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MATERIALS REQUIREMENTS AND CANDIDATE MATERIALS FOR SCWRs

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(SC24) Materials requirements and candidate materials for SCWRs

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CONTENTS OF SC24

1. GenIV Materials requirements and needs
2. Main components and materials selection for SCWR
3. Test programmes and sequencies for materials selections
   - mechanical and chemical properties
   - irradiation properties

GOALS OF THE LECTURE

To learn about the materials requirements and challenges for a high temperature LWR application.

To learn about the test programmes needed for materials specification for a new concept.

NEEDS FOR MATERIALS AND CHEMISTRY RESEARCH

•The Generation IV (Gen IV) initiative will push nuclear reactor technology to completely new performance requirements for components, due to:

►**Higher temperatures and process efficiency**

►**Longer lifetimes and higher neutron fluxes**

►**Challenges in materials technologies**

►**Novel technologies introduced for reactor fuel and fuel cycles**

•In Super Critical Water Reactors (SCWR) beside the design concept choice of construction materials is the most important question.

GENERAL FEATURES OF GENIV CONCEPTS LISTED FOR THE EURATOM PROJECTS

System	GFR	SFR	LFR & ADS	VHTR Thermal neutrons	SCWR Thermal neutrons & Fast	Fusion
Coolant	He, 70 bars 480-850°C	Na, few bars 390-600°C	Lead alloys (Pb, LBE)	He, 70 bars 600-1000°C	SC H_2O, 250bars, 280-500°C	He, 80bar 300-480°C
Fuel	(UPu)C / O2 in plates of pins in hexagonal subassemblies	(UPu)O2 in pins in hexagonal subassemblies	various concepts	Coated particles (SiC or ZrC) in a graphite matrix	UO_2 enrich	Dual coolant blanket
Core structure	SiC-SiCf composite or (backup) ODS	Cladding: ODS Wrapper: 9Cr MS	Cladding: 9Cr MS, ODS Wrapper: 9Cr MS	Graphite Composites C/C, SiC/SiC for control rods	Cladd. Aust SS, (Ni alloys?), ODS	SiCf-SiC MS, ODS FS
Temp.	500-1200°C	390-750°C	350-480°C	600-1600°C	280-750°C	Up to 650°C
Dose	60-90dpa	up to 200dpa	100dpa	7-25dpa	10 – 40dpa	100dpa + He
Out of core struct. and others	vessel & core struct: 9-12Cr MS 350-500°C <<1dpa	prim/sec/steam circ.: 9-12Cr MS 390-600°C	ADS target: 9Cr MS 350-550°C 100dpa+He+H	-----	Fossile fuel SC-boiler technology	------

