RCS flow (RCSCF01/2/3/4_TR) lowers. | |
| DBA Phase | | | | |
| 4 | Reactor trip on main feedwater flow combined with low variation of temperature between hot leg and cold leg at t = 0,5s | Alarm/Overview Display | • Shutdown and control banks at bottom.<br>• Neutron power (RCSNP01_TR) lowers to zero. | |

| **MULFUNCTION:** | IS CODE | **DESCRIPTION:** | SBO with AFW Turbine Driven Pump failure | |
|---|---|---|---|---|
| **STEP ID.** | **PROCEDURE STEPS** | **GUI SHEET** | **EXPECTED RESPONSE** | **STATE** |
| 5 | Turbine trip<br>1. Verify Turbine Control valve close at t = 0,6s<br>2. Verify Turbine Bypass valve does not open<br>3. MSS safety/relief valves opens since Turbine by-pass is not available at t = 600s | Alarm/Overview Display | • Steam to TUR flow (MSSCF05_TR) goes to zero.<br>• Steam pressure drops (MSSPT01_TR, MSSPT02_TR, MSSPT03_TR, MSSPT04_TR). | |
| 6 | Main feedwater pumps trip | Overview Display | • FW flow (FWSCF01_TR, FWSCF02_TR, FWSCF03_TR, FWSCF04_TR) lowers. | |
| 7 | Loop through applicable EOP (Complete loss of AC) | | | |
| 8 | Verify reactor and turbine trip | Alarm/Overview Display | | |
| 9 | Verify AFW unavailable<br>1. Verify discharge pump pressure does not increase<br>2. Verify there is no flow entering the steam generators<br>. | Overview Display | • FW flow to steam generators goes to zero (AFWCF01_TR, AFWCF02_TR, AFWCF03_TR, AFWCF04_TR). | |
| 10 | Attempt to recover any safety bus (assumed unsuccesful) | Alarm/Overview Display | • Electrical voltage (ELXCV01_TR) is zero | |
| 11 | Check SG intact | Alarm/Overview Display | | |

| **MULFUNCTION:** | IS CODE | **DESCRIPTION:** | SBO with AFW Turbine Driven Pump failure | |
|---|---|---|---|---|
| **STEP ID.** | **PROCEDURE STEPS** | **GUI SHEET** | **EXPECTED RESPONSE** | **STATE** |
| 12 | Depressurize intact SG at t = 11,517s | Overview Display | • Steam Pressure is maintained in safety/relief valves setpoint | |
| 13 | Attempt to depressurize RCS to allow accumulators discharge<br>1. SGs unavailable by loss of FW<br>2. Normal/auxiliary PRZ spray unavailable by RCP trip and charging pumps loss on AC loss at t = 1,204s<br>3. PRZ PORVs assumed available. Rupture of pressurized relief tank disc at t = 6,737s | Overview Display | • RCS pressure (RCSPT01_TR) drops | |
| 14 | Verify containment isolation at t = 12,156s | Overview Display | • Associated isolation valves closed | |
| 15 | Core damage diagnosis: core exit temperature higher than 1.000 ºC (SAMG) or containment radiation → exit EOPs / enter SAMGs. | Overview Display | • Core exit thermocouples to 1.000ºC (RCSCT01/02.._TR)<br>• High containment radiation (CBSCR01_TR) | |
| Severe Accident phase (following PWR-OG SAMG strategies) | | | | |
| 16 | Control Room actions (initial response according Control Room SAMGs)<br>Block automatic actuation of non-operating safeguards (not designed for BDBA; accident management carried out through manual actions), including:<br>• AFW pumps | Overview Display | • All automatic actions change to manual | |

| MULFUNCTION: | IS CODE | DESCRIPTION: | SBO with AFW Turbine Driven Pump failure | |
|---|---|---|---|---|
| **STEP ID.** | **PROCEDURE STEPS** | **GUI SHEET** | **EXPECTED RESPONSE** | **STATE** |
| | • SI pumps<br>• Containment spray<br>• … | | | |
| 17 | Monitor containment hydrogen | Severe Accident Display | • Check CBSCH01_TR | |
| 18 | Establish containment isolation | Overview Display | • Associated isolation valves closed | |
| 19 | If SG level < setpoint then Inject to SGs using any available source<br>Depressurize SGs if needed<br>• AFW MDP unavailable by loss of AC<br>• AFW – TDP failure<br>• Start portable equipment deployment (injection delay)<br>• SG depressurization by opening SG PORV valves to allow injection | Overview Display | • SG level increases (MSSCL01/2/3/4_TR) | |
| 20 | Depressurize RCS to allow accumulators injection at t = 12,971s – 17,939s<br>• Depressurization using SGs unavailable by loss of FW<br>• PRZ PORVs (assumed available) | Overview Display | • RCS pressure drops (RCSCP01_TR) | |
| 21 | Inject into RCS using one or more of the following sources | Overview Display | • RCS level increases (RCSCL01_TR) | |

| **MULFUNCTION:** | IS CODE | **DESCRIPTION:** | SBO with AFW Turbine Driven Pump failure | |
|---|---|---|---|---|
| **STEP ID.** | **PROCEDURE STEPS** | **GUI SHEET** | **EXPECTED RESPONSE** | **STATE** |
| | • SI unavailable (except accumulators)<br>• Start portable equipment deployment (involving injection delay) | | | |
| 22 | Technical Support Center (TSC) assumed staffed and ready to make SAMG based decisions and determine strategies | | | |
| Note | Technical Support Center actions<br>According to the PWR-OG Severe Accident Management Guidelines approach, the priority for implementing each guideline depends on the existing plant condition and the associated severity level of the challenges to FP barriers<br>This severity level is determined by the existing values of representative parameters in a Diagnostic Guideline<br>In the following table, the parameter conditions allowing to identify FP barriers challenges are related to the high level actions proposed to mitigate these challenges, the involved plant systems and, depending on their assumed availability during the scenario, the actions that could be implemented | | | |

| **Parameter / condition** | **FP boundary challenges** | **Mitigation / recovery High Level Actions** | **Involved systems** | **SBO** | |
|---|---|---|---|---|---|
| | | | | **Availability** | **Action** |
| SG water level / less than a calculated setpoint (typically U-tubes covered) | SG tubes creep rupture | Inject into SGs | AFW-TD/MD pumps | NA | |
| | | | Condensate pumps (LP injection) | NA | |
| | | | Portable or firewater pumps | With delay | ✓ |
| | | Depressurize SGs (if needed to inject) | SG PORV valves | Assumed | |
| | | | Steam dump to condenser | NA | |
| RCS Pressure / in excess above a given setpoint | SG tubes creep rupture | Depressurize RCS | SG cooling (FW and steam dump) | NA | |
| | | | PRZ PORVs | Assumed | ✓ |
| | | | Normal PRZ spray | NA | |

| Parameter / condition | FP boundary challenges | Mitigation / recovery High Level Actions | Involved systems | SBO | |
|---|---|---|---|---|---|
| | | | | Availability | Action |
| (typically allowing LP injection into RCS) | RPV failure at high pressure (HPME, DCH) | | Auxiliary PRZ spray | NA | |
| RCS Injection Flow Rate / not enough to remove residual heat as latent or sensible heat | Increasing fuel temperature and melting progression | Inject into RCS | HPSI | NA | |
| | | | LPSI | NA | |
| | | | SI accumulators | Assumed | ✓ |
| | | | Portable or firewater pumps | With delay | ✓ |
| | | | RWST gravity drain | NA (high P) | |
| Containment water level / not enough to protect containment basemat and allow injection/spray recirculation modes | Core concrete interaction | Inject into Containment | Containment spray (with deinerting precautions) | NA | |
| | | | RWST gravity drain | NA | |
| Containment $H_2$ condition / flammable mixture or containment integrity challenged | Hydrogen / Carbon monoxide explosion Potential containment failure | Reduce Containment Hydrogen (concentration / accumulation) | Steam inert containment (stopping containment heat sinks) | NA | |
| | | | $H_2$ burn (Triggered by Instructor console) | Instructor Console | |
| | | | Passive Autocatalytic Recombiners | Passive | ✓ |
| | | | Filtered containment venting | Assumed | ✓ |
| Containment Pressure / higher than containment design pressure or near ultimate pressure capability | Containment overpressure failure | Control Containment Pressure | Containment spray system | NA | |
| | | | Filtered containment venting | Assumed | ✓ |
| | Increasing dose rates | | Penetrations isolation | Assumed | (automatic) |

| Parameter / condition | FP boundary challenges | Mitigation / recovery High Level Actions | Involved systems | SBO | |
|---|---|---|---|---|---|
| | | | | Availability | Action |
| FP releases / defined onsite or offsite radiation dose rates | | Mitigate FP release (depending on the release location) | Containment depressurization (spray) | NA | |
| | | | SG isolation | Assumed | ✓ |
| | | | Recirculation leaking systems isolation | NA | |
| | | | Leaking penetration plume spray | NA | |

# LOCA with Safety injection and Containment spray systems failure

The phenomena involved consist of:

Design Basis Accident phase:

- Initiating Event: 6" Cold leg LB-LOCA with SI and containment spray failure (CSS can be recovered during simulation)
- RCS sharp depressurization
- Reactor & turbine trip on low RCS pressure
- SI signal (SI failure)
- Containment pressurization
- Extensive Departure from Nucleate Boiling (DNB)
- Core blowdown
- RCP coastdown
- Accumulators discharge (non-effective because of core bypass)
- Safeguard systems loss
- HP and LP Safety Injection loss (except passive SI accumulators)
- Containment spray loss
- Fuel overheating
- Fission products released to RCS. Mainly fuel gap content.

Severe Accident phase:

- High clad temperatures promoting oxidation
- Extensive clad failures
- FP release to RCS
- RCS hot gases circulation
- Generation of H2
- Steam and H2 discharge into containment through broken leg

- H2 (and later in the accident CO) recombination by autocatalytic recombiners assumed available (H2 explosions should be avoided[1]: this point will be checked during the project)
- Increased FP release to containment
- Core melting and relocation
- Corium slump in RPV lower plenum
- Potential RPV lower head failure (different criteria considered by ASTEC's models)
- Corium discharge into containment
- Corium-Concrete Interaction
- Ex-vessel H2 / CO generation
- H2 and CO recombination by autocatalytic recombiners
- Containment basemat ablation
- Containment pressurization
- Potential RCS depressurization, with potential release of FP (throughout controlled valves).
- Potential long term containment overpressure failure
- Potential release of FP (throughout filtered containment venting system).

The table below describes the different steps of the accidental sequence, assuming a good application of EOPs and SAMGs. The response of the simulator may be different depending on the actions of the trainee.

[1] The relatively coarse nodalization used to model the containment in the simulator will not capture local concentration of combustible gases that would favor explosions.

| MULFUNCTION: | IS CODE | DESCRIPTION: | LOCA with SI and containment spray failure | |
|---|---|---|---|---|
| **STEP ID.** | **PROCEDURE STEPS** | **GUI SHEET** | **EXPECTED RESPONSE** | **STATE** |
| Setup | Reset the Simulator to IC #1 '100% EOL'. | | | |
| Initial Conditions | Check the following variables are stable:<br>1. Neutron power (%).<br>2. Thermal power ($MW_t$).<br>3. Generator load ($MW_e$).<br>4. Steam pressure (MPa).<br>5. FW flow (kg/s).<br>6. FW temperature (ºC).<br>7. Pressurizer pressure (MPa).<br>8. Pressurizer level (%).<br>9. Cold leg temperature | Overview Display | All variables stable at:<br>1. 100 %<br>2. 4.000 MWt<br>3. 1.300 MWe<br>4. 6,45 MPa<br>5. 536 kg/s<br>6. 227 ºC<br>7. 15,5 Mpa<br>8. 41%<br>9. 561,57K | |
| 1 | Check there are no active alarms | Alarm Display | | |
| 2 | Load ' LOCA in cold leg' with 'SI failure' and 'containment spray failure' malfunctions | System Display | | |
| 3 | Verify malfunction:<br>1. Reactor coolant pressure lowers | System Display | • RCS pressure (RCSCP01_TR) lowers. | |
| DBA Phase | | | | |
| 4 | Reactor trip on high containment pressure combined with low pressure in the PZR at t = 6,6s | Alarm/Overview Display | • Shutdown and control banks at bottom. | |

| MULFUNCTION: | IS CODE | DESCRIPTION: | LOCA with SI and containment spray failure | |
|---|---|---|---|---|
| **STEP ID.** | **PROCEDURE STEPS** | **GUI SHEET** | **EXPECTED RESPONSE** | **STATE** |
| | | | • Neutron power (RCSNP01_TR) lowers. | |
| 5 | Turbine trip<br>1. Verify Turbine Control valve close at t = 6,7s<br>2. Verify Turbine Bypass valve opens | Alarm/Overview Display | • Steam to TUR flow (MSSCF05_TR) goes to zero.<br>• Steam to steam dump increases (MSSCF06_TR). | |
| 6 | Loop through applicable EOP (LOCA) | | | |
| 7 | Verify reactor and turbine trip | Alarm/Overview Display | | |
| 8 | Verify MFW isolation signal at t = 9,6s<br>1. Verify MFW isolation valves close at t = 16,8s<br>2. Verify MFW pump stops. | Overview Display | • MFW isolation valves closed (FWSV01/2/3/4)<br>• MFW pump stops (FWSP01/2/3) | |
| 9 | Verify containment isolation at t = 129s | Overview Display | • Isolation main steam valves closed (MSSV01/2/3/4)<br>• And another associated isolation valves | |
| 10 | SI:<br>1. SI signal at t = 9,5s<br>2. Verify SI (failed) | Overview Display | • HPI pumps stopped (HPIP01/2..)<br>• LPI pumps stopped (LPIP01/2)<br>• Spray pumps stopped (CCSP01/2) | |
| 11 | Verify AFW flow at t = 9,5s | Overview Display | • AF pump starts (AFWP01/2)<br>• AFW Flow increases (AFWCF01/2/3_TR) | |
| 12 | Verify containment pressure<br>1. Actuate containment spray (failed) | Overview Display | • Containment pressure increases (CCSCP01_TR)<br>• Spray pumps stopped (CCSP01/2) | |

| MULFUNCTION: | IS CODE | DESCRIPTION: | LOCA with SI and containment spray failure | |
|---|---|---|---|---|
| **STEP ID.** | **PROCEDURE STEPS** | **GUI SHEET** | **EXPECTED RESPONSE** | **STATE** |
| | 2. Possibility of being restored | | | |
| 13 | Verify automatic stop RCP s at t = 23,9s | Overview Display | • RCPs coastdown (RCSCN01/2/3/4_TR) | |
| 14 | Verify intact SGs | Overview Display | • Steam pressure maintained (MSSCP01/2/3/4_TR)<br>• No high radiation in steam line (MSSCR01/2/3/4_TR) | |
| 15 | Verify intact RCS → LOCA | Overview Display | • Reactor coolant system pressure decreases (RCSPT01_TR)<br>• Containment radiation increases (CCSCR01_TR) | |
| 16 | Core damage diagnosis: core exit temperaturehigher than 1.000ºC (SAMG) or high containment radiation - exit EOPs / enter SAMGs | Overview Display | • Core exit thermocouples to 1000ºC (RCSCT01/2.._TR)<br>• High containment radiation (CBSCR01_TR)<br>• Operator changes the accident procedure | |
| Severe Accident phase (following PWR – OG SAMG strategies) | | | | |
| 18 | Control room actions (initial response according Control Room SAMGs)<br>• Block automatic start of non-operating equipment and safeguards (not designed for BDBA; accident management | Overview Display | • All automatic actions change to manual | |

| MULFUNCTION: | IS CODE | DESCRIPTION: | LOCA with SI and containment spray failure | |
|---|---|---|---|---|
| **STEP ID.** | **PROCEDURE STEPS** | **GUI SHEET** | **EXPECTED RESPONSE** | **STATE** |
| | carried out through manual actions), including:<br>○ AFW pumps<br>○ SI pumps<br>○ Containment spray and fan coolers<br>○ … | | | |
| 19 | Stop any operating RCPs | Overview Display | • RCPs stopped (RCSCN01/2/3/4_TR) | |
| 20 | Monitor containment hydrogen | Severe Accident Display | • Containment hydrogen (CBSCH01_TR) | |
| 21 | Establish containment isolation | Overview Display | • Isolation valves closed | |
| 22 | If SG level < setpoint then Inject to SGs using any available source if needed (not needed)<br>• Water level regulation at 44 NR | Overview Display | • SG level maintained (MSSCL01/2/3/4_TR) | |
| 23 | Depressurize RCS to allow accumulators injection (not needed) at t = 453s – 1.018s | Overview Display | | |
| 24 | Inject into RCS using one or more of the following sources<br>• SI (unavailable)<br>• RWST gravity drain (depending on RWST water | Overview Display | • RCS level increases (RCSCL01_TR)<br>• PES pump starts (PESP01/2)<br>• PES pump stops (PESP01/2) | |

