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WP4: Safety Performance of VHTR/GFR

Meeting at Imperial College, 22nd September 2006

CFD Studies of Heat Transfer for Innovative Fuel Element Surfaces

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WP4 and WP1

- WP4, ‘Safety performance of VHTR/GFR’ cross-cuts with WP1, ‘Fuel, thermal hydraulics, and reactor systems’.

- Under WP1 Dr. Yacine Addad (PDRA) will conduct *Large Eddy Simulations* of flow parallel to fuel rods.

- Also within WP1, Amir Keshmiri (Ph.D. student) will exploit the LES database to validate advanced *Reynolds-Averaged Navier-Stokes* (RANS) models.

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WP4 programme

- Amir Keshmiri will then proceed to employ the RANS models to optimize fuel/coolant interactions for VHTR-GFR ceramic-prismatic fuel cells.

- Seek to increase heat transfer rates while avoiding extra head losses. Innovative channel geometries are to be defined by/in collaboration with stakeholders.

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Some RANS heat transfer results for reactor safety

- Ascending and descending, ‘mixed convection’, flows
- Buoyancy effects in PWR boron dilution scenarios (vertical and horizontal flow components)
- Thermal hydraulics of Magnox/AGR reactor pressure vessel insulation (laminar flow)
- Heat transfer enhancement in spirally-fluted tubes/AGR ‘multi-start’ fuel pins

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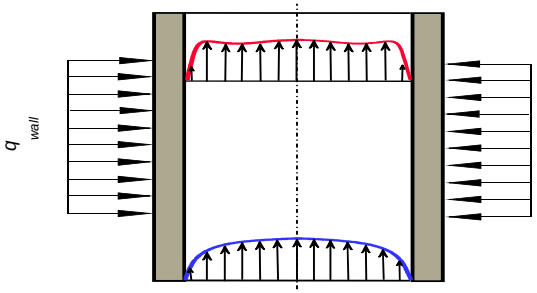
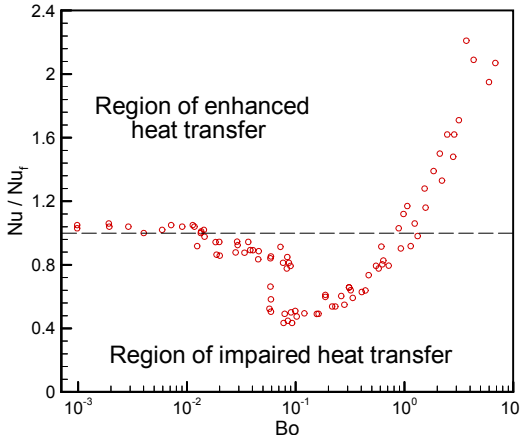
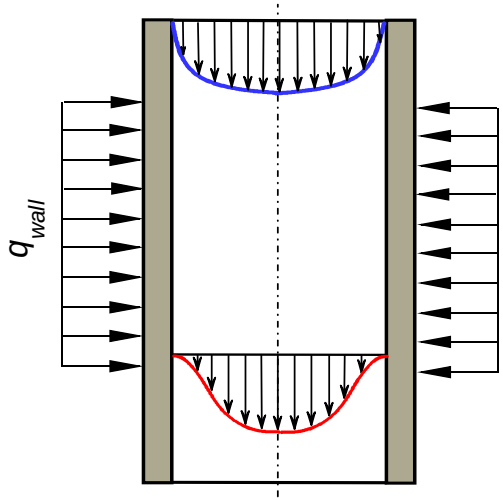
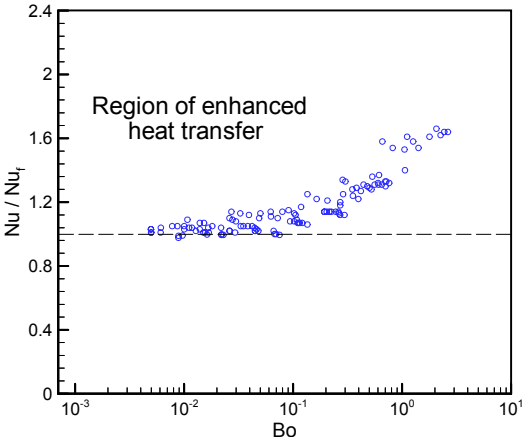
Vertical ‘mixed convection’ flows – Effects of buoyancy are very different in ascending and descending flow (Li 1994; Gerasimov 2005)









