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IAEA Coordinated Research Project on Heat Transfer Behavior and Thermo-Hydraulics Code Testing for Super Critical Water Cooled Reactors

Bilbao Y Leon S.

IAEA
Vienna
AUSTRIA

International Atomic Energy Agency

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Sama BILBAO Y LEON
S.Bilbao@iaea.org

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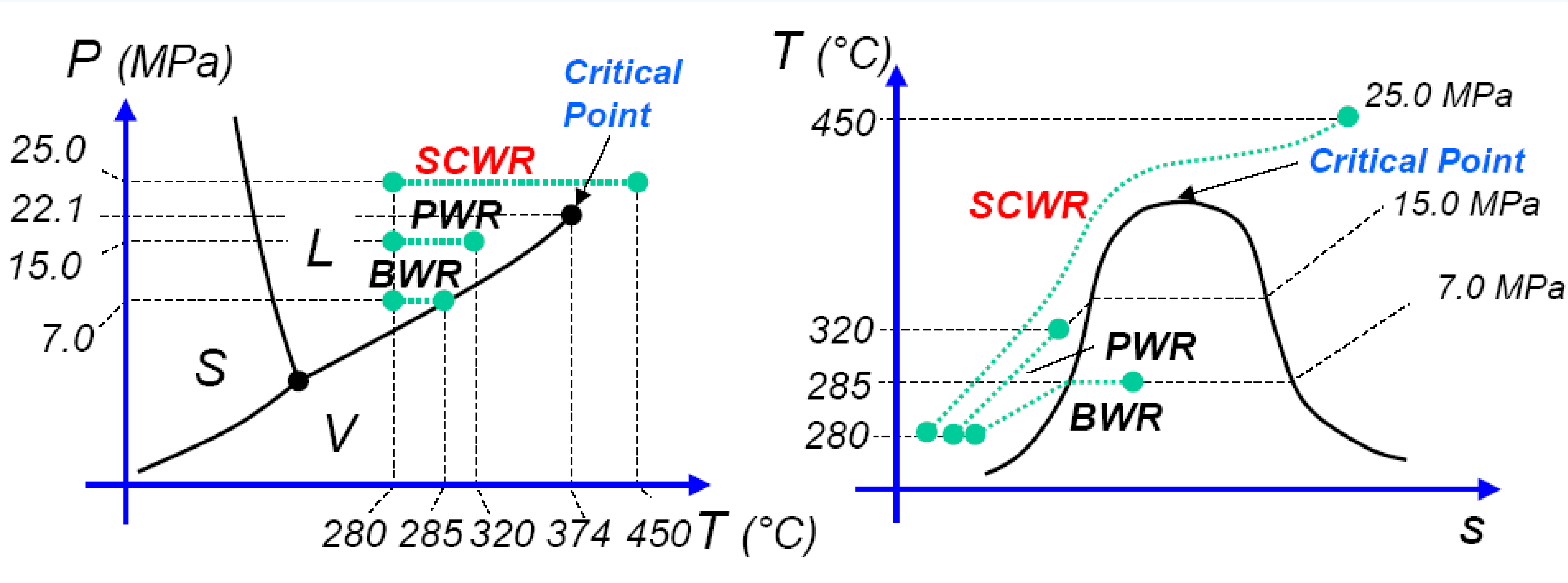
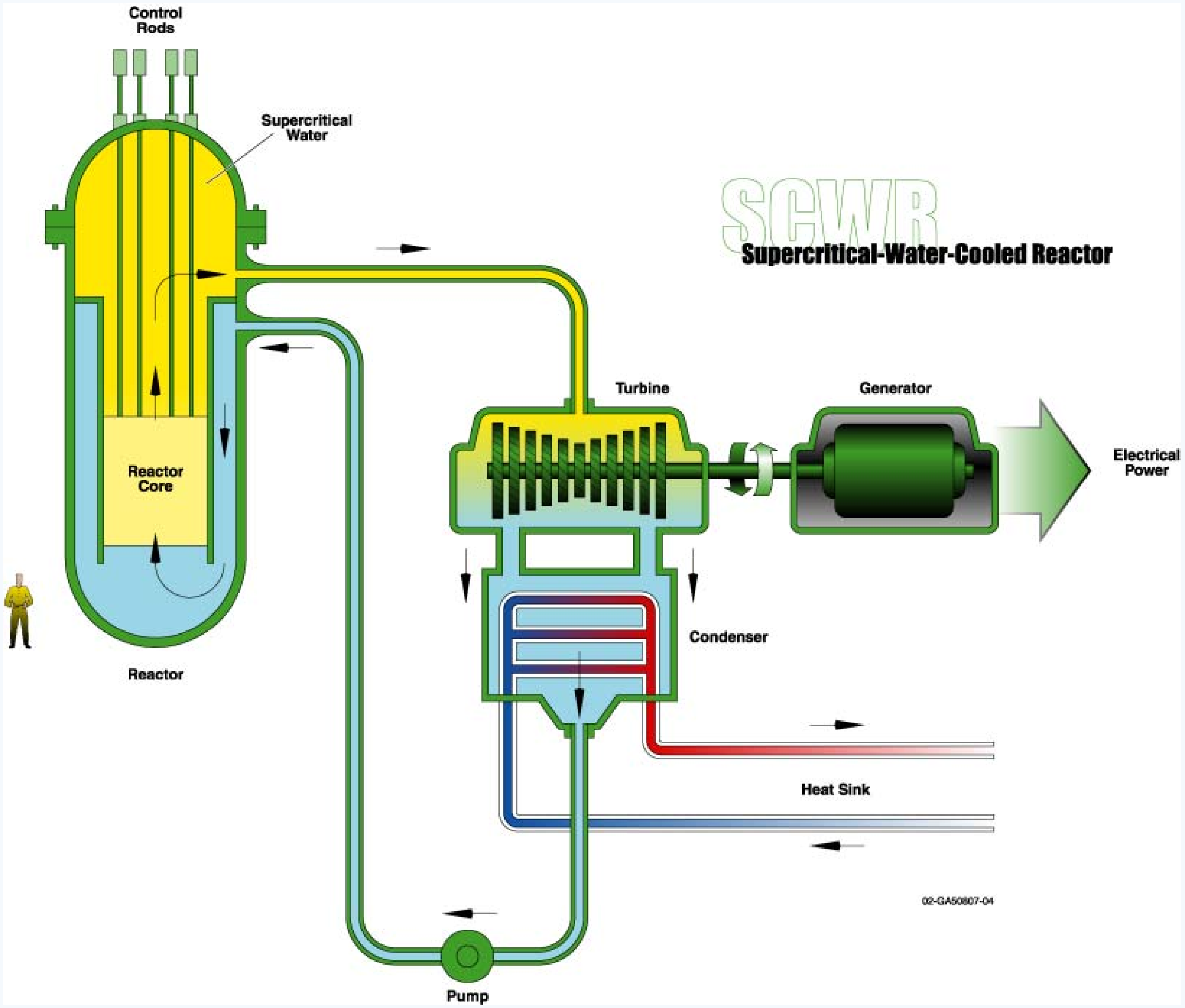
CRP on Heat Transfer Behaviour and Thermo-hydraulics Code Testing for SCWRs

