framatome

Current MELCOR-related Activities of Framatome

BRAUN, Matthias

Ljubljana, 12-14.04.2023

C0 – Unrestricted
AL:N, ECCN:N

Confidentiality

This document contains Framatome's know-how

EXPORT CONTROL

AL = N	ECCN = N

Goods labeled with "AL not equal to N" are subject to European or German export authorization when being exported within or out of the EU.
Goods labeled with "ECCN not equal to N or EAR99" are subject to U.S. export authorization. Even without a label, or with label: "AL:N" or "ECCN:N" or "ECCN:EAR99," authorization may be required due to the final whereabouts and purpose for which the goods are to be used.

FRAMATOME'S INFORMATION PROTECTION RULES

C1 – This document and any and all information contained therein and/or disclosed in discussions supported by this document are **Framatome Restricted**.

C2 – This document and any and all information contained therein and/or disclosed in discussions supported by this document are sensitive and **Framatome Confidential,** such as its disclosure, alteration or loss are detrimental with a significant-to-high impact for Framatome.

The document, if disclosed, and any information it contains are intended for the sole attendees. The disclosure or reference to such information or document shall be made only on a proper judgment basis and by mentioning expressly "this information shall not be disclosed / transferred without prior consent".

C3 – This document and any and all information contained therein and/or disclosed in discussions supported by this document are classified **Framatome Secret**.

Each one must commit to keep secret any written or oral information disclosed during the meeting. It is forbidden to disclose it to any legal entity and any individual (including within Framatome) without prior consent of the meeting chairman.

Content

framatome

AMHYCO

General information

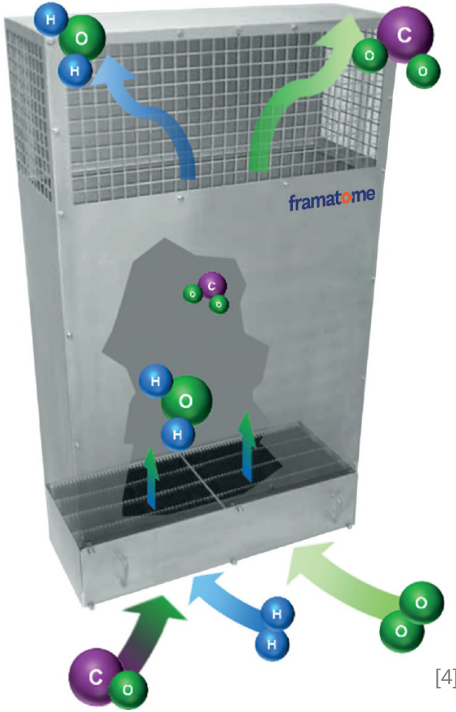
- Improve knowledge about late phase containment atmospheres containing Hydrogen (**H2**) and Carbon monoxide (**CO**)
- 12 Partners (EU & Canada) [1]
- EU funding period 2021-2024
- **Work ongoing,**
  only preliminary results shown here

The following is not a full program overview, but only the parts likely moist interesting for the broader MELCOR community

[1] https://amhyco.eu/

Work Package 3: Improvement of the PAR engineering correlation

- In Lumped Parameter codes, PAR are modeled as mass/energy source/sinks
  - Fast-running engineering correlation describes PAR recombination rate depending on CV-parameters
  - Engineering correlations always have validation limits
  - MELCOR PAR model is based on NIS-PAR and only recombine hydrogen[2]
- Original AREVA PAR engineering correlation
  - Well validated in a wide range of parameters e.g. in the THAI facility[3]
  - Used extensively in safety demonstrations (PAR back-fitting / new builds)
  - Describes H2-recombination and CO-recombination (**and their interaction**)
  - Not publicly available
  - Newer experiments (THAI-3 & THEMIS) show deviations at O2<3vol% in presence of CO - **CO-Poisoning**
  - Not very safety-relevant (low O2 → no combustion, and Framatome PAR restart when O2 con. rises again), but still an avoidable uncertainty



[4]

[2] MELCOR Reference Manual Version 2.2.18019
[3] Gupta et al. Summary of THAI Experimental Research on PAR Behavior and related Model Development, CSARP 2013
[4] Framatome Passive Autocatalytic Recombiner

