IAEA Technical Meeting on Experience in Codes and Standards for Fusion Technology

Comparison of potential code & standards for tritium breeding blanket and application of RCC-MRx in CN ITER HCCB TBM-set

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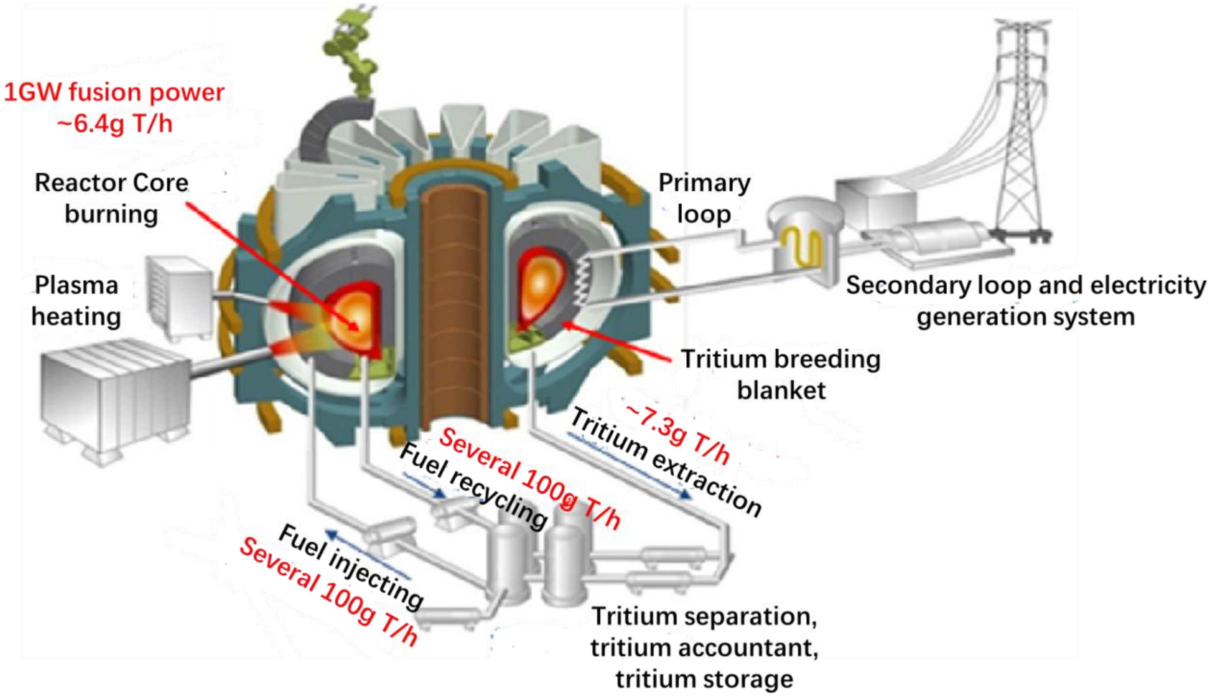
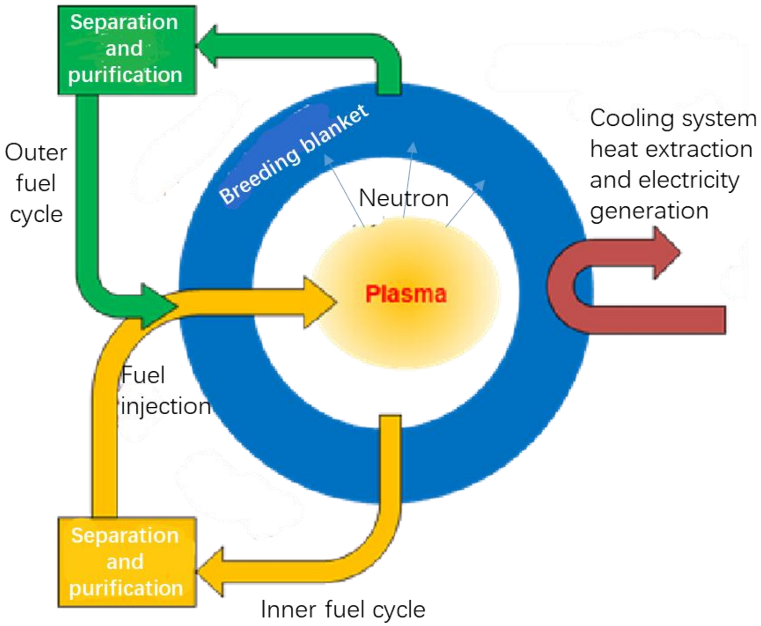
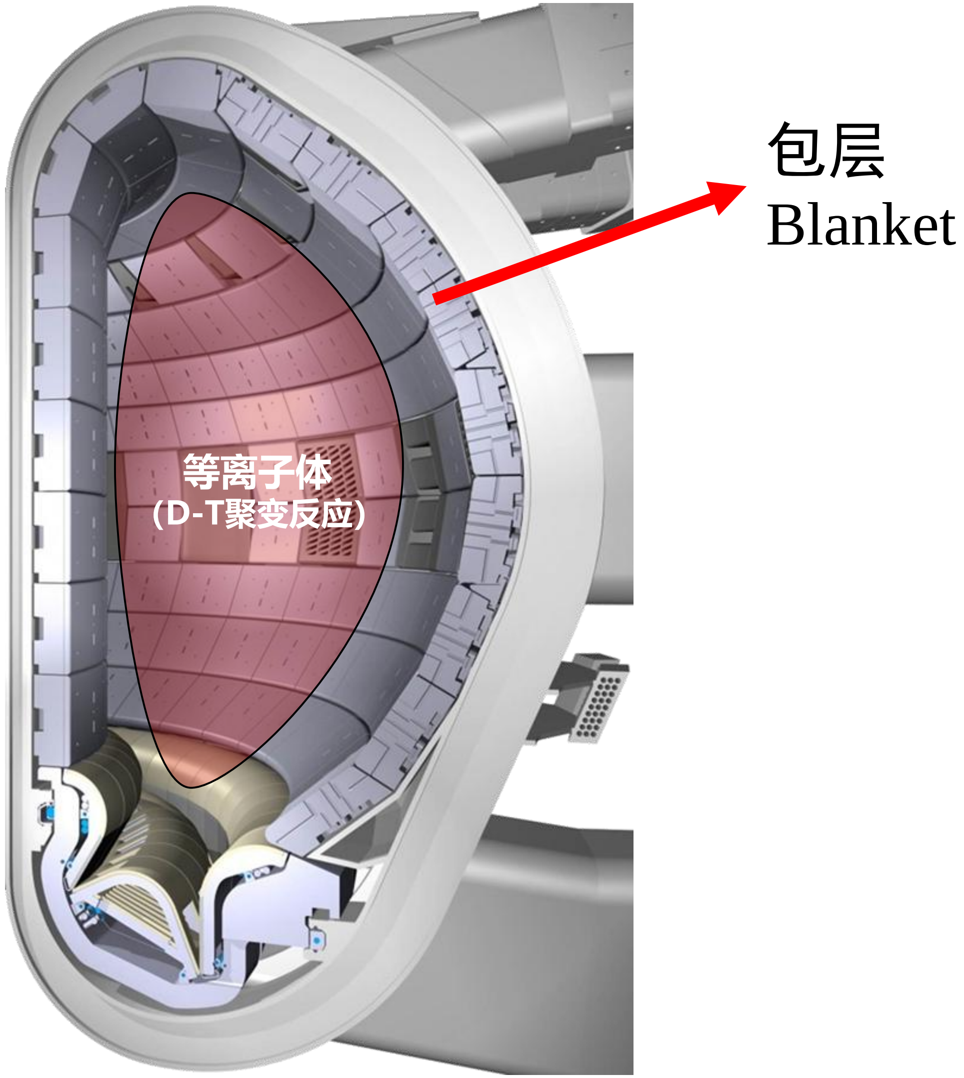
Fusion reactor fuel cycle and energy utilization





