Super-Critical Water-cooled Reactors (SCWRs)

SCWR System Steering Committee

T. Schulenberg, H. Matsui, L. Leung, A. Sedov

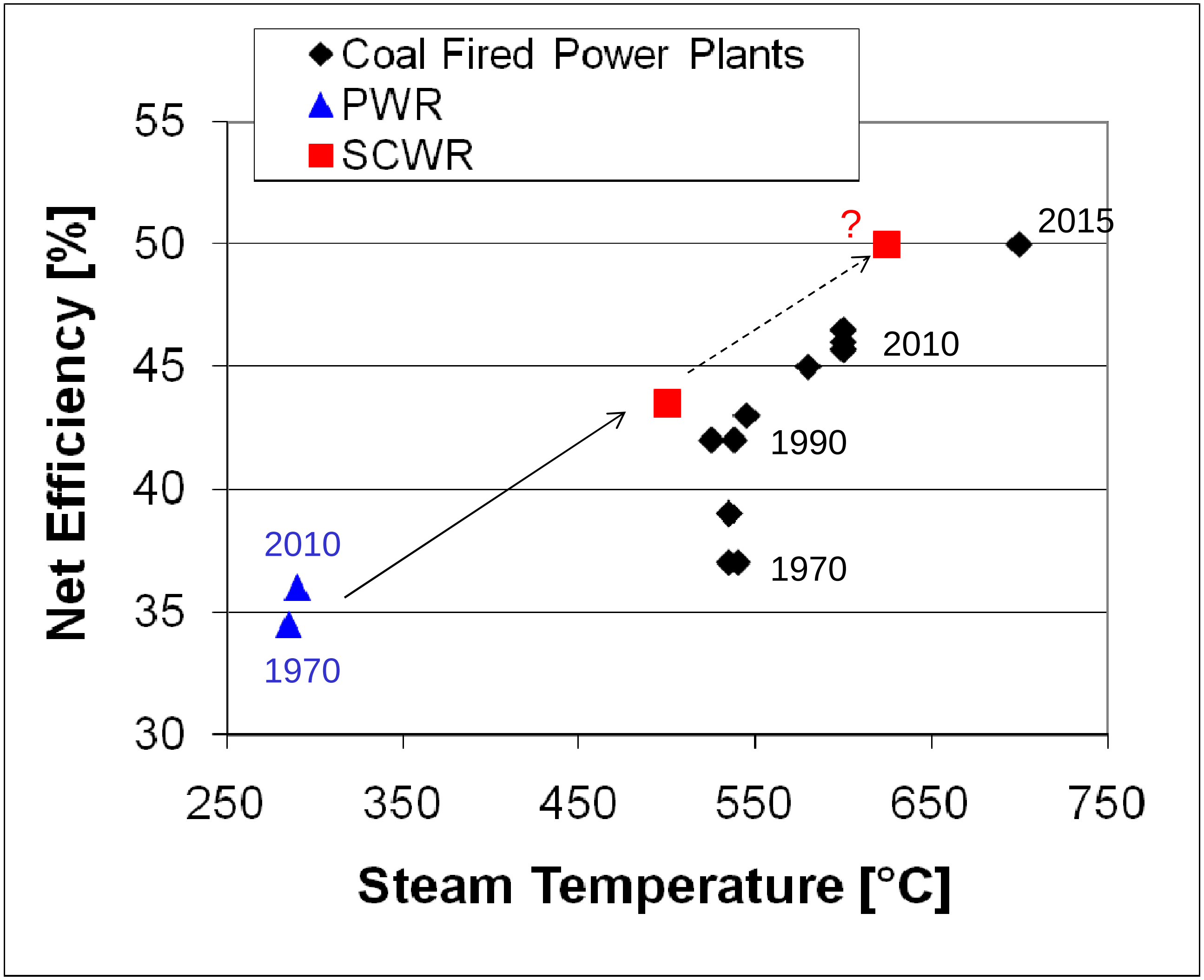
Presented by C. Koehly

GIF Symposium, San Diego, Nov. 14-15, 2012

General Features of SCWR

- *Evolutionary development from current water cooled reactors*
- *Cooled with light water and moderated with light or heavy water*
- *System pressure > 22.1 MPa (supercritical)*
- *Focus on thermal neutron spectrum with option on fast spectrum*
- *Once through steam cycle*
  - *No coolant recirculation in the primary system*
  - *No steam generators, steam separators or dryers*
  - *Compact containment with pressure suppression pools*
  - *High steam enthalpy, enabling compact turbines*
- *Plant net efficiency > 44%*
- *Minimum capital costs at given power (improved economics)*
- *Improved safety, proliferation resistance & sustainability*

The SCWR concept is following the trend of coal fired power plants to improve the economics of LWRs.



General Challenges of SCWR compared with conv. LWR

- *Coolant enthalpy rise in the core up to 10x higher*
  - ➢ *Intermediate coolant mixing in the core?*
- *Higher coolant core outlet temperatures > 500℃*
- *Hotter peak cladding temperatures > 600℃*
  - ➢ *Stainless steel instead of Zircalloy claddings?*
- *Prediction of cladding temperatures*
- *Different safety strategy*
  - ➢ *Control of coolant mass flow rate instead of control of coolant inventory?*
  - ➢ *Demonstration and use of passive safety system*
- *Different water chemistry strategy*
- *Proliferation resistance, e.g. in case of fast neutron spectrum*

Agreements on SCWR Research and Development in the Generation IV International Forum (GIF)