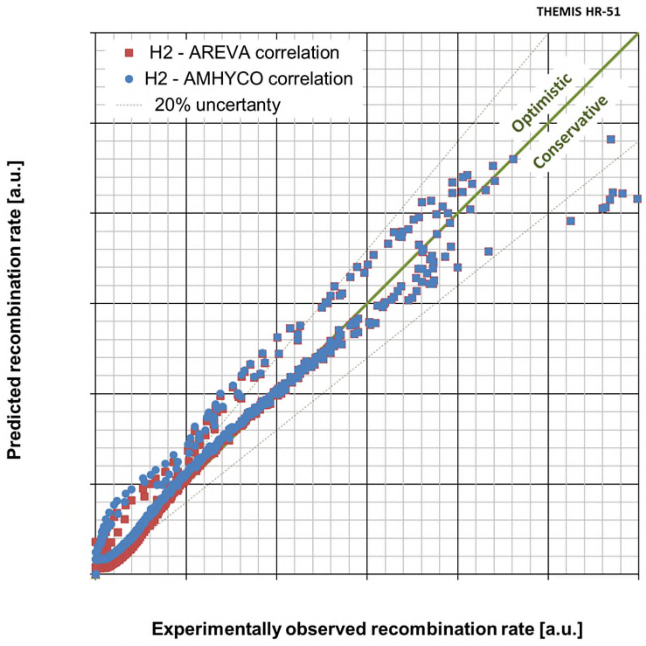
Work Package 3: Improvement of the PAR engineering correlation

- Scale experiments in the REKO-facility (FZ Jülich)[5], complementary to THAI experiments
  - Reduction of uncertainties
  - Evaluation of the CO poisoning phenomena
- Development of AMHYCO PAR correlation which shall
  - have an extended validity for the CO + low O2 regime
  - be publicly available
- Current status:
  - Basic AMHYOC-correlation defined
  - In the limit of high O2 concentration,
    the AMHYCO-correlation goes over into the AREVA-correlation
  - Numerical implementation tested
    (MELCOR, ASTEC, GOTHIC, SPECTRA)
  - Validation at the vast PAR validation history **ongoing**

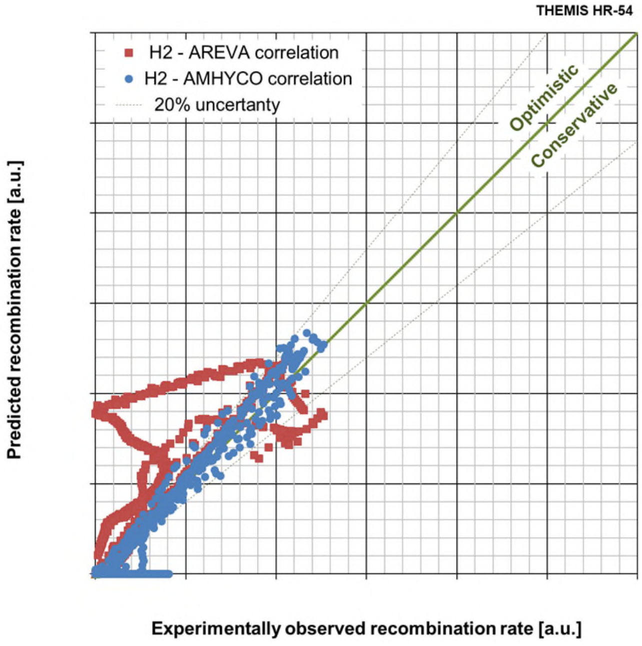
[5] Severe accident related activities of the research center Jülich/Germany