- The fuel required for fusion reactors to operate is deuterium and tritium. Deuterium is abundant in seawater, while tritium needs to be recycled.
- Tritium that has not reacted in the fusion reactor core needs to be recovered and separated through a kilogram-scale tritium circulation system for reuse.
- Fusion neutrons react with lithium in the blanket to produce tritium, which is extracted online to replenish the tritium consumed by the core, achieving tritium self-sufficiency.
- Most of the fusion energy is deposited in the blanket and is carried through the primary loop into the conventional island for power generation.

Key functions of Tritium breeding blanket



☐ Key functions:

1. Tritium breeding → Tritium cycling → Tritium self-sustaining

- Using neutron to generate tritium, complement Tritium, complement the tritium consumption in DT fusion reactions, achieve tritium self-sufficiency in the fusion reactor

2. Nuclear heat deposition and exchange → Heat-electricity conversion

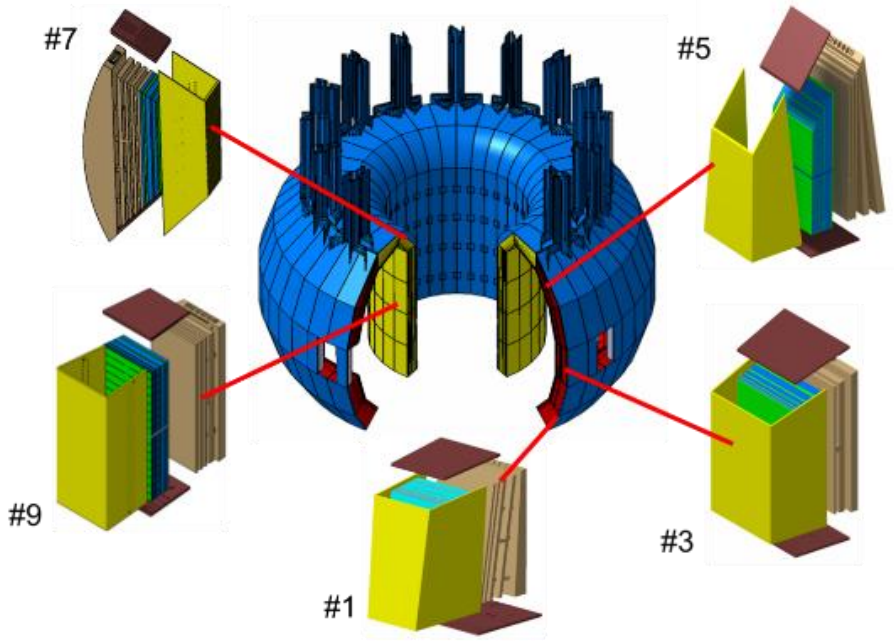
- Convert fusion neutron energy into usable heat and transfer it to the cooling circuit;
- Transfer the energy radiated from the plasma to the first wall to the cooling circuit;
- Enable power generation in the fusion reactor

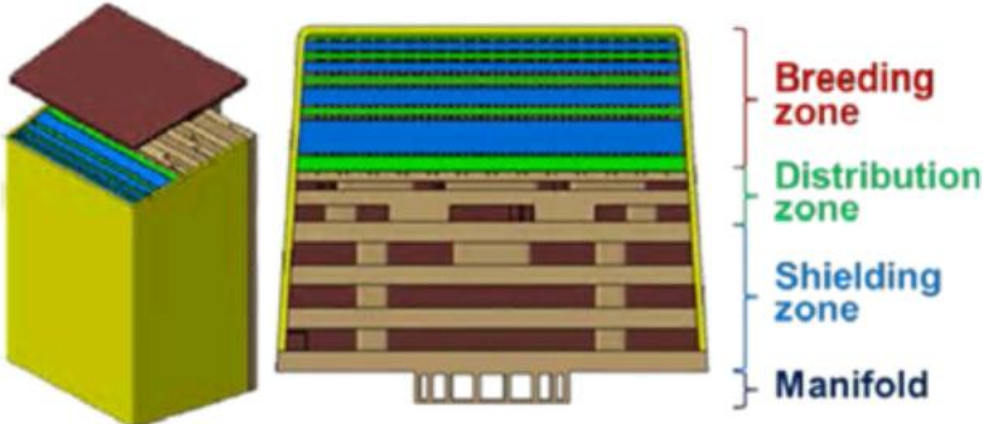
3. Radiation shielding → In-site person and environment protection

- The first radiation shielding barrier; together with other components of the tokamak
- Protect external equipment and the environment.

Tritium breeding blanket is the iconic component as a 'nuclear reactor' !