- **SCWR (Super Critical Water Cooled Reactor)**
  - **Critical condition of water: 22.4 MPa, 374℃**
  - **High thermal efficiency**
  - **Thermal & fast spectrum**



Typical Supercritical Water Cooled Reactor



HISTORY AND STATUS OF SCWR CRP

- Suggested by INL
- Proposed as an IAEA activity by U.S. representative on the IAEA Nuclear Energy Department's TWG-LWR
- Jointly endorsed by TWG-LWR and TWG-HWR
- The CRP Plan was developed
  - with advice from experts in organizations conducting SCWR development
  - taking into account comments from GIF SCWR Steering Committee
- Approved within IAEA and included into IAEA's 2008-2009 Programme & Budget
- Coordination has been agreed with the OECD-NEA
- Conducted in Division of Nuclear Power in cooperation with Division of Nuclear Installations Safety

HISTORY AND STATUS OF SCWR CRP

- **Started in 2008**
- **1st Research Coordination Meeting**
  - **July 2008**
  - **Better understanding of participants capabilities and contributions**
  - **Integrated Research Plan Developed**
  - **Timeline Developed**
- **2nd Research Coordination Meeting**
  - **August 2009**

Organizations involved in CRP

- OECD-NEA
- Atomic Energy of Canada, Ltd. (Canada)
- China Institute for Atomic Energy (China)
- Shanghai Jiao Tong University (China)
- Tsinghua University (China) → before University of Manchester, UK
- VTT Technical Research Centre, Finland
- Bhabha Atomic Research Centre (India)
- University of Pisa, Italy
- Korea Atomic Energy Research Institute (Rep. of Korea)
- EC/JRC/Institute for Energy, Petten (Netherlands)
- Nuclear Research and Consultancy Group (NRG) (Netherlands) → observer for HPLWR
- Gidropress (Russia)
- Institute for Physics and Power Engineering (Russia)
- University of Wisconsin (USA)

Interest shown by additional organizations to participate in the CRP

PROBLEM DEFINITION AND OBJECTIVES

- **PROBLEM: For the design and safety analyses of SCWRs**
  - **Data for HT from fuel to coolant are required** over a range of flow, pressure and temperature conditions. Collection, evaluation and assimilation of existing data as well as conduct of new experiments for needed data are necessary to establish accurate prediction techniques.
  - **Validated T-H codes are required**. Existing codes for LWRs and HWRs need to be improved to model the phenomena (pressure drop, critical flow, instability and transition to two-phase conditions) and predictive models for HT from fuel to super-critical water and pressure drop need to be incorporated

- **Specific Research Objectives:**
  - to establish a base of accurate data for heat transfer, pressure drop, critical flow, natural circulation, and stability for conditions relevant to super-critical fluids.
  - to test computer methods for analyses of SCWR thermo-hydraulic behaviour, and to identify code development needs

Heat Transfer Behaviour and Thermo-hydraulics Code Testing for SCWRs

IAEA Division of Nuclear Power in cooperation with the Division of Nuclear Installation Safety

In co-ordination with OECD/NEA

CRP Objectives

1) Establish accurate databases for heat transfer, pressure drop, blowdown, natural circulation, and stability for conditions relevant to super-critical fluids.

2) Test computer methods for analyses of SCWR T-H behaviour, and identify code development needs

Research Coordination Meetings

Related International Activities
Related CRPs (e.g. Natural Circulation CRP)

CRP Activities

CRP Outputs

- **Supercritical Heat Transfer and Pressure Drop Database**
- **IAEA TECDOC(s) synthesising the results and technology advancements**
- **Joint papers by CRP Participants for International Meetings and Technical Journals**
- **Course on SCWR Technology**

The CRP Plan addresses a range of SCWR concepts

Table 1. Modern concepts of nuclear reactors cooled with supercritical water

Parameters	Unit	SCW CANDU	HPLWR	SCLWR-H	SCFBR-H	SCWR	B-500 SKDI	ChUWR	ChUWFR	KP-SKD
Reference	–	Bushby et al. 2000	Squarer et al. 2003	Yamaji et al. 2004	Oka, Koshizuka 2000	Bae et al. 2004; Bae 2004	Silin et al. 1993	Kuznetsov 2004 (project from 80s)	Gabaraev et al. 2003	Kuznetsov 2004
Country	–	Canada	EU	Japan		Korea	Russia	Russia	Russia	Russia
Organization	–	AECL	EU	University of Tokyo		KAERI / Seoul NU	Kurchatov Institute	RDIPE (НИКИЭТ)		
Reactor type	–	PT	RPV	RPV	RPV	RPV	PT	PT	PT	PT
spectrum	–	Thermal	Thermal	Thermal	Fast	Thermal	Thermal	Thermal	Fast	Thermal
Power thermal	**MW**	2540	2188	2740	3893	3846	1350	2730	2800	1960
electrical	**MW**	1140	1000	1217	1728	1700	515	1200	1200	850
linear max/ave	**kW/m**		39/24	39/18	39	39/19		38/27		69/34.5
Thermal eff.	**%**	45	44	44.4	44.4	44	38.1	44	43 (48)	42
Pressure	**MPa**	25	25	25	25	25	23.5	24.5	25	25
T_{in} coolant	**ºC**	350	280	280	280	280	355	270	400	270
T_{out} coolant	**ºC**	625	500	530	526	508	380	545	550	545
Flow rate	**kg/s**	1320	1160	1342	1694	1862	2675	1020		922
Core height	**m**		4.2	4.2	3.2	3.6	4.2	6	3.5	5
diameter	**m**	~4		3.68	3.28	3.8	2.61	11.8	11.4	6.45
Fuel	–	UO_2/Th	UO_2 or MOX	UO_2	MOX	UO_2	UO_2	UC	MOX	UO_2
Enrichment	**% wt.**	4	<6%	~6.1		5.8	3.5	4.4		6
Cladding material	–	Ni alloy	St. st.	Ni alloy	Ni alloy	St. st.	Zr alloy / St. st.	St. st.	St. st.	St. st.
# of FA		300	121	121	419	157	121	1693	1585	653
# of FR in FA		43	216/252	300		284	252	10	18	18
D_{rod}/δ_w	**mm/mm**	11.5 and	8	10.2/0.63	12.8	9.5/0.635	9.1 (Zr), 8.5	12/1	12.8	10/1
Pitch	**mm**	13.5	9.5		108	11.5	(St. st.)			
T_{max} cladding	**ºC**	<850	620	650	620	620	425	630	650	700
Moderator	–	D_2O	H_2O	H_2O	H_2O	ZrH_2		Graphite		D_2O