SCWR System Arrangement signed

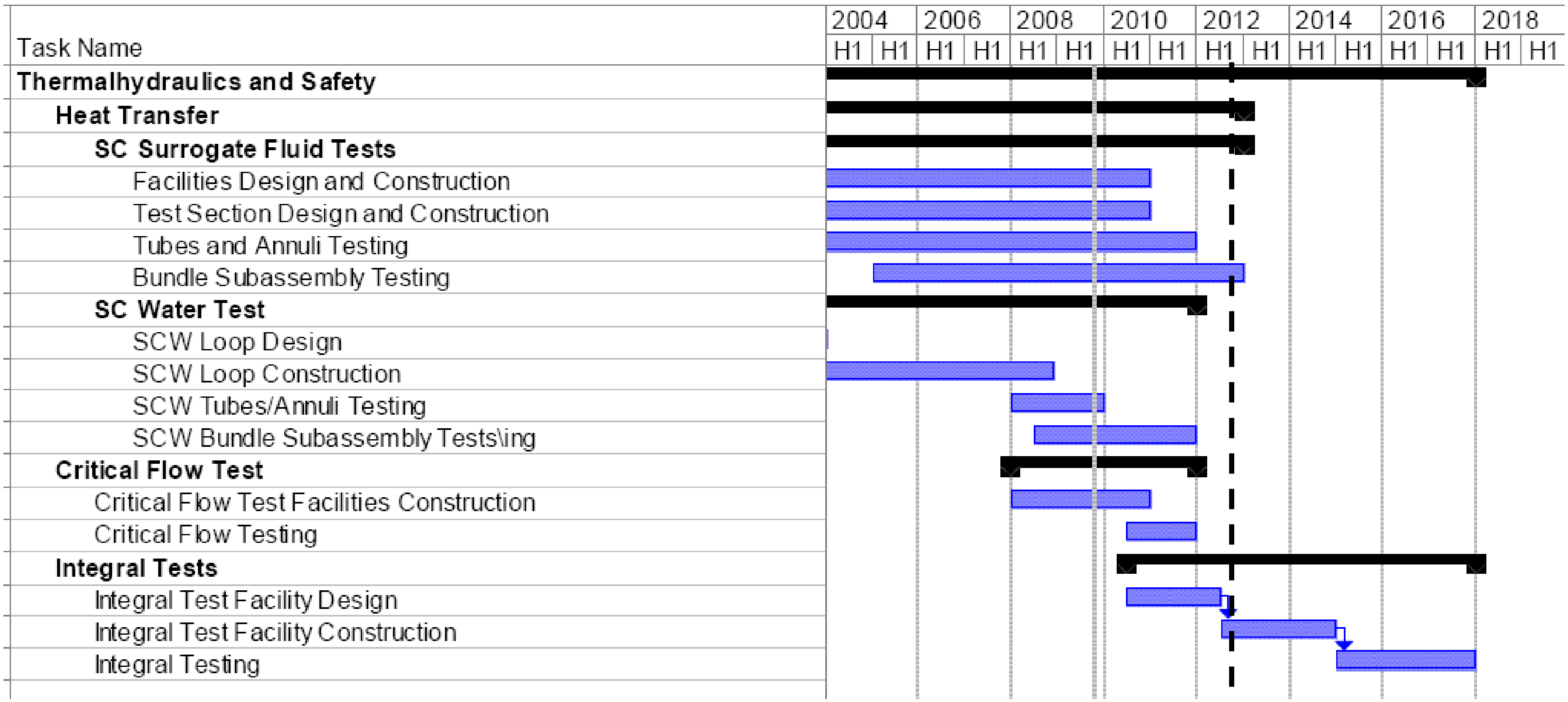
by Canada, Euratom and Japan (2006) and Russia (2011)

Joint Projects (Canada, Euratom and Japan):

- *Thermal-Hydraulics and Safety (PA signed in 2009)*
- *Materials and Chemistry (PA signed in 2010)*
- *Fuel Qualification Test (provisional)*
- *System Integration and Assessment (provisional)*

Thermal-Hydraulics and Safety

SCWR System Research Plan, Version 1, Oct. 2009



Thermal-Hydraulics and Safety: Status 2012

Data for heat transfer in tubes and annuli are available,

- *but reliable data for rod bundles are still required.*

***We can accurately predict normal or enhanced heat transfer**,*

- *but predictions of deteriorated heat transfer are still a challenge.*

***Several system codes can simulate a depressurization from supercritical to sub-critical conditions**,*

- *but transient heat transfer models have not been validated.*

***Active safety systems have been designed and tested numerically**,*

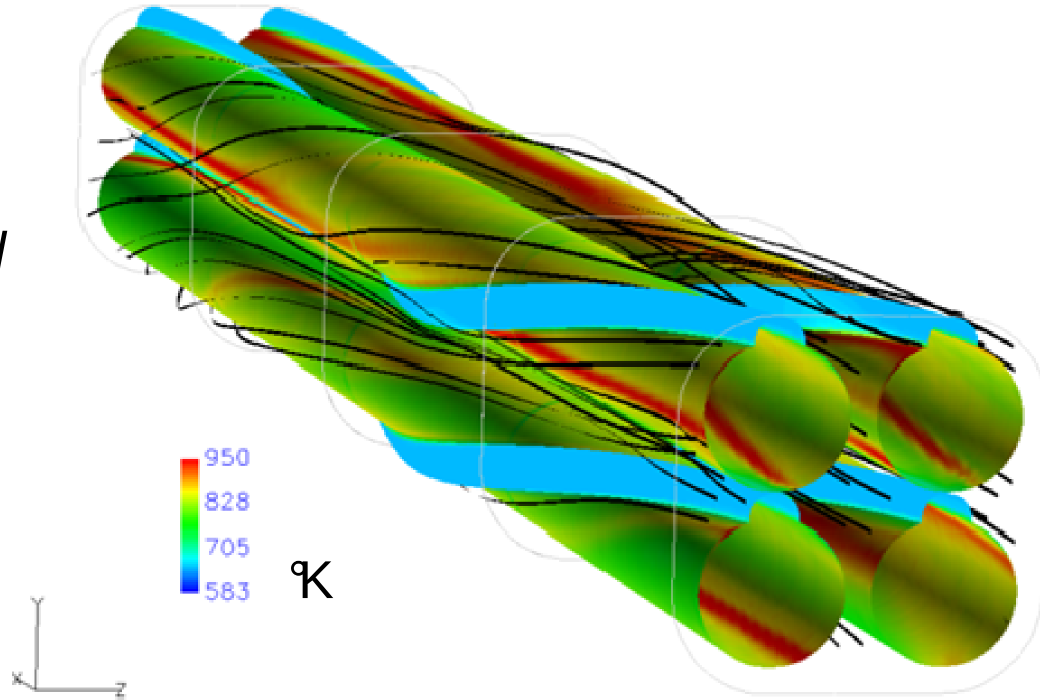
- *but passive safety systems remain to be a challenge.*

GIF-SCWR Project "Thermal-Hydraulics and Safety"

Project Arrangement signed Oct. 2009 by Canada, Euratom and Japan

Including

- *Heat transfer tests*
- *Critical flow tests*
- *CFD analyses of flow and heat transfer*