| MULFUNCTION: | IS CODE | DESCRIPTION: | LOCA with SI and containment spray failure | |
|---|---|---|---|---|
| **STEP ID.** | **PROCEDURE STEPS** | **GUI SHEET** | **EXPECTED RESPONSE** | **STATE** |
| | column and RCS counterpressure)<br>• Start portable equipment deployment (involving injection delay) at t = 1.007s<br>• Stop portable equipment at t = 3.009s | | | |
| 25 | Restored containment spray<br>• Containment spray pumps start | Overview Display | • CBS pressure decreases (CBSPT01_TR)<br>• CCS pump starts (CCSP01/2)<br>• Spray flow increases (CCSCF01/2_TR) | |
| 26 | Technical Support Center (TSC) assumed staffed and ready to make SAMG based decisions and determine strategies | | | |
| Note | Technical Support Center actions<br>According to the PWR-OG Severe Accident Management Guidelines approach, the priority for implementing each guideline depends on the existing plant condition and the associated severity level of the challenges to FP boundaries. This severity level is determined by the existing values of representative parameters in a Diagnostic Guideline<br>In the following table, the parameter conditions allowing to identify FP boundary challenges are related to the high level actions (HLA) proposed to mitigate these challenges, the involved plant systems and, depending on their assumed availability during the scenario, the actions that could be implemented. | | | |

| Parameter / condition | FP boundary challenges | Mitigation / recovery High Level Actions | Involved systems | LB-LOCA | |
|---|---|---|---|---|---|
| | | | | Availability | Action |
| SG water level / less than a calculated setpoint (typically U-tubes covered) | SG tubes creep rupture | Inject into SGs | AFW-TD/MD pumps | ✓ | |
| | | | Condensate pumps (LP injection) | NA | |
| | | | Portable or firewater pumps | With delay | ✓ |
| | | Depressurize SGs (if needed to inject) | SG PORV valves | ✓ | ✓ |
| | | | Steam dump to condenser | ✓ | |
| RCS Pressure / above a given setpoint (typically allowing LP injection into RCS) | SG tubes creep rupture<br>RPV failure at high pressure (HPME, DCH) | Depressurize RCS | SG cooling (FW and steam dump) | ✓ | |
| | | | PRZ PORVs | Assumed | ✓ |
| | | | Normal PRZ spray | NA | |
| | | | Auxiliary PRZ spray | NA | |
| RCS Injection Flow Rate / not enough to remove residual heat as latent or sensible heat | Increasing fuel temperature and melting progression | Inject into RCS | HPSI | NA | |
| | | | LPSI | NA | |
| | | | SI accumulators | ✓ | |
| | | | Portable or firewater pumps | With delay | ✓ |
| Containment water level / not enough to protect containment basemat and allow injection/spray recirculation modes | Core concrete interaction | Inject into Containment | Containment spray (with deinerting precautions) | Initially NA and restored at t=(1-24)h | |
| | | | RWST gravity drain | NA | |
| Containment $H_2$ condition / flammable mixture or containment integrity challenged | Hydrogen / Carbon monoxide explosion Potential containment failure | Reduce Containment Hydrogen (concentration / accumulation) | Steam inert containment (stopping containment heat sinks) | NA | |
| | | | $H_2$ burn. Triggered by Instructor console | Instructor Console | |

| Parameter / condition | FP boundary challenges | Mitigation / recovery High Level Actions | Involved systems | LB-LOCA | |
|---|---|---|---|---|---|
| | | | | Availability | Action |
| | | | Passive Autocatalytic Recombiners | Passive | ✓ |
| | | | Filtered containment venting | Assumed | ✓ |
| Containment Pressure / higher than containment design pressure or near ultimate pressure capability | Containment overpresure failure | Control Containment Pressure | Containment spray system | Initially NA and restored at t=(1-24)h | ✓ |
| | | | Filtered containment venting | Assumed | ✓ |
| FP releases / defined onsite or offsite radiation dose rates | Increasing dose rates | Mitigate FP release (depending on the release location) | Penetrations isolation | ✓ | ✓ |
| | | | Containment depressurization (spray) | NA | |
| | | | SG isolation | ✓ | |
| | | | Recirculation leaking systems isolation | NA | |
| | | | SFP spray | NA | |
| | | | Leaking penetration plume spray | NA | |

# ASSAS Simulator Systems

The ASSAS simulator scope covers just the Design Basis Accident (DBA) and the Severe Accident (SA) and not the normal operation, so Turbine, Condenser, Condensate, Circulating water, Reactor Heat Removal and Chemical and Volumetric control systems are out of scope.

The systems that are present to be operated or monitored by the GUI are:

- Auxiliary Feedwater System (AFW)
- Reactor Coolant System (RCS) including PORVS, RCP and safety valves
- Main Steam Supply System (MSS) including SGs.
- Containment Cooling Sprays (CCS). It will fail but recoverable.
- High Pressure Injection System (HPI). It will fail.
- Low Pressure Injection System (LPI). It will fail.
- Accumulator Injection System (ACI)
- Portable Equipment System (PES)
- Containment venting

AFW has been removed from ASTEC input deck and it will be developed by Team_SUITE® tools (Team_Flow for thermohydraulics and Team_Logic for logics).

PES will be developed by Team_SUITE® tools from scratch as it is not present in current ASTEC input deck.

# PES scope

In the event of an accident, it is necessary to connect external pumps at some plant locations to provide cold water to transfer the accumulate latent heat in the coolant and materials, such as the residual heat generated after the trip occurs.

It is considered that the system has a limited number of portable pumps that can be used in the simulator: three high-pressure and three low-pressure pumps.

These six extra pumps must be installed to:

- Inject water in Steam generators,
    - Medium pressure portable pump (2)
    - Low pressure portable pump (2)
- Inject water in RCS (cold legs and hot legs simultaneously)

- Medium pressure portable pump (1)
- Low pressure portable pump (1)

These types of pumps comply with the requirements of the system in both situations: In the need of high-pressure water injection and in the other case where a high flow of water is needed to avoid an induced SGTR on hot and dry SGs.

The features of these pumps in operation are:

- Medium pressure Portable pump. 68$m^3$/h for 21Kgr/$cm^2$
- Low pressure Potable pump. 900$m^3$/h for 12Kgr/$cm^2$
- 300K
- They are available at the same time, connected immediately and work at their nominal capacity.
- The necessary time to connect the pumps varies between 20 min and 24 h.
- The operator can decide to activate the pumps when they are available.

# Operator Actions

The following boundaries can be considered in a first approach for the different operator actions available with the simulator:

- Steam Generator Pressure Operated Relief Valve (SG-PORV):
  - Operator can open SG-PORV a first time at a certain percentage (0-100%) and have a second action on it to fully open it (just once[2]).
  - These two actions are avalaible (and independent) for each SG.
  - The opening of the SG-PORV is possible since the beginning of the scenario.
  - Scenarios include the possibility of induced Steam Generator Tube Rupture (SGTR): the input deck must allow the possibility to close the PORV of the concerned SG after this event. The main steam line will be closed with the same action.
- Pressurizer PORV:

[2] Some actions can only be performed once to limit the complexity of the training database generation for the development of surrogate models. Giving the possibility to perform actions as many times as wanted would also require modelling the involved systems with TEAM_SUITE® instead of ASTEC.

- Operator can change the PORV mode from standard to feed and bleed mode (just once[3]).
- The valve automatically closes when the Reactor Coolant System (RCS) pressure reaches 8 bar.

- Portable Equipment Systems (SGs and RCS):
  - All pumps (3 medium-pressure and 3 low-pressure pumps) are available at the same time, connected immediately and work at their nominal capacity.
  - The necessary time to connect the pumps varies between 20 min and 24 h (decided by the instructor).
  - The operator can decide to activate the pumps when they are available:
    - 4 pumps (high and low pressure) for all SG at the same time.
    - 2 pumps (high and low pressure) for the RCS at the same time.
  - After an induced SG tube rupture:
    - The PES is deactivate in the affected SG (to avoid injecting in the primary through the broken tubes).
- Boundaries must be defined for the induced SGTR, in terms of pressure and temperature. It will be manually triggered by the instructor within these boundaries. The number of failed tubes will be fixed in the input deck.
- The SG level will automatically by regulated at 44% NR if the AFW system is available.
- Containment Cooling System (CSS) is recovered between 1h and 24h after the beginning of the accident (defined by the instructor) in the LOCA scenario. Once recovered, the operator can decide to activate them, then they are managed automatically (automatic switch to recirculation mode when the RWST tank is empty and automatic stop of the recirculation when the temperature in the sumps exceeds a threshold)
- The containment venting can be performed when the pressure exceeds 5bar. Once opened, the corresponding valve cannot be closed again.
- If calculations showed that flammable conditions can be reached in the containment, boundaries would be provided for the manual triggering of combustion by the instructor.

[3] Some actions can only be performed once to limit the complexity of the training database generation for the development of surrogate models. Giving the possibility to perform actions as many times as wanted would also require modelling the involved systems with TEAM_SUITE® instead of ASTEC.

- The simulator will warn the user when systems are recovered (PES or CSS)

# Data displayed to the user

The selected data displayed to the user is based on the one required for the operation of the scenarios defined and to have a good knowledge of the severe accident.

It will be used to train the surrogate models and can be divided into three groups according to the phase of the severe accident scenario.

### Typical instrumentation parameters for nominal operation and transients

- Reactor thermal power (MWt, %) (including decay heat)
- RCS mass flow rates
- RCS / pressurizer pressure
- RCS HL/CL temperatures
- RCS average temperatures
- RCS Subcooling (ΔTsat)
- Core exit temperature (Core exit thermocouples, CETs)
- Pressurizer level
- Steam mass flow to turbine
- Turbine bypass steam mass flow rates
- SG pressures
- SG steam mass flow rates
- SG WR/NR (wide range / narrow range) water reference level (44%)
- SG WR/NR water level
- MFW flow to each SG
- MFW temperatures to each SG
- AFW flow to each SG
- AFW pressure to each SG
- AFW tank level
- AFW tank reference level
- AFW tank temperature

- AFW tank pressure
- Containment dome pressure
- Containment dome temperature
- Containment sump water level
- Containment dome dose rate

DBA associated variables

- Break mass flow rates
- Accumulated break mass flows (discharged mass)
- RPV water level (RVLIS)
- Peak temperatures for the fuel and the cladding
- Valves mass flow rates (Pressurizer PORVs and safety valves)
- Valves mass flow rates SGs safety & relief valves
- % of opening for SG and Pressurizer PORVs
- High Pressure Safety Injection mass flow rate
- Low Pressure Safety Injection mass flow rate
- Containment spray flow rate
- Accumulators mass flow rate
- Accumulators pressure
- Portable equipment mass flow into RCS (each pump)
- Portable equipment mass flow into SG (each pump)
- RWST level
- Accumulators level

Severe accident phase associated variables / flags

- Core exit temperature (CET) → SAMG enter flag
- Peak temperatures for the fuel and the cladding until first fuel relocation or first clad rupture respectively
- Release rate of fission products from the core to the RCS in Bq/h
- Release rate of fission products from the RCS to the containment in Bq/h
- Release rate of fission products from the containment to the environment in Bq/h

- Core hydrogen generation rate
- RCS hydrogen concentration
- Temperature, Total, Debris, Magma and Intact core mass at 15 core heights[4] and 5 concentric radial meshes[5] (so 75 meshes) --> 75*5 = 375variables.
- Temperature, Total, Debris, Oxide pool, heavy metal pool, light metal pool corium mass in lower plenum
- Temperature, Total, oxide and crust corium mass in cavity
- Radial and Axial concrete erosion at cavity
- Containment dose rate → SAMG enter flag
- Containment fission product isotopic activity
    - Noble Gas (Xe)- Xe133
    - Halogens (I) – I131/2 (organic, inorganic, aerosol forms)
    - Alcali Metals (Cs, Rb) – Cs134/6/7
    - Tellurium group (Te, Sb) – Te132
    - Barium, Strontium (Ba, SR) – Sr90
    - Noble Metals (Ru, Rh, Pd, Mo, T) – Ru103
    - Lanthanides (La, Zr, Nd, Eu, Nb) – La140, Cm242
    - Cerium Group (Ce, Pu, Np) – Pu241
    - Early transition Elem. – Mo99
    - More volatile metals – Sb127
- Containment venting flow
- Isotopic activity released to the environment: same radionuclides as mentioned above
- Shapiro variables
    - 1. Axe: Air compounds ($O_2$+$N_2$)
    - 2. Axe: Combustible gases ($H_2$+CO)
    - 3. Axe: Inert gases ($H_2O$ + $CO_2$)

[4] 12 for active core, 1 for upper strucutres and 2 for lower structures
[5] 3 for the active core, 1 for the downcomer and one for the by-pass

- Steam-gas mixture in containment
  - %Steam
  - %Oxygen
  - %Hydrogen
  - %Carbon monoxide
  - %CO2
- Total amount of Hydrogen and Carbon monoxide recombined (kg)
- Reference variables from FP barrier threats display. (Note: Reference is a threshold that tiggers an alarm)
  - Reference RCS pressure
  - Reference RCS injection
  - Reference SUMP level
  - Reference [H2]
  - Reference Containment pressure
  - Reference Containment radiation
- Flags to be calculated
  - IS failure
  - Vessel failure
  - SG tubes failure
  - Containment failure
  - Isolation failure
  - Containment venting
- "Game over" flag
  - High-pressure vessel rupture (above 20 bar): The simulator will inform the user of a "simulator out of scope: high-pressure vessel rupture possibly leading to direct containment heating and containment threat".
  - High-pressure containment failure (above 6 bar): the message "simulator out of scope: probable containment failure due to overpressure" will be displayed.
  - Basement melt-through: the message "Simulator out of scope: containment failure due to basement melt-through" will be displayed.

- A maximum simulation time of 5 days is considered, after which the simulator can stop and display "End of simulation: severe accident mitigation considered successful".

Alarms

- Low RWST level
- SI actuated
- AFW actuated
- Cont. Spray (CCS) actuated
- High pressurizer pressure
- Low pressurizer pressure
- High pressurizer level
- Low pressurizer level
- Low RCS coolant flow rate
- Reactor trip
- Core uncover
- High Core exit (CET)
- First clad rupture
- Core meltdown/relocation
- Reactor pressure vessel failure
- High containment pressure
- High containment radiation
- CIS actuated
- Filtered containment venting actuated
- High-high containment radiation
- Containment failure
- Main steam flow pressure
- SG low level
- SG high level
- MS lines isolation actuated

- Turbine trip
- Low FW flow
- Loss of offsite power (LOOP)
- Station Blackout (SBO)

Not all of this instrumentation will be available in an actual control room or in SBO conditions.

The ASSAS Graphical User Interface (GUI) will show which variables will be present in a real MCR (boxed in green in GUI section) and those for educational purposes (which will be boxed in red and green in GUI section). Same idea for those which are not battery backed and will fail during the SBO. There will be a selector in the GUI to distinguish.

# ASSAS Simulator Validation

Three implementations of ASTEC are planned in the ASSAS Project:

1. Reference ASTEC version (best estimate version)
2. ASTEC with surrogated and optimized models (ASSAS version)
3. ASTEC (ASSAS version) - TEAM_SUITE integration (ASSAS simulator)

The validation of the ASSAS version of ASTEC with respect to the best estimate version will be dealt with in the work-package 2 of the project. Specific evaluation criteria will be defined. The integration of ASTEC (ASSAS version) with TEAM_SUITE should add practically no regression, since most physical models are managed by ASTEC.

The performance of the simulator will be evaluated by comparing the data displayed to the user for the different versions of ASTEC, taking the best estimate version as a reference.

# ASSAS Simulator Graphical User Interface (GUI)

## Displays

The GUI interface will be developed by the TEAM_SUITE® graphical tool Team_Skecth.

The simulator displays are organized under a display tree such as the one shown below:

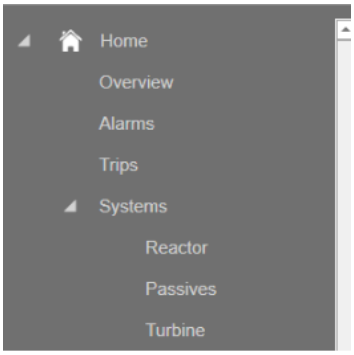



*Figure 1 Display tree*

There are 5 displays available in the ASSAS simulator GUI:

- Home display
- Overview display
- Systems display
- Severe Accident display
- Alarm display

Home display shows the layout of the NPP. The user can navigate from Home to System displays clicking on each system box.

The second display level is the Overview display where most important variables of each system are shown.

The third level is the Systems display. This display is a larger one showing all the systems. The user can move through it by moving the scroll. As this is a basic principles simulator, not an operator training one, this design will help users to understand better the functioning of the NPP.

The user can operate the equipment by clicking on the active components (valves/pumps) icons and can graph any of the variables that appears in the screen by clicking on each readout.

In general, when a pump is running or a valve is opened, they will be shown with the same colour of the line representing the pipe where they are. On the other hand, if a pump is stopped or a valve is closed, they will be shown in grey colour.

