IAPWS 2012 Annual Meeting (Boulder, Sep. 30 – Oct. 5, 2012)
Power Cycle Chemistry WG

A Consideration of Design Procedures Related to Water Chemistry of BWR Power Plants

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Introduction

Design of nuclear power plants

- **Design Concept** Principal policy for plant construction and operation
- **System design** basic systems and equipment arrangement
- **Hardware design** specification of equipment, hardware, materials
- **Operational plan** cycle period, fuel type, water chemistry

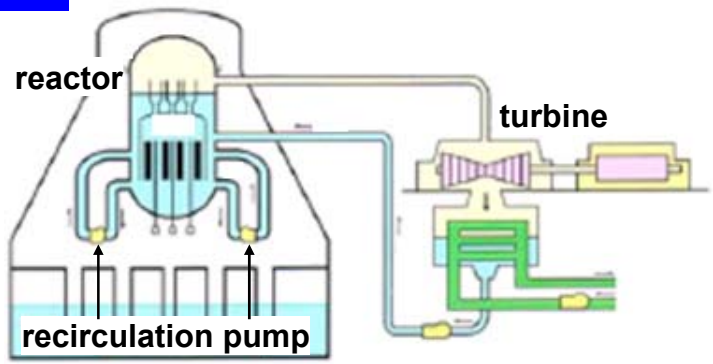
All are designated as design of plant in the broad sense

- To determine reactor power and type, arrangement of major equipment based on demands of plant utility and social needs.
- To carry out system design and hardware design based on plant safety, economics and easy to handle
- To decide most efficient operational plant under miscellaneous restrictions

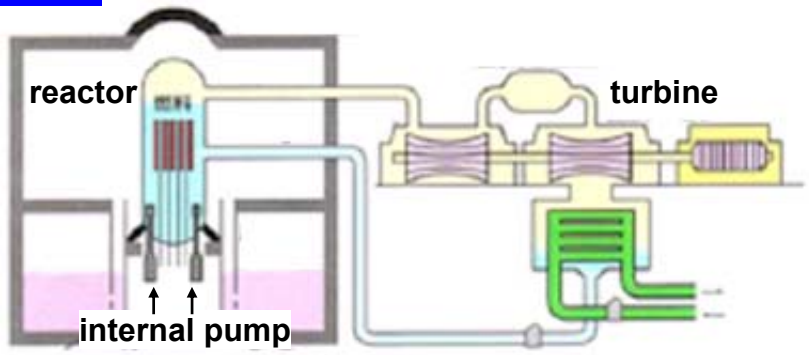
Cooling water should meet the most basic role for plant (moderator and coolant)