Work Package 3: Improvement of the PAR engineering correlation

O2 ~ 15 vol%

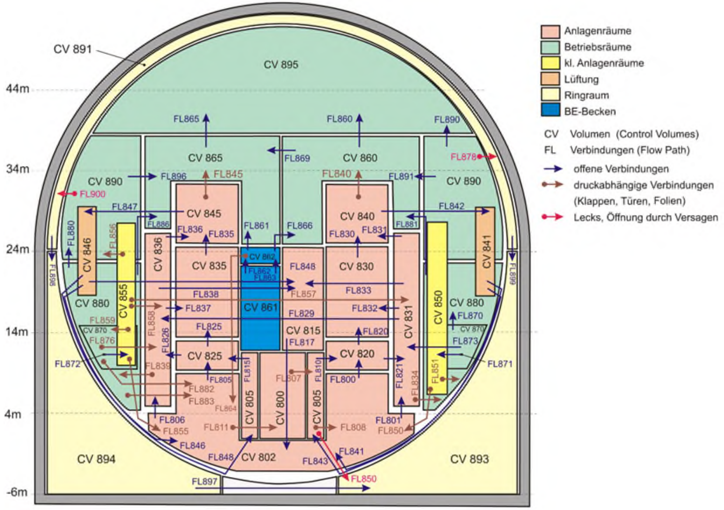


O2 ~ 3 vol%



Work Package 4: Comparison of Containment Simulations

- Lumped parameter codes (ASTEC, MELCOR, GOTHIC)
- CFD-Simulation tools
- Generic containment types for PWR-W, PWR-KWU, WWER
  - not necessarily the most physically accurate models
  - generic to be publishable
  - minimization of user approach influences
- Goal:
  - Identification of main influence aspects
  - Modelling best practices
  - Systematic tendencies of the different codes (LP overestimates convective mixing)



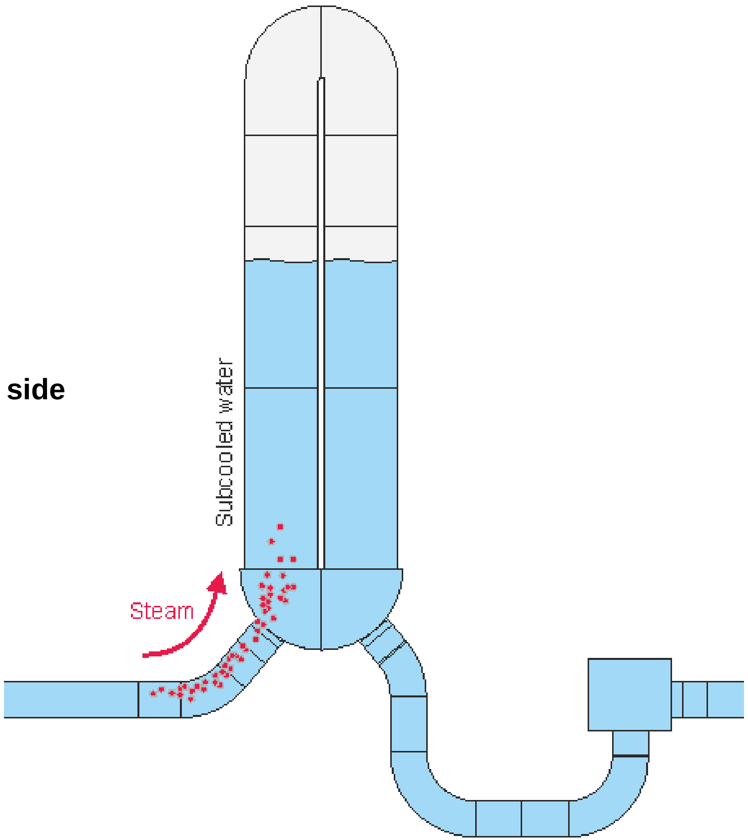
Content

framatome

2) MELCOR Issues during Secondary Cool-Down

- **EPR Steam generator cool-down in case of emergency**
  - Normal plant operation ~78 bar
  - After SCRAM p_{set} =95 bar-a (via roof) and 90 bar (via condenser)
  - In case of LOCA → partial cool-down to 60 bar (pressure lower than the HP ECCS pumps)
  - As manual measure, fast cool-down to near atmospheric pressure