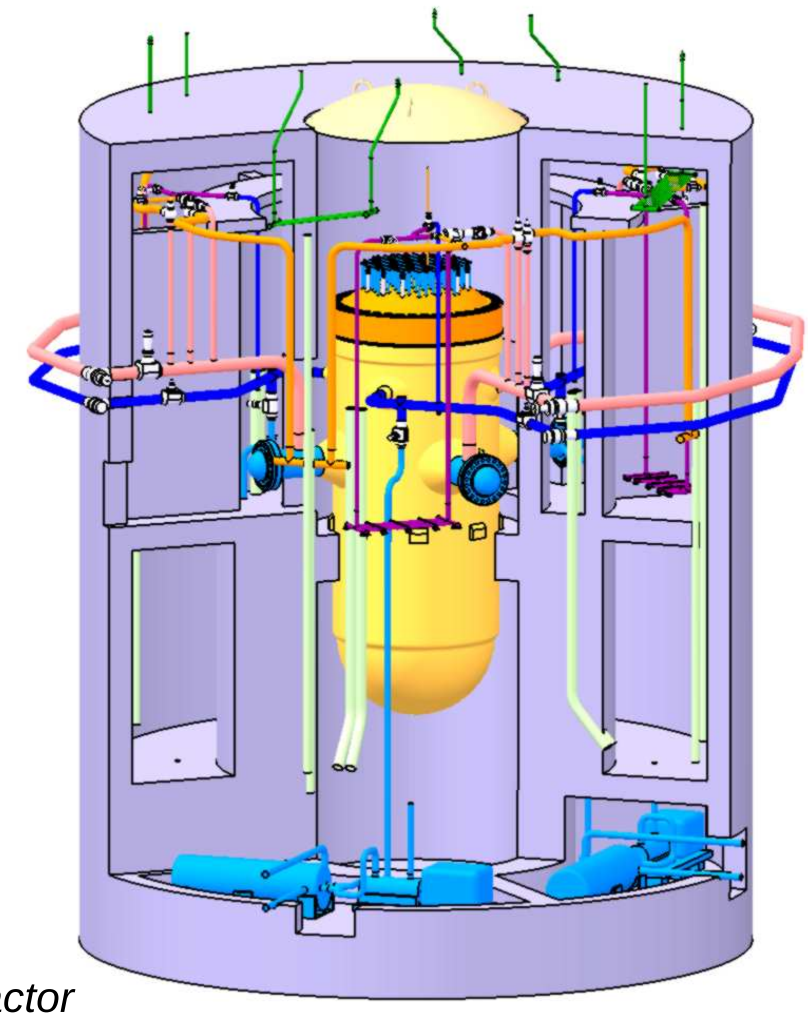


Example: flow around fuel rods with wires wrapped as spacers and predicted hot spots on the cladding surface

GIF-SCWR Project "Thermal-Hydraulics and Safety"

Including

- *Safety system configuration*
- *System code analyses of*
  - *Loss of coolant accidents*
  - *Loss of power accidents*
  - *Loss of flow accidents*
  - *… and other accident scenarios*



Example:
Safety system configuration of the High Performance Light Water Reactor

Thermal-Hydraulics and Safety: Future Tasks

- *Validation of numerical predictions with rod bundle tests, out of pile*
- *Integral Tests of Safety Systems*
  - *Test of the SCWR primary system performance*
  - *Development and test of passive safety systems*
  - *Simulation of loss of coolant accidents*
  - *Simulation of loss of flow accidents*
  - *Test of fuel rod cladding ballooning*
  - *… etc.*

GIF-SCWR Project "Materials and Chemistry"

Project Arrangement signed Dec. 2010 by Canada, Euratom and Japan

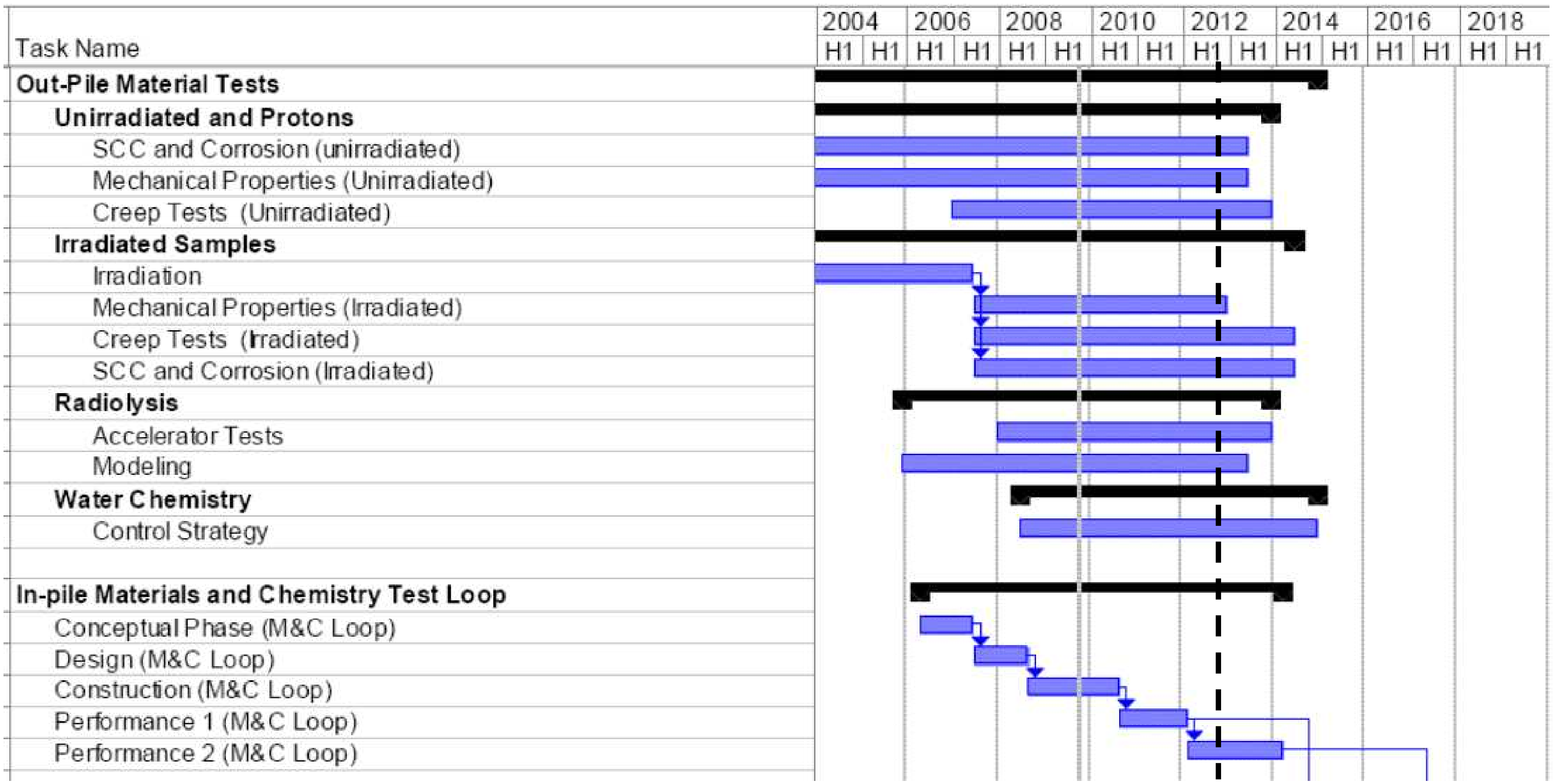
Including

- *Corrosion tests*
- *Creep tests*
- *Stress corrosion cracking tests*
- *Out-of-pile and in-pile test*
- *Radiolysis tests*
- *Water chemistry tests*
- *…etc.*