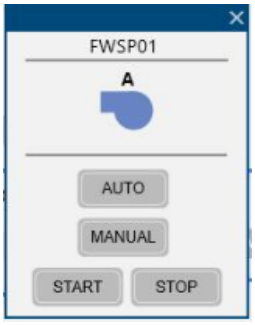



*Figure 2 Pump control view*

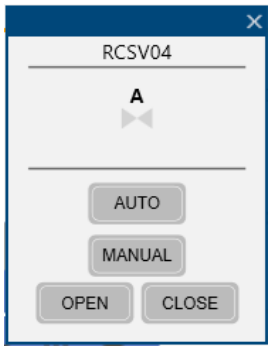



*Figure 3 Valve control view*

The last display is the Severe Accident display which includes the following functionalities:

- Shapiro diagram for H2 (CO) flammability. Draft representation.
- Next to activity, a button with a pop-up window will appear showing the isotopic composition in the containment and released to the environment.
    - Noble Gas (Xe)- Xe133
    - Halogens (I) – I131/2 (organic, inorganic, aerosol)
    - Alcali Metals (Cs, Rb) – Cs134/6/7
    - Tellurium group (Te, Sb) – Te132
    - Barium, Strontium (Ba, SR) – Sr90
    - Noble Metals (Ru, Rh, Pd, Mo, T) – Mo99
    - Lanthanides (La, Zr, Nd, Eu, Nb) – La140, Cm242
    - Cerium Group (Ce, Pu, Np) – Pu241
    - Early transition Elem. – Mo99
    - More volatile metals – Sb127
- Next to O2 level, a button with a pop-up window will appear showing the steam-gas mixture in the containment.
    - %Steam
    - %Oxygen
    - %Hydrogen
    - %Carbon monoxide
    - %CO2
- In the component safeguard area, the basic alignment of each safety equipment is identified by highlighting in black colour the labels of its present suction source and discharge point.

- Vessel water level. Draft representation.
- Corium mass at different core heights (core, lower plenum and out of vessel)
    - Next to core total corium mass, a button with a pop-up window will appear showing the temperature, the Debris, Magma, Intact and total at 15 core heights and 5 radials
    - Next to lower plenum total corium mass, a button with a pop-up window will appear showing the temperature, the Debris, Oxide pool, heavy metal pool, light metal pool at lower plenum
    - Next to out of the cavity total corium mass, a button with a pop-up window will appear showing the temperature, the Radial and Axial concrete erosion, oxide and crust mass in the cavity
- Fission Product barrier threats. Such potential threats are associated to certain plant parameters exceeding established values. The objective of this table is showing important information for making decisions regarding the applicable mitigation strategies. The graph shown below the table shows the time evolution of the variables selected in the table.

There will be a selector for the user to choose between monitoring all the variables present in the HMI or just the ones from a real MCR.

- Variables present in a real MCR are boxed in green.
- Variables for educational purposes are boxed in red and green.

When SBO malfunction is loaded, the transmitters boxed in red will lose their indication if they are not battery backed.