Working environment and design requirements



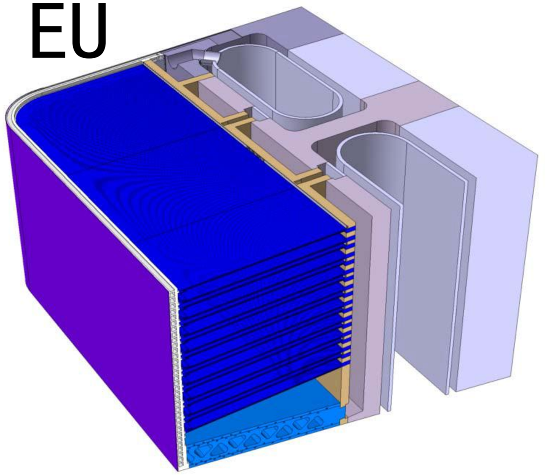


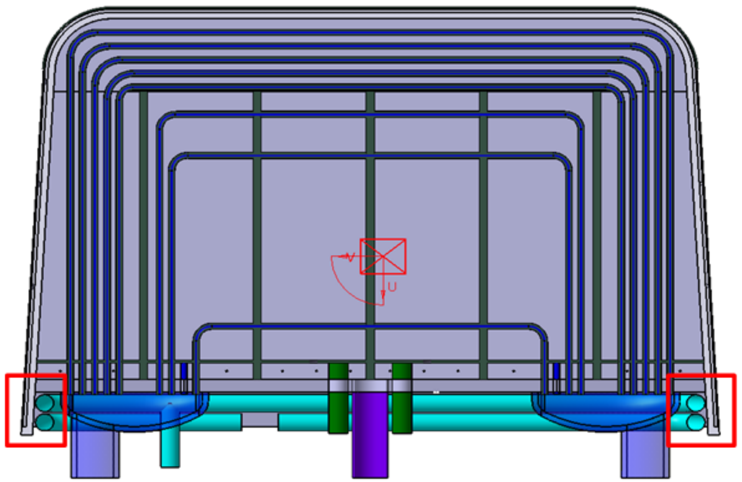
Typical breeding blanket module

- **Facing plasma temperatures of hundreds of millions of degrees**
  - high-energy particle bombardment → Equipped with surface armor protection without affecting the plasma
  - High surface heat load (~1MW/m²) → Good cooling and high-temperature resistance
  - 14 MeV high-energy neutron irradiation → Structural radiation resistance and nuclear heat deposition
- **Located in a complex strong electromagnetic environment**
  - ~5-7T transient magnetic field → Good electromagnetic compatibility and structural integrity
- **Achieve tritium production and extraction functions**
  - Neutron-multiplying materials, tritium breeding materials → Optimized structural layout
  - Tritium extraction → Consider tritium extraction channels (for solid blankets)
- **Achieve energy deposition and extraction functions**
  - Surface heat load, neutron nuclear heat deposition → Good heat dissipation performance
- **Achieve radiation shielding function**
  - 14 MeV high-energy neutron irradiation → Good shielding performance
- **Adequate Reliability, Maintainability, Safety, Economic**

Breeding blanket concepts——DEMO TBBs

EU





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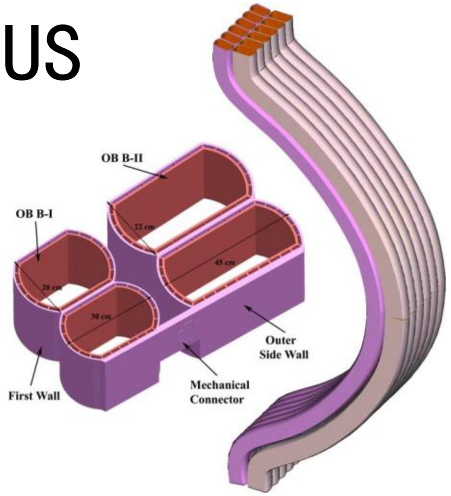
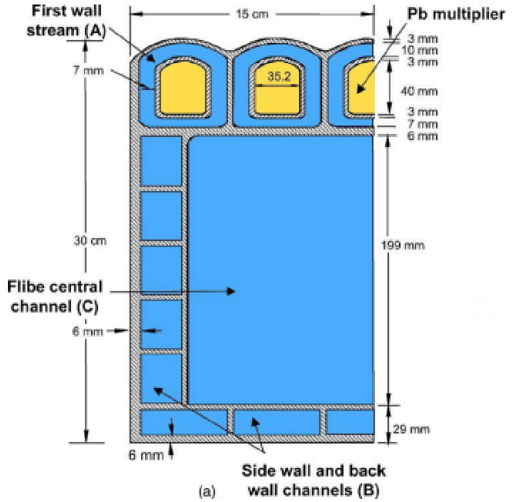
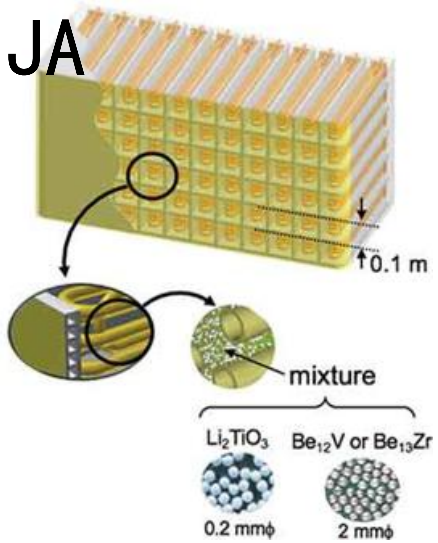
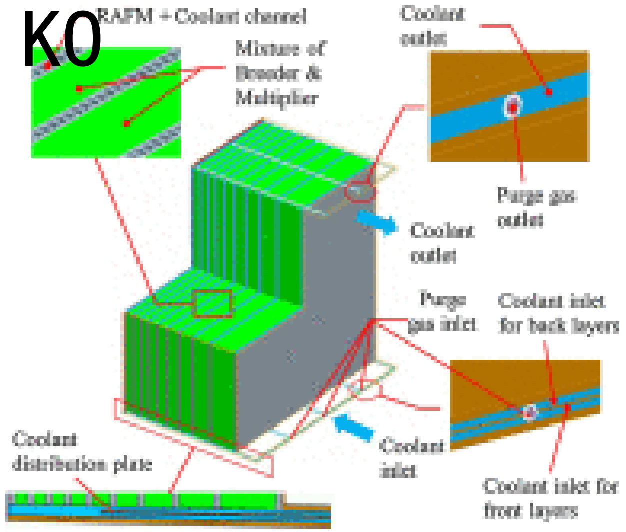