Example: Autoclaves for supercritical water tests up to 650℃ and 25 MPa at VTT and JRC Petten

Materials and Chemistry

SCWR System Research Plan, Version 1, Oct. 2009



Materials and Chemistry: Status 2012

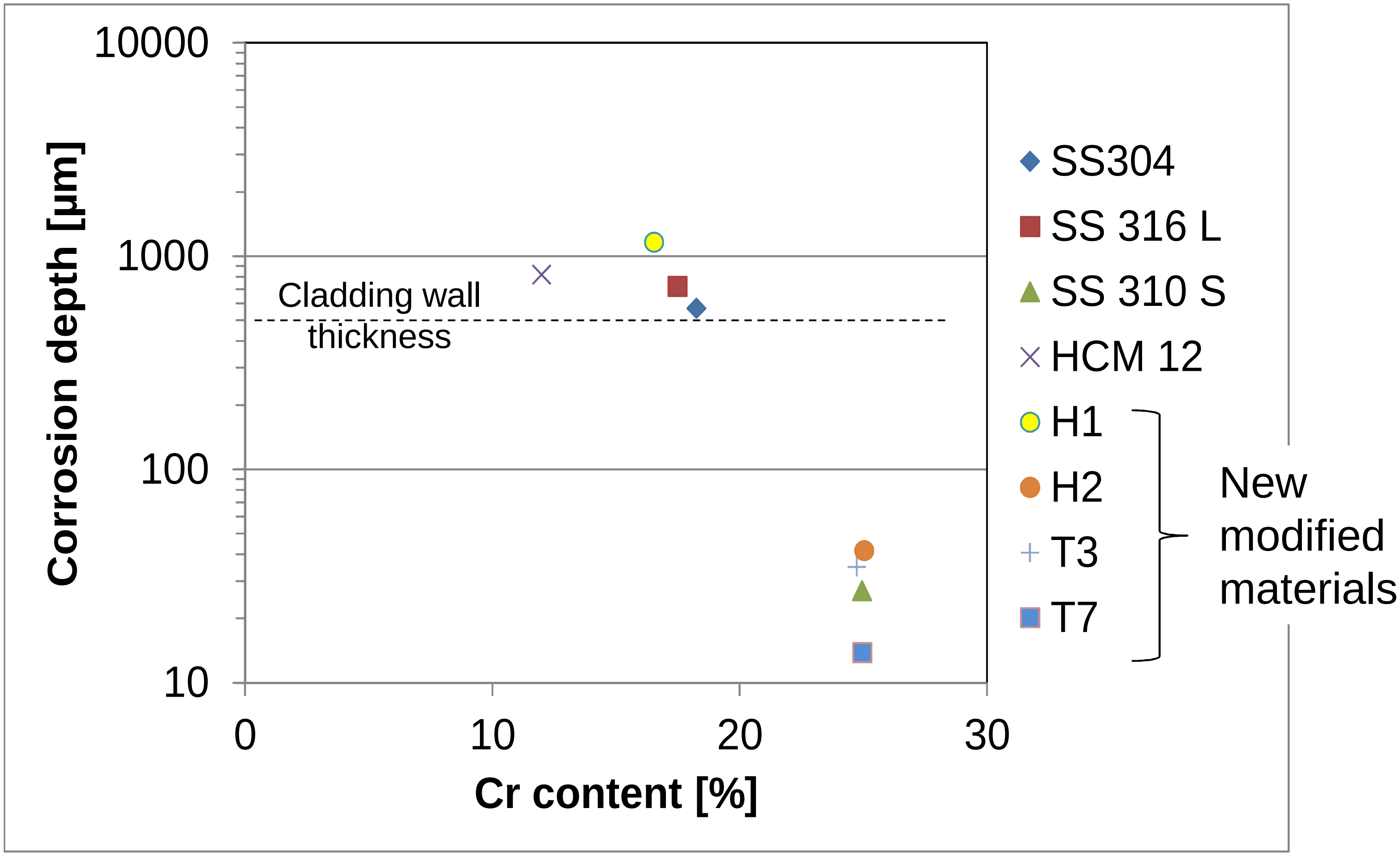
Stainless steels which are qualified for nuclear applications can be used up to 550℃ surface temperature,

- *high Cr steels for higher temperatures are promising but need further qualification tests.*
- *Coatings or surface treatment are still under development.*

***Autoclaves with supercritical water up to 695℃ are available**,*

- *but an in-pile radiolysis and water chemistry test facility with continuous flow of supercritical water is still under preparation.*

