Coolant fluids for fast neutron reactors, Scientific and technical issues: An overview

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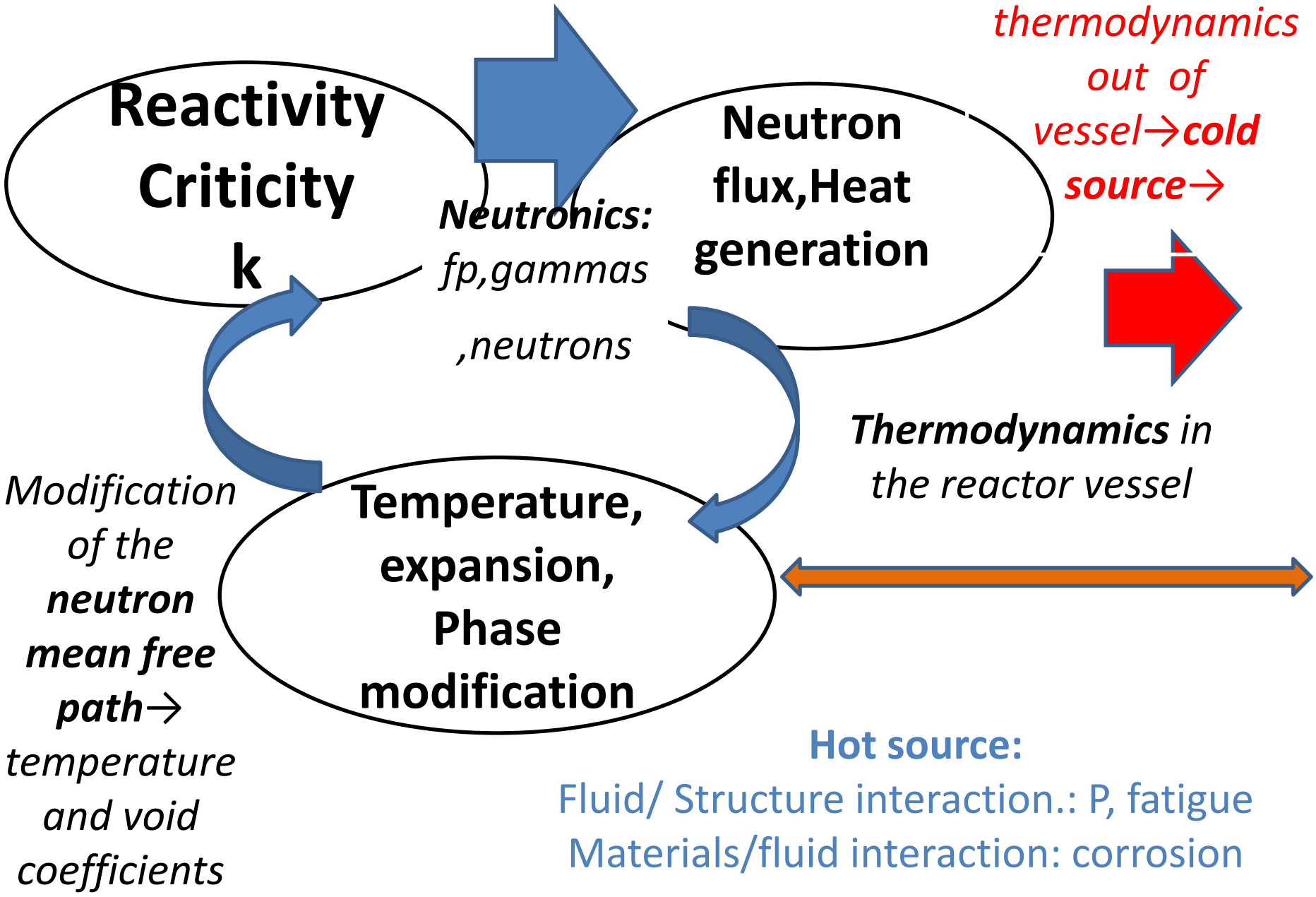
Driving forces

Fast neutrons

- Toward a better management of transuranic fissile nuclides (especially Pu isotopes) generated by PWR technology
- Toward a better use of potentially fissile nuclides material resources

Efficient electric power generation

- Toward more efficient generation of electricity : increase the temperature of the thermodynamic cycle


Reactivity
Criticity
k
Neutronics:
fp,gammas
,neutrons
Neutron
flux,Heat
generation
Heat Extraction
thermodynamics
out of
vessel→cold
source→
Thermodynamics in
the reactor vessel
Temperature,
expansion,
Phase
modification
Modification
of the
neutron
mean free
path→
temperature
and void
coefficients
Hot source:
Fluid/ Structure interaction.: P, fatigue
Materials/fluid interaction: corrosion

Functions of the Coolant fluid

- **Relate the « interior » (i.e. Nuclear Part) to the « outside » (i.e. the Non nuclear Part, the conversion system)** via a fluid which is transported to **extract working power from heat**
- **Possible emergency Passive evacuation of the RESIDUAL POWER**
- Cool down the fuel and possibly modify the core dynamics

Key of safety physics issues is TIME AND DURATION

Chemical shock wave: 40 цs

Nuclear Shock wave 50 ns,

Its neutron Chain reaction : 3 ns,

Life time of a neutron in reactor: 0,01/0,1 ms,

No possible nuclear explosion, but which best way to **contain RADIOACTIVITY** and **simultaneously exhaust its HEAT**?