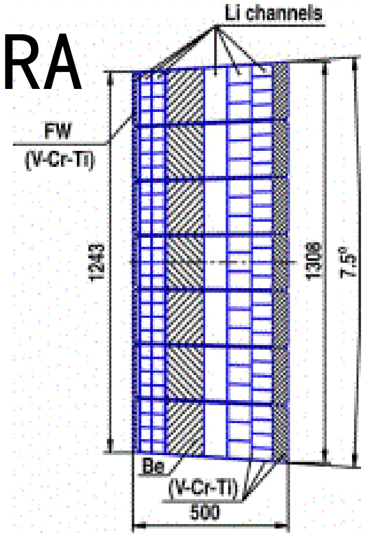
JA



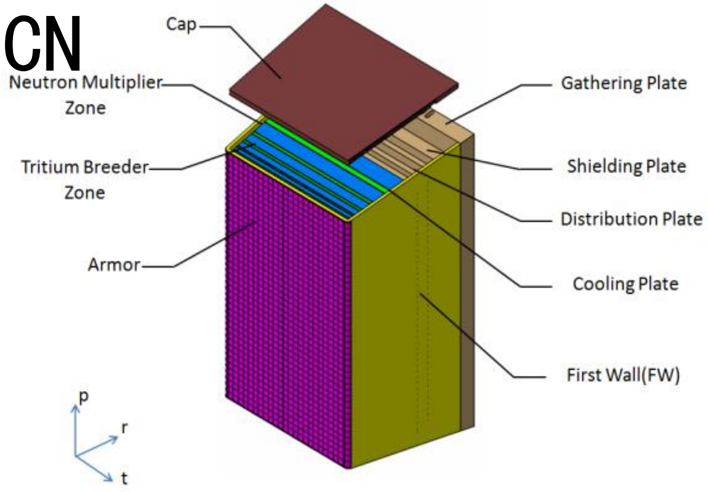
KO



RA

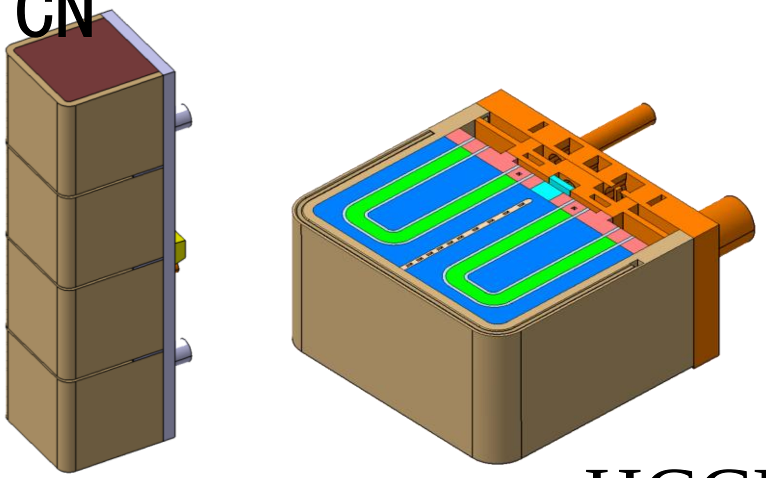


CN



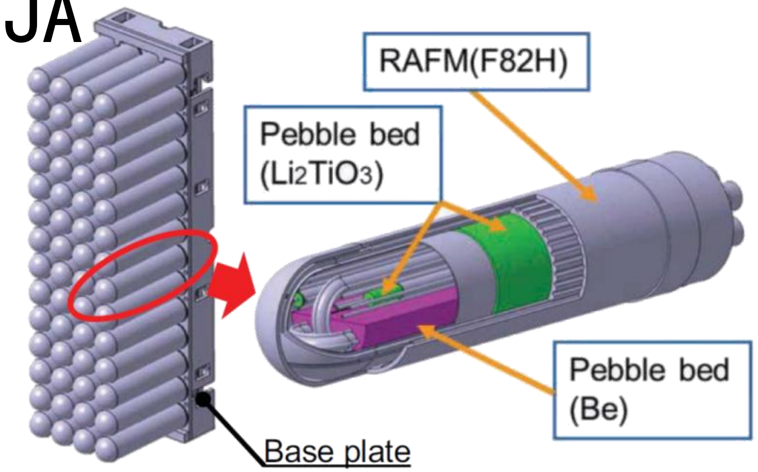
Breeding blanket concepts——ITER TBMs

CN



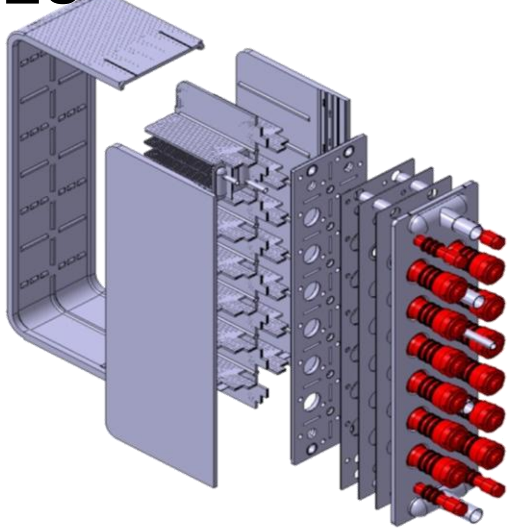
HCCB
TBM

JA



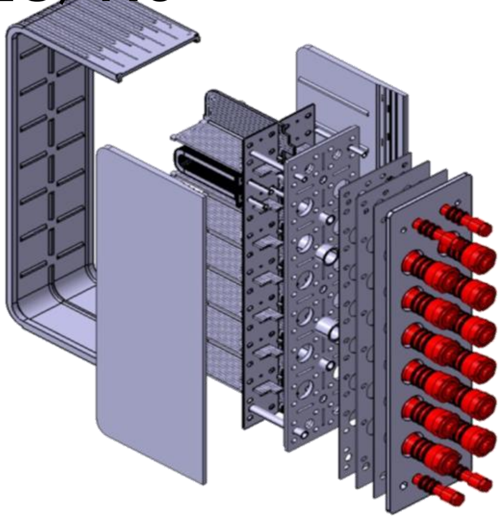
WCCB
TBM

EU



WCLL
TBM

EU/KO



HCPB
TBM

2

Comparison of potential code & standards for tritium breeding blanket

List of potential code & standards

- **The following code & standards for nuclear industry or pressure equipment might be considered for tritium breeding blanket:**
  - TSG 21 Supervision Regulation on Safety Technology for Stationary Pressure Vessel
  - GB/T 150 Pressure Vessels
  - JB 4732 Steel Pressure Vessels-Design by Analysis
  - EJ/T 321 Design criterion of reactor internals for pressurized water reactor nuclear power plants
  - EJ/T 322 Design Code for Reactor Pressure Vessels of Pressurized Water Nuclear Power Plants
  - NB/T 20407 Specification for design and fabrication of reactor vessel internals in pressurized water reactor nuclear power plants
  - GB/T 16702 Design code for mechanical components in nuclear island of pressurized water reactor nuclear power plants
  - ASME BPVC III Rules for Construction of Nuclear Facility Components
  - ASME BPVC VIII Rules for Construction of Pressure Vessels