Predicted corrosion depth after 50,000h at 700℃

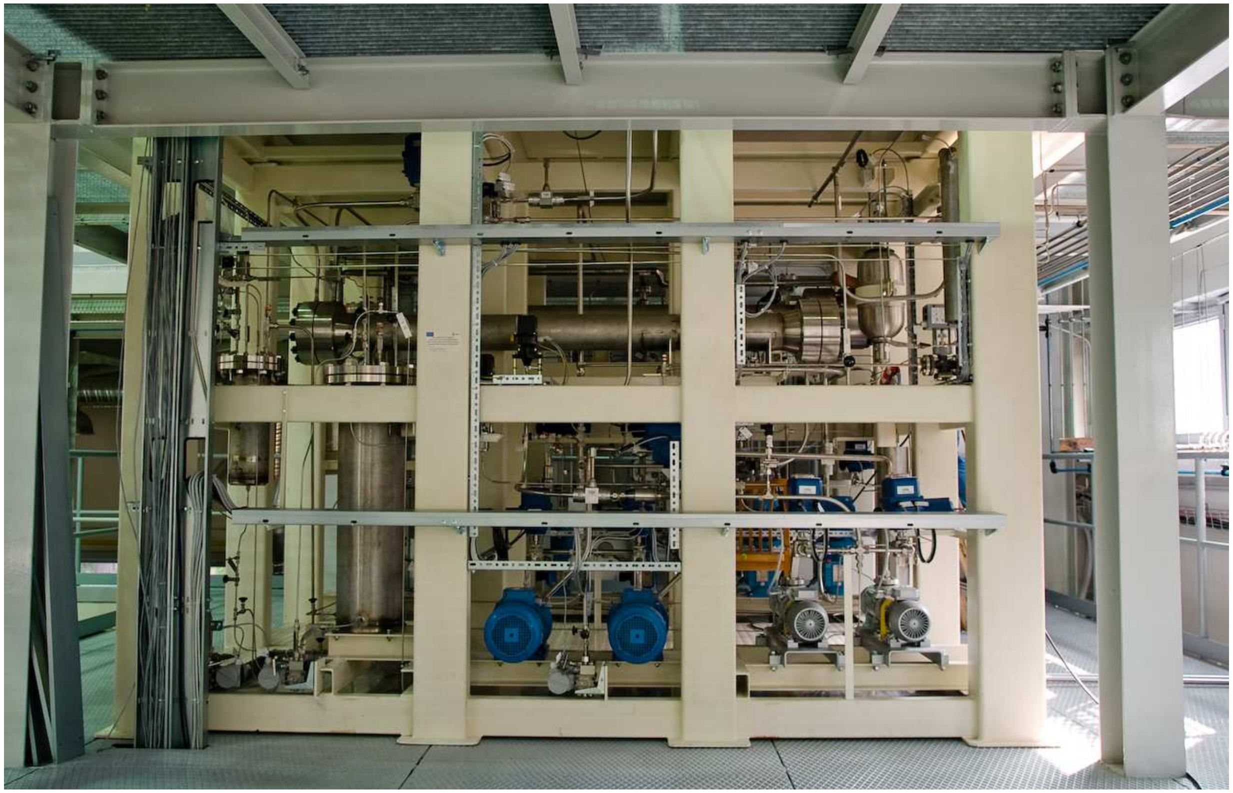


Stainless steel cladding alloys need to be modified to meet the design target

Materials and Chemistry: Future Tasks

Effect of radiolysis and water chemistry on corrosion

In-pile Supercritical Water Loop ready to be installed in the LVR-15 Reactor in Řež



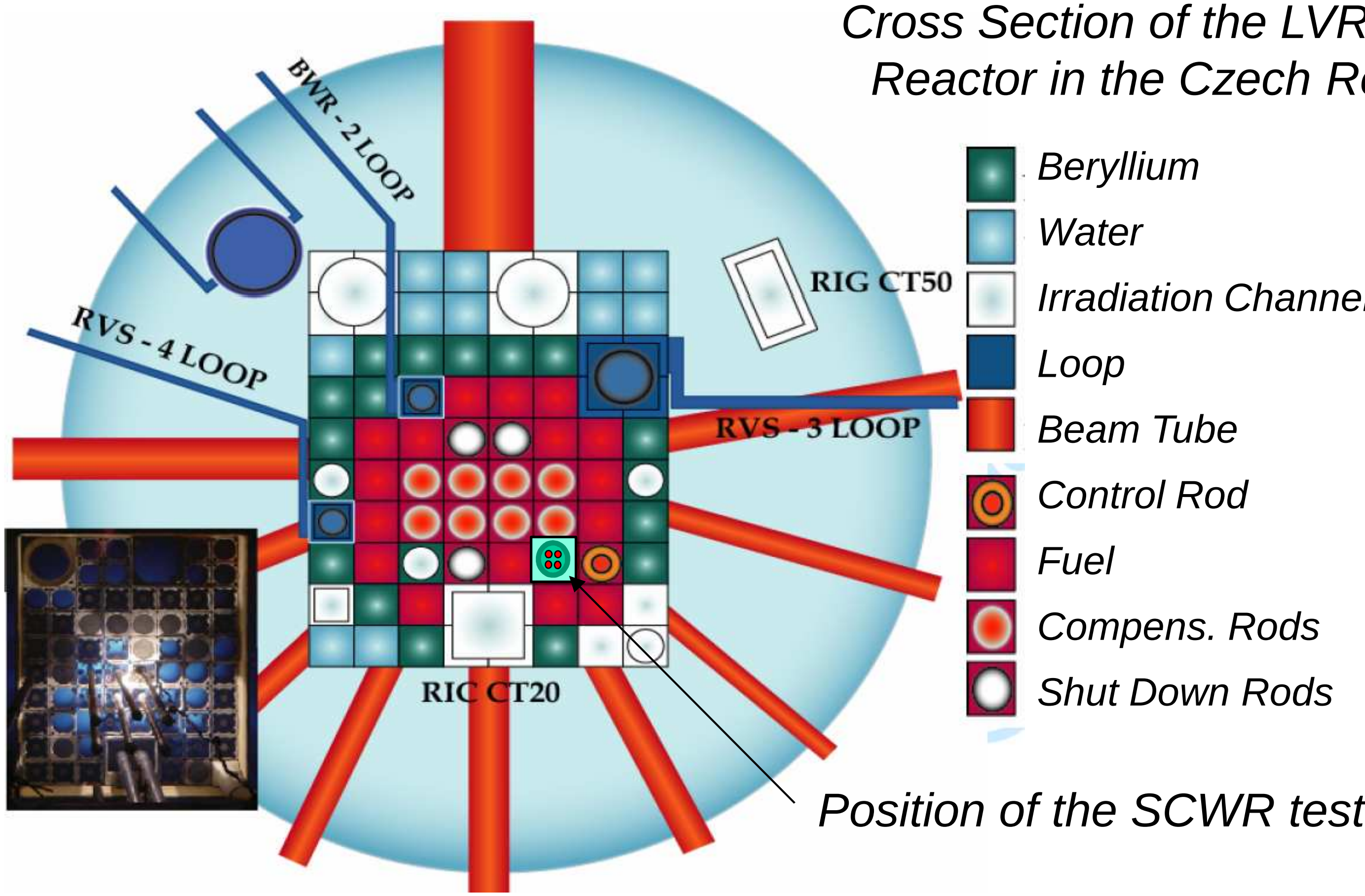
Measurement and Auxiliary Systems

GIF-SCWR Project "Fuel Qualification Test"