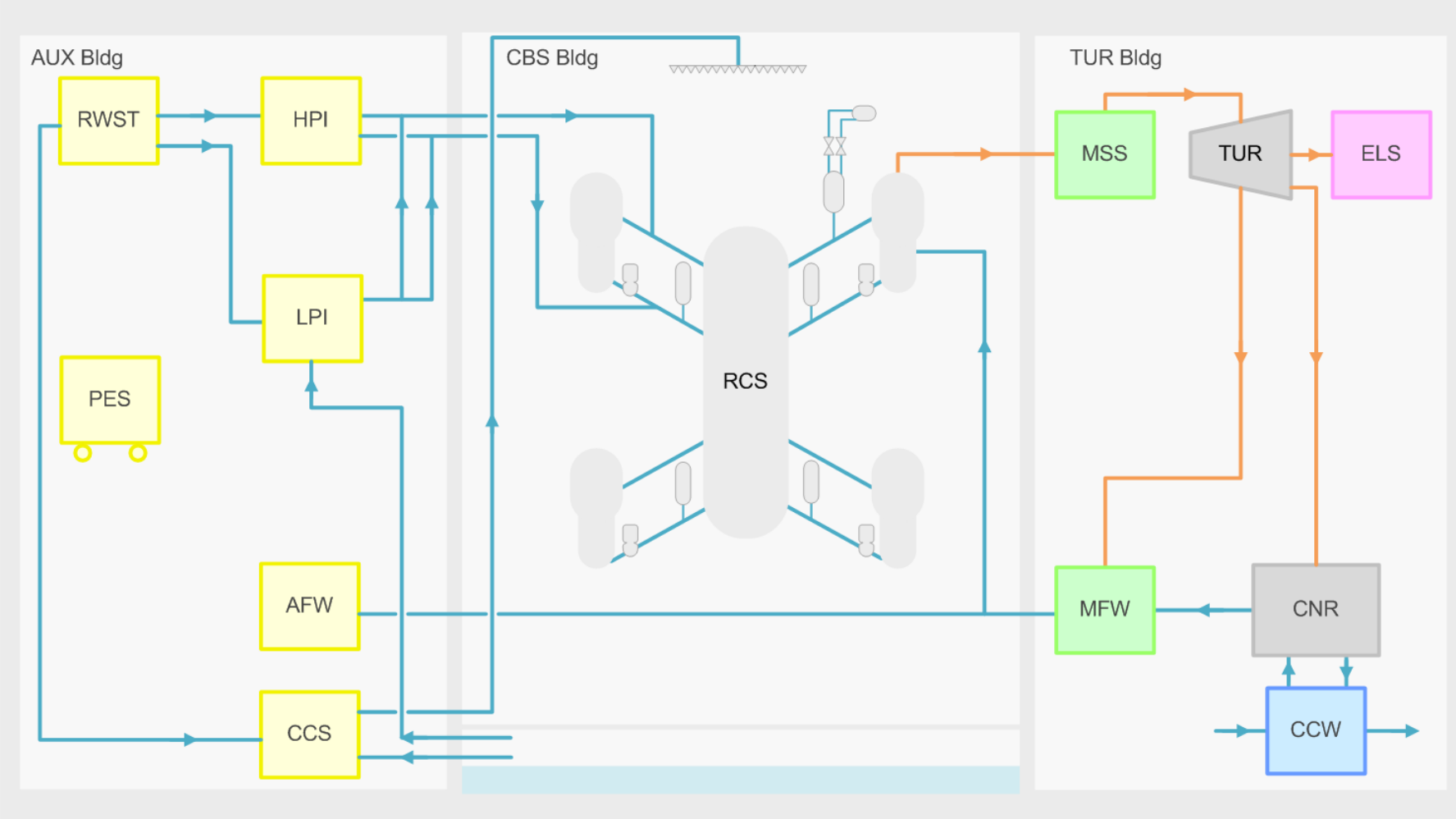



*Figure 4 Home display*

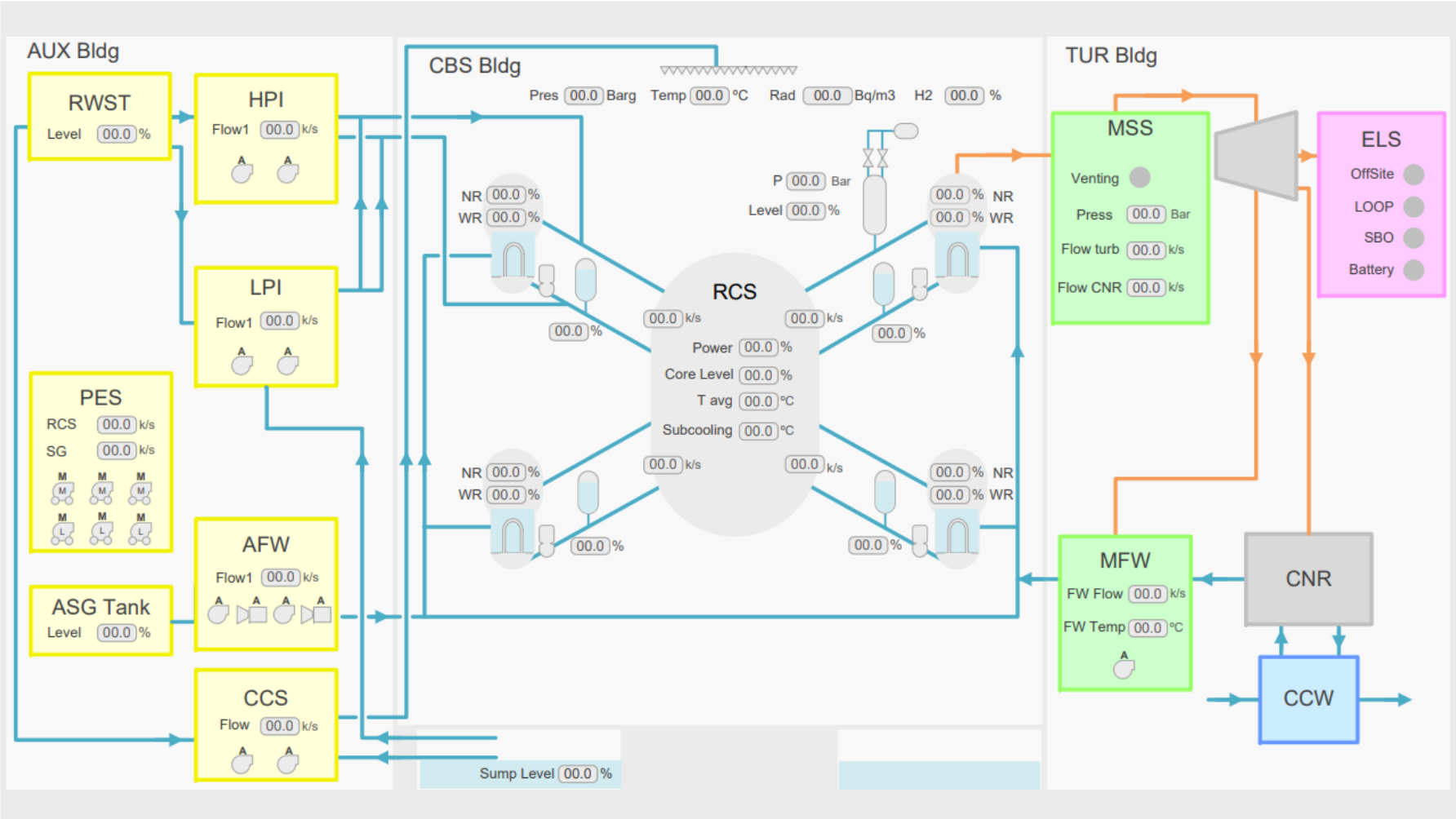



*Figure 5 Overview Display*

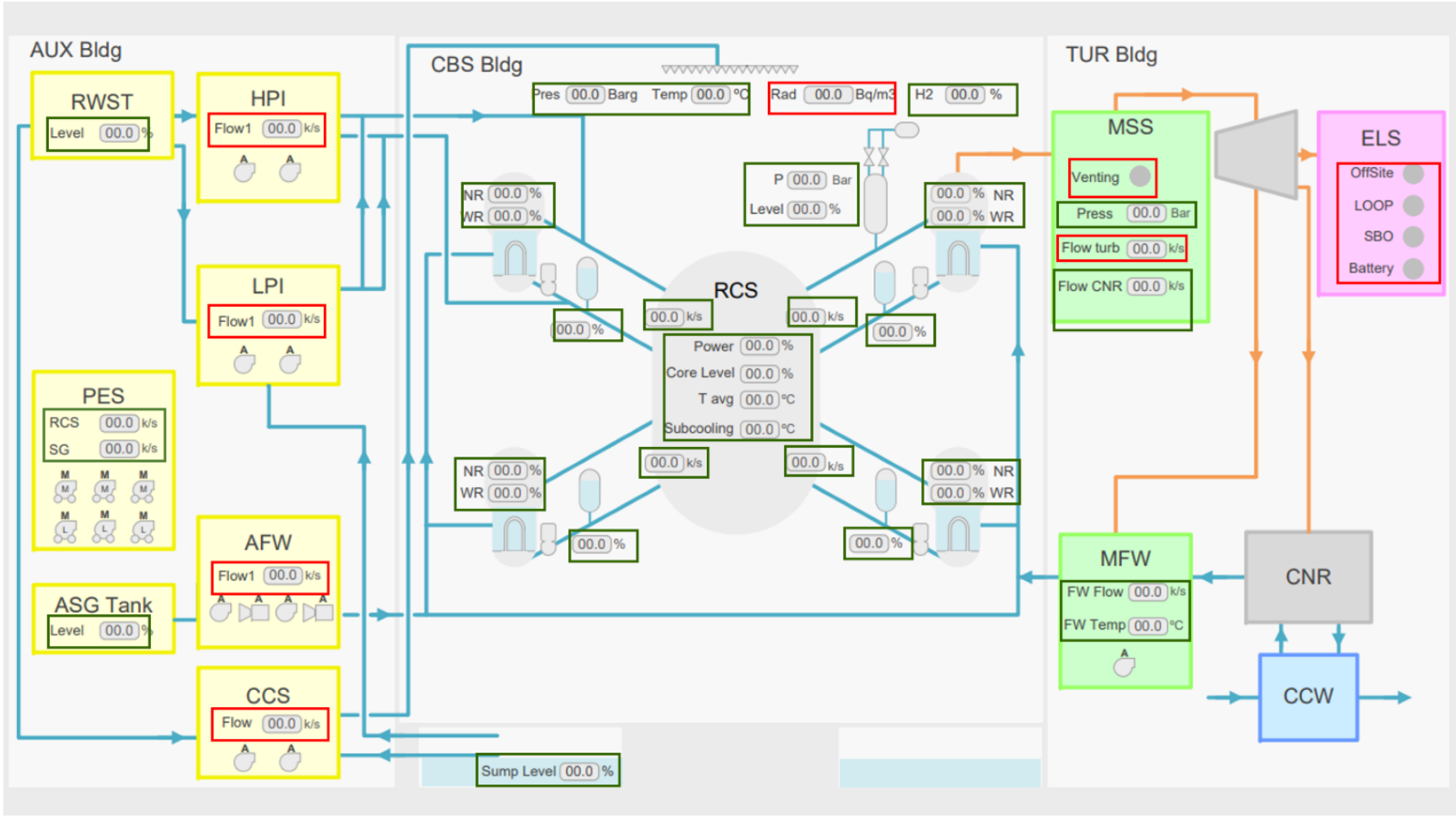



*Figure 6 Overview Display - Variables distinguished*

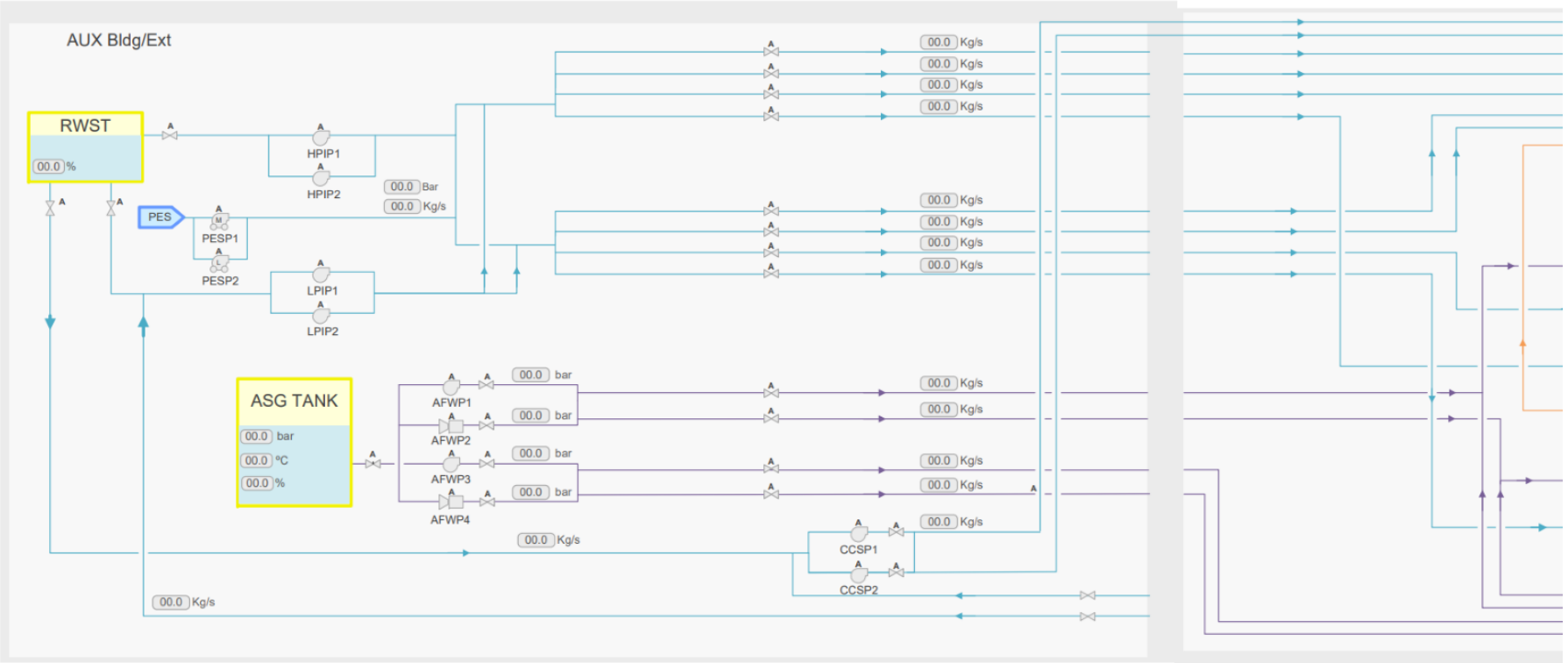



*Figure 7 System Display (1)*

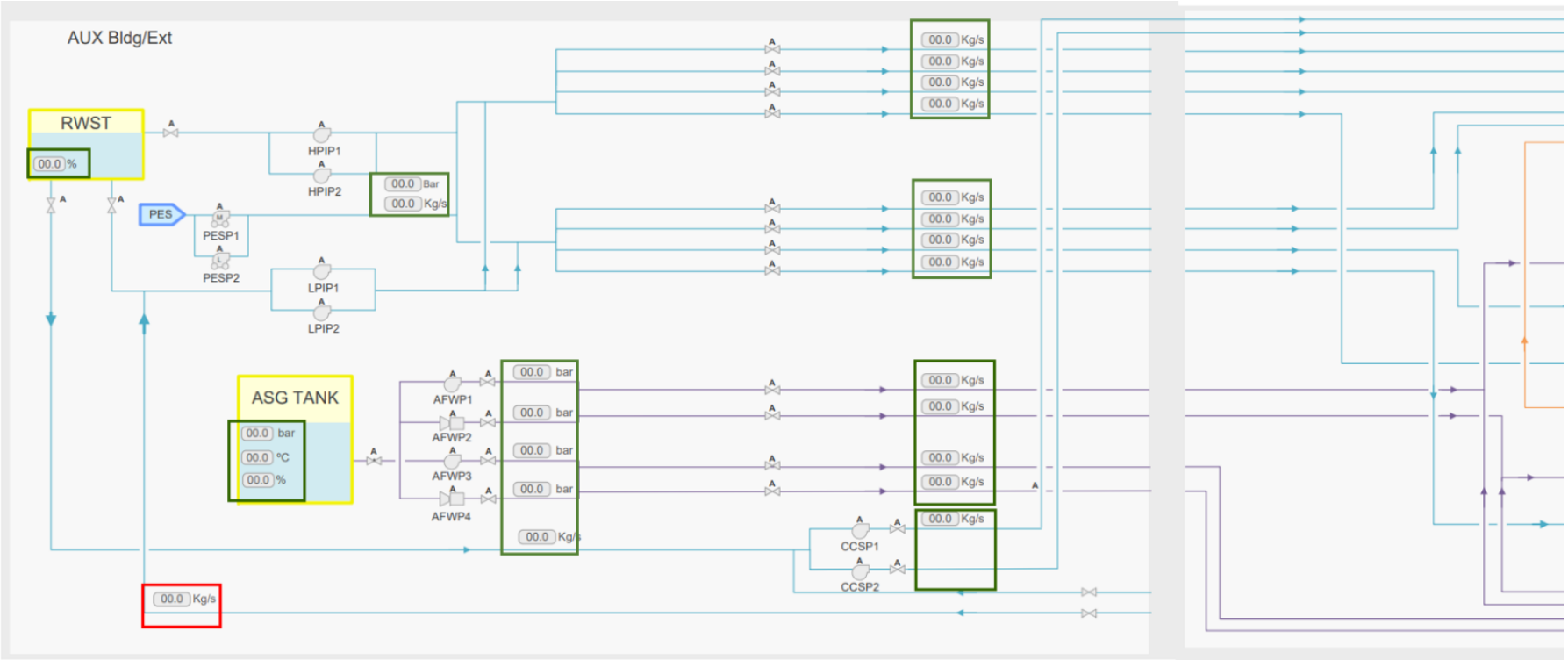



*Figure 8 System Display (1) - Variable distinguished*

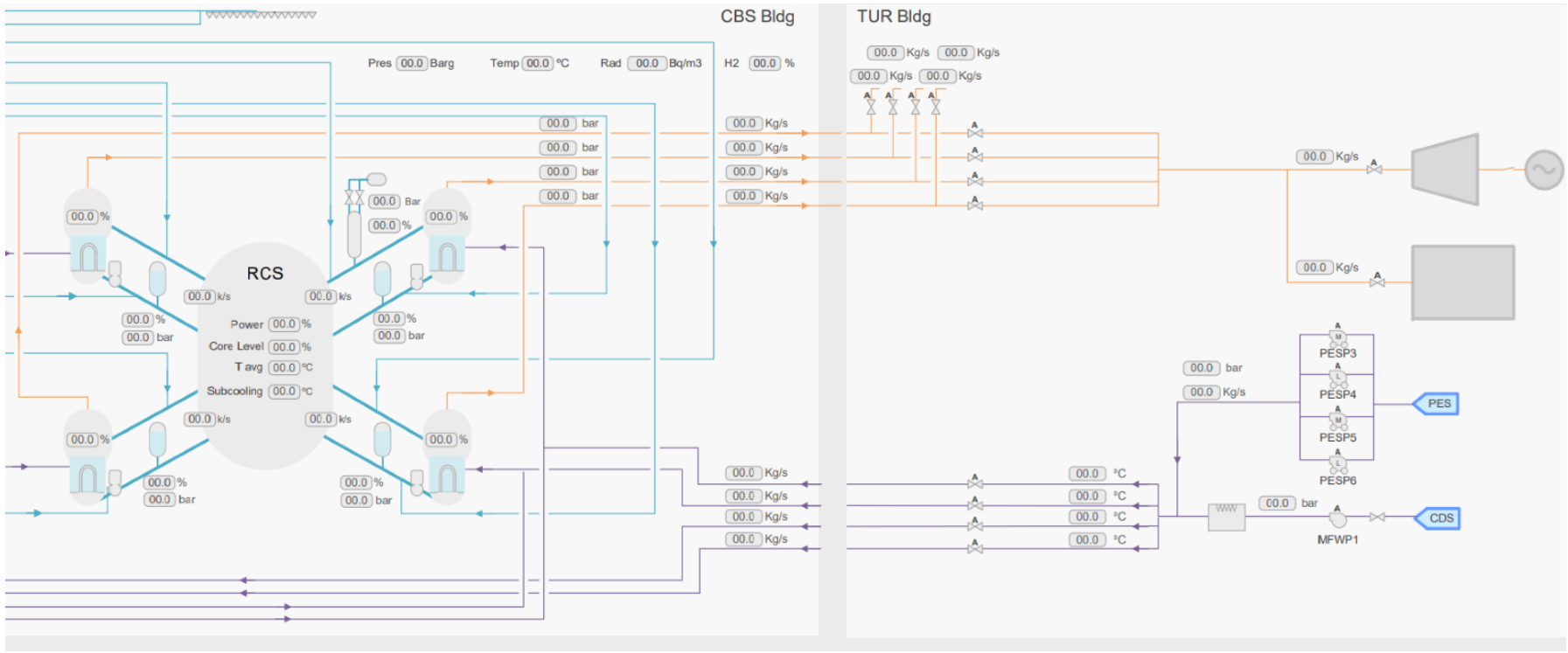



*Figure 9 System Display (2)*

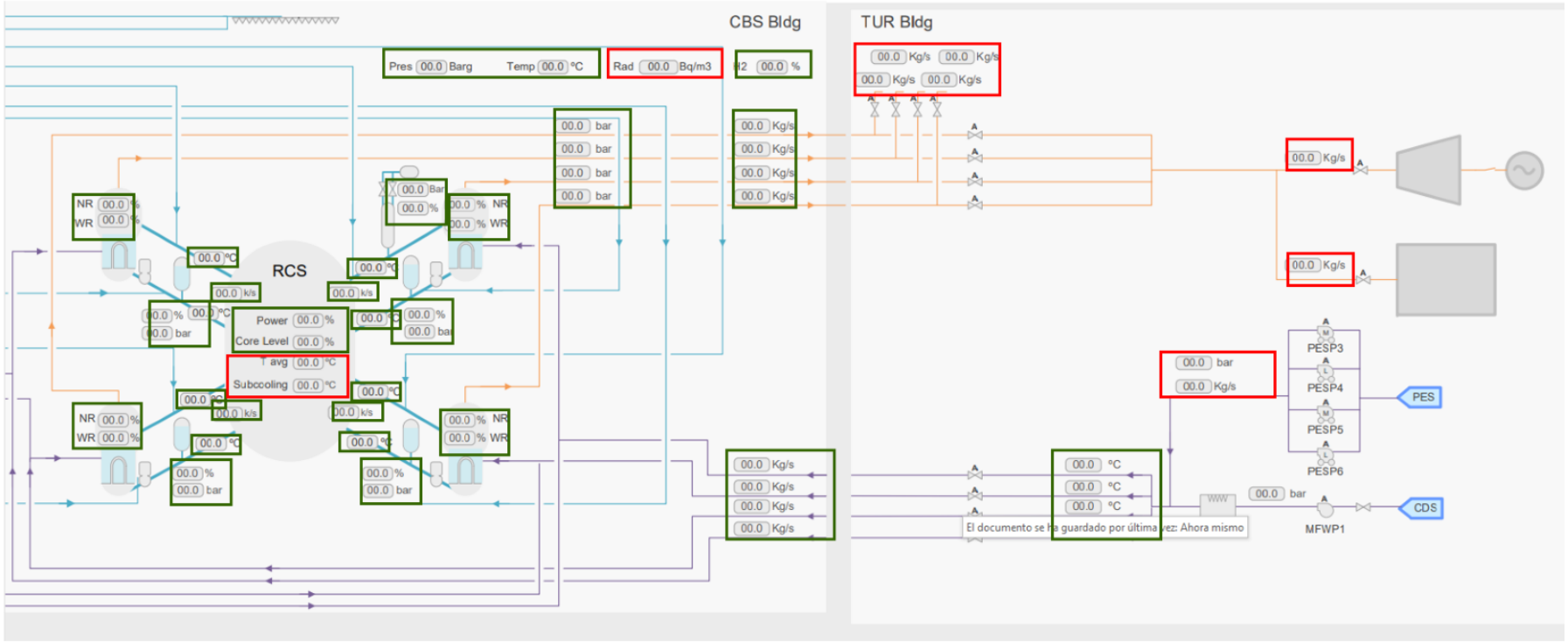



*Figure 10 System Display (2) - Variables distinguished*

*Figure 11 Accident Severe Display*

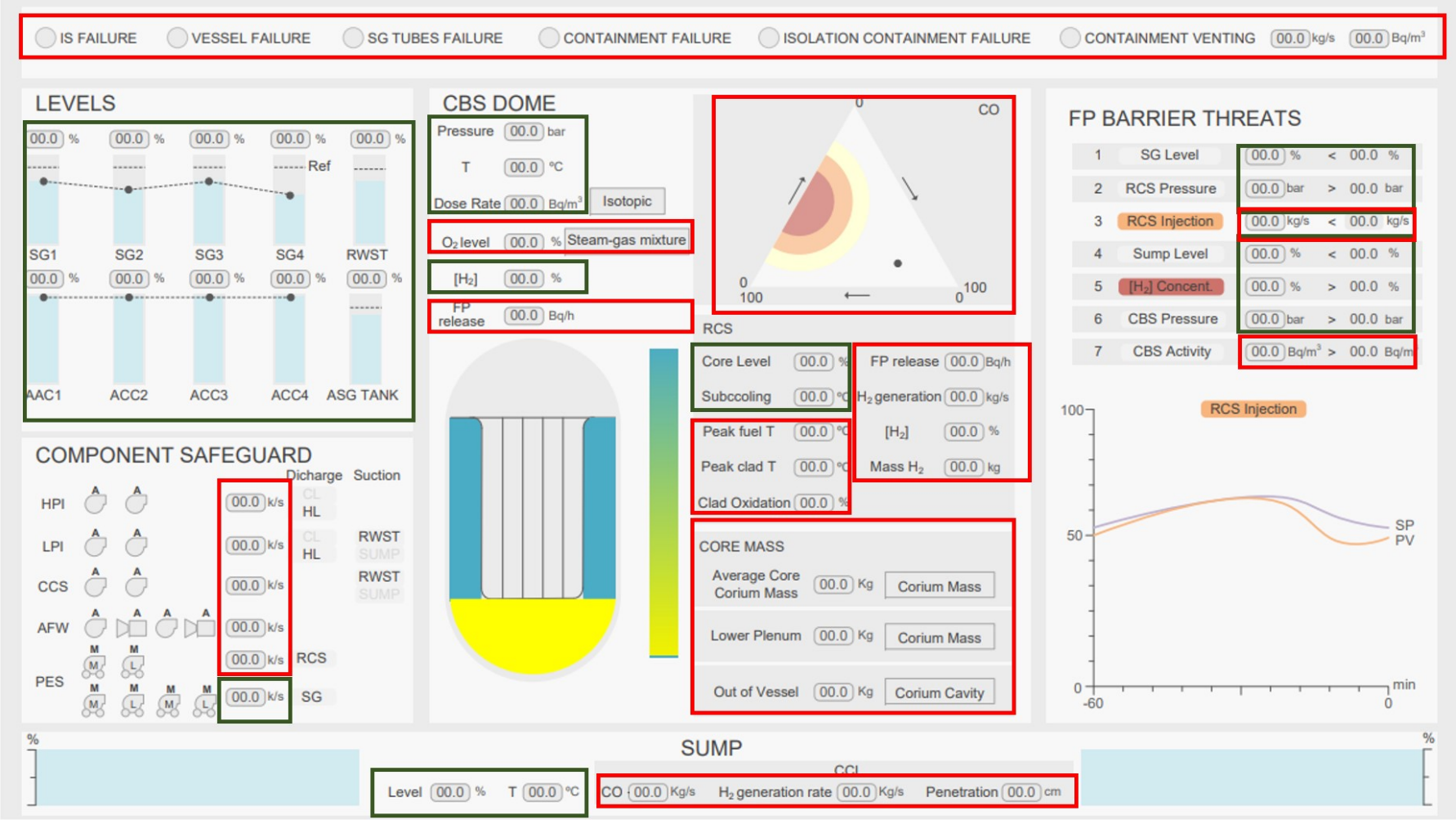



*Figure 12 Accident Severe accident - Variables distinguished*

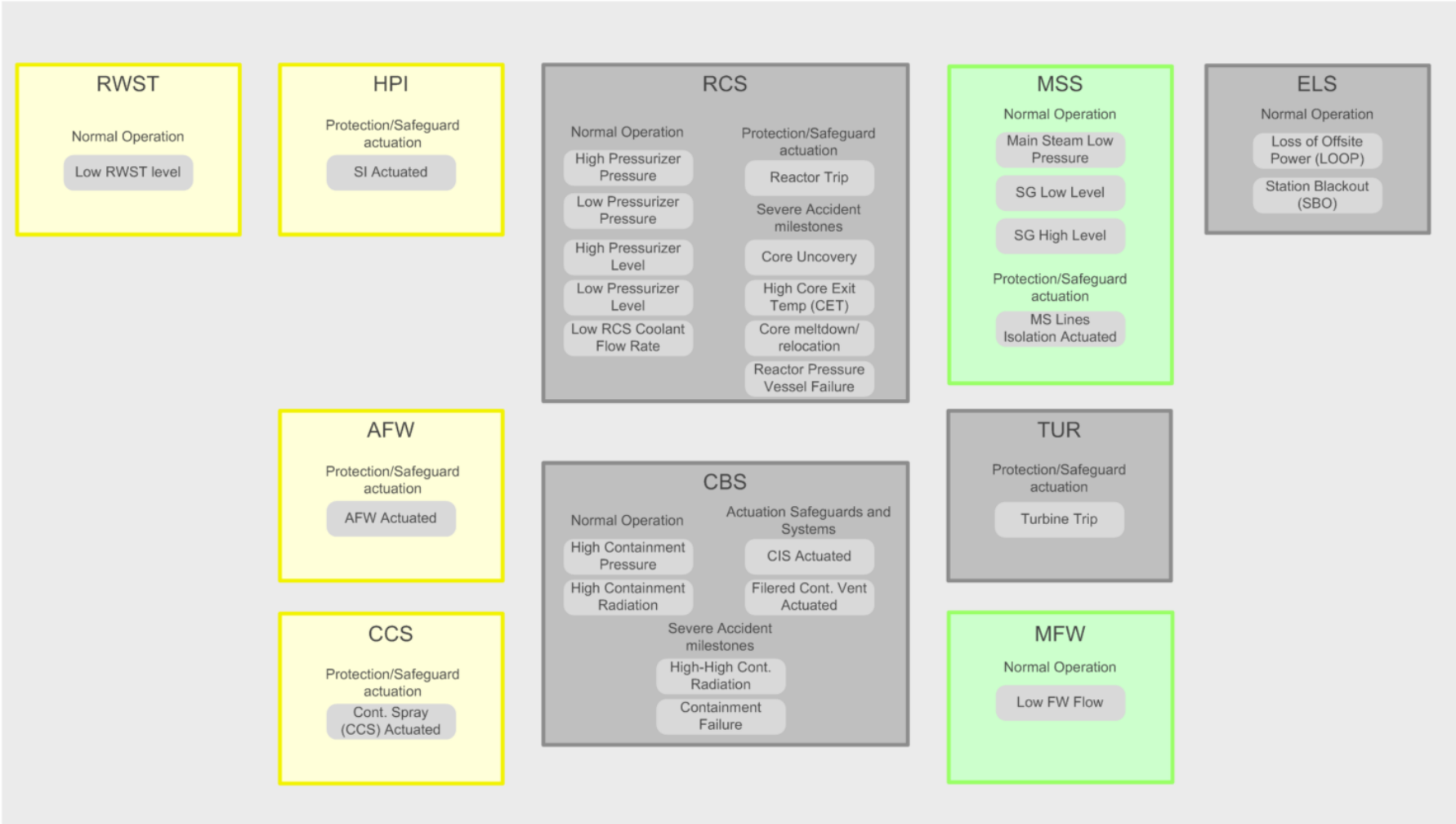



*Figure 13 Alarm Display*

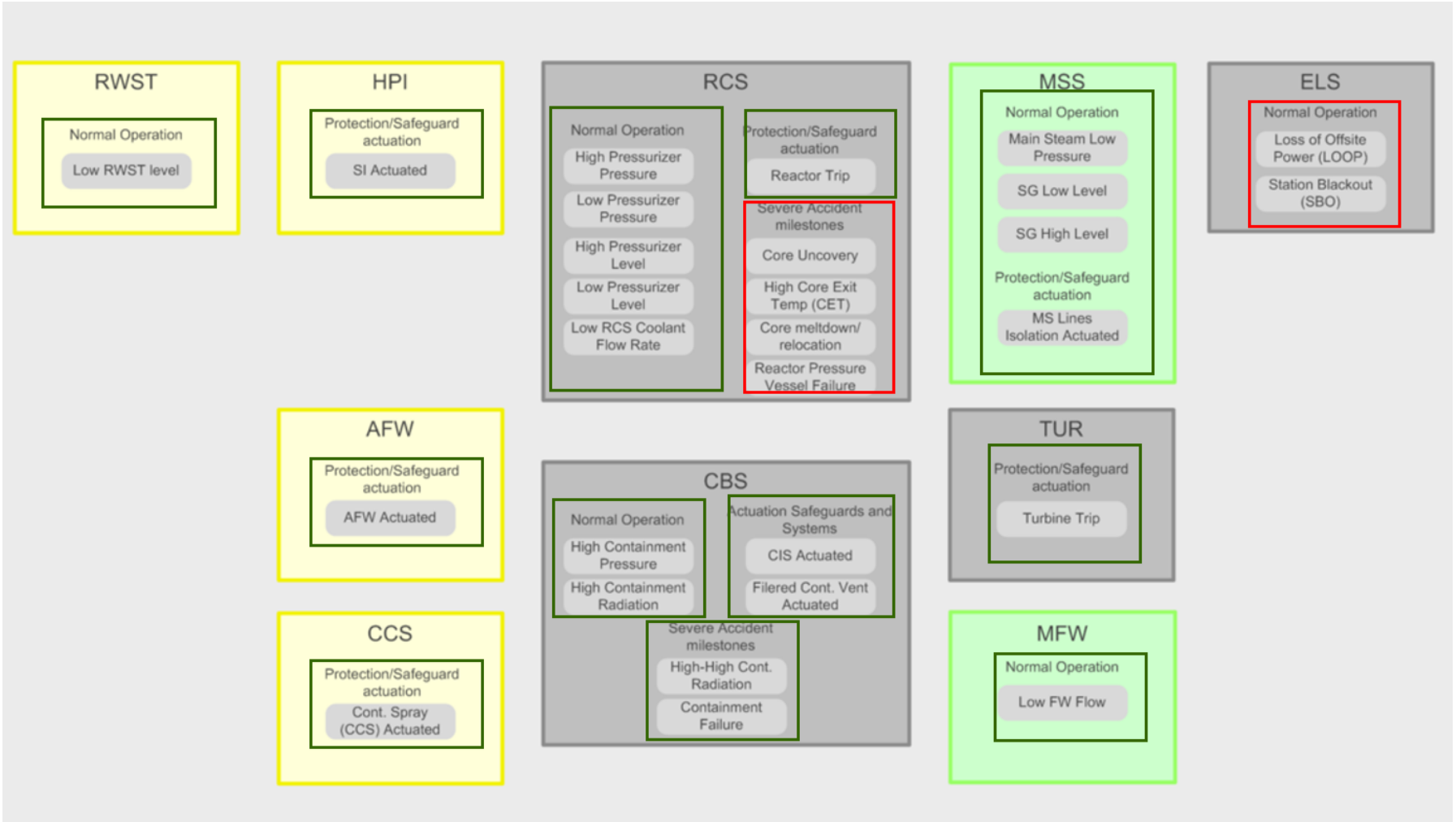



*Figure 14 Alarm Display - Variables distinguished*

# GUI Start-Up

To start the Graphical User Interface just run the corresponding application by double clicking on the icon:

This provides direct access to the main tool bar.

# GUI Closing

To stop the GUI application, use the button and the associated screens and applications will close.

# Display tree

To start the GUI for ASSAS, the user should click on the desired display from the tree.

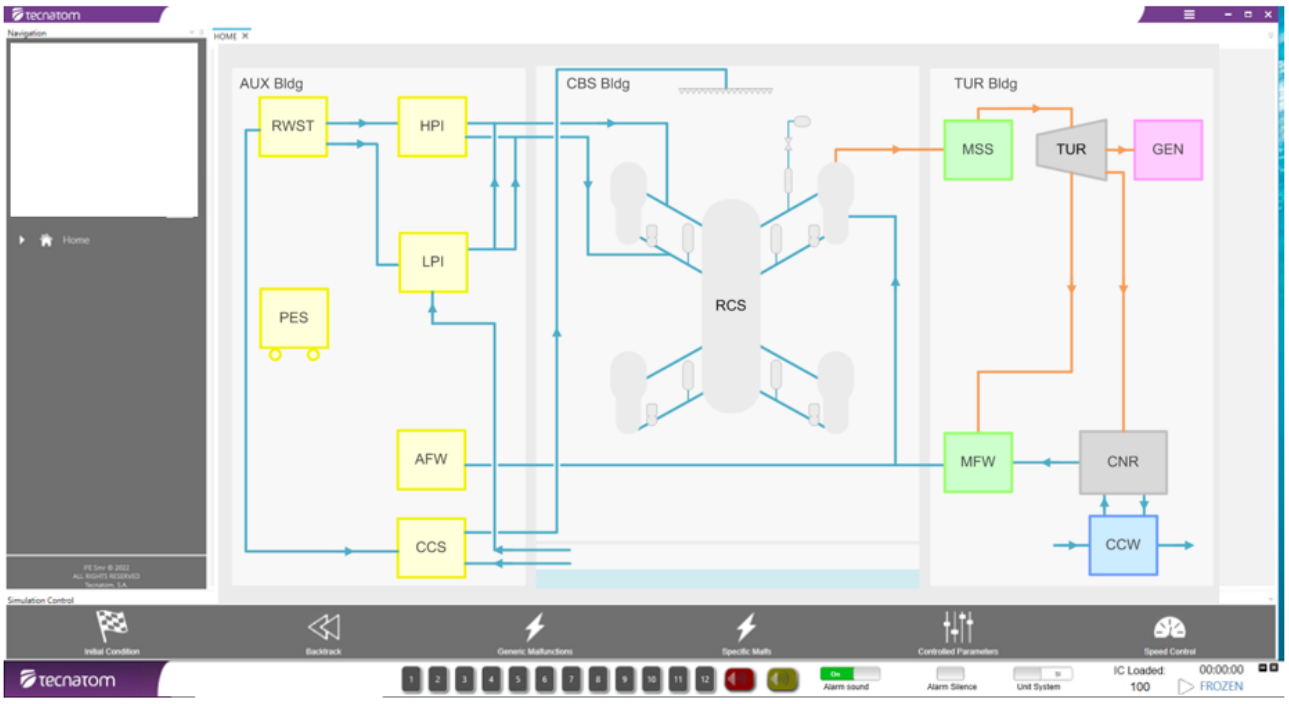



*Figure 151 GUI Example*

Communication between the operation displays and the simulation load is automatic, so no additional action is required. The values of the corresponding initial condition must be displayed correctly, and all the functionality of the application must be available.

# Simulation status

This area provides information about the simulation status and allows the operator to start or stop the execution of the simulation models.

The last IC loaded, and the simulation execution time are shown in this area:

# Start/stop

The access to the Running function is provided through the toolbar in the Diagram Viewer, selecting the icon in the Status Area.

The access to the Stop function is provided through the toolbar in the Diagram Viewer, selecting the icon in the Status Area.

When the simulation is stopped, the FROZEN text appears on the toolbar in the status area.




When the simulation is running, the text RUNNING appears on the toolbar in the status area.

Tool Bar includes high (red) and low (yellow) priority alarm icons.

When an alarm is activated, the red and/or yellow alarm icons will flash, until the alarms are acknowledged. When they are acknowledged pushing the acknowledge button, the alarm icons will stop flashing and will be kept highlighted in red/yellow while the alarm is active.

# Alarm sound

When an alarm is activated, an alarm sound is triggered. When the alarm is acknowledged, the alarm sound goes silent.

The alarm sound can be disabled from the slider on the Main Tool Bar, and it will remain disabled for the whole HMI session.

The temporal deactivation until the next trigger of alarms is possible by clicking the Alarm Silence button.