  - RCC-M Design and Construction Rules for Mechanical Components of PWR Nuclear Islands
  - RCC-MR/MRx Design and Construction Rules for Mechanical Components of Nuclear Installations
  - EN 13445 Unfired pressure vessels
  - ITER SDC-IC Structural Design Criteria for Internal Components

Design allowable stresses in different C&S

		Minimum of S_1、S_2、S_3、S_4、S_5、S_6、S_7、S_8							
		$S_1/S_{y,min}(20^oC,0)$	$S_2/S_{y,min}(\theta,0)$	$S_3/S_{y,min}(\theta,\varphi t)$	$S_4/S_{u,min}(20^oC,0)$	$S_5/S_{u,min}(\theta,0)$	$S_6/S_{u,min}(\theta,\varphi t)$	$S_7/S_D(\theta)$	$S_8/S_n(\theta)$
Carbon steel, low-alloy steel	TSG 21		1/1.5		1/2.4			1/1.5	1
	GB/T 150	1/1.5	1/1.5		1/2.7			1/1.5	1
	JB 4732	1/1.5	1/1.5		1/2.6				
	NB/T 47003	1/1.5	1/1.5		1/2.4				
	JB/T 4735	1/1.5	1/1.5		1/2.5				
	GB/T 16702	1/1.5	1/1.5		1/3（Class 1） 1/4（Class 2、3）	1/3（Class 1） 1/4（Class 2、3）			
	NB/T 20407								
	EJ/T 321	1/1.5	1/1.5		1/3	1/3			
	EJ/T 322	1/1.5	1/1.5		1/3	1/3			
	ASME BPVC III	1/1.5	$R_Y/1.5$		1/3（Class 1、TC、SC） 1/3.5（Class 2、3）	R_T*1.1/3（Class 1、TC、SC） R_T*1.1/3.5（Class 2、3）		F_{ave}（Class 2、3）	1（Class 2、3）
	ASME BPVC VIII	1/1.5	$R_Y/1.5$		1/2.4	1/2.4		F_{ave}	1
	EN 13445		1/1.5		1/2.4				
	RCC-M	1/1.5	1/1.5		1/3（Class 1） 1/3.5（Class 2、3）	1/3（Class 1） 1/3.5（Class 2、3）			
	RCC-MR/MRx	1/1.5	1/1.5		1/3	1/2.7			
	SDC-IC	1/1.5	1/1.5	1/1.5	1/3	1/2.7	1/2.7		