Project Arrangement being prepared by Euratom and Canada

Bilateral agreement outside GIF signed 2012 between Euratom and China

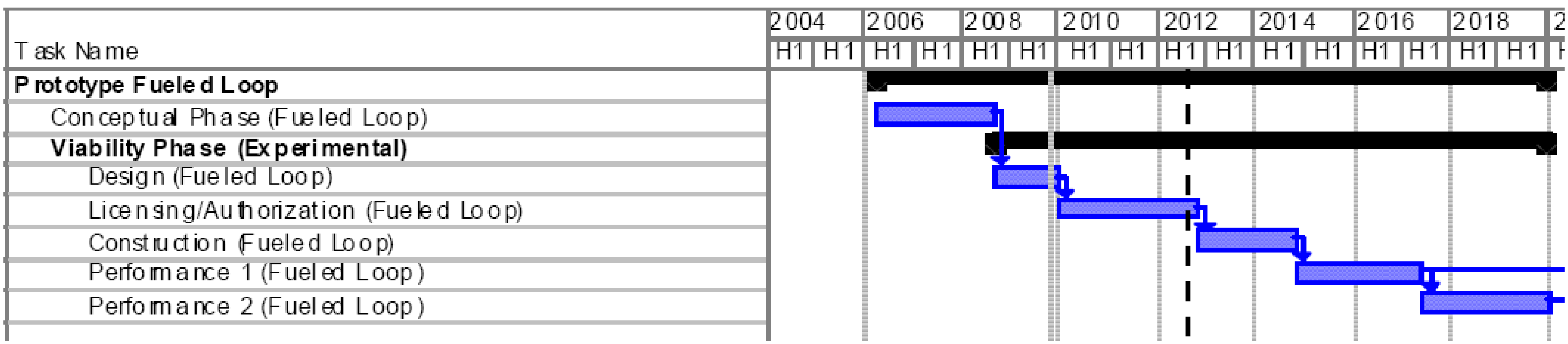
Cross Section of the LVR-15 Test Reactor in the Czech Republic



Position of the SCWR test assembly

Fuel Qualification Test

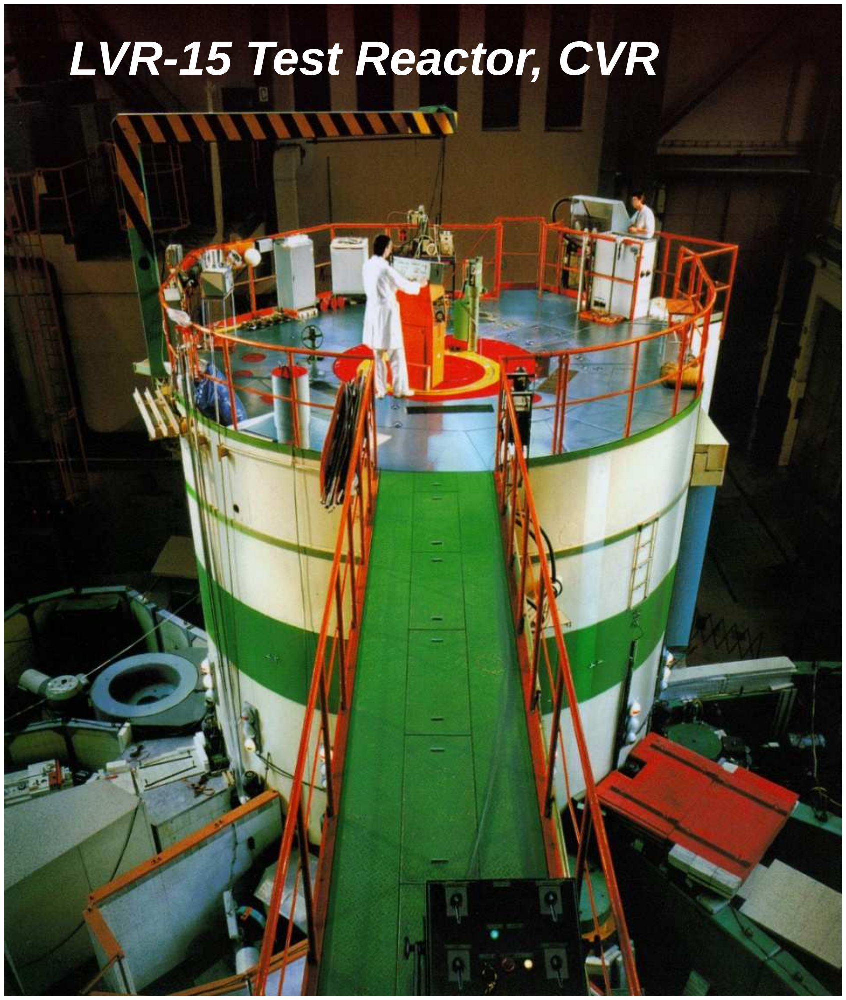
SCWR System Research Plan, Version 1, Oct. 2009



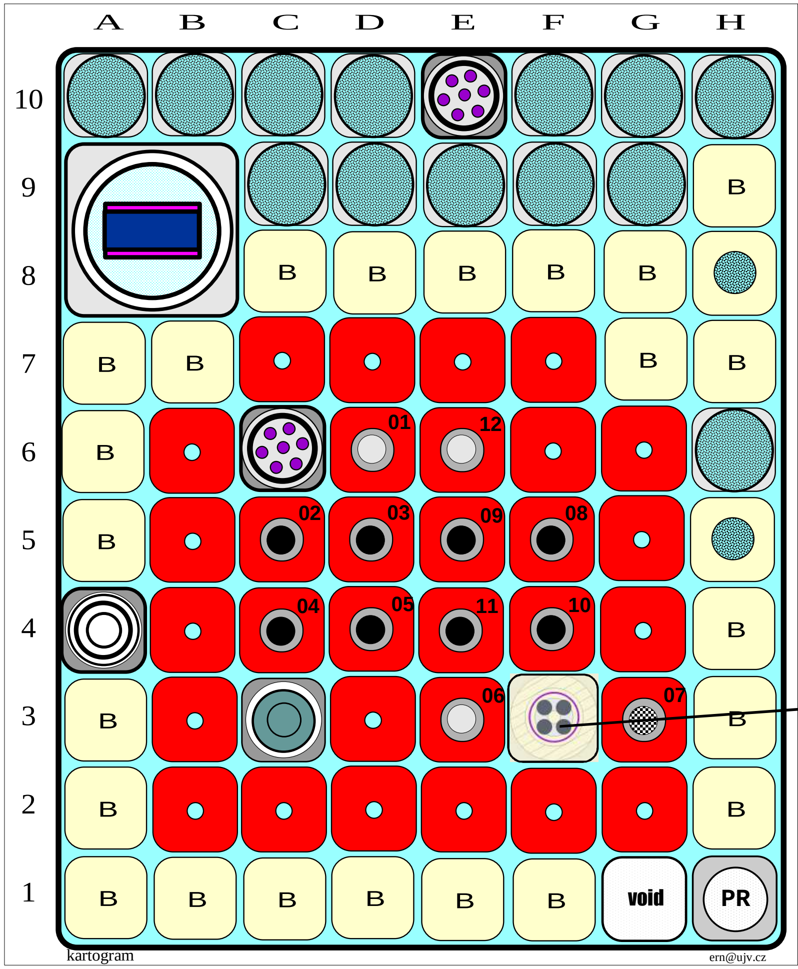
Fuel Qualification Test, Available Test Facilities