Water chemistry control would be determined under stage of operational plan

BWR

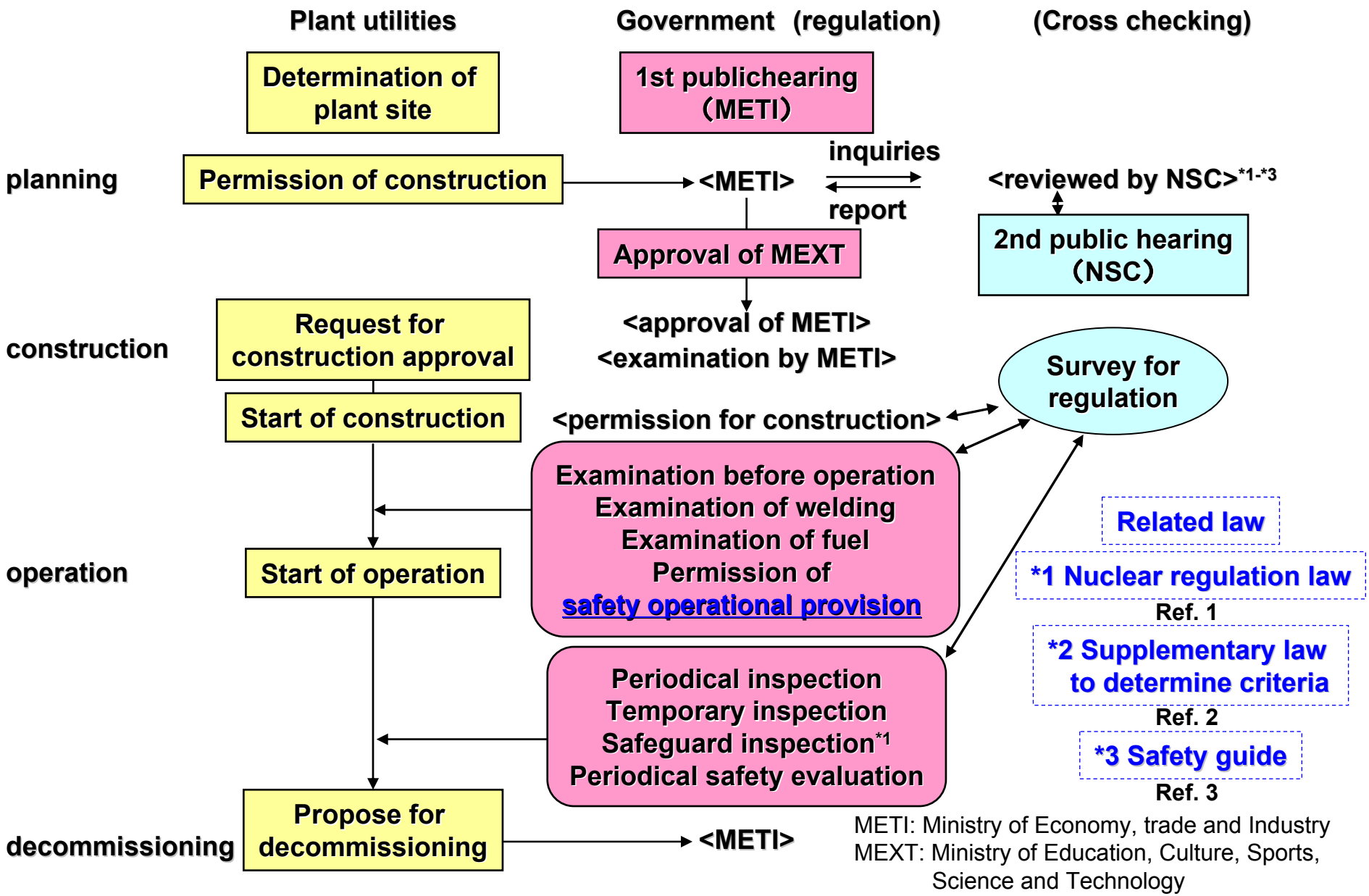


ABWR



Flow diagram of regulation of nuclear power plant No.2

Planning, design, construction, operation and decommissioning

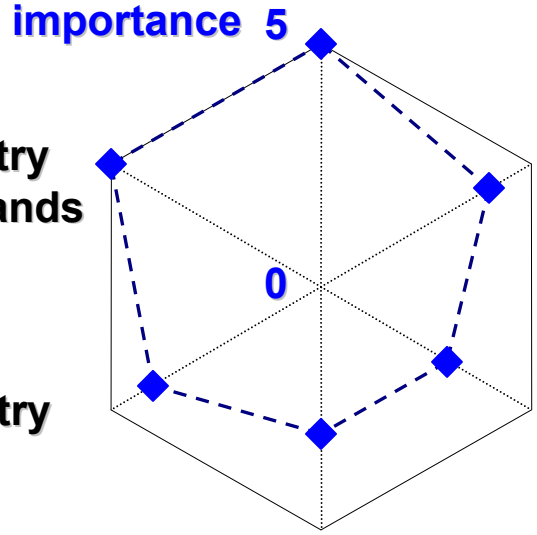


METI: Ministry of Economy, trade and Industry
MEXT: Ministry of Education, Culture, Sports, Science and Technology

Importance of water chemistry related design

Differences in design scopes of structural materials, fuel and water chemistry				
	applied locations	changes in operation	designed lifetime	design criteria
structural materials	fixed	impossible	as same as plant lifetime	function for pressure boundary
fuel	fixed	impossible (every cycle)	depend on burn-up	integrity of fission products
cooling water	flowing	easy	non	coolant and moderator (in area of nuclear design)

Design concept:
what philosophy to treat water chemistry on



Water chemistry control:
to determine water chemistry based on operational demands

System design:
to determine coolant related system based on the design concept

Water chemistry control:
to determine water chemistry based on design concept

Hardware design:
to determine functions, sizes and materials of major components

Plant material design:
to determine materials for component form the viewpoints of entire plant

Major subjects on water chemistry design

Water chemistry does not place its position on the center of NPP design but support fuel and major component

- Fuel (Guarantee for fuel integrity)
- Structural materials (mitigation of SCC, FAC)
- Occupational exposure (capacity of CUW, low Co materials) under balance of cost and benefit
- Radwaste system (water chemistry locating at upstream of radwaste) Water chemistry might affect system performance
- Water chemistry is required total balance in the plant design.

Major items to be determined during plant design

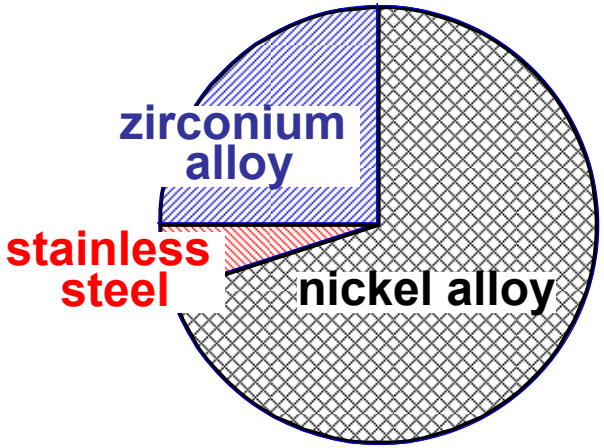
- Design concept for cooling system（BWR/PWR, jet pump/internal pump), strategy for occupational exposure reduction
- System design for clean-up system and its capacity
- Hardware design for clean-up component
- Operational plan for minimum influence against major component