Design allowable stresses in different C&S

		Minimum of S_1、S_2、S_3、S_4、S_5、S_6、S_7、S_8							
		$S_1/S_{y,min}(20^\circ C,0)$	$S_2/S_{y,min}(\theta,0)$	$S_3/S_{y,min}(\theta,\varphi t)$	$S_4/S_{u,min}(20^\circ C,0)$	$S_5/S_{u,min}(\theta,0)$	$S_6/S_{u,min}(\theta,\varphi t)$	$S_7/S_D(\theta)$	$S_8/S_n(\theta)$
Carbon steel, low-alloy steel	TSG 21		1/1.5		1/2.4			1/1.5	1
	GB/T 150	1/1.5	1/1.5		1/2.7			1/1.5	1
	JB 4732	1/1.5	1/1.5		1/2.6				
	NB/T 47003	1/1.5	1/1.5		1/2.4				
	JB/T 4735	1/1.5	1/1.5		1/2.5				
	GB/T 16702	1/1.5	1/1.5		1/3（Class 1） 1/4（Class 2、3）	1/3（Class 1） 1/4（Class 2、3）			
	NB/T 20407								
	EJ/T 321	1/1.5	1/1.5		1/3	1/3			
	EJ/T 322	1/1.5	1/1.5		1/3	1/3			
					SC))	R_T*1.1/3（Class 1、TC、SC） R_T*1.1/3.5（Class 2、3）		F_{ave}（Class 2、3）	1（Class 2、3）
						1/2.4		F_{ave}	1
					)	1/3（Class 1） 1/3.5（Class 2、3）			
						1/2.7			
						1/2.7			

②Different coefficients

③Different scope for determination

- **Strength under temperature**
- **Strength under radiation**
- **Durable strength**
- **Creep strength**

①Different material classification

- **Carbon, low-alloy, martensitic high-alloy, austenitic high-alloy**
- **Ferrite, austenitic, Ni-Cr-Fe alloy, Ni-Fe-Cr alloy**
- **Carbon, low-alloy, quenched and tempered high strength alloy, high-alloy**
- **Other than austenitic, austenitic, cast**
- **Other than annealed austenitic, annealed austenitic**

④Consideration for nuclear safety class

- **Class 1, TC, SC**
- **Class 2, 3**

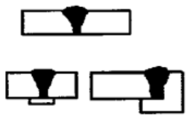
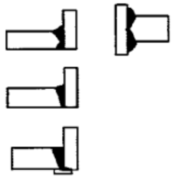
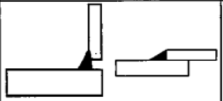
Welding joint coefficient in different C&S

- **The classification of welding joint types is different in national standards and European standards.**

Welding joint types in GB/T 16702:

- Cat. I: Full-penetration butt joints or welded parts with an included angle of less than 30°, welded from both sides
- Cat. II: Full-penetration butt joints or welded parts with an included angle of less than 30°, welded from single side
- Cat. III-a: Full-penetration joints with an included angle of 30°~90°, welded from both sides
- Cat. III-b: Full-penetration joints with an included angle of 30°~90°, welded from single side
- Cat. IV: Partially penetration butt joints or fillet weld with double-sided groove
- Cat. V: Fillet weld without groove, welded from both sides
- Cat. VI: Partially penetration butt joints or fillet weld with single-side groove
- Cat. VII: Fillet weld without groove, welded from single side