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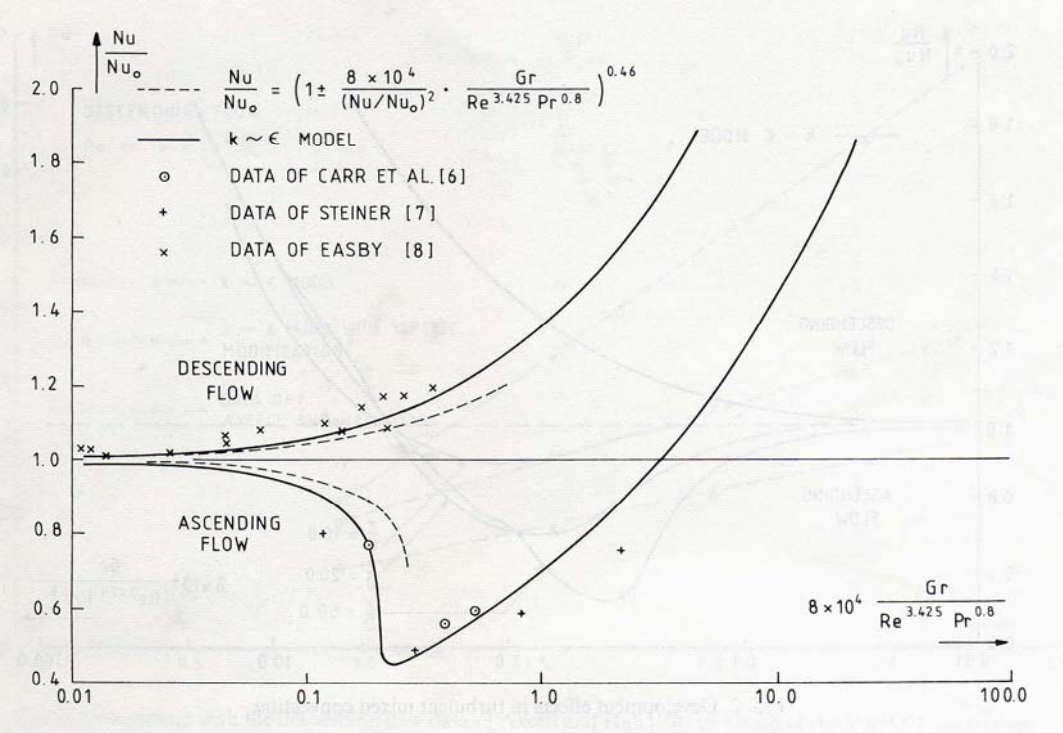
Mixed convection: low-Re k-ε model

- Departures from near-wall 'universality' parameterized in terms of a local 'turbulent Reynolds number', Re_t (Launder & Sharma, Lett. Heat Mass Transfer, 1, 1974)
- General trends of heat transfer impairment and enhancement are captured (Cotton & Jackson, Int. J. Heat Mass Transfer, 33, 1990):



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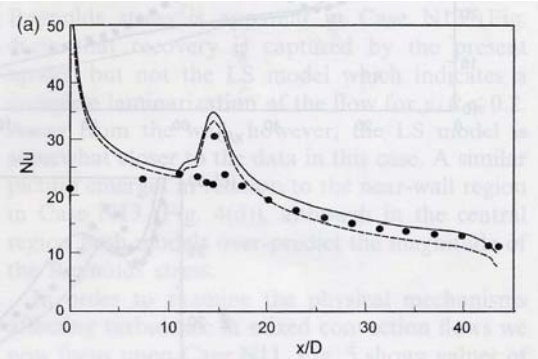
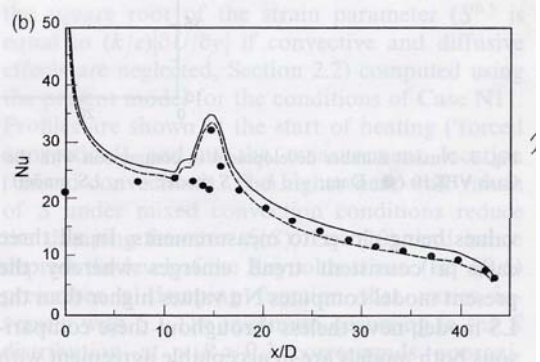
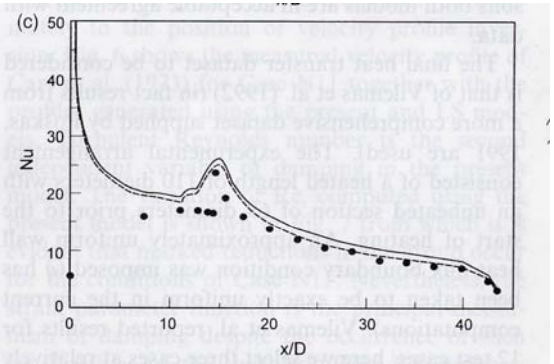
Mixed convection: Strain Parameter model