Constraints on the coolant fluid

Thermal constraints

- Transport Heat : **Heat capacity** ρCp
- Remain **single phase** : Tf, Te, **pressure**
- Being pumped: **density, viscosity**

Neutronic constraints : thermal neutrons vs fast neutrons depending on the neutrons/atoms interaction : **Capture/fission**;

chemical nature/atomic density

heat extraction $Q = \dot{m}\ C_p\ \Delta T = \rho\ S\ v\ C_p\ \Delta T$

Pumping capacity $P_{pump} = \frac{\dot{m}\ \Delta p}{\rho} = \frac{\dot{m}}{\rho}\ C.\ \rho\ \frac{v^2}{2\Phi}\ L$

(Henri SAFA)

Q/P= efficiency of heat extraction => « Merit Index »

$$F = \left(\frac{\rho^2\ C_p^{2.8}}{\mu^{0.2}}\right)$$

Caloporteurs

		Réacteur	Température	Température de fusion à Patm	Température d'ébullition à P atm	Pression	Densité de puissance	Rendement	Facteur de mérite	Facteur de mérite	Densité	Capacité calorifique	Viscosité dynamique
			(°C)	(°C)	(°C)	(MPa)	(MW/m3)	(%)	relatif Na		(kg/m3)	(J/kg/K)	(kg/m/s)
Eau liquide	H_2O	REP	330		100	15,7	100	33%	65	1,17E+17	660,0	6 154	8,10E-05
	H_2O	REB	285			7,6	50	34%	52	9,26E+16	760,0	5 212	1,03E-04
	H_2O	RBMK	285			6,8	6	31%	52	9,26E+16	760,0	5 212	1,03E-04
	D_2O	CANDU	300			13,0	12	29%	65	1,16E+17	785,0	5 489	9,40E-05
Métal liquide	Na	RNR	550	96	892	0,1	500	42%	**1**	1,80E+15	830,0	1 273	2,43E-04
	Pb	RNR ADS	573	327	1 744	0,1	112	42%	0,251	4,50E+14	10 477,0	147	1,89E-03
	PbBi			125	1 670				0,243	4,37E+14	10 180,0	146	1,50E-03
Gaz	CO_2	UNGG	400			3,0	2	29%	0,0008	1,46E+12	22,9	1 122	2,94E-05
	CO_2	MAGNOX	400			1,0	1	28%	0,0001	1,63E+11	7,6	1 122	2,94E-05
	$CO_{2\ sc}$	SCWR	546			20,0		44%	0,0323	5,81E+13	128,0	1 243	3,74E-05
	He	HTR	775			4,8	6	40%	0,0005	8,09E+11	2,1	5 200	4,61E-05
	He	GTMHR	850			7,1	7	48%	0,0007	1,20E+12	2,5	5 200	4,85E-05
	He	GFR	850			7,1	50	42%	0,0007	1,20E+12	2,5	5 200	4,85E-05
Sels fondus	Fluorures	MSR	650	l de la comp	de la comp	0,1	22	44%	12,8	2,31E+16	1 622,0	2 390	3,84E-03
	Chlorures		580	l de la comp	de la comp	0,1	130		1,6	2,81E+15	1 812,0	1 004	2,32E-03

Issues with the coolant fluid (1)

- Possible radio-activation of the coolant
  - **Chemical nature** + impurities
- Interaction fluid /**materials**
  - Corrosion
- Interaction fluid /structure
  - **Pressure** => creep, plasticity, fracture
  - Vibrations =>**fatigue**
- Interaction fluid /**surfaces**
  - Boundary layers (hydrodynamics, chemistry)
  - **Exchange layers** (heat transfer, phase transformation)

Issues with the coolant fluid (2)

- Fluid **etancheity** (pumps, valves…)
- Control (non destructive testing)
- maintenance (reparation, replacement of components…)

- Loading / unloading the fuel while cooling
- Interaction with
  - air, with the secondary circuit
  - the whole cold source
  - thermodynamic work

Structure of the seminar

- 4 different coolants : Sodium, Lead, Molten salt, Helium
- Specific issues for each coolant
  - Feedback from past experience
  - Interaction between fluid and structure
  - Operation technologies
- Generic fundamental questions Fluid/Solid interfaces
  - Non reactive contact
  - Reactive contact

Fluid coolants: assets and hindrances

	Sodium	Lead	Molten Salt	Helium
Better use of fuel resources (U, Pu, Th…)				
Better efficiency of heat conversion (higher T)				
Better interaction fluid structure (corrosion)				
Easier operation condition and maintenance				