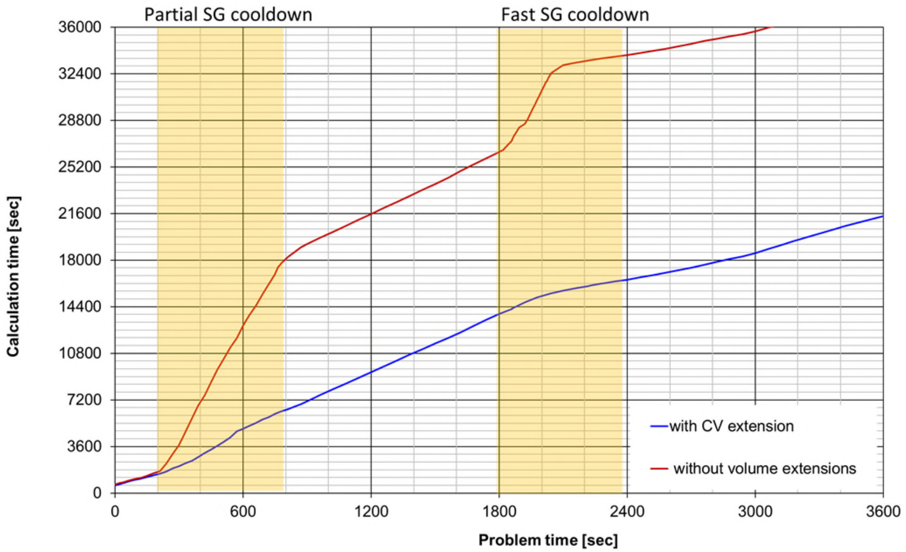
- **Issue: Reflux-condenser mode with very cold water in the SG secondary side**
  - Secondary cool-down sub-cools the water in the HX tubes CV
  - Steam enters from below into solid CV
  - Strong condensation of the steam
  - Water is incompressible → CVH-package has hard time to converge
    → MELCOR starts limiting time steps
  - The worse the more detailed the SG is modelled (more CV → smaller CV → higher pressure fluctuations)

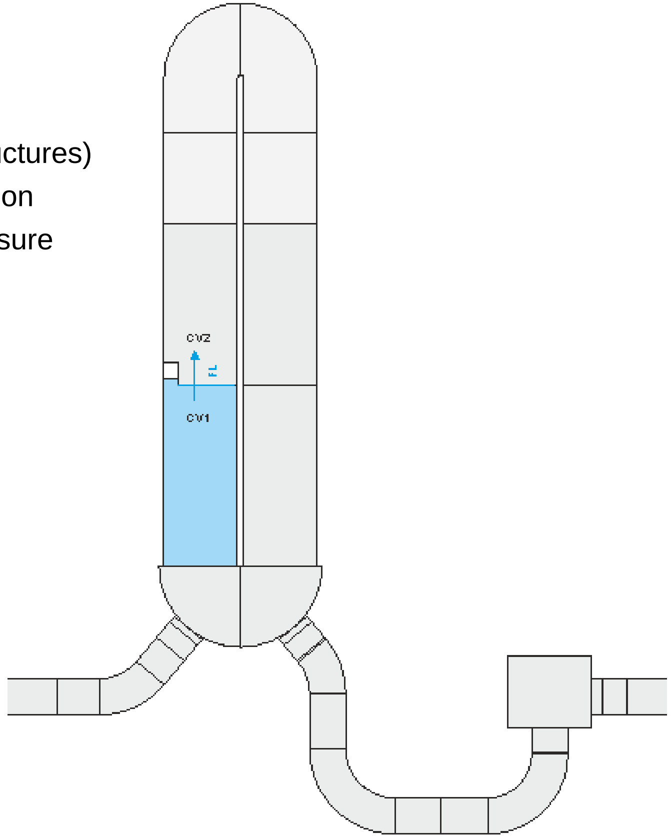


2) MELCOR Issues during Secondary Cool-Down

- **Solution / Fix**
  - Reduce the number of CV in the SG tubes as far as reasonable possible (what is reasonable depends what the scope of the model is)
  - Add small volume extension on top of SG HX volumes (above the HX heat structures)
  - Set FL_JLF / FL_JLT heights so that no fluid is drawn from that volume extension

  → a small stream bubble can remain in that small volume, stabilizing the CV pressure