- Reference now made to $S = (k/\varepsilon)\partial U/\partial y$ – the ratio of the *turbulence timescale* to the *mean strain timescale* (Cotton, Ismael & Kirwin, Nuc. Eng. Des., 208, 2001)
- Comparable performance in terms of heat transfer results (Data: Shehata & McEligot, Idaho Nat. Eng. Lab. Report INEL-95/0223, 1995):







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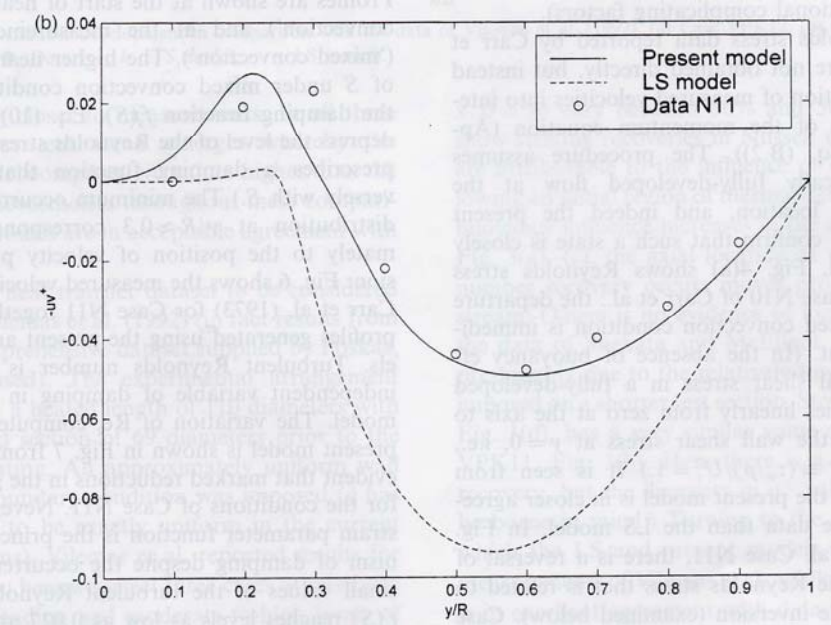
Mixed convection: Strain Parameter model (2)

- But differences in terms of detailed flow profiles:
- The figure below shows a Reynolds shear stress distribution (Data: Carr, Connor & Buhr, ASME J. Heat Trf., 95, 1973):



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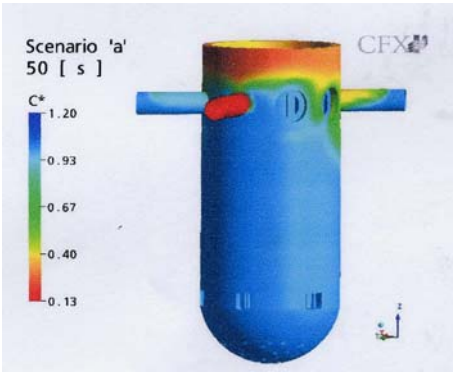
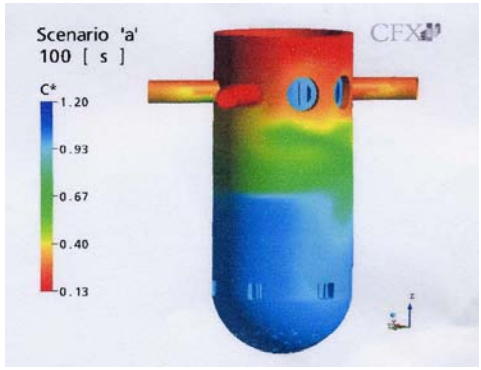
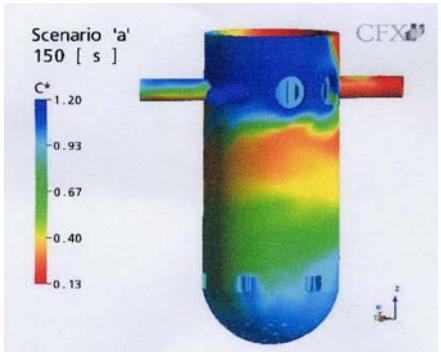
Buoyancy effects in PWR boron dilution scenarios