Interaction of structural materials and cooling water

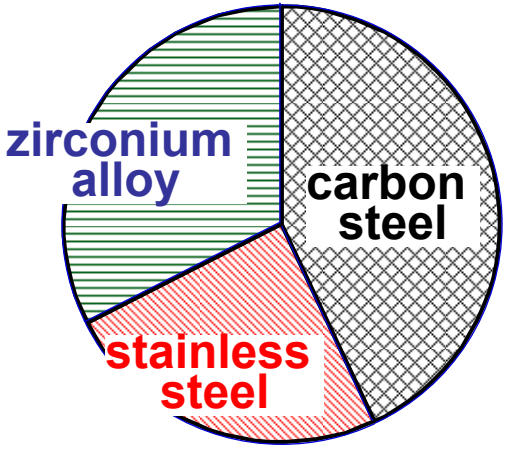
Major materials in primary system

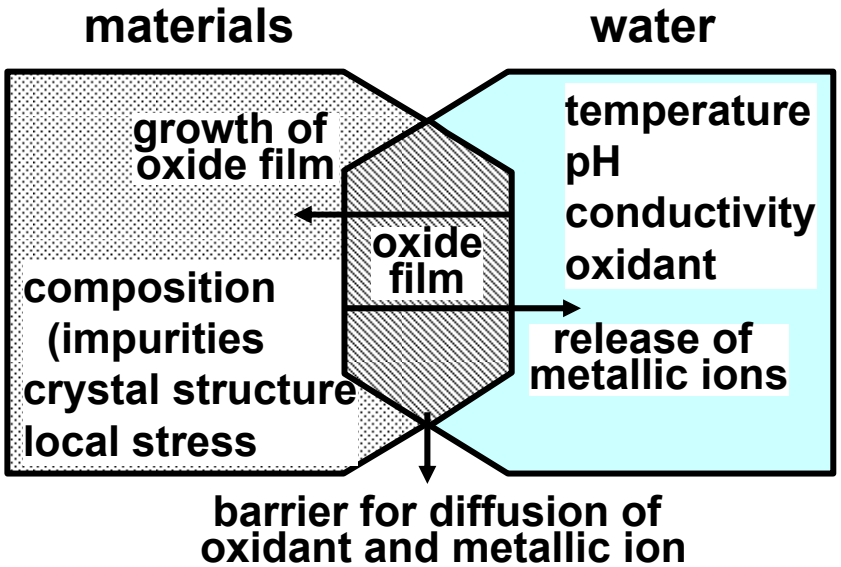
Their wetted surface

PWR (primary system)



BWR





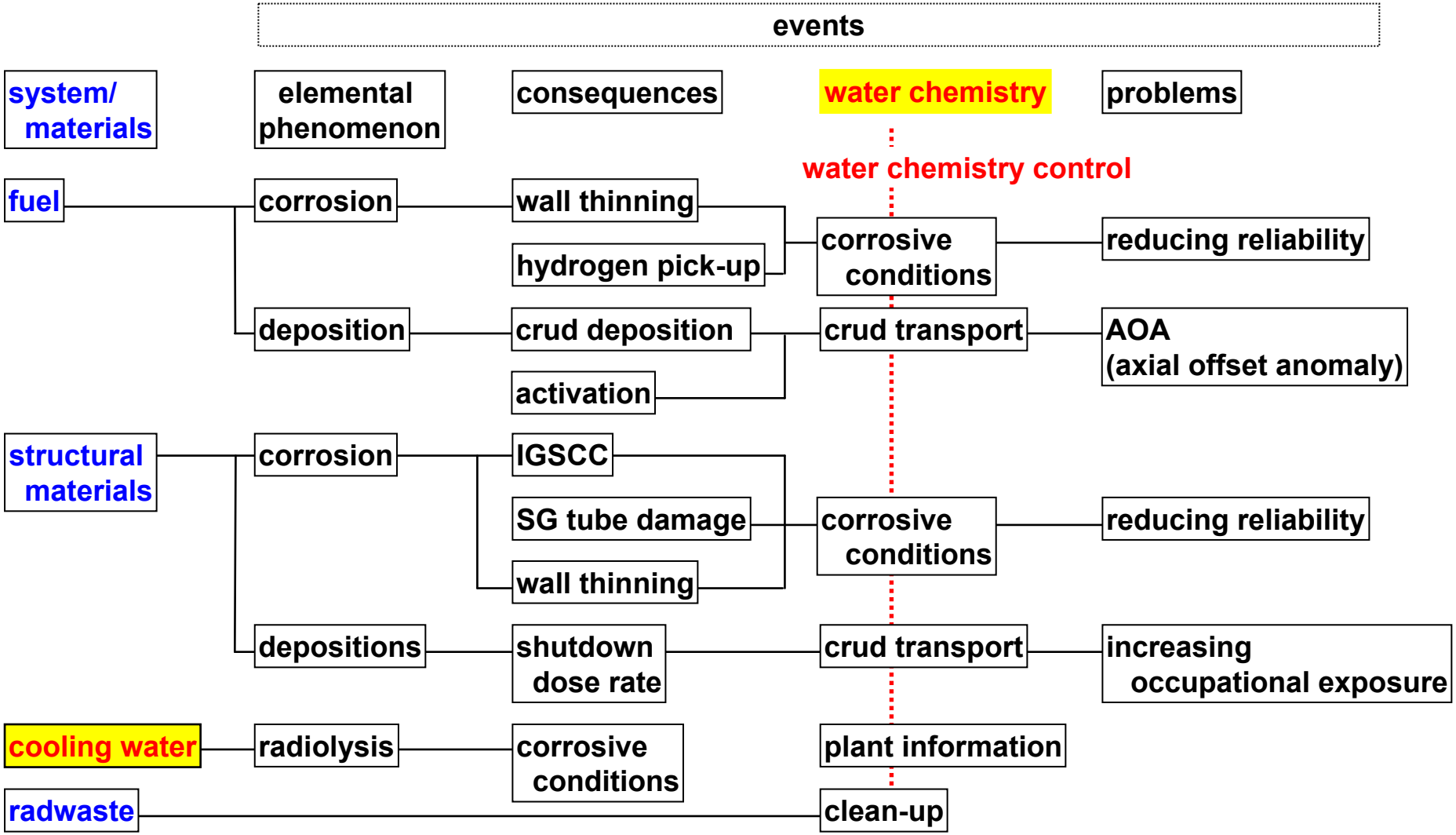
consequence of corrosion/control corrosion