Content

framatome

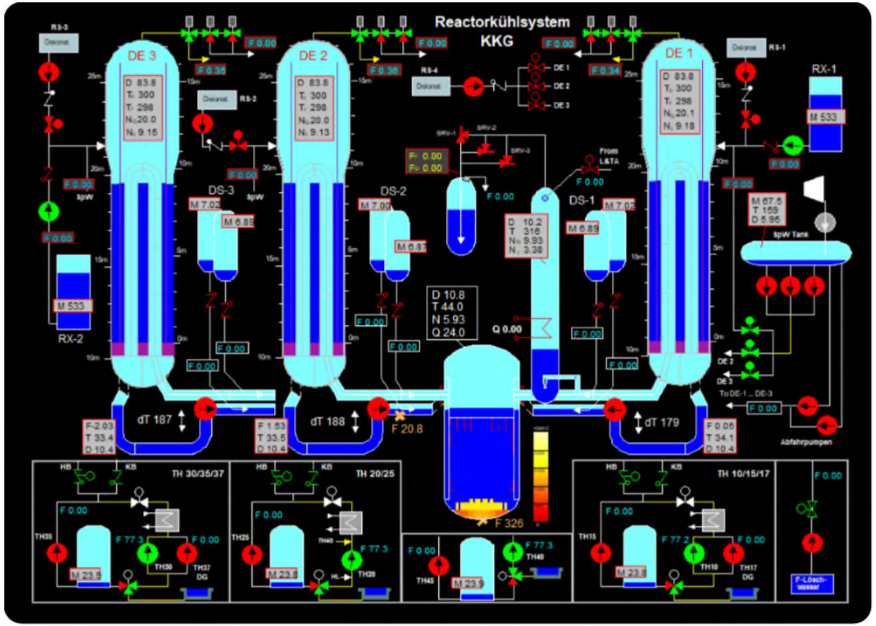
3) PSA Level 2 for the NPP Gösgen

Kernkraftwerk Gösgen

RMA Risk Management Associates, Inc.

- **Series of MELCOR simulations to support the probabilistic risk assessment Level 2**
  - Initiating events: TLAP, SB-LOCA, LB-LOCA, SGTR, Interface-LOCA, ...
  - Emergency actions: primary depressurization, secondary cool-down, filtered venting, ...
  - FP release via early or late containment failure modes
  - Combinations lead to large number of simulations

- **MELSIM model / software by RMA [6]**
  - Based on MELCOR
  - Graphical simulation representation
    (very beneficial for quality assurance)
  - Interactivity
    (less relevant for the PSA L2, but great for training)
  - Clear definition of accident sequence



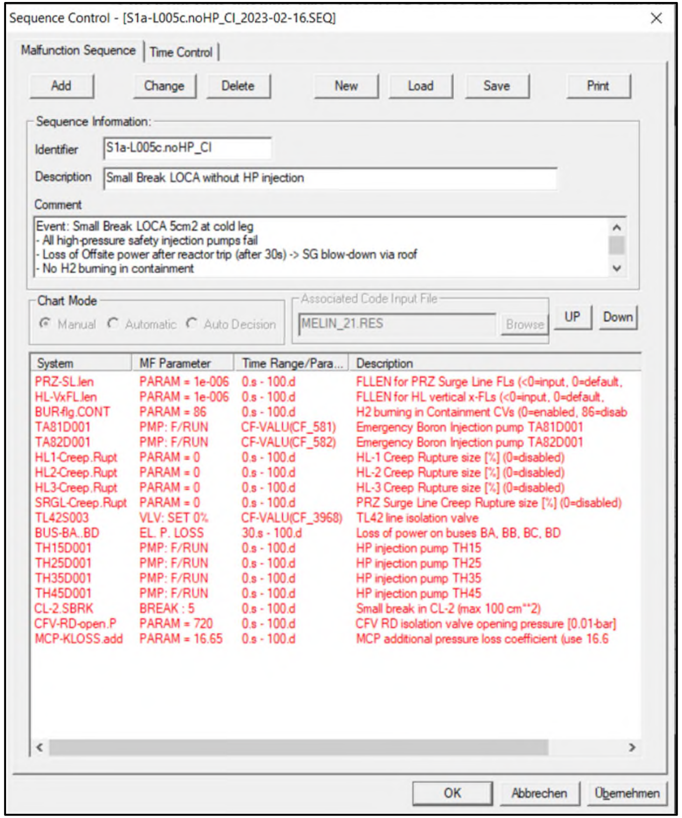
[6] https://www.psi.ch/sites/default/files/2019-04/EMUG_2019_11.pdf

3) PSA Level 2 for the NPP Gösgen

Kernkraftwerk Gösgen

RMA Risk Management Associates, Inc.