# Trend graphic

Every second the historical record function saves on disk the value of all the process variables included within the group called graphic variables. The Trend Graphic feature allows the graphical representation of these values against time.

The access is through the icon , located over the display tree or clicking in the different readouts.

This function allows the user to display an arbitrary number of Trend Graphic dialog windows and within the same dialog window it allows displaying an arbitrary number of graphic areas (grouped in tabs). Inside a graphic area an arbitrary number of curves can coexist.

Below is the Trend Graphic dialog window. This (empty) window is the one that appears when the function is accessed.

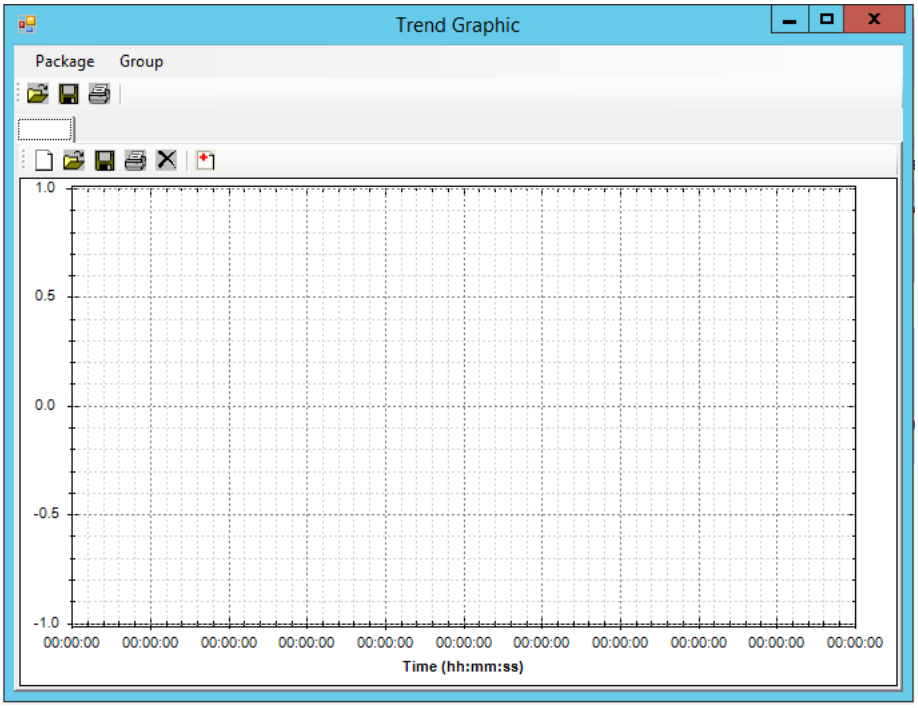



*Figure 16 2 Trend graphic dialog window*

The following areas are distinguished:

Main menu: gives access to most functions. These functions apply to the complete package or graphic group currently selected.

Package Toolbar: contains buttons that give access to the most common functions of the package as a whole.

Variable Group Tabs: area that contains all the groups of variables that make up the package and are grouped into different tabs.

Selecting a tab displays the corresponding graphic area. For each tab the following zones are distinguished:

Variable Group Toolbar: Contains buttons that give access to the most common functions of the group of variables being displayed.

Graphic area: shows the trend chart. In this area, the curves corresponding to the variables of the group are shown, as well as boxes that indicate the moment in which various actions were taken (actions of both student and instructor such as malfunctions, plant actions, flags such as vessel failure, clad rupture, corium slump into the lower plenum etc.).

This area has a context menu that contains access to all functions associated with the variable group. In particular, it allows access to the Properties dialog window of graphic groups. This dialog displays all the information about the groups of variables that make up the package. There is a main menu that gives access to all the functions of the dialog. This menu contains buttons that group actions on the entire package, on the group of variables being displayed, or on the variable being displayed.

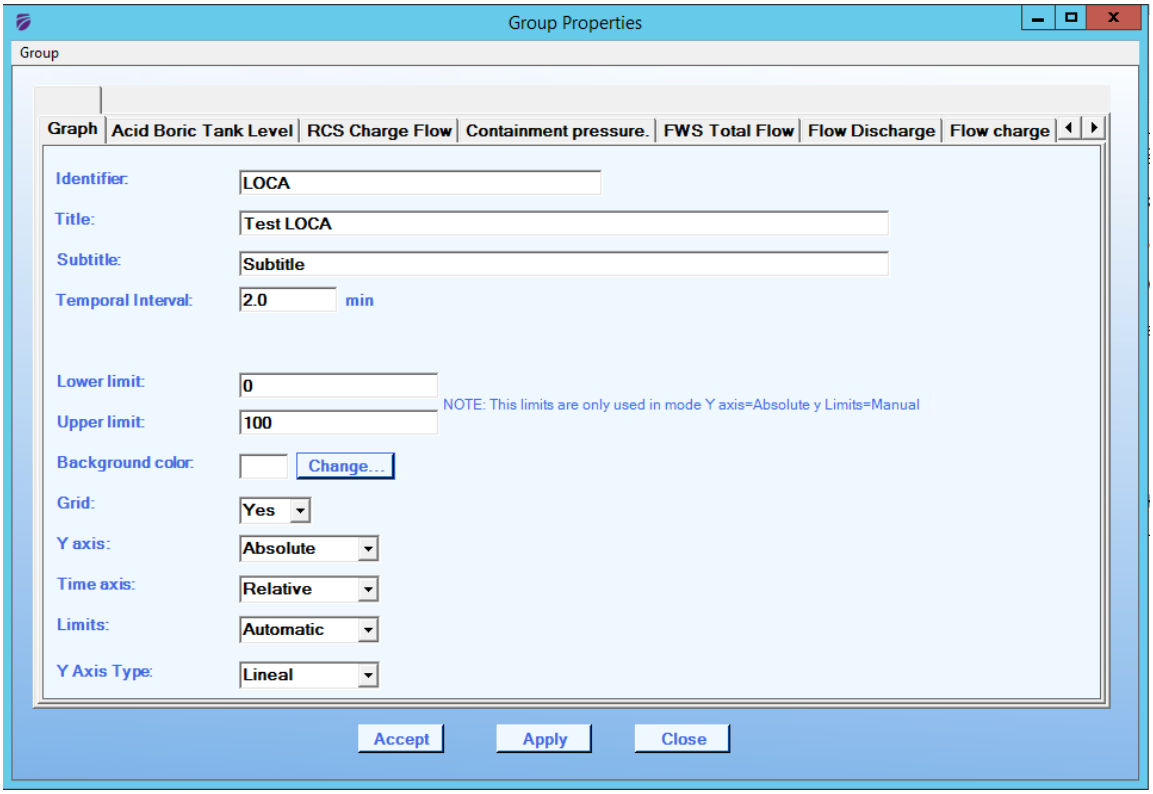



*Figure 17 3 Properties dialog window of graphic groups displayed information from a group*

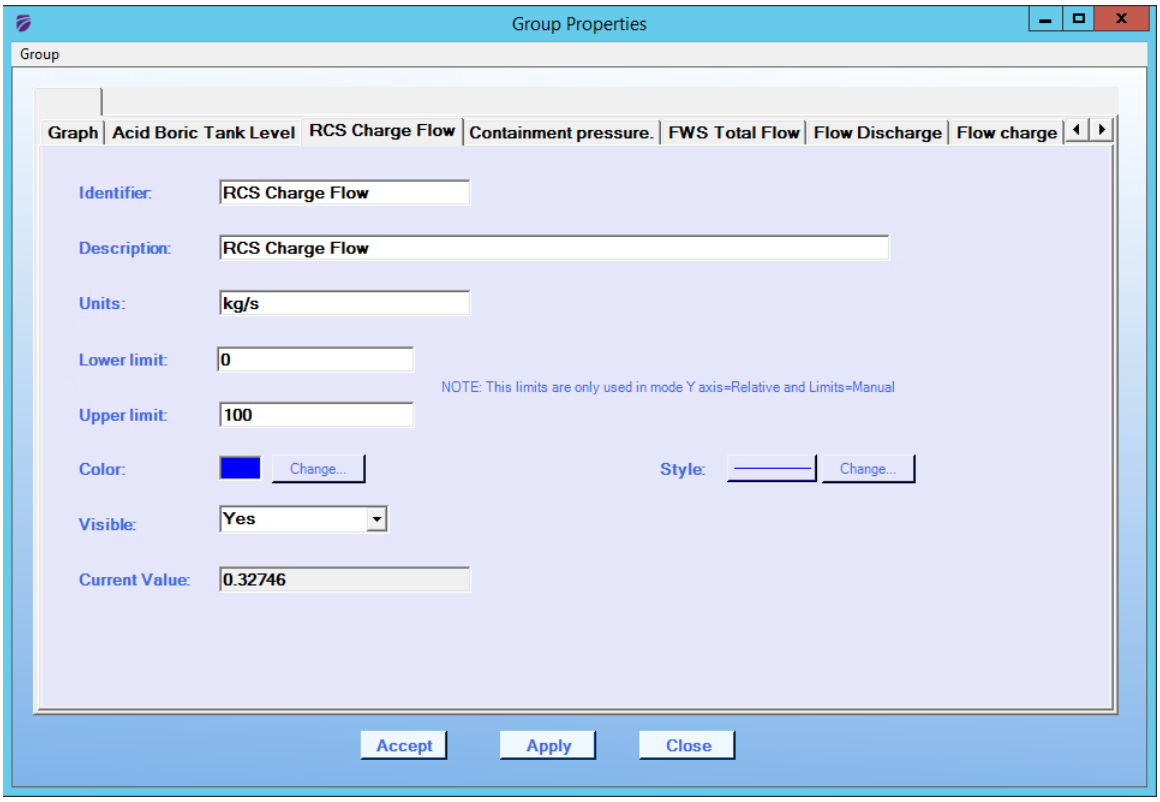



*Figure 18 4 Plot group properties dialog window displays information for a variable*

# Numerical values and historical record

This function manages the list of historical record variables. The values of all the variables in this list are recorded every second creating the so-called Historical Record File. This allows to visualize trend graphs in real time as well as the analysis after the end of the simulation session.