SUPERCRITICAL POINT @ 374 ^{O}C - 22.1 MPA

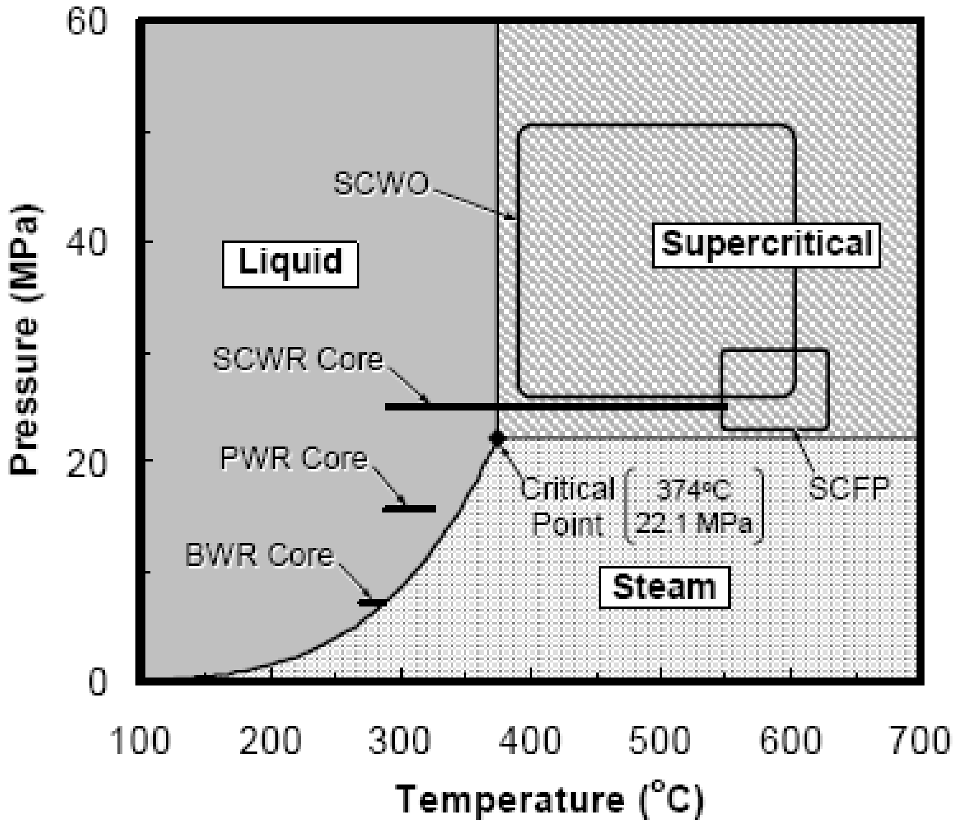
The temperature-pressure phase diagram of water showing the critical point and the supercritical regime.

The operational regions of present BWR and PWR plants, as well as SCFP are presented along with the design area of SCWR reactor.

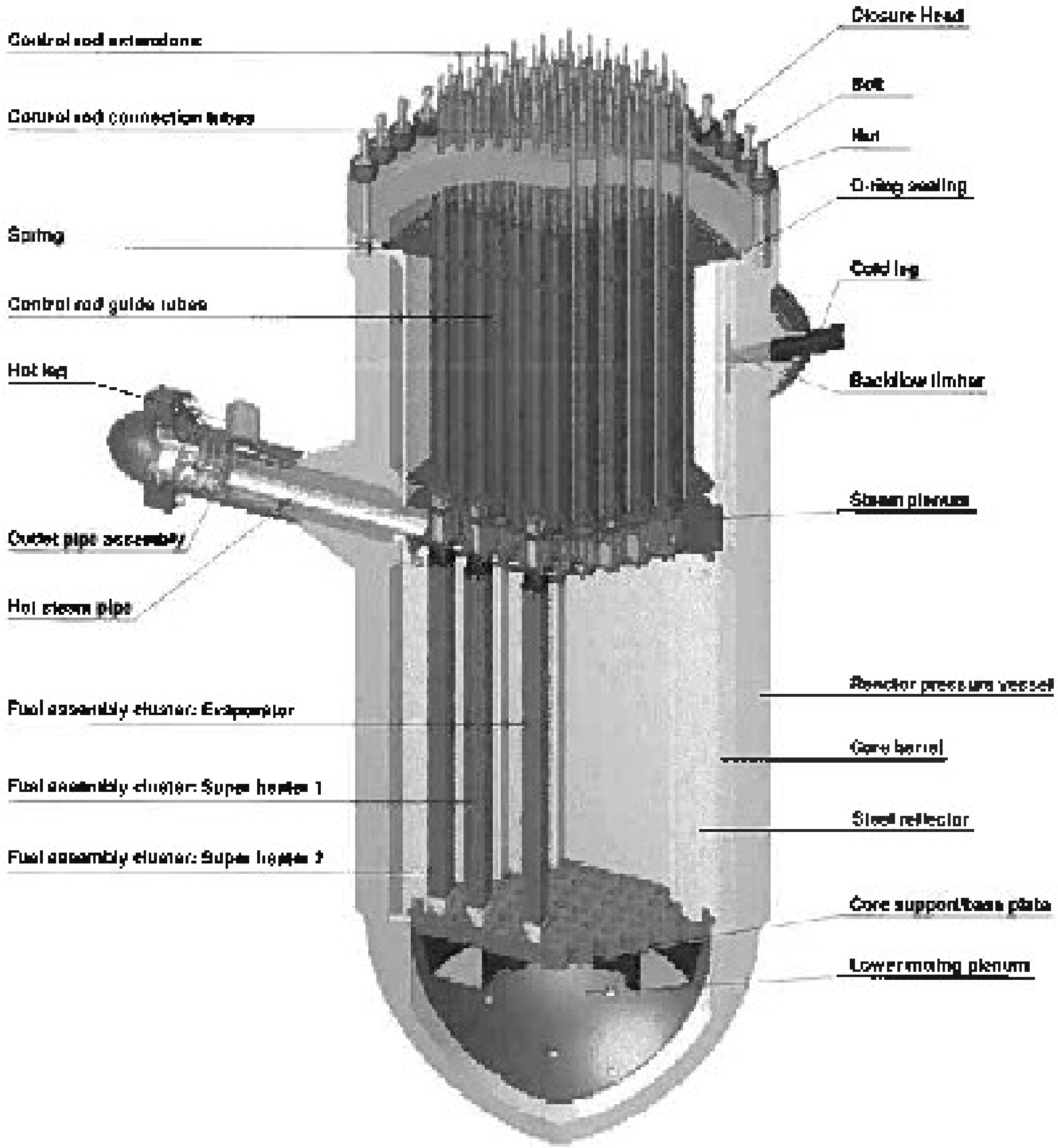
The large area covered by SCWO processes is fully in the SCW region.

