Conference and Workshop on the Research Needs of Boiling Water Reactors, Bangor University, 25th-27th October 2016

Summary of Breakout Session on "Research Needs Discussions for BWR Thermal Hydraulics"

A Conference and Workshop on the research needs of BWRs was recently held at Bangor University (October 2016), attended by Hitachi, representatives of the UK nuclear industry and UK academia. On 26th October two parallel "Breakout Sessions" took place in order to begin to establish areas of research of mutual benefit to Hitachi and the UK.

This memo summarises the proceedings of the "BWR Thermal Hydraulics" session (the other session was concerned with "BWR Core and Fuel" and will be reported separately). The breakout session comprised discussing and then compiling a list of potential research areas, followed by an attempt to identify the areas of greatest interest to both Hitachi and UK industry and academia.

List of potential research areas of mutual benefit

Whole-Systems Code Developments (from presentation on research needs for BWR high performance core and fuel)

Systems codes are used to analyse the transient performance of reactor systems, including significant elements of the power conversion system, to analyse and demonstrate the behaviour of the whole system during normal operational transients, anticipated operation occurrences (AOOs) and during fault conditions. System codes are used to build up very complicated flow, heat transfer and control logic networks to mimic the plant using fairly simple building blocks. The basic hydraulic building block is essentially a pipe element. Complex structures such as a reactor core are formed by assembling a bundle of such pipe-elements, with transverse cross-junctions if discrete cross flows between the channels are possible. This approximation is reasonable for a set of shrouded fuel elements, as in the ABWR, but it becomes less applicable if taken down to the level of individual sub-channels with any given bundle. Further, the move to half-height pins encourages transverse redistribution of flow within bundles.

To date Hitachi have based their analysis of ABWR transients on the TRACG systems code, sometimes coupled with a neutronics model for transients in which resolution of thermal-neutronic feedbacks is important. TRACG is a customised version of the Los Alamos code TRAC, with the customisation performed by General Electric, to produce a version specific to BWRs.

As in the case of standard TRAC, TRACG is based on a two-fluid model of two-phase flow.

The session attendees identified two potential areas for development of modelling for the reactor core:

First, the parallel pipe approximation of the reactor core that is achievable with TRACG misses a lot of detail that occurs at the sub-channel level, particularly in the vicinity of grids and other discontinuities (or continuous features, such as an imbalance in sub-channel powers) which promote transverse flow.

Second, whilst the two-fluid model performs well in regions of low (or no) heat flux, such as in the external piping circuit, this does not accurately capture the behaviour and interaction between the vapour, film and droplet fields within the core sub-channels.

The proposal is to develop a new “core component” that can be linked together with a TRACG model of the rest of the BWR system to resolve both issues. Such a component would be based on a sub-channel scale representation of a fuel bundle, with the capacity for the model to include an arbitrary number of parallel bundles. Ideally this core component would be based on a multi-fluid model (with at least three fluids for vapour) of the two-phase flow within the core. The precedent for this type of model already exists in the form of COBRA/TRAC, in which COBRA is a detailed continuum and/or sub-channel-scale code based on a two-fluid, three-field model of two phase flow.

Development of TRACG to replace the two fluid model with a multi-fluid model was considered to be too onerous and would undermine the existing validation basis of the code. If the application of the code is limited to non-core components, the following areas for development were identified:

- A consideration of / or improvement to the treatment of interfacial friction.
- Friction and heat transfer correlations in mixed and natural convection regimes

Thermal Hydraulics Developments

Test rigs and instrumentation:

“Big” test rig to examine two phase flow behaviour in core channels at representative heat flux, temperature and pressure.

Instrumentation to measure, and ideally visualise:

- Film thickness, interface structure and liquid flowrate measurement (film characterisation) in isothermal, heating and cooling conditions.
- Bubbles and droplets, spatial and size distributions and velocities.
- Understanding the structure and behaviour of churn flow
- Turbulence – understanding the relationship between vapour-phase turbulence intensity and droplets for annular dispersed flows.

To facilitate some of the above, it would be good to investigate use of radioactive tracers, or temporarily induced radioactivity in the liquid phase (^{17}O)from a pulsed neutron source to carry out gamma tomography (PET in the latter case) imaging of the distribution of liquid in the two-phase region in real time.

“Small” test rig to investigate same phenomena by optical means in glass.

Analytical methods:

There is a strong cross over between the needs of the core component model for transient analysis discussed above with the needs of a detailed thermal hydraulics model of the core to carry out coupled neutronics / thermal hydraulics analyses. Such a model will have an improved capability to predict void distribution and power levels/shapes at which critical heat flux occurs.

The best of the generally available codes appears to be based on two-fluid, three-field models. The use of true multi-fluid models appears to be restricted to “academic” codes, so there is scope to implement a true three fluid two-phase model in a core thermal hydraulics code, which could be transferable to other industrial problems where accurate resolution of phase change is important.

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