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# MELCOR and Level 2 PRA State of the Art and State of the Practice

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**Focus of Presentation:**

- On technical issues (physical phenomena) and on recent advances in MELCOR uses and in the Level 2 PRA State of the Art (SoA)
- Specifically, on SoA issues that are not yet the general State of Practice (SoP)

# Variability of MELCOR Results

- MELCOR exhibits a high degree of variability particularly in the core package where a minor change can lead to a substantially different accident progression.
- Many of these variabilities can be traced to the threshold or step-change modeling of many of the MELCOR phenomena and parameters. These variabilities have brought about a new emphasis on multiple MELCOR accident progression analyses for a single accident sequence in order to assess accident progression uncertainties, as opposed to the traditional single case "best estimate" accident progression analyses with uncertainties assessed on the basis of expert judgement.
- This combined with the slower running MELCOR 2.2 increases the time and effort required for the accident progression tasks, such as for a Level 2 PRA.

# Hydrogen Combustion

- The general State of Practice in PRA is to model in MELCOR and MAAP the Hydrogen to ignite at a fixed concentration, typically 6%, 8% or 10%, if the $O_2$ concentration is >5% and the Steam concentration is <53%.
- These burns do not challenge the containment.
- These burns consume the released hydrogen before it can accumulate to levels that would challenge the containment.
- This practice may be OK for the best estimate $H_2$ behavior, but it is not useful to assess uncertainties.
- The more recent practice is to suppress all $H_2$ and CO burns and to use the peak Adiabatic Isochoric Complete Combustion (AICC) pressure to determine when and under what conditions the worst $H_2$ burn could occur.
- This also allows a determination of whether conditions for Flame Acceleration (FA) and Deflagration to Detonation Transition (DDT) could develop.
- This provides a more informed basis for estimating the uncertainties for $H_2$ burns.

# Dynamic Limits for Hydrogen Flame Acceleration (FA) and Deflagration to Detonation Transition (DDT)

- If H2 burns are suppressed it is not uncommon for FA and DDT conditions to develop in an accident sequence at least locally.
- Report NEA/CSNI/R(2000)7 “Flame Acceleration and Deflagration-to-Detonation Transition in Nuclear Safety” was developed by an international expert group assembled by the NEA.
- NEA/CSNI/R(2000)7 has shown that the FA and DDT limit curves are highly dynamic, depending on the local containment pressure, temperature and steam content.
- These dynamic limits can have a substantial impact on when and at what condition and for how long FA and DDT conditions could occur.
- Modeling these dynamic FA and DDT limits requires significant source code changes in MELCOR or MAAP.
- Determining the limiting conditions for FA and DDT has become more complex than just looking at a hydrogen concentration curve.
- Note: The limits for Hydrogen Flammability (HF), the old Moffett-Shapiro Diagram, are also dynamic, but to a lesser extent.

# Local Hydrogen Behavior

- Hydrogen emerges from the RCS at very specific locations, for example from the PORVs into the Pressure Relief Tank (PRT) in a PWR or from the lead Safety Relief Valve (SRV) into the Suppression Pool of a BWR or into a flooded containment.
- In such a sequence the steam in the discharge would condense in the pool and concentrated $H_2$ would emerge at the top of the pool.
- At the point of emergence from the pool local $H_2$ concentrations in the FA and DDT range can occur.
- Tracking the movement and the local concentrations of Hydrogen in such situations requires either a CFD analysis or a very detailed containment nodalization with on the order of 50 to 100 Control Volumes.
- If local conditions for FA and DDT can develop they should be considered at least as part of the uncertainty analysis. MELCOR currently does not have FA and DDT models.
- The main question is: Can a local DDT occur and could it challenge the containment integrity locally. There are currently no generally accepted methods for this assessment.

# Passive Autocatalytic Recombiner (PAR) and Passive Igniters (PI)

- PARs are installed in many BWRs and PWRs in Europe, in addition to the active Igniters.
- PARs are passive but slow acting, Igniters require DC power.
- In a Fukushima type total loss of AC and DC power sequence traditional Igniters would not be available.
- Fast acting passive igniters could help.
- Fast acting Passive Igniters (PI) have now been developed and are being installed at least at one plant in Europe.
- The limiting feature of PIs is that hey need some time to activate and that they will deactivate, compared to the instant and continuous readiness of active Igniters.

# Accident Progression Analyses SoA

- The current Version of MELCOR is MELCOR 2.2. MELCOR 1.8.6 is no longer considered SoA because of significant improvements in MELCOR 2.2 and Sandia no longer supports MELCOR 1.8.6. MELCOR is widely used by National Laboratories and NRC Contractors in the US and throughout the rest of the world.
- The current Version of MAAP is MAAP 5.04. MAAP 4 is no longer considered SoA because of significant improvements in MAAP 5. MAAP 5 is widely used in the US and in Europe and throughout the rest of the world.
- SOARCA – State of the Art Reactor Consequence Analysis – was sponsored by the USNRC. It is the major recent Level 2 Activity in the US:
  - SOARCA is mainly specific to MELCOR.
  - SOARCA best practice recommendations are time consuming to implement.
  - Some SOARCA recommendations require source code changes in MELCOR.

## Severe Accident Management Guidelines (SAMGs) and Training

- All western Nuclear Plants have introduced SAMGs with various degrees of formalized procedures and training for operators and that are linked to the Emergency Procedures (EP) preceding the SAMGs. The operators are required to follow the EPs and linked SAMGs when an initiating event occurs.
- Some EP/SAMGs are set up like flowcharts with trigger entry points and a roadmap through the EP/SAMGs with branching based on physical conditions. Operators are instructed to iterate through these procedures until the plant condition is stabilized.
- An important question is: Are the current methods for analyzing Human Errors (HRA) in PRAs, which were developed before the introduction of formalized SAMGs, still consistent with the SAMG instructions and training?
- For example during 75% of the time there are only a handful of operations-qualified staff on-site (evenings, nights, weekends, holidays). For many important accident sequences coming out of full scope PRAs core damage may already be in progress when the crisis team becomes effective.
- Timing studies with the EP/SAMGs modeled as flowcharts linked to the running MELCOR or MAAP model have shown that some 15 to 20 teams consisting of 1 to 3 operations or radiation protection qualified staff may be needed in the first 2 hours of a time-zero-failure accident sequence.
- More advanced SAMG training has made use of Desktop Simulators driven by the plant's MAAP or MELCOR model for real-time training using real-time severe accident simulation and visualization.