This function also allows:

- View the list of variables that are being recorded.
- Add variables to the group of variables that are recorded by default.
- See in real time the instantaneous value of the variables.

The main dialog window of this function is:

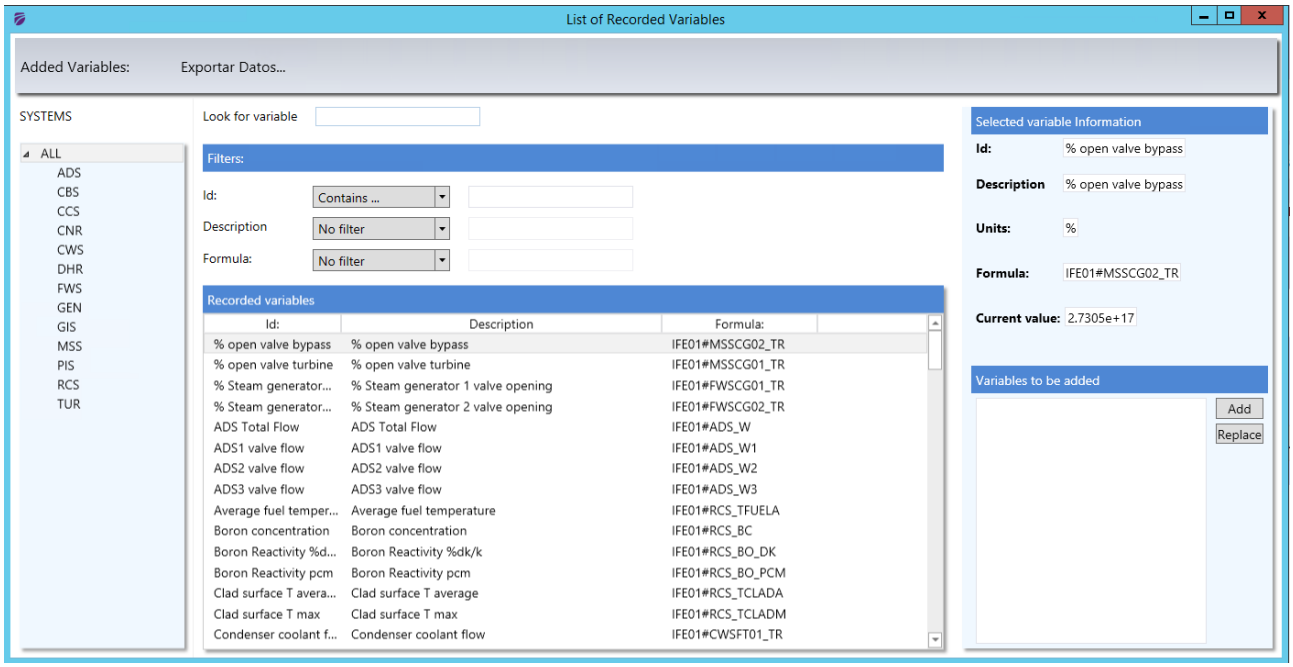



*Figure 19 5 Numerical values and historical record dialog window*

Which is constituted by the following areas:

- Main menu.
- System Tree
- Variable List: Displays the list of variables that are being recorded periodically.
- Area with information of the selected variable.
- Area that allows you to add variables to the list
- Plot a variable in the list

Drag a variable to a previously opened trend chart.

To search for a variable by name, type the name of the variable you want to search in the text field associated with the Look for variable label. As the name is typed, the list is updated to display the variable with the name most similar to typing.

To filter the list of variables by system, select a system or subsystem in the System Tree. Only variables belonging to that system or subsystem will be displayed in the list.

# General properties of the instructor station

Most of the functions of the IS have a very similar appearance and distribution of information. For example:

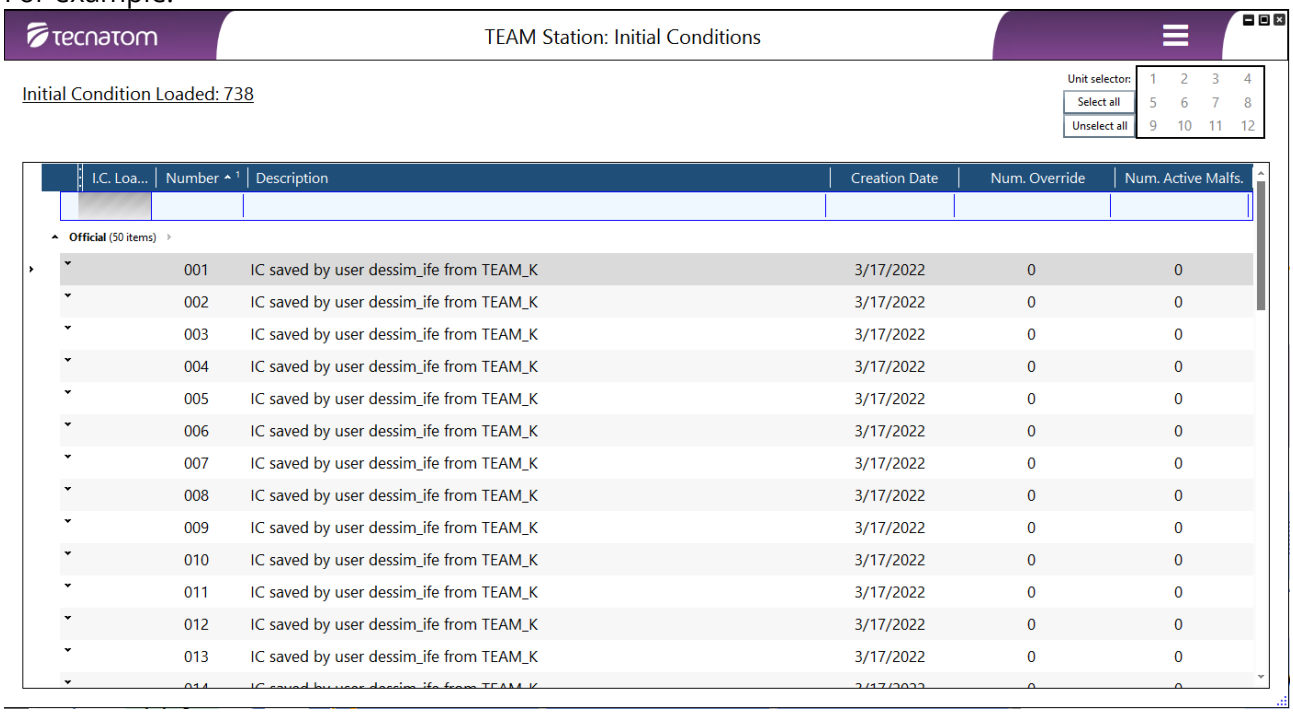



*Figure 20 6 Initial Condition window*

In general, they present:

- An upper toolbar that includes:
  - Westinghouse logo
  - Title with the name of the Instructor Station function
  - Menu type 'hamburger' that gives access to functionality that affects the entire window (it is located in the upper right part of the dialogs)
  - Minimize, maximize, and close window buttons
- One or more tables

- Properties and general operation of tables
- Filter by different values
- Filter by text
- Sort by columns

# Load and record initial condition

An Initial Condition (IC) is a set of values of the variables needed to initialize the simulator's mathematical models at a given state of the plant. Before starting any simulation session, the simulator must always be initialized in a certain starting situation.

This function comprises 2 types of operations:

- Start the simulation from an Initial Condition: LOAD function.
- Save an Initial Condition for later loading: SAVE function.

The system administrator will configure the maximum number of initial conditions as well as the different groups to distribute the initial conditions. If necessary, the system administrator will assign them an access key to prevent their accidental recording. There are at least two groups of initial conditions:

- Official: initial conditions protected with access key during the recording.
- Free: initial conditions for general purpose, with no access protection during recording

The access is through the toolbar in the Diagram Viewer, selecting the icon

.

The main dialog of the function is:

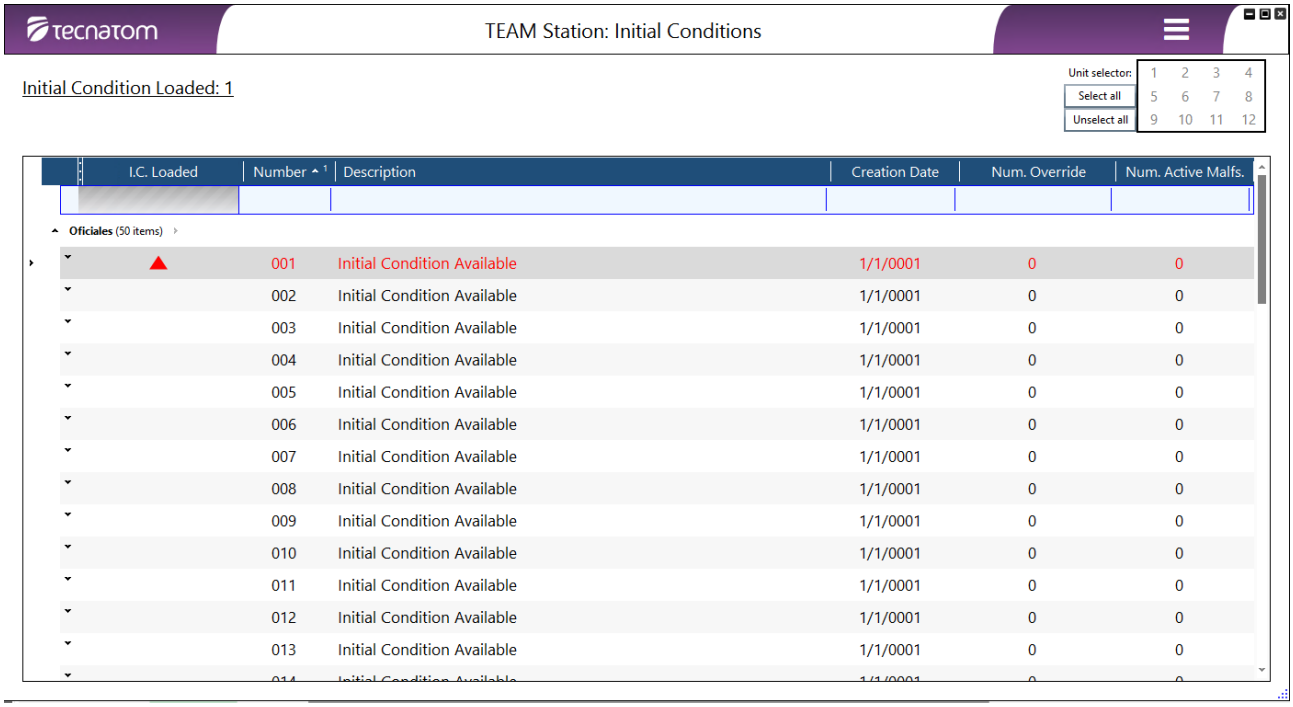



*Figure 21 7 Initial Conditions dialog window*

Dialog content:

- A main menu .
- The list of initial conditions grouped as specified in the conFiguretion file. Each record displays the following columns:
  - IC Loaded: indicates the initial condition loaded by a red triangle.
  - Number: initial condition number
  - Description: description of the initial condition. This text is defined during the salvage process of an initial condition.
  - Creation Date: date the initial condition was generated.
  - Num. Override
  - Num. Active Malfs.: number of active malfunctions in the initial condition.

# Backtrack

This function allows you to restart the simulation in any of the previous states of it, using the so-called backtrack records.

A backtrack record is a copy of the state of the simulation variables at any given point in the simulation session. The "history" of the sessions is recorded in records within a circular data file (Historical Record of States file). The capacity of such a file depends on the conFiguretion of the simulation platform.

The access is through the toolbar in the Diagram Viewer, selecting the icon

.

The main dialog of the function is:

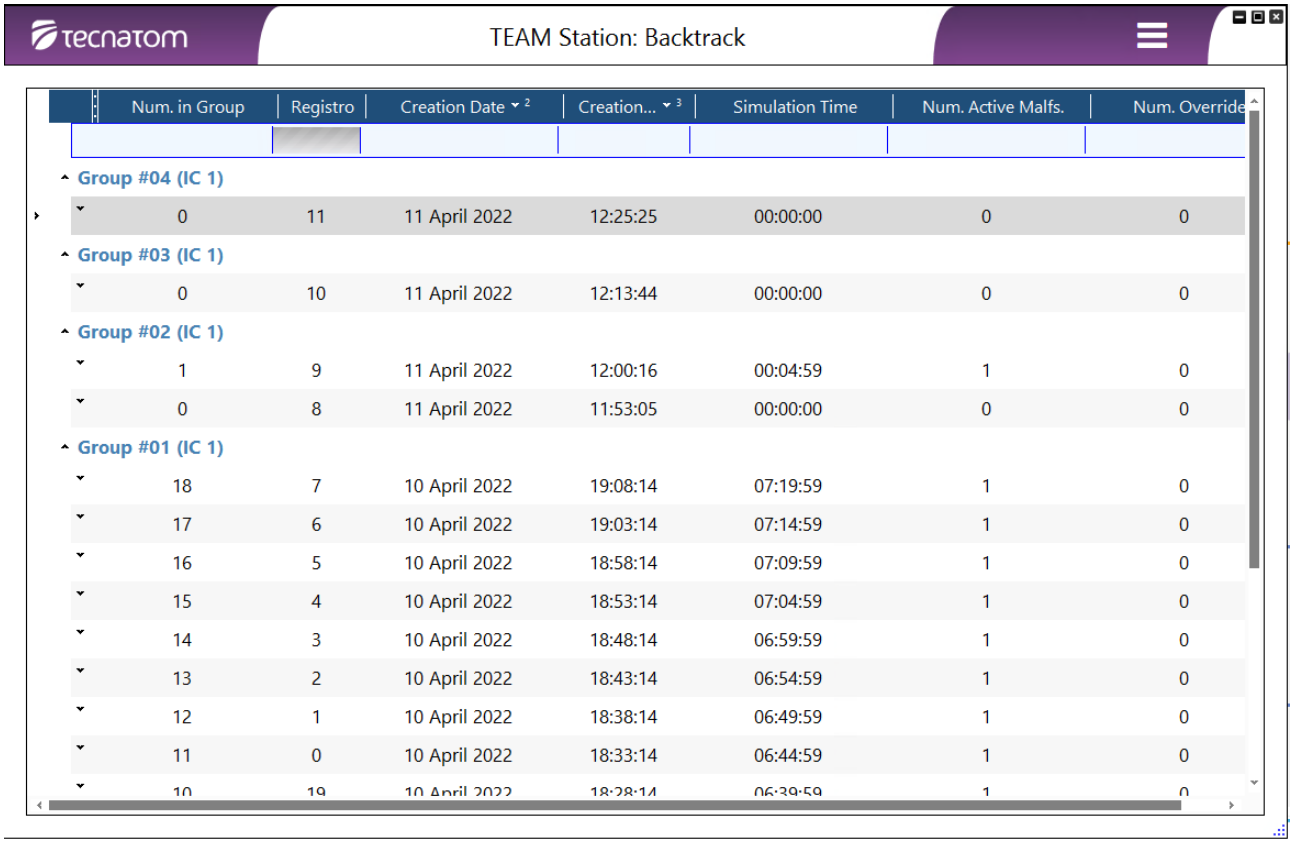



*Figure 22 8 Backtrack dialog window with all groups displayed*

Dialog content:

- A main menu
- The list of rollback records grouped by initial condition. Each record displays the following columns:
  - No. in Group: sequential number of the record within a group
  - Logging: sequential number of the record within the log file
  - Creation date: date the record was generated
  - Creation time: time the record was generated

- Simulation Time: the simulation time at which the log was generated.
- No. Instr. Altered: number of instruments altered at the time of recording the record.
- No. Malfs. Active: number of active malfunctions at the time of recording the log.