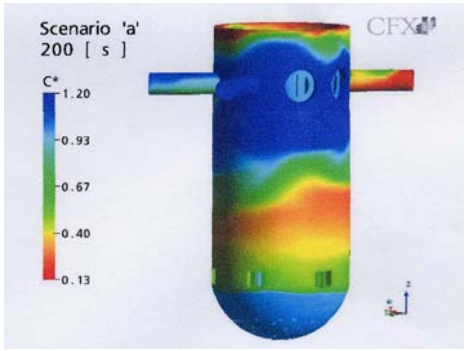
(Sponsored by British Energy)

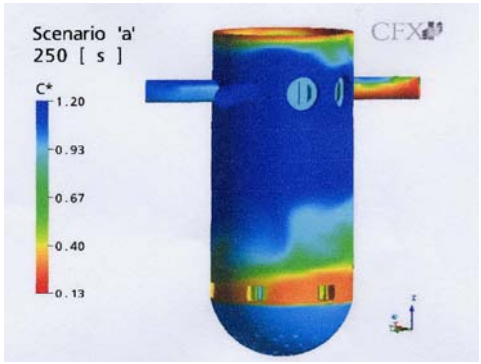
- Relatively warm and low-borated water injected from a single cold leg into the downcomer of a PWR
- High-Re k-ε model using CFX (Galindo-Garcia, Cotton & Axcell, 14th ASME Int. Conf. on Nuclear Engineering, 'ICONE14', Miami, 2006)











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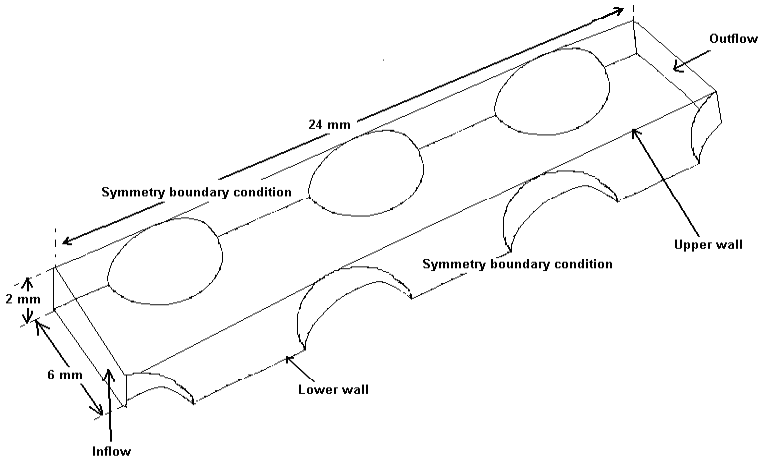
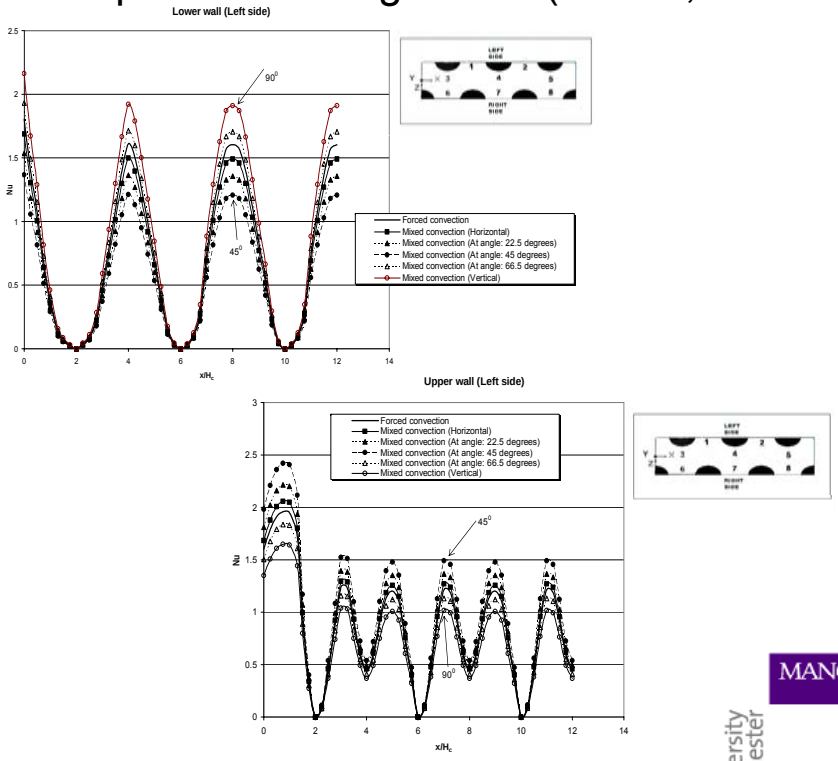
Laminar flow: Magnox/AGR RPV insulation