SCWR concepts themselves are evolution of LWR and HWR designs.

BWR = Boiling water reactor
PWR = Pressurised water reactor
SCWR = supercritical water reactor
SCWO = supercritical water oxidation
SCFP = supercritical fossil fuel power plant



ASSEMBLY OF THE RPV FOR THE THREE PASS CONCEPT,



Assembly of the RPV for the three pass core concept [Koehly, 2009]

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SCWR MATERIAL CHALLENGES AND CANDIDATES

- The Reactor Pressure Vessel

the material will be either the same type as that used today in LWRs, or a steel with a higher alloying content or higher creep resistance (e.g., T/P91).

- The pressure tube design

the insulated fuel channel concept is the current reference design.

- The fuel cladding material

Zr-alloys oxidise too quickly at SCWR temperatures.
the choices are likely to be either a stainless steel or a novel oxide dispersion strengthened (ODS) alloy;
ODS-alloys with a Cr-content of 9 – 19 % have been widely studied in Japan. Irradiation tests are underway today as well.

MATERIAL TYPES AND PERFORMANCE UNDER SCWR CONDITIONS

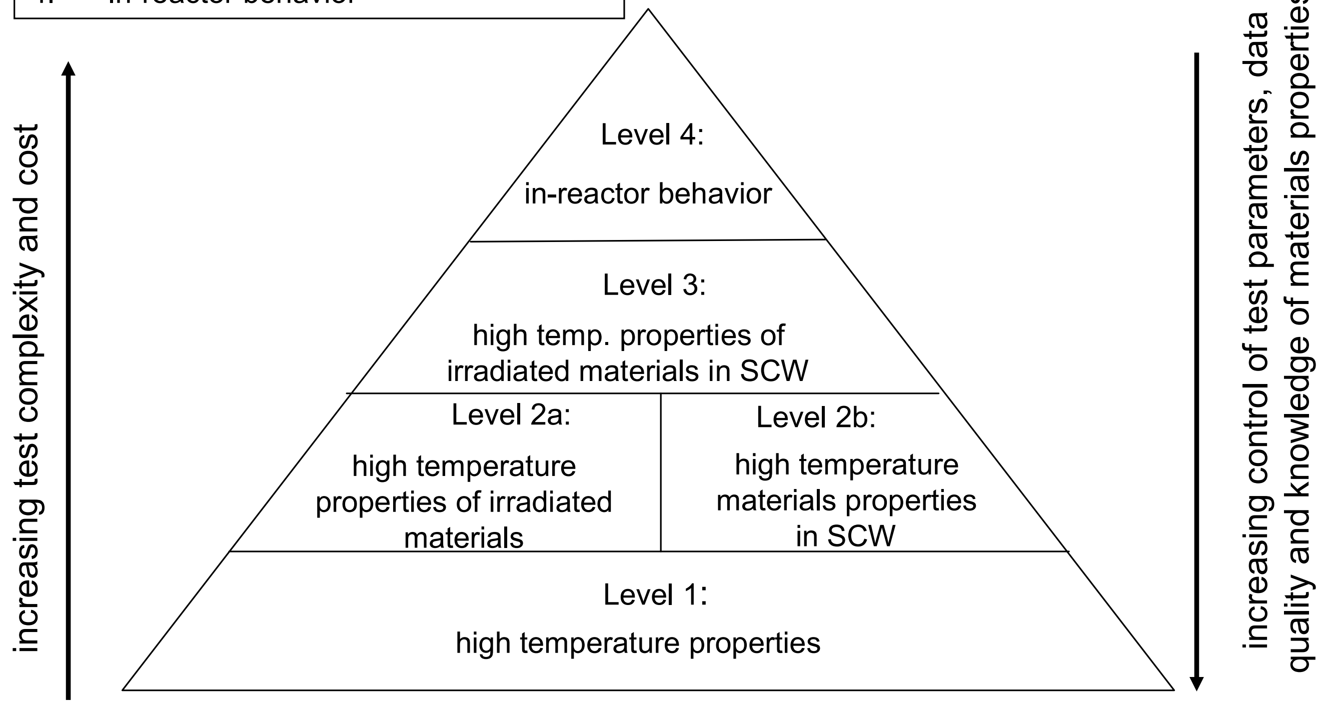
Alloy type	Corrosion resistance		Radiation damage resistance		HT mechanical integrity	"Economics"
	General corrosion	SCC	Swelling	Embrittlement		
Austenitic steel	High	Medium	Low	High	Medium	Good
Ferritic steel	Medium	High	High	High	Low	Good
Ni-base alloy	High	Medium	Low	Medium	High	"Tolerable"
Ti-base alloy	Medium - High	Limited data			Medium - High	Expensive

ODS alloys = very expensive

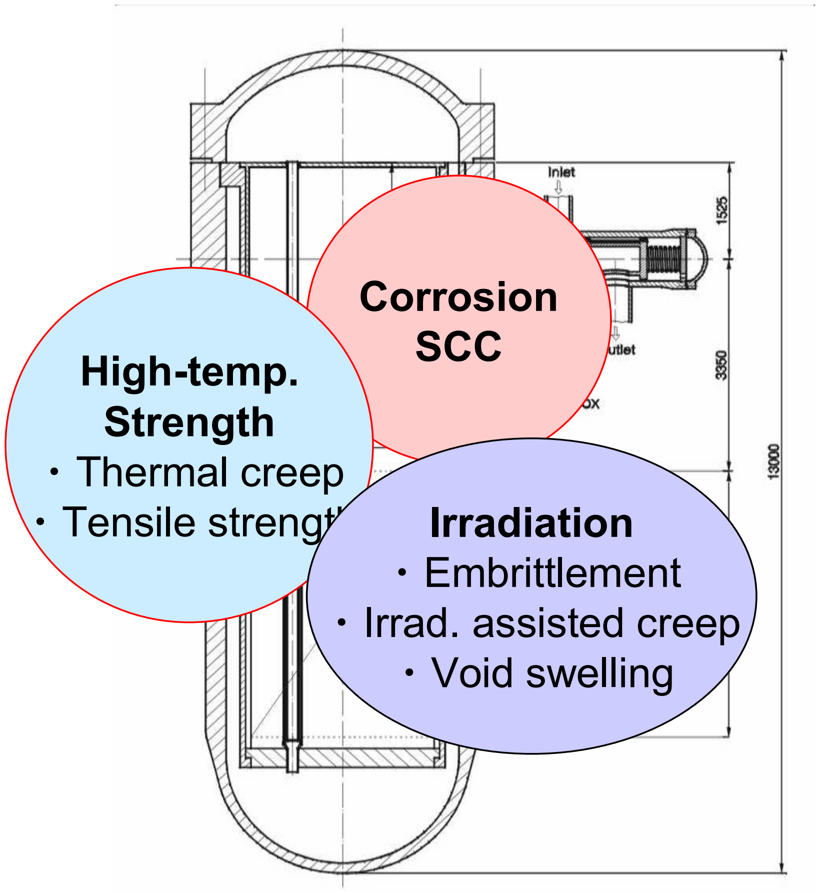
TRIANGLE FOR TESTING AND ALLOCATION OF WORK IN THE GIF SCWR MATERIALS AND CHEMISTRY FORUM