# Generic malfunction

This function allows to alter the normal development of a session by introducing component failures, breaks, etc., in the simulated systems. Generic malfunctions affect components of the same type. The user can load several malfunctions.

IThe access is through the toolbar in the Diagram Viewer, selecting icon


The main dialog of the function is:

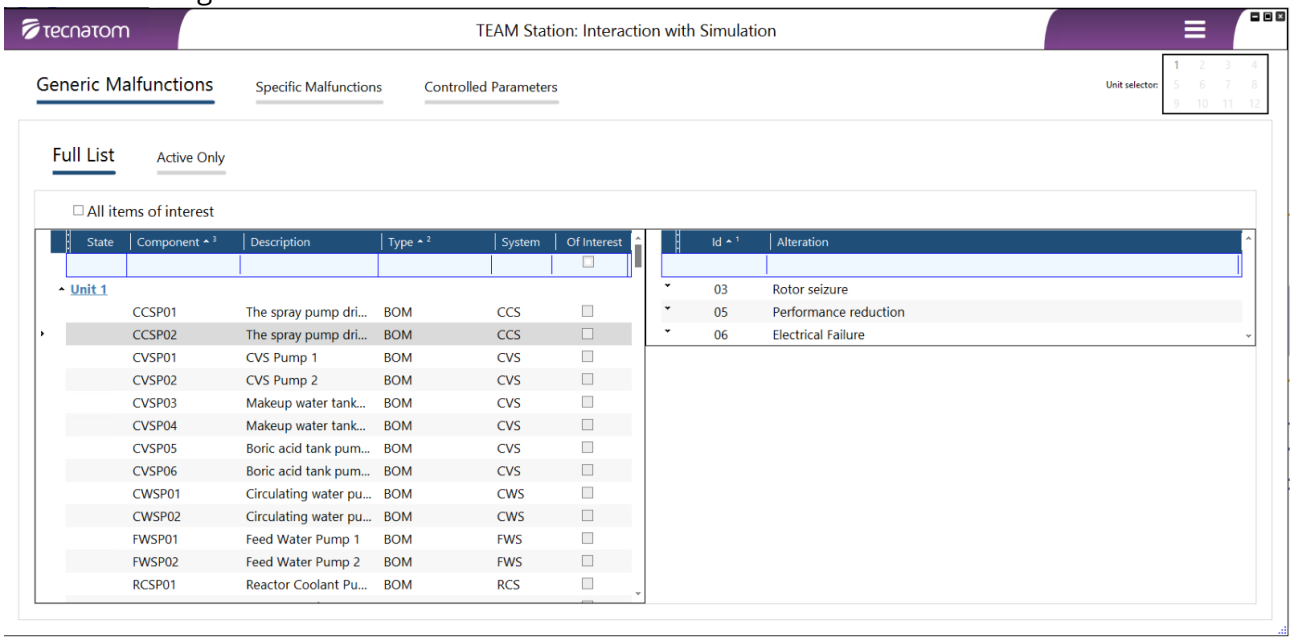



*Figure 23 9 Generic malfuncions dialog window*

Dialog content:

- A main menu
- Two tabs that display the full list of malfunctions (Full List) and the list of active malfunctions (Active Only)
- A table with the components of the plant that have generic malfunctions:
  - State: Graphical indication of the status of the component (if it has any active malfunctions)
  - Component: Component IDENTIFIER

- Description: Component Description
- Type: Component Type
- System: System to which the component belongs.
- Of interest: If it has ever been activated/visited.

A table with the alterations of the selected component:

- ID: Identifier of the alteration
- Alteration: Description of the alteration

The generic malfunctions activated are displayed in the Instructor Station.

The user interface of the Generic Malfunction Schedule dialog is:

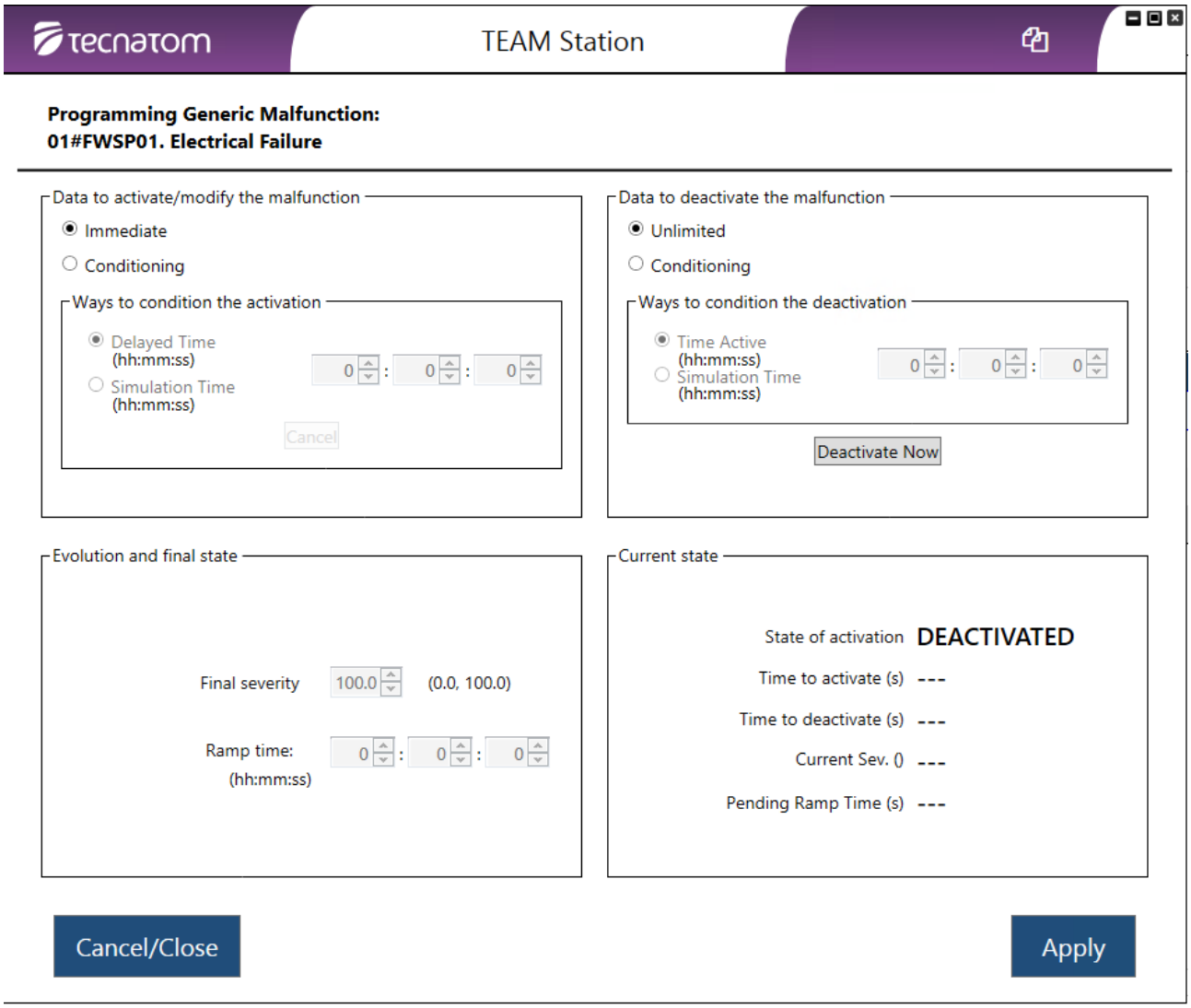



*Figure 24 10 Generic malfunction dialog window*

Malfunctions can be activated in different ways:

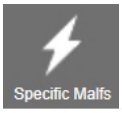
- Immediate activation: there is no condition for activation. It will be activated as soon as requested.
- Conditioned:
  - Delayed Time: The malfunction will be activated when the specified number of seconds has elapsed.
  - Simulation Time: the malfunction will be triggered when the simulation time matches the specified time.

This dialog, in addition to allowing you to schedule the activation/deactivation of the malfunction, contains an area with the current state of the malfunction:

- State of activation: DEACTIVATED, PENDING, RISING SEV, FINAL SEV.
- Time to activate: Time (seconds) remaining for the malfunction to be activated automatically
- Time to deactivate: Time (seconds) remaining for the malfunction to be automatically deactivated.
- Current sev.: Current severity of the malfunction
- Pending Ramp Time: Time remaining for the malfunction to reach its maximum programmed value.

# Specific malfunction

This function allows to alter the normal development of a session by introducing component failures, breaks, etc., in specific parts of the simulated systems such as SBO, pipe breaks, isolation falures... Specific malfunctions affect individual components, not all of them in the same class.

The access is through the toolbar in the Diagram Viewer, selecting the icon 

.

The main dialog of the function is:

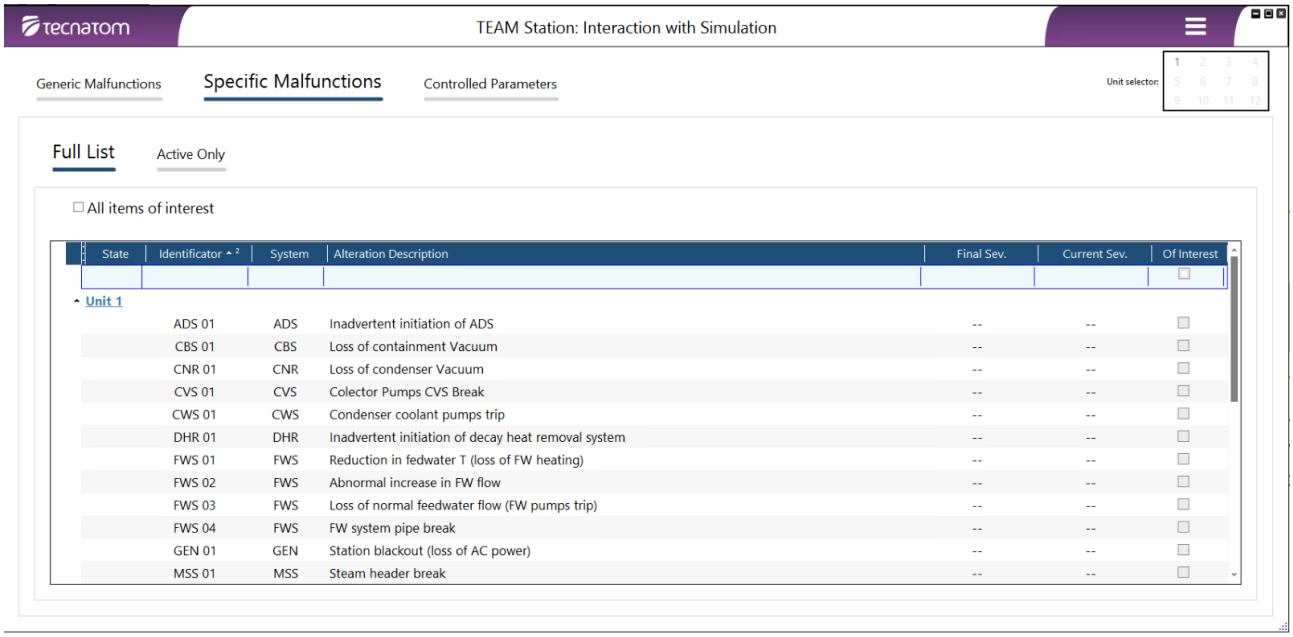



*Figure 25 11 Specific malfunctions dialog window*

Dialog content:

- A main menu
- Two tabs that display the full list of malfunctions (Full List) and the list of active malfunctions (Active Only)
- A table with the plant components that have specific malfunctions with the following columns:
- State: Graphical indication of the status of the component (if it has any active malfunctions)
- Identifier: Id of the malfunction
- System: System to which the component belongs.
- Alteration Description: Description of the alteration
- Final Sev.: Scheduled Final Severity

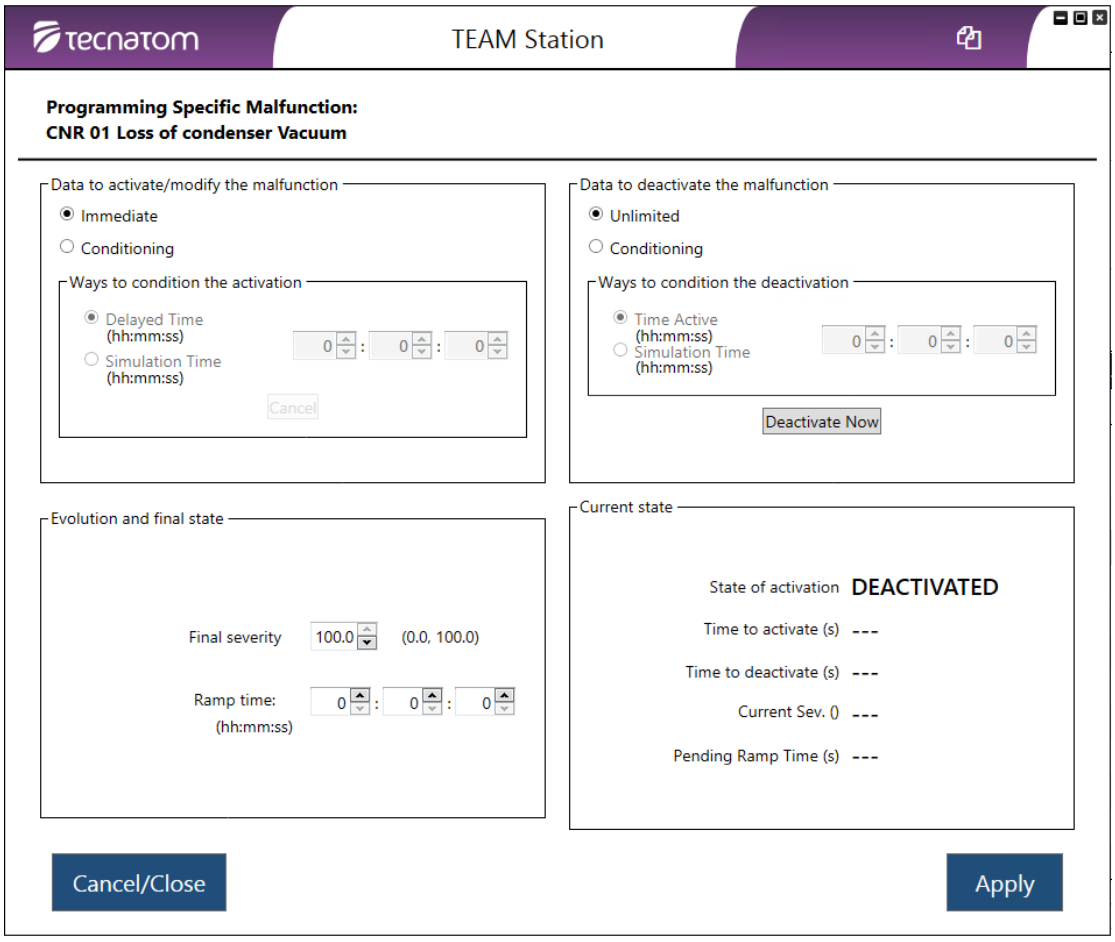



*Figure 2615 Malfunction example*

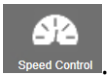
Malfunctions can be activated in different ways:

- Immediate activation: there is no condition for activation. It will be activated as soon as requested.
- Conditioning:
  - Delayed Time: The malfunction will be activated when the specified number of seconds has elapsed.
  - Simulation Time: the malfunction will be triggered when the simulation time matches the specified time
- This dialog, in addition to allowing you to schedule the activation/deactivation of the malfunction, contains an area with the current state of the malfunction:
  - State of activate: DEACTIVATED, PENDING, RISING SEV, FINAL SEV.
  - Time to activate: Time remaining for the malfunction to be activated automatically

- Time to deactivate: Time remaining for the malfunction to be automatically deactivated
- Current Sev.: Current severity of the malfunction
- Pending Ramp Time: Time remaining for the malfunction to reach its maximum programmed value.

# Execution speed control

Allows the user to increase the execution speed of some simulation models (fast time) or decrease the speed of all (slow time).

The access is through the toolbar in the Diagram Viewer, selecting the icon 

.