(Sponsored by BNFL Magnox Generation)

- Multiple sheets of stainless steel thermal insulation used on the inside of current gas-cooled reactor pressure vessels
- Complex flow paths through the 2 mm deep ‘dimpled’ passages of porous insulation
- Laminar flow forced and mixed convection computations using Fluent (Cotton, Lim & Axcell, sub. to Nuc. Eng. Des., 2006)





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Heat transfer enhancement in spirally-fluted tubes

- No penalty in terms of pressure loss
- Internal flow geometry, but similarities with ‘multi-start’ external fluting used in later AGR fuel pins (the earlier designs had unconnected transverse ribs)
- Possible use of advanced ‘Two-Component-Limit’ (TCL) stress-transport model of Craft and Launder (Int. J. Heat Fluid Flow, 17, 1996); Craft (Int. J. Heat Fluid Flow, 19, 1998) to resolve complex strain fields (streamline curvature; rotation; separation; impingement)

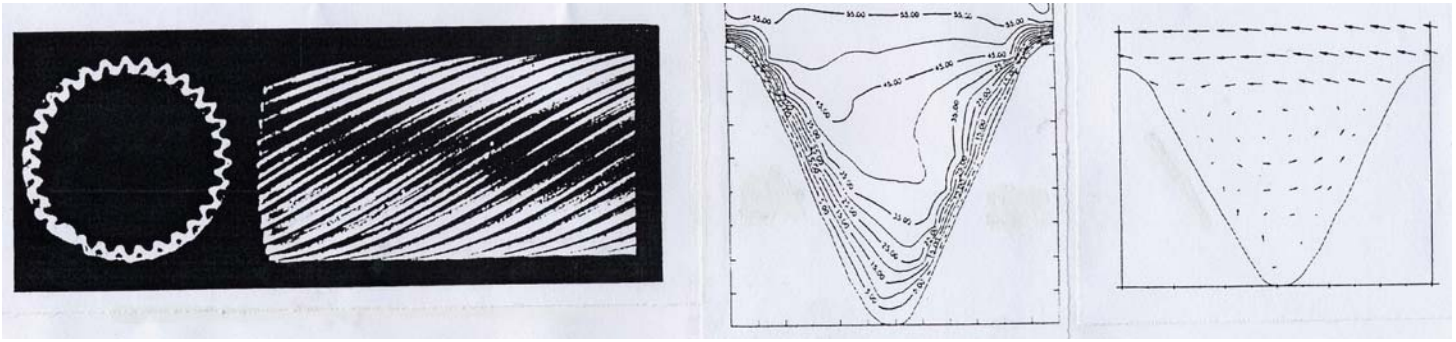

Photo: spiral fluting Axial velocity contours Secondary flow pattern

(Cheah, Leng, Cooper & Launder, 5th Int. Symp. on Refined Flow Modelling and Turbulence Measurements, Paris, 1993)

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Concluding remarks - 1

- The CFD/turbulence modelling research grouping at Manchester has an established track record in the development and application of RANS models with reference to the safety performance of nuclear power plant.

- Research has been undertaken into the strengths and weaknesses of different basic classes of turbulence closure (k-ε; Reynolds-stress-transport); also refinements of those schemes (low-Re forms; two-component-limit methodologies).

- There are long-established collaborations with stakeholders in industry and with regulators, as well as with researchers in the UK and internationally.

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Concluding remarks - 2

- It is planned for KNOO that RANS closures would be developed using in-house software (access to source code).
- The Group's close links with CFD software houses (ANSYS-CFX/Fluent and CD-Adapco/Star-CD) mean that modelling innovations developed in the course of KNOO might be rapidly incorporated in commercial software - of direct benefit to stakeholders.
- Under WP4 it is sought to study the heat transfer properties of innovative fuel element surfaces – a proposed point of departure is the spirally-fluted tube/AGR-type multi-start fuel pin design.