carbon steel
low alloy steel
stainless steel
nickel base alloy
zirconium alloy

PWR (primary): H_2addition, LiOH
PWR (secondary): N_2H_4 addition, AVT
BWR (neutral): pure water
fossil fuel plant: N_2H_4 addition, AVT, AVTO, OT
chemical plant: miscellaneous

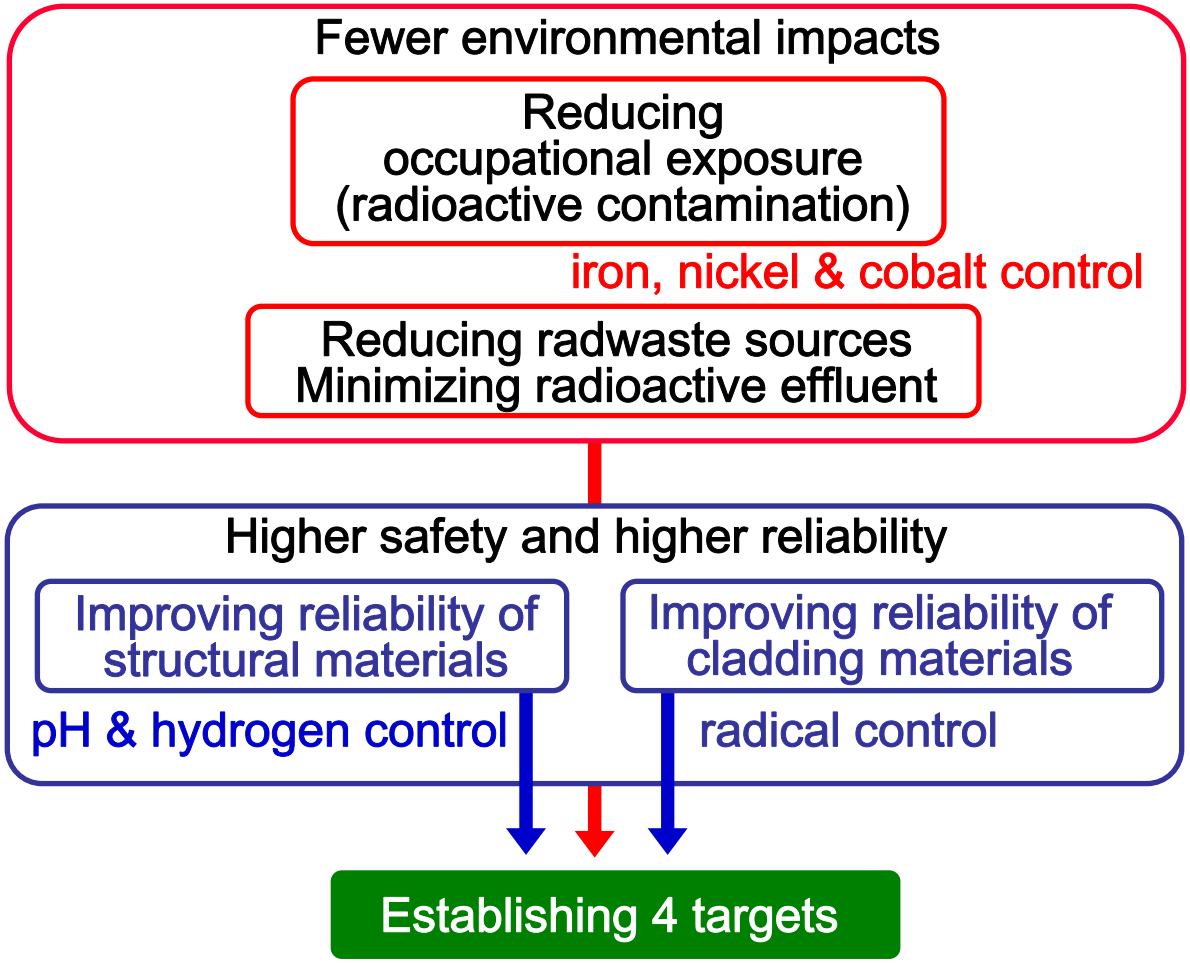
Ref. 4

Relationship of materials and cooling water



Ref. 5

Optimal water chemistry control



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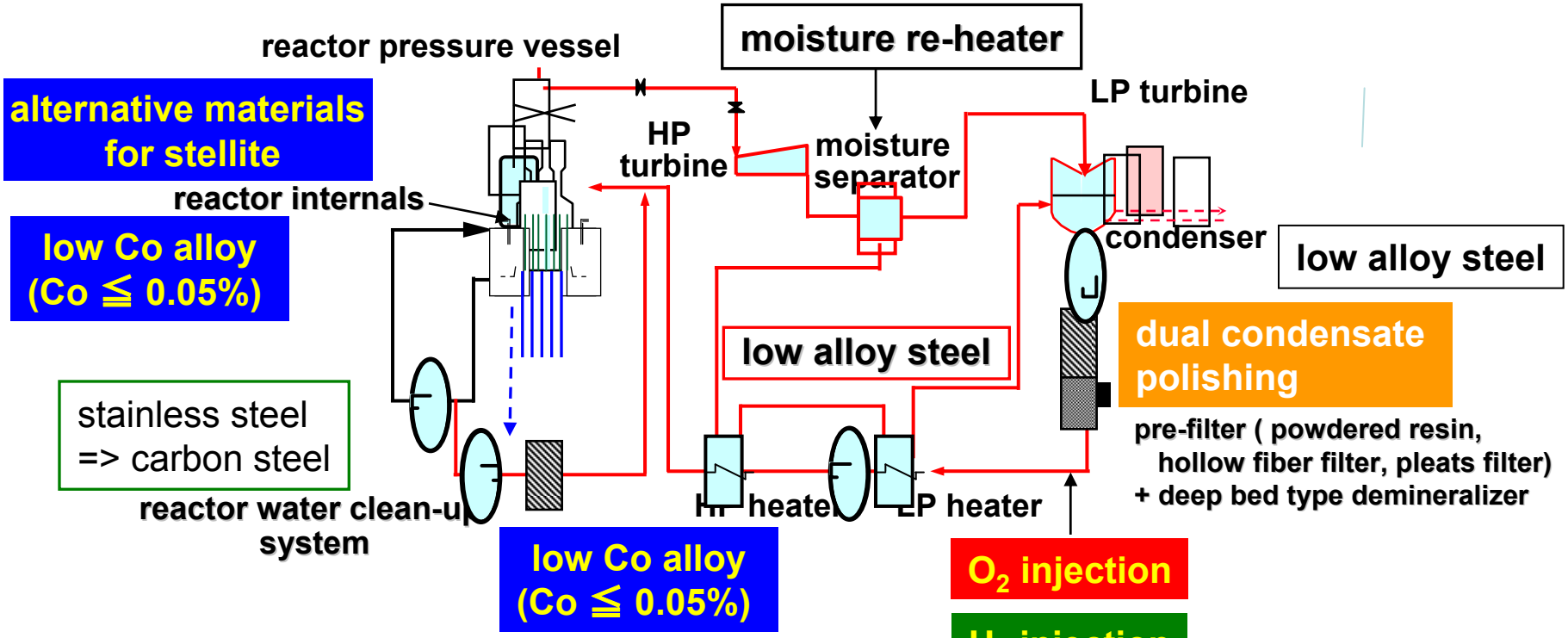
Trend of structural materials in BWR

	Dose rate reduction			Preventive maintenance	Fuel integrity
	Crud control	Co reduction	FP reduction		
Water chemistry control	■	■		■	■
Material improvement	□			□	
Improved fuel			⬚		
Improved plant efficiency					



■ :countermeasure for crud reduction

■ :countermeasure for cobalt reduction

Ref. 7

Major control items and target values

Only targets restricted by the law were shown in the operational safety provision, which was determined by plant utility owners for the plant and authorized by the government

Items	PWR primary system	PWR secondary system	BWR cooling system
temperature (°C)	310	285	285
pressure (MPa)	13.4	6.7	6.7
Reactivity control	control rod + chemical shim (B)		control rod + void (flow rate)
pH (-)	6.8-7.4*1	8.8-10*2	5.6-8.6
conductivity (μS/cm)	～1 *3	3-5*4	<1
boron (ppm)	100-2,000*3		-
lithium (ppm)	<3.5 *3	-	-
Oxygen (ppb)	<5	<5	200 [<10]*5
hydrogen (ppm)	2-3	-	10 [50]*5
Chroride (ppm)	<0.05		<0.1
^{131}I（Bq/mL）	plant unique*6		plamnt unique*6
Turbine dose rate		dose rate free	operation: ^{16}N shutdown: ^{60}Co