The main dialog of the function is:

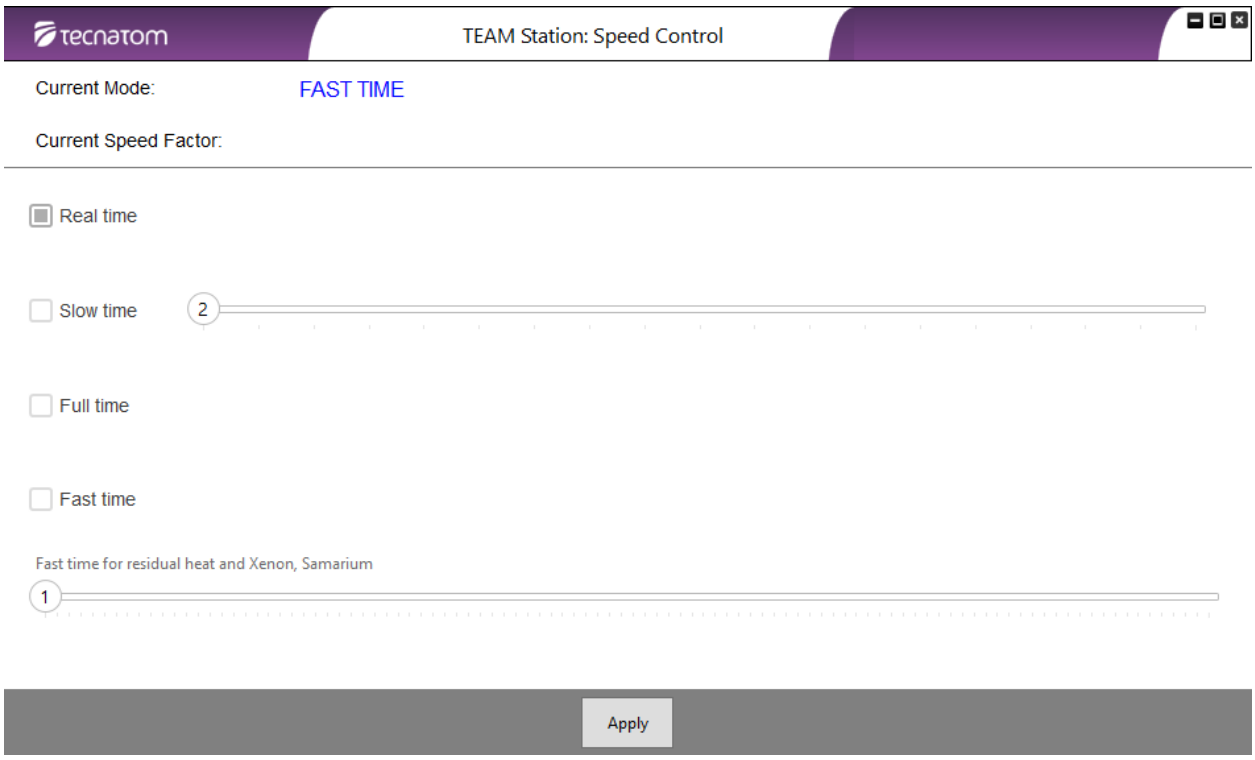



*Figure 27 Execution Speed Control dialog window*

Dialog content:

- An area (top) that contains the current mode (Real Time, Fast Time, or Slow Time) and the current speed factor

- Four checkboxes that allow you to activate each of the four possibilities: real time, slow time, full time and fast time for residual heat and Xenon and Samarium (not available in ASSAS simulator since there is no neutronics model).
- Sliders to be able to adjust the speed factor, if needed
- A button to apply the changes

# Virtual Reality

VR would be accessible through the main simulator GUI.

The objective of this product is to provide 3D animated and interactive visualizations of the core, reactor vessel, reactor coolant system, steam generators and containment building to give the user an additional insight into the behaviour of a four loop PWR NPP during severe accident scenarios. The visualisation has an educational purpose but it cannot be considered as a quantitative representation of the phenomenology, which is not known and calculated with such a level of details.

The main functionalities are the visualization through Virtual Reality (VR) images of the main physical parameter values (temperature, void fraction, pressure, hydrogen concentration, water level, etc.) provided by the HMI and the simulation information in the containment area, the primary circuit and different sections of the reactor core.

The VR is composed of the containment area, the primary circuit, the detailed reactor core and partially the secondary circuit with steam generators. The main components must have open sectors allowing to see the inner parts and structures of these components.

The model should include several visualization layers allowing to shift from the outer layers to inners layers, mainly by transparent boundary walls and open sectors. It will also allow to hide the outer layers and focus the virtual cameras on the internal components.

There will be different cameras (with a camera mode that allows three dimensional movements around the focused component and zoom in or out on it) depending on the focused component and visible layers: main camera focused on containment area, second camera providing a closer vision focused on primary circuit (usually with hidden containment walls). Finally, it should be interesting to have a camera mode allowing the movement throughout the full scene (free camera).

According to the described scene, the graphic model will consist on the representation of the containment building of a four loop PWR NPP, the necessary information/documentation to build the 3D representation will be available to build up the model conFiguretion of the vessel, reactor core, steam generators, pressurizer, and pumps for each loop, as well as the main pipes of the

primary circuit and some supplementary ones of the secondary one. Only public data can be used in the project, so the representation is not supposed to be a perfect replication of a real plant.

Different sections of the whole volume inside the containment building and primary and secondary system components will be shown according to dynamic colour scales representing the calculated values and evolution of selected parameters.

These volumes/objects/spaces will be divided into connected cells that define the colour continuity flows of the variables represented in each of them (nodal model).

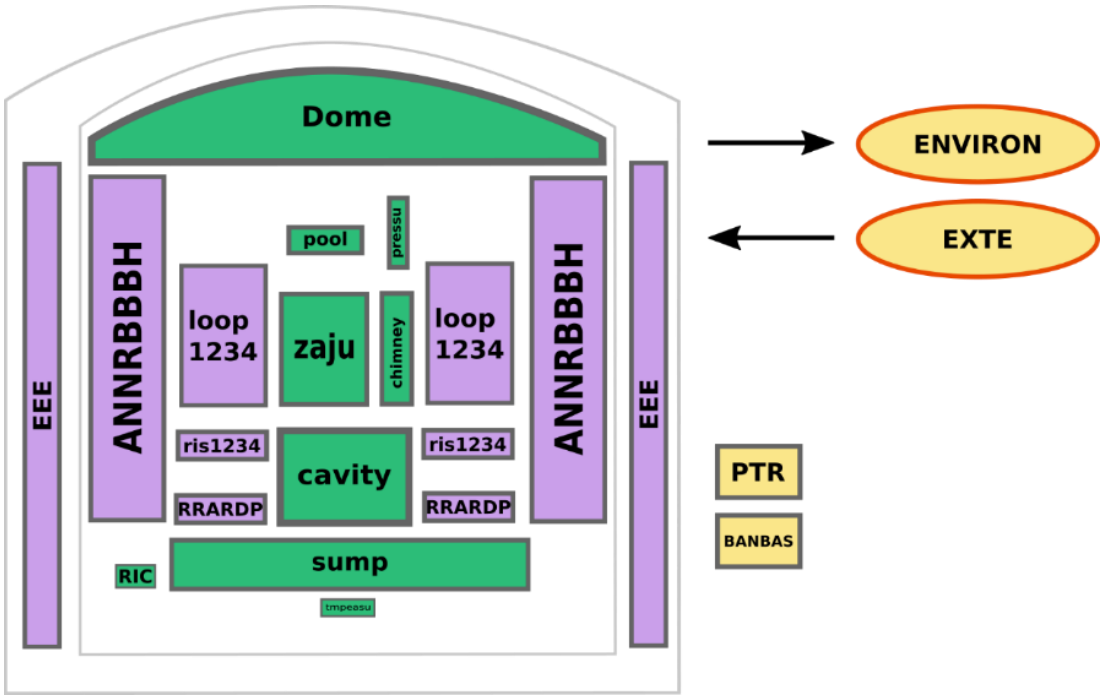



*Figure 28 ASTEC containment nodalization*

The VR must include two main features: first, a realistic animated representation of the accident involved phenomena and physical behaviour of components through:

- Components inside views
- Transparent representation
- Hiding layers: Containment > Primary circuit > Reactor Core
- Physical fidelity

The second feature is the representation of 3D model slices coloured according to the calculated local values of the user selected simulation parameters. For the containment area, the following parameters should be represented: (using a sliced solid space according to the nodal model with coloured transparency)

- Pressure

- Temperature
- H2 concentration
- Radiation rate

For the primary circuit: (using a sliced solid space inside the primary circuit and according to the nodal model with coloured transparency)

- Temperature
- Void fraction

For the reactor core: (using a sliced solid space inside the reactor core and according to the nodal model with coloured transparency)

- Void fraction
- Fuel temperature
- Water level

For each cell of nodal model, the application should allow selecting the calculated variables to represent and the way they are shown (colour scale, limits, etc.).

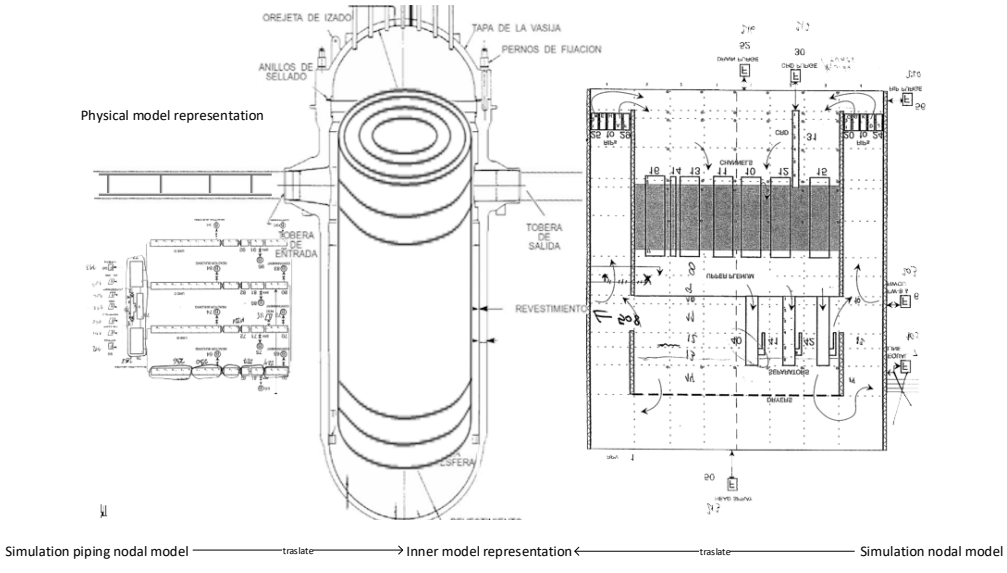



*Figure 29 16 Core nodalization example*

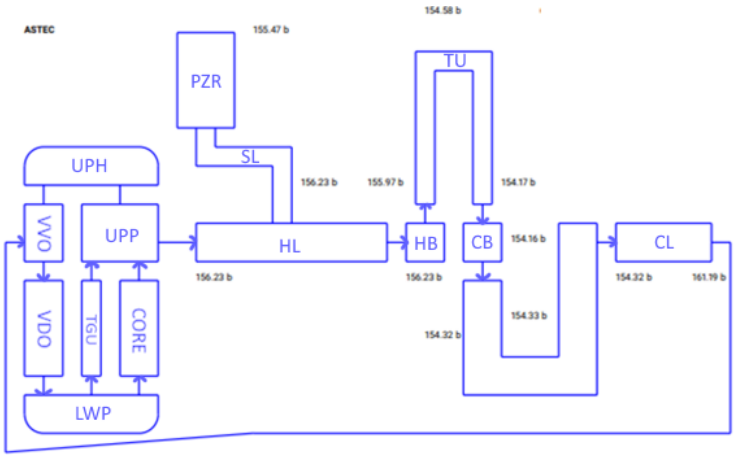
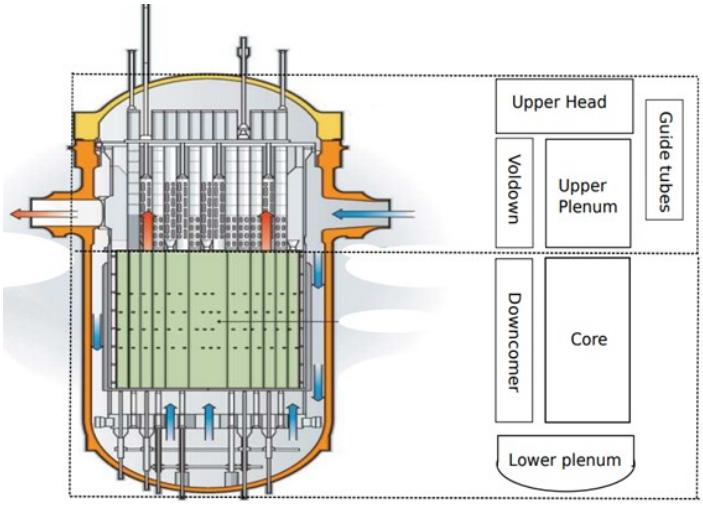
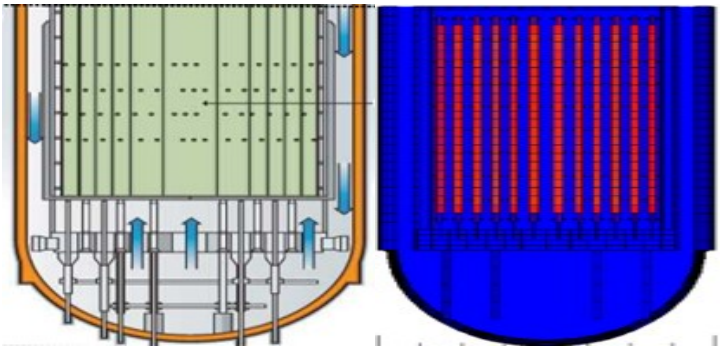



*Figure 30 17 RCS nodalization detailed*




- Primary circuit is composed of (volume/pipe):
  - Downcomer volume (VDO)
  - Reactor core control guide tube (TGU)
  - Upper plenum (UPP)
  - Upper vessel head (UPH)
  - Hot leg (HL)
  - Surge line (SL)
  - Pressurizer (PZR)
  - Steam generator hot box (HB)
  - Steam generator tubes (TU)
  - Steam generator cold box (CB)
  - Cold leg (CL)
  - Lower plenum (LWP)
  - Voldown volume (VVO)
  - Core volume (CORE)



- Definition of intact geometry:
  - CHANNEL,
    - Number of channels: (radial discretisation)
    - Number of axial levels: (axial discretisation)
  - MACR (baffle, barrel, fuel rod, fuel cladding, control rod, ...)
  - Lower vessel plenum
  - Vessel wall discretisation
  - Lowerplenum wall discretisation

Depending on the severity of the malfunction of cold leg break, a steam flow will start filling the free space internal to the containment and which is not sumped with water.

In case the containment layer is not shown, this space filled with steam will not be displayed and only the steam flow coming out the pipe break will be represented.

When the containment spray is actuated according to the simulation model calculation, water jets from the nozzles of several concentric pipes in the top of the containment is represented.

Such effect will only be visualized if the containment layer is shown.

Core uncovering will be represented by the liquid water level becoming lower the core top elevation. As water level continues to decrease, steam will replace the liquid water in the uncovered section, and consequentially, heat removal from the core upper parts will be degraded and fuel temperature will increase.

The fuel temperature increase will eventually cause the fuel melting and downward relocation as corium, finally reaching the vessel lower plenum where it accumulates.

This evolution will be represented in the model by the liquid water decreasing level, core volume emptying as it melts and relocates and corium accumulation in the lower plenum.

There are 3 kinds of interfaces according to the origin or information type:

- VR to simulation engine bridge
- ConFiguretion 3D / model variable assignement :
    - Simulation calculated variables, which should be defined in a dictionary including the variables to be shown to the VR from simulation engine bridge.
    - Control variables also obtained from the simulator calculations and including component status.
    - Malfunctions signals indicating the status for specific malfunctions.

Following a summary of the sets of variables from the simulator calculation (plus a number of estimated variables):

- Containment building: 18 volumes * 4 variables/volume = 72 variables
- Primary and secondary circuits: 158 volumes * 2 variables/volume = 316 variables
- Core, including liquid water level: 100 volumes *3 variables/volume = 300 variables/volume
- Core degradation: 75 variables
- Malfunctions: 4 variables
- Containment spray: 4 variables

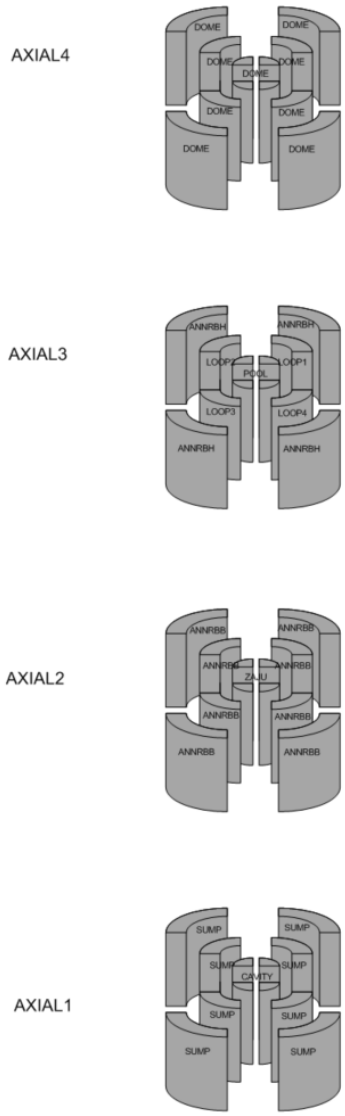



*Figure 31 18 VR containment nodalization*

The product will work as a client for the simulation and it will be developed compatible with windows system and .Net application. The final product will embed the VR to simulation engine bridge software provided by Westinghouse and it will use it to communicate with the simulation engine in order to obtain all the required information (variables, malfunctions, status of simulation, etc.).

Application will be conFigureble using a proper conFiguretion file and it can be run on any windows machine compliant with 3D minimum requirements.

# References

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