Scaling of Containment Experiments
Summary Abstract for NURETH-10, session Q: Miscellaneous Subjects

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Nuclear safety technologies are in many cases based on information obtained from scaled experiments. In such cases it is necessary to show how the experimental results can be transferred or applied to real, prototypical reactor conditions. The SCACEX Thematic Network was created in the EURATOM 5th Framework Programme with the aim to perform such transfer by application of scaling methods in a selected area of nuclear reactor safety research related to the nuclear reactor containment. The acronym SCACEX stands for SCAling of Containment EXperi ments. A group of European experts was asked to conduct and document scaling analyses for reactor safety experiments done or planned in their laboratories. The results are presented in this paper as follows:

- Turbulent and radiative heat transfer
  Experiments studied the heat transfer in vertical flow channels with spherical or rectangular cross section, partly or fully heated walls, subject to natural convective flow. The scaling analysis quantifies the changes of the heat transfer caused by the non-uniform flow profile and the effects caused by radiation heat exchange of the walls. The application is for decay heat removal from the outer gap of innovative containment designs.

- Heat transfer by steam condensation and evaporation
  Steam condensation or evaporation is applied as an efficient decay heat removal process in innovative containment designs. Experiments were done with an evaporating film on a heated plate, and condensation of a steam-air mixture in an inclined tube. The scaling analysis demonstrates the applicability of the classical analogy of heat and mass transfer to determine the steam mass exchange rates. Additional effects (e.g., flow thermal and fluid-dynamic development and film distribution) are also briefly addressed.

- Containment spray effects
  A scaling analysis is conducted to simulate the expected spray effects upon atmospheric cooling and gas mixing in a small scale facility, in support of a forthcoming test series. Important results from the analysis are that a non-prototypical spray nozzle shall be applied, such that the spray jet leaves sufficient space for atmospheric recirculation flow. Conditions for the droplet size spectrum, water flow rate and subcooling are established to provide a reasonable time frame for atmospheric cooling (depressurisation) in the test facility.

- Bubble condenser containment thermal hydraulics
The classical scaling criteria for simulating DBA blow-down transients in a reduced-scale test facility are documented in support of an ongoing experimental programme for VVER reactor safety. Specific criteria are established for the bubble condenser system which is represented by a reduced number of prototypical units. Time-preserving scaling is applied consistently for the blow-down injection rate and the containment response.

- **Natural convective flow processes in the containment atmosphere**
  Natural convective flow in the containment atmosphere is addressed as most relevant mixing mechanism during long-term severe accident transients. Driving forces are the distributed heat sources like hydrogen recombiners or decay heat from fission products. The analysis gives similarity criteria for the spatial distribution of the heat sources. It is shown that previous hydrogen experiments were reasonably scaled, but test with notable impact of decay heat are still missing.

- **Cable ageing**
  The reliability of electrical cables during 40 years of service is investigated in the laboratory by means of accelerated ageing procedures. The scaling of the time co-ordinate is based on an accelerated oxidation of the cable insulation material by enhanced temperature or radiation dose rate. The analysis shows that the acceleration is limited by a scaling criterion related to the oxygen diffusion in the insulation material, which was not always met in the past experiments.

- **Containment penetration sealings**
  Functionality tests of gaskets under accident conditions were undertaken with a prototypical large containment airlock. Leaks may occur after returning from the maximum pressure peak due to irreversible plastic deformation of the material. The analysis indicates that equivalent results could be obtained from small-scale experiments where only a limited part of a gasket is tested. Material ageing effects are treated similar to the cable ageing analysis.

- **Leakage through concrete walls**
  Experiments with reduced-scale models of concrete containment walls related to leakage under accident conditions are analysed. An important result for the integral test facility is that scaling distortions from the geometric construction of the facility lead to distortions of the simulated leakage, even if the tested wall has prototypical thickness and materials. It is concluded that a more realistic picture of the leakage can be synthesised by combining results from the integral test facility and a several separate-effects facilities that are also available.

- **Fluid-structure interactions of steel components**
  Experiments related to steam explosion inside the reactor pressure vessel are analysed, which are associated with highly dynamic fluid-structure interactions. Scaling criteria are established on the basis of the governing equations for liquid and solid. The validity of the scaling criteria was successfully checked by a series of simplified experiments covering a scaling range of 1:10, and by slug acceleration tests under two different reduced scales. The work confirms that the experimental data can be transferred to prototypical dimension.

The analyses conducted in the SCACEX project cover important aspects of thermal hydraulics, structural mechanics and material behaviour. They demonstrate that the existing methods of scaling and similarity analysis have an almost universal range of applicability. They require a good knowledge of the phenomena associated with the individual experiments, which is conveniently documented in a simplified Phenomena Identification and Ranking Table (PIRT). Several ways to establish dimensionless numbers were taken, and it was found that this can be a more challenging task where no straightforward recipes are available, especially in areas where scaling methods are not well established.
As result of the work, common features of scaling in different application fields can be identified as follows:
- Identification and ranking of relevant phenomena (simplified PIRT)
- List of relevant parameters associated with the phenomena
- List of dimensionless numbers associated with the relevant parameters
- Interpretation taking into account the geometric (or time-related) scale ratios.

Network participants agreed that scaling analysis is a very useful approach to show how experimental data can be transferred to the prototype. The method reveals the limitations of this transfer, it helps to get a more complete understanding of the investigated processes, and it can be used to specify more effective and less costly experiments.