Relationship to operational safety provision

Corresponding to the important notice shown in the operational safety provision

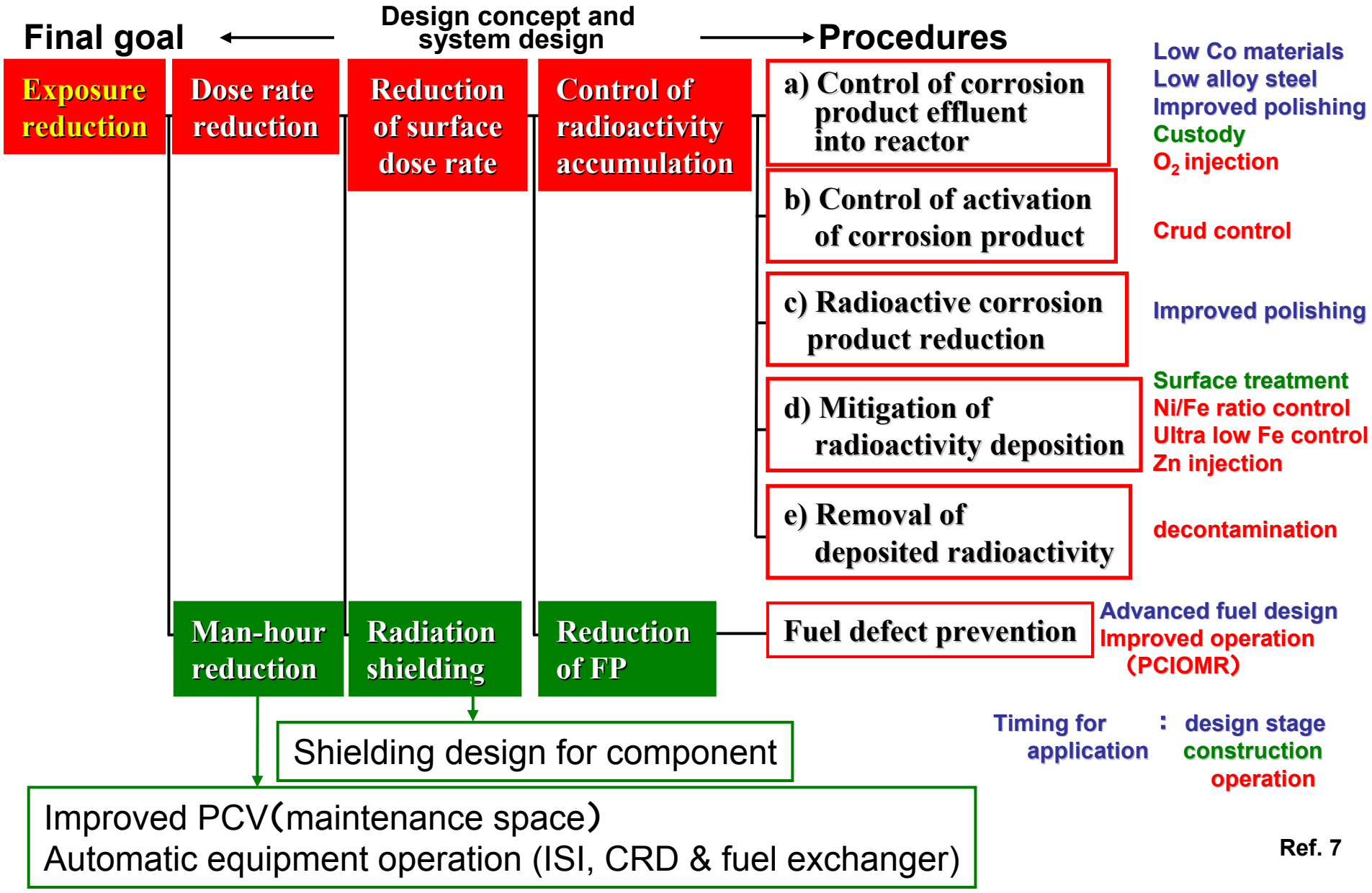
As same as the target values shown in the operational safety provision

*1 high temperature pH
*2 room temperature pH
*3 coupled control of [B] and [Li] due to burn-up
*4 plant unique values were reported
*5 under hydrogen injection
*6 for guarantee for fuel integrity

Ref. 8

Occupational exposure reduction

Design concept, system and hardware design, construction& operation plans



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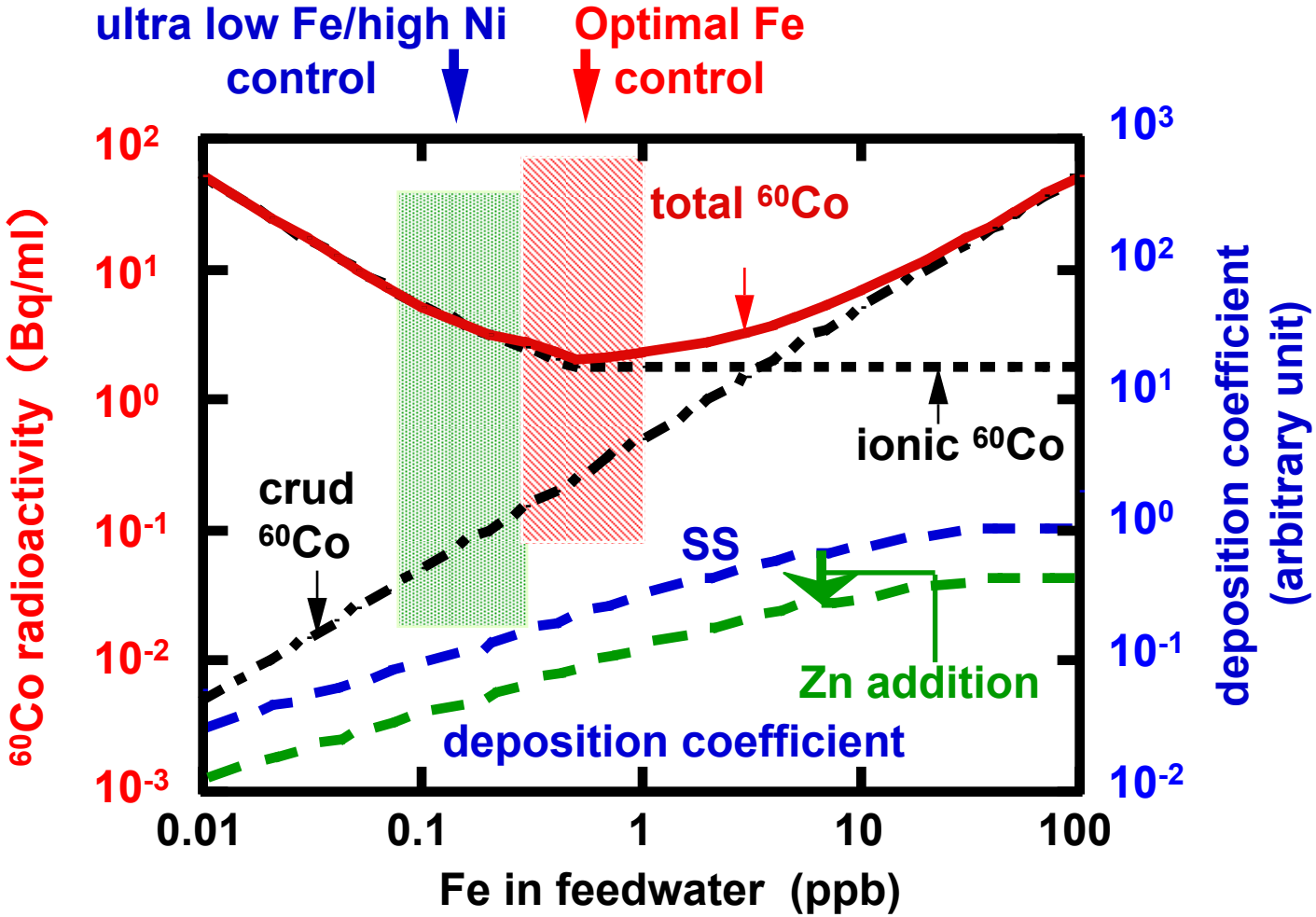
Optimal water chemistry