Types of Materials Studies Required

1. High temperature materials properties
2. Irradiated materials properties
3. Properties of materials in SCW
4. In-reactor behavior



EURATOM HPLWR ”STARTING POINT” FOR MATERIALS R&D



HPLWR Data (5th FP)

Gross power	1000 MW_e
System pressure	25 MPa
Core coolant mass flow rate	≈1160 kg/s
Core coolant inlet temp.	280 °C
Core coolant outlet temp.	500 °C
Active core height	4200 mm
Fuel pin outer diameter	8.0 mm
Fuel pitch	9.5 mm
Fuel assembly shape	hex. or square
RPV total height	13000 mm
RPV inner diameter	3380 mm

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THE EXPERIMENTAL PROGRAM FOR M&C IN HPLWR PHASE 2 PROJECT

Materials database

Water chemistry

SC Loop

Partner	Test/activity type	Material and environment	Potential component
CEA	Materials performance studies (review): Provider for a SCW-materials database including all tests and literature data	Austenitic stainless steels Ni-based alloys Simulated irradiated materials	Fuel cladding RPV internals
VTT *)	Corrosion and creep studies: - Oxidation and general corrosion with coupons - SCC with U-bend and 3-point bend specimens - Creep-oxidation using bellow loading (500 - 600^{o}C) for controlled slow tensile loading	Ferritic steels Ferritic and austenitic stainless steels Ni-based alloys at 300^{o}C -> 600^{o}C H_2 & O_2 water chemistry	Fuel cladding RPV internals Out of core components
AREVA	Expert contribution: specifications, evaluation of results and water chemistry concept	-	Fuel cladding Internal support Out of core components
UJV	Supercritical Water construction and qualification out-of-pile. Preparation of the loop for future in-pile tests.	Varying water chemistry (H_2 content optimisation to suppress radiolysis)	Fuel cladding Internal support Out of core components

PIE* PROGRAM UNDERWAY OR PLANNED FOR THE EU GETMAT PROJECT

PIE = post irradiation examination

Experiment/ Reactor	MATRIX Phenix	STIP 4-5 SINQ	MEGAPIE	ASTIR BR2	LEXUR II BOR60	IBIS & SUMO HFR
Spectra	Fast neutrons	High energy protons and neutrons	High energy protons and neutrons	Thermal & fast neutrons	Fast neutrons	Thermal & fast neutrons
Materials	**T91, T92, EUROFER T91,T92 GESA treated ODS (9-20Cr)**	**9-12 Cr Welds ODS (9-20Cr)**	**T91 AISI 316L**	**T91, T91 GESA treated, welds, ODS**	**T91, T91 treated & welds, SS316L**	**T91, Eur-ODS T91 coated, SS316L, welds**
Tests Examinations	Tensile Impact CT, fractog. SEM, TEM	Tensile Bending Charpy, SPT, TEM	Tensile, Bending, SPT, SIMS, XPS, XRD SEM, TEM	Pressurised tubes, CT, tensile, Charpy	Tensile Corrosion	Tensile KLST, SEM, TEM
Irradiation Temperature	390 – 530°C	300-700°C	250-375°C (T91 beam window)	350, 450°C	400°C: 316L 480 & 550°C: T91	300, 500°C
Dose Range	30-65 dpa	10 – 20 dpa	~7 dpa (T91 beam window)	~ 5 dpa	Up to 20 dpa	2 dpa
Environment	Na	Inert gas	Pb-Bi	Pb-Bi, inert gas	Pb, inert gas	Pb-Bi Na (SUMO)

THANK YOU

See SC25 for more specific material properties and choice of materials