In-pile

Out-of-pile

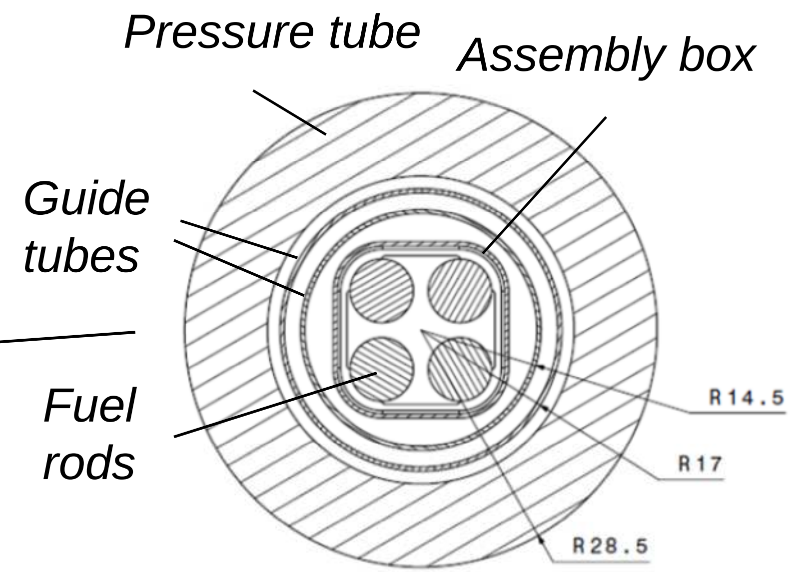


Planned Fuel Qualification Test at UJV in Řež



Core of the LVR-15 Reactor

SCWR 4 rod fuel bundle



Status 2012: Design of the FQT system ready for assessment

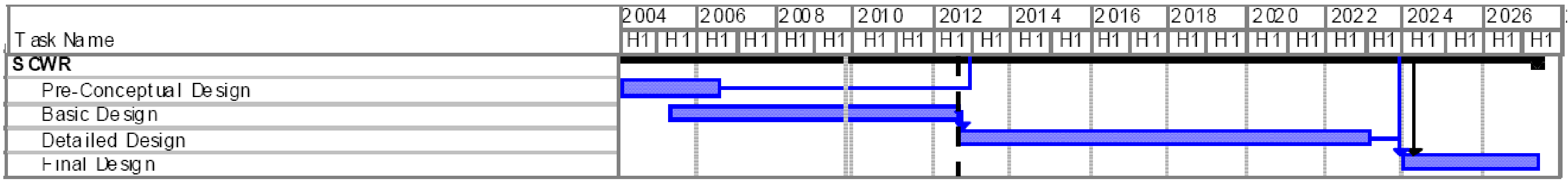
Objectives of the Fuel Qualification Test

The first time to use supercritical water in a nuclear reactor

- *Test of the licensing procedure, identify general problems*
- *Validation of thermal-hydraulic predictions*
- *Validation of transient system code predictions*
- *Validation of material performance*
- *Validation of stress and deformation predictions*
- *Qualification of fuel rod and spacer manufacturing processes*
- *Test of measurement systems for supercritical water*
- *Test of fuel-cladding interaction*
- *… etc.*

System Integration and Assessment:
Pre-Conceptual Design and Basic Design without Project Arrangement

SCWR System Research Plan, Version 1, Oct. 2009



Assessment of different design concepts with respect to the Generation IV criteria

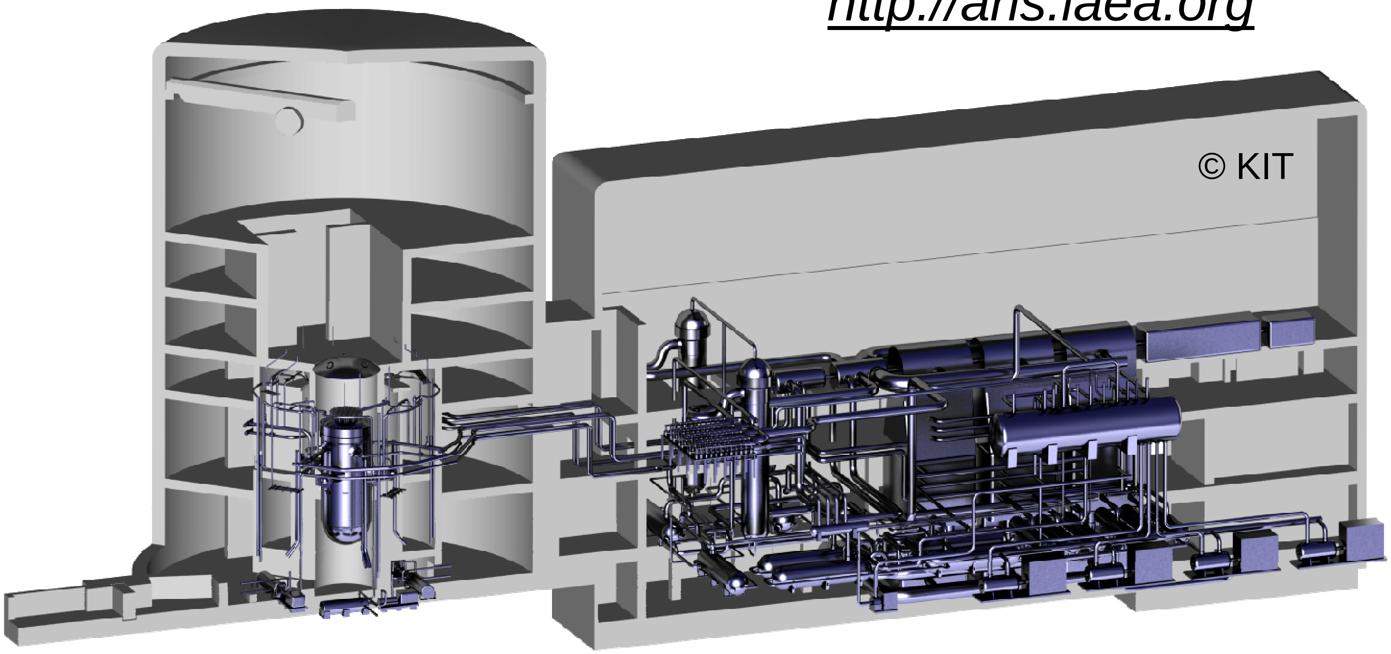
- *European HPLWR concept in 2010*
- *Japanese SCWR concept in 2010*
- *Canadian SCWR concept in 2015*

SCWR System Integration and Assessment, Euratom

Concept of a pressure vessel type reactor, completed: High Performance Light Water Reactor (HPLWR)