Major targets	BWR	PWR	Control procedures	Adverse effects	Remarks
Dose rate reduction	○		optimal Ni/Fe ratio control	fuel contamination	applied
			ultra low Fe high Ni control	dose rate for CS lines	applied
			Zn addition	fuel contamination	applied
		○	high pH control	fuel defects	applied
			Zn addition	fuel defects	applied
Structural integrity	○		H_2 addition	dose rate increase	applied
			H_2+ noble metal addition		applied
	○ FW line		O_2 addition (FAC)		applied
			low alloy steel		applied
		○ primary	higher [H_2]	dose rate	EPRI
			lower [H_2]	monitoring	JAPC
		○ 2ndary	high pH control	heater tube integrity	applied
			[O_2] addition	SG tube integrity	JAPC
			low crevice pH	monitoring	KEPCO
Fuel integrity	○		neutral, low crud control	dose rate increase	applied
			low [Li] control	dose rate increase	applied
Radwaste source reduction	○		applied low alloy steel		

Optimal water chemistry for dose rate reduction

shutdown dose rate ∝ ^{60}Co deposition ∝ ^{60}Co in Rw x deposition rate



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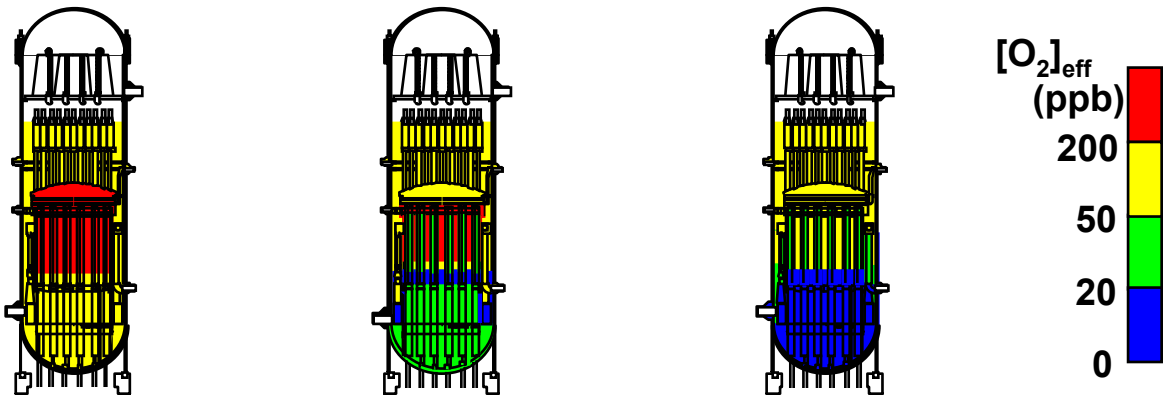
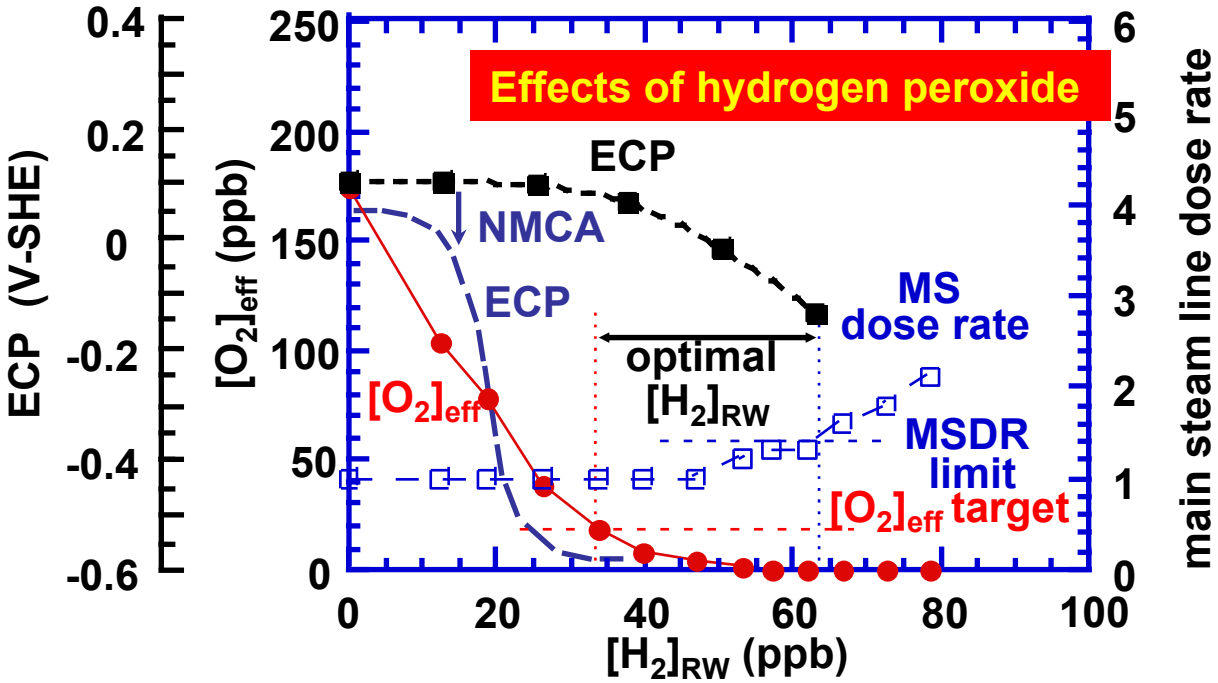
Effects of HWC on corrosive conditions