CRP on Heat Transfer Behaviour and Thermo-hydraulics Code Testing for SCWRs

- **CRP Activities**
  - ***Heat transfer, pressure drop and flow behaviour:***
    - **Activity 1 *:* collect and share sets of typical SCWR core design parameters**
    - **Activity 2 : collect, share and analyze existing data for supercritical working fluids (CO2, Freon, He)**
    - **Activity 3 : collect, share and analyze existing data for supercritical water**
    - **Activity 4 : perform collaborative fluid-to-fluid scaling analyses**
    - **Activity 5 *:* compare existing data, and identify needs for further experiments**
    - **Activity 6 : collect, share and analyze existing data for critical flow during blowdown from super-critical pressures, and collaboratively develop correlations and relationships**
    - **Activity 7 : define and potentially conduct new experiments to obtain necessary data at super-critical conditions with surrogate fluids and with water**
    - **Activity 8 : develop physical models, correlations and relationships based on new data**
    - **Activity 9 : conduct experimental and analytical investigations of power-flow instability**
    - **Activity 10 : conduct experiments with supercritical natural circulation**
  - ***Thermo-hydraulics Code Testing:***
    - **Activity 11 : collaboratively define "standard problems"**
    - **Activity 12 *:* conduct experiments as necessary to support the standard problems**
    - **Activity 13 : conduct comparisons of analyses, and identify areas where further development is required**
    - **Activity 14 : conduct analyses with system analysis codes for more complex integral test supercritical system configurations for normal operation and for transients and accidents, and compare results**
  - ***Documentation of results:***
    - **Activity 15: Establishment of the data base**

Integrated Research Plan

10 Tasks:

1. Establishment of DB
2. Collecting and sharing typical SCWR core design parameters
3. Collecting, sharing and analyzing existing heat transfer data
4. Collecting, sharing and analyzing existing pressure drop data
5. New experiments on heat transfer and pressure drop at SC conditions
6. Develop new correlations and prediction methods for heat transfer and pressure drop
7. Study of critical flow during blowdown at SC conditions
8. Study of instability and natural circulation in SCWR systems
9. Thermohydraulics code testing for SC conditions
10. Documentation of results