- **General consideration: Where to define the scenario input?**
  - In the MELGEN-input **is highly discouraged**
  - In the MELCOR-input (as CF-re-definition) **is feasible**
    - Error-prone due to large list of parameters
    - Cumbersome by CF limitations
      (only multiplier and additive constant changeable)
  - In MELSIM handled within the GUI
    - Pushed internally onto CF during simulation
    - Changeable during the simulation (good for bug-fixing)
    - Documentation / Archiving in log file
    - Flexible (time-dependence or
      condition depending on other parameter)
    - Additional software layer



MELSIM scenario definition interface

framatome

Content

framatome

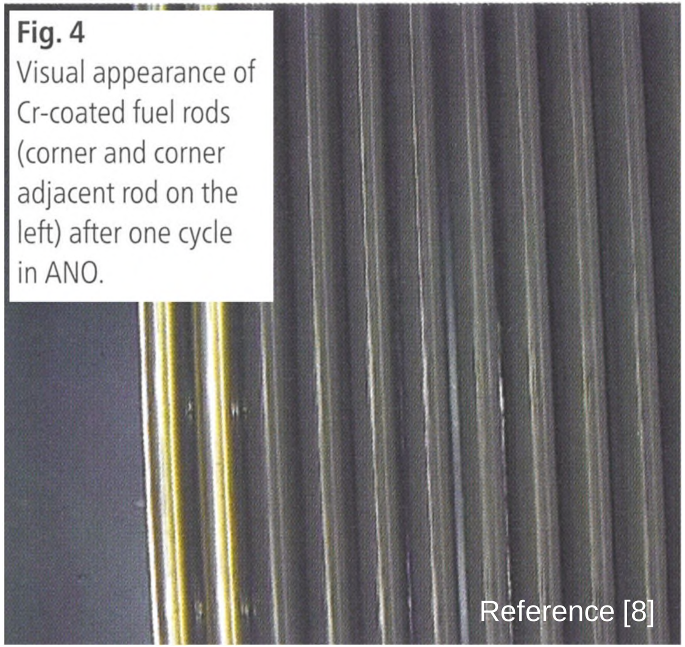
4) Framatome R&D Roadmap

Accident Tolerant Fuel

- **Framatome PROtect**
  - Cr-coated fuel rods [7]
  - Test rods & full assembly tests in KKGö, Vogtle, ANO, Calvert Cliffs... [8]

- **OECD-NEA *QUENCH-ATF* joint project [9]**

- **Impact on Numerical Simulations (MELCOR)**
  - Change in onset of fast oxidation → Entry into SAMG
  - Change of oxidation characteristics → PAR system design basis
  - Change of core degradation → Core melt stabilization



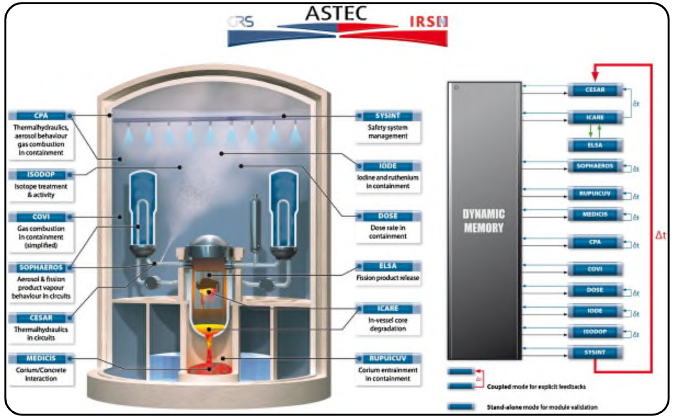
Expectation is that ATF is conservatively enveloped by normal fuel simulations, but its nuclear, thus, it has to be evaluated ...

[7] https://www.euronuclear.org/archiv/topfuel2018/fullpapers/TopFuel2018-A0152-fullpaper.pdf
[8] Current Trends in Fuel Assembly Development from a Materials Perspective, ATW 2-2023
[9] https://www.oecd-nea.org/jcms/pl_36597/quench-atf-project

4) Framatome R&D Roadmap

Code-to-Code Comparisons

- **MELCOR**
  - Installed base plants
  - Support for SA-back-fittings
- **MAAP**
  - New builds (EPR / EPR2) - Design
  - New builds (EPR / EPR2) - Licensing
- **ASTEC**
  - French development - Export control / licensing restrictions
  - Long-term availability
- **Agreement between the codes is in part improvable [10]**
  - Different model assumptions
  - Difference of users
  - Best-estimate or conservative philosophy



[10] Di Giuli et al. MELCOR 2.2-ASTEC V2.2 crosswalk study

Legal Notice

framatome

Thank you for your attention!

To discover more about how we can help, visit us at www.framatome.com/solutions-portfolio