- Response of Electrochemical Corrosion Potential (ECP) -



NWC HWC $[H_2]_{FW}$: 0.2 ppm $[H_2]_{FW}$: 0.4 ppm



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Influence of water chemistry on other systems

Experience with water chemistry design of the author (late 1960s)

Radiation shielding（assumption for design）

- **Source term for turbine design: ^{16}N**
  - **^{16}N produced by ^{16}O (n.p)^{16}N reaction and its carry-over to turbine**
  - **Estimated results were confirmed by plant**
- **Source term of condenser and demineralizer: fission products**
  - **Radioactive corrosion products at present time.**
- **Source term for biological shield: gamma rays from $^{1}H(n,\gamma)^{2}D$ reaction**

Radioactive effluent into environment (not assumed)

- **Effluent from turbine off gas: noble gas hold-up system**
- **Effluent from turbine shaft sealing: clean steam from house boiler**
- **Effluent through HVAC: source reduction**

Effects on fuel

- **Hydrogen pick-up of zirconium alloy: confirmation by evaluation**

Influence on radwast system

- **Obstruction of liquid waste solidification: filter slug**

Major targets to be cared in design processes

Fuel design: fuel

Structure design: structural material

Water chemistry design: fuel, structural materials, radwaste system, water chemistry itself

Clear restriction on water chemistry was not defined by the law, while corrosion effects were mentioned in the law, which influenced indirect regulation.

Even if the restriction of water chemistry control was minimum, optimal operation of the plant was much depended on water chemistry.

- **Optimal water chemistry control, which can obtain the final targets as high as possible and minimize adverse effects as small as possible, are required.**
- **The control should be support by logical and quantitative evaluation but not by only empirical knowledgebase.**
- **Instrumentation and analytical technology are essential for reliable control.**
- **The control targets should not be forced by the low but determined for better plant management.**

Experience with technologies for trouble shooting

	Relationship between the trouble and water chemistry		
	Intentional favorite effects	Affected (givers)	Influenced (receivers)
Fuel	-	defects (crud, H_2, Zn, Pt)	FP release surface effects (^{60}Co activation)
Structural materials	HWC、NMCA、O_2 injection (FAC mitigation)	SCC（high ECP）	crud generation Co generation
Occupational exposure	crud control	turbine dose rate (^{16}N) contamination by ^{60}Co	-
Radwaste treatment	source volume reduction (slim radwaste system)	liquid waste (concentrated waste) filter element （prevention of solidification）	-

File-up the experiences and transfer them to next generation
"What's good? How affected?" with considering their mechanism
Trade-off of benefits and costs.
(application of low Co materials, clean-up capacity; good but expensive)

Summary

1. Design concept is important for water chemistry design as well as fuel and material design, while flexible design for plant operation is more important than system and hardware design and there are lots option to be applied.

2. System design and hardware design are less restricted by the law. Water chemistry design is not limited by severe design criteria while it is set toward better plant operation,

3. Interactions of water chemistry with fuel and structural materials have not been completely understood and lots efforts have been paid for quantitative control to carry on optimal and effective plant operation based on not only empirical understanding but also theoretical understanding.

4. Huge amount of data base coupled with theoretical thinking base should be effectively applied for plant operation , which should be transferred to the next generation.

The document was translated from Japanese slides presented at the Joint Summer Seminar of the Nuclear Fuel, Materials and Water Chemistry Divisions of the Atomic Energy Society of Japan (Sep. 11-12, 2012, Hotel Ichibata, Matsue-Shinjiko Onsen, Japan)

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