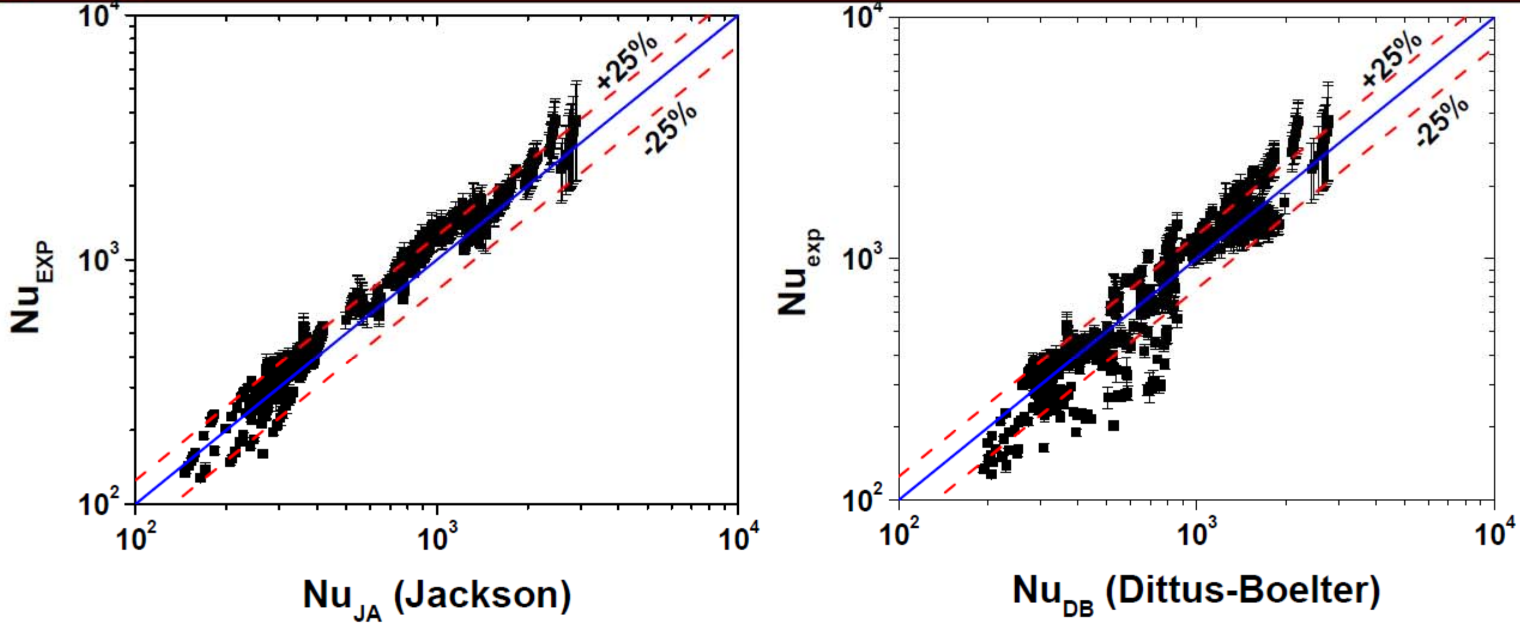
Accomplishments

- **Database for heat transfer, pressure drop, critical flow, natural circulation and stability in SC conditions**
  - **Hosted by OECD/NEA**
  - **Structure of DB and template abstract developed**
  - **Database capabilities and user-friendliness in testing**
- **Data for heat transfer, pressure drop and critical flow contributed and under development**

Accomplishments

- Two benchmark exercises in progress:
  - "Steady state Flow in a Heated Pipe" (Cases 1 & 2), hosted by Gidropress
  - “Benchmark on Stability”, hosted by University of Pisa
- Newer methods and correlations to predict heat transfer in SC conditions
- Detailed plan for the compilation of Final report

Jackson Nusselt Correlation Works Best



$$Nu_{JA,b} = 0.0183\,\mathrm{Re}_b^{0.82}\,\mathrm{Pr}_b^{0.5}\left(\frac{\rho_w}{\rho_b}\right)^{0.3}\left(\frac{\bar{c}_p}{c_{pb}}\right)^{n}$$