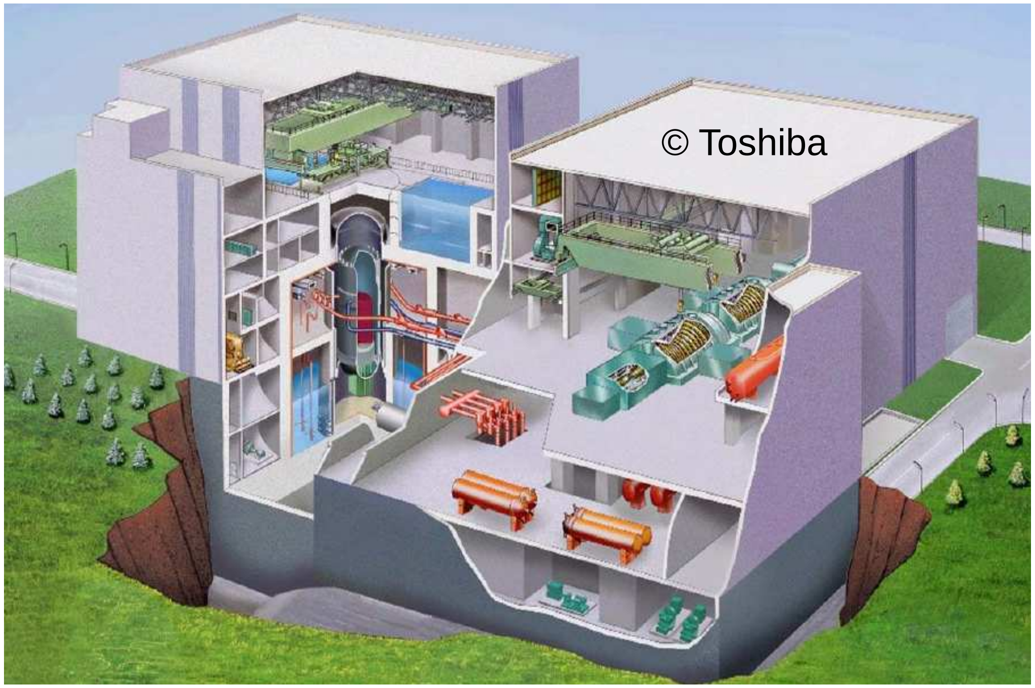
Net electric Power: 1000 MW_e
Efficiency 43.5%
UO_2 or MOX fuel

Details in IAEA Advanced Reactor Information System http://aris.iaea.org



SCWR System Integration and Assessment

Concept of a pressure vessel type reactor, completed: Japanese Supercritical Water Cooled Reactor (JSCWR)

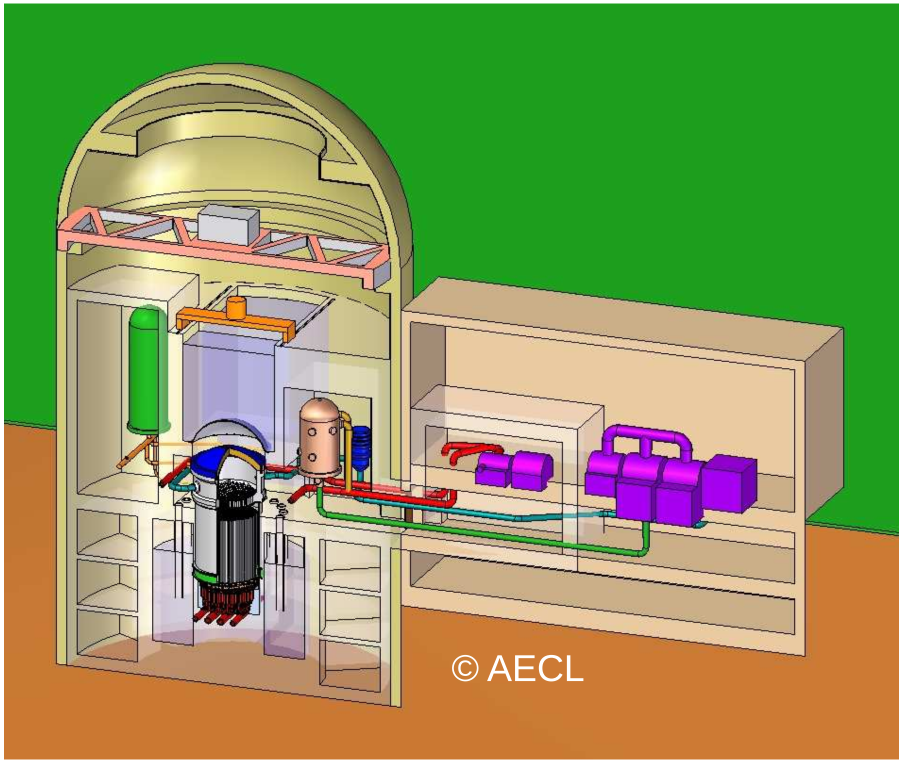


Net el. power: 1620 MW_e
Efficiency ~44%
Thermal neutron spectrum
UO_2 fuel

Details in IAEA Advanced Reactor Information System http://aris.iaea.org

SCWR System Integration and Assessment

Pre-conceptual design of a pressure tube reactor, under development: Canadian SCWR



Net el. power: 1200 MW_e
Efficiency ~48%
Heavy water moderator
Thermal neutron spectrum
Thorium fuel
Vertical pressure tubes with batch refueling
Direct once through steam cycle

New:
Draft Russian R&D Plan on SCWR Development in GIF

Focuses:

- *Hydrodynamics and heat/mass - transfer in SCW fluids in reactor cores and circuits, like critical flow, depressurization, transients etc.;*
- *Neutron physics: complex spectrum spatial distribution; dynamic processes; feed-backs of thermal-hydraulics;*
- *Selection of fuel and structure materials candidates of reactor, structures and core;*
- *Development of safety concept for vessel-type SCW reactors;*
- *Investigation of TH, neutron/TH instabilities, thermo-acoustic oscillations, flashing, water hammer, etc.;*

Use of Cross-Cutting Methodologies

- *Use of the GIF cost estimating guidelines:*
  - *SCWR electricity generation costs expected to be comparable to conventional LWR of similar size.*

- *Use of IAEA Technical Report 392 to assess proliferation resistance and physical protection:*
  - *SCWR with thermal neutron spectrum expected to have good proliferation resistance features*

- *Assessment will be continued using latest codes and methods of the GIF methodology working groups, e.g. PRPP Methodology rev 6.*

Summary

- ***SCWR concepts have been developed***
- ***Technology development ongoing with a focus on GIF objectives of improved safety, proliferation resistance, economics and sustainability***
- ***A fuel qualification test is being designed and licensed***
- ***SCWR R&D is progressing according to the 2009 System Research Plan with minor delays***
- ***Design and construction of a prototype or demonstration unit is planned to be included in the next SCWR System Research Plan***