$$n = f\left(T_b, T_w, T_{pc}\right)$$

$$Nu_{DB,f} = 0.023\,\mathrm{Re}_f^{0.8}\,\mathrm{Pr}_f^{0.4}$$

Benchmark

SNSE

- ✓ **Codes:**

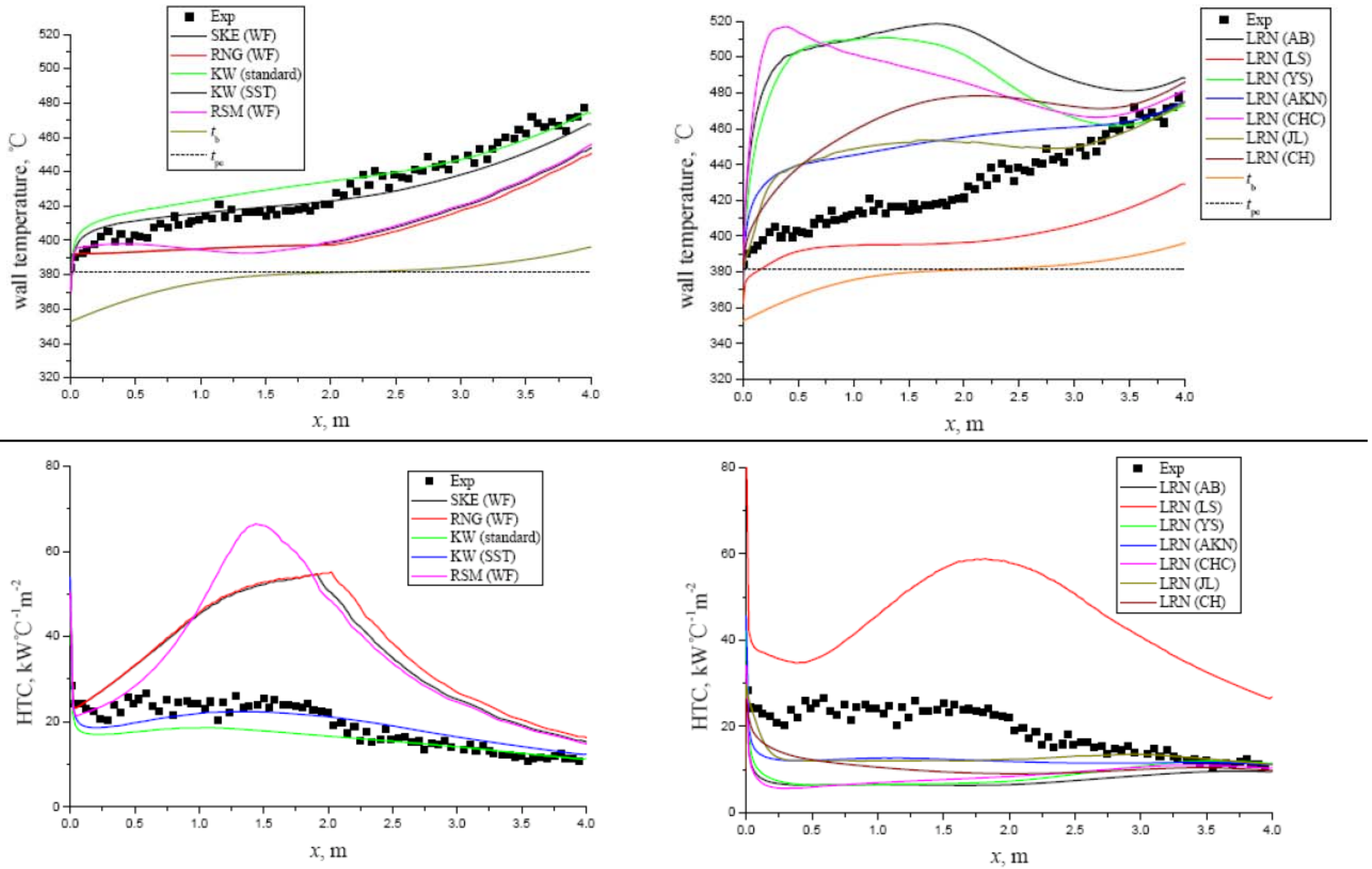
  Fluent; Home-made

- ✓ **Turbulence models**

standard *k*-ε model (wall function)	SKE (WF)
RNG (wall function)	RNG (WF)
low Reynolds number model (Abid)	LRN (AB)
low Reynolds number model (Launder-Sharma)	LRN (LS)
low Reynolds number model (Yang-Shih)	LRN (YS)
low Reynolds number model (Abe-Kondoh-Nagano)	LRN (AKN)
low Reynolds number model (Chang-Hsieh-Chen)	LRN (CHC)
low Reynolds number model (Jones-Launder)	LRN (JL)
low Reynolds number model (Chen)	LRN (CH)
k-ω model (standard)	KW (standard)
k-ω model (SST)	KW (SST)
Reynolds stress model （wall function）	RSM (WF)

Benchmark

SNSE



Future Plans

- IAEA Technical Meeting on ‘Heat Transfer, Thermal-hydraulics and System Design for Supercritical Water Cooled Reactors’, University of Pisa, July 5-8, 2010
  - Embedded International Meeting of Specialists on Supercritical Pressure Heat Transfer and Fluid Dynamics
- Third Research Coordination Meeting, Obninsk, Russian Federation, August 24-27, 2010
- Preparation of Courses on SCWRs
- Young researcher exchange program

...Thank you for your attention!

email:S.Bilbao@iaea.org