Table RB 3834.3: definition of types welded joints

Examples	Definition of types welded joints				
	I.1	butt welding	full penetration	two sides accessible	back welding
	I.2	butt welding	full penetration	two sides accessible	gaseous back protection with or without insert
	I.3	butt welding	full penetration	two sides accessible	on temporary backing strip can be inspected after removal of the strip
	II.1	butt welding	full penetration	back side inaccessible	gaseous protection with or without insert
	II.2	butt welding	full penetration	back side inaccessible	permanent backing strip
	III.1	fillet or T	full penetration	two sides accessible	back weld or back machining
	III.2	fillet or T	full penetration	back side inaccessible	gaseous back protection
	III.3	fillet or T	full penetration	back side inaccessible	permanent backing strip
	IV.1 IV.2	fillet or T butt welding	partial penetration	double opening preparation	double bead
	V	fillet or T	partial penetration or no penetration	straight edges or single opening preparation	double bead
	VI	fillet or T butt welding	partial penetration	single opening preparation	single bead
	fillet or T	no penetration	straight edges preparation	single bead	single bead

Welding joint coefficient in different C&S

■ **The welding joint coefficient is basically similar.**

4.5.2.1 焊接接头系数 ϕ 应根据对接接头的焊缝形式及无损检测的长度比例确定。

4.5.2.2 钢制压力容器的焊接接头系数规定如下：

a) 双面焊对接接头和相当于双面焊的全焊透对接接头

1) 全部无损检测，取 $\phi=1.0$；

2) 局部无损检测，取 $\phi=0.85$。

b) 单面焊对接接头(沿焊缝根部全长有紧贴基本金属的垫板)

1) 全部无损检测，取 $\phi=0.9$；

2) 局部无损检测，取 $\phi=0.8$。

4.5.2.3 其他金属材料的焊接接头系数按相应引用标准的规定。

表 82 许用的焊接接头和设计系数[a]

接头型式	许用的接头类型	X 射线和渗透检验	超声波与渗透检验	焊道间的渗透检验	第一道和最后一道焊道渗透检验
Ⅰ	A、B、C	$n=1$ $f=1$	—	—	×[b]
	D、E	$n=1$ $f=1$			$n=0.75$ $f=1$
Ⅱ	B、C	$n=1$ $f=2$			×
	D、E	$n=1$ $f=2$			$n=0.75$ $f=2$
Ⅲ-a	D、E	×			$n=0.75$ $f=1$[c]
Ⅲ-b	D、E	×	—	—	$n=0.75$ $f=2$
Ⅳ、Ⅴ	D、E	×			$n=0.7$ $f=4$
Ⅵ、Ⅶ	D、E	×			$n=0.45$ $f=4$

[a] 表中 n 为焊缝系数，f 为疲劳系数，见 9.3.3.3。
[b] 表中×表示不能采用这样(类型、型式和检验方法)的组合。
[c] 当要求对焊缝进行两面检查时，允许采用疲劳系数为 1.0；在其他情况下疲劳系数应取为 2.0。

Table IC 4121-1: Joint efficiency coefficient n

Type of welded joint / Examinations	I.1, I.2, I.3, III.1	II.1, III.2	II.2, III.3, IV, V, VI, VII
Volumetric examination[1] + Surface examination[2] after welding (both sides)	1.0		
Surface examination[2] during welding + Surface examination[2] after welding (one side)	0.85	0.85	0.5
Surface examination[2] after first pass + Surface examination[2] after welding (one side)	0.7	0.7	0.5
Surface examination[2] after welding (one side)	0.5	0.5	0.5

1 radiography or ultrasonic
2 liquid penetrant (for components not exposed to high vacuum) or magnetic particle

Table RB 3291.1: joint coefficient n

	Types of welded joints			
Examinations Volumetric examinations: radiography or ultrasonic examinations Surface examinations: liquid penetrant or magnetic particle examinations	I.1 I.2 I.3 III.1	II.1 III.2	II.2 III.3	IV V VI VII
Volumetric examinations + surface examinations after welding (both sides)	1			
Volumetric examinations during welding + surface examinations after welding (one side)	0.85	0.85	0.5	0.5
Volumetric examinations after first pass + surface examinations after welding (one side)	0.7	0.7	0.5	0.5
Surface examinations after welding (one side)	0.5	0.5	0.5	0.5

Regulatory test pressure in different C&S

中核集团 CNNC

- **Regulatory test pressure is also similar, with slight difference considering the law and regulations of different country.**

	Vessel with internal pressure			Vessel with external pressure		
	Hydrostatic	Pneumatic	Hydrostatic-pneumatic	Hydrostatic	Pneumatic	Hydrostatic-pneumatic
TSG 21	1.25*pd*Sm(Ttest)/Sm(Td)	1.1*pd*Sm(Ttest)/Sm(Td)	1.1*pd*Sm(Ttest)/Sm(Td)			
GB/T 150	1.25*pd*Sm(Ttest)/Sm(Td)	1.1*pd*Sm(Ttest)/Sm(Td)	1.1*pd*Sm(Ttest)/Sm(Td)	1.25*pd	1.1*pd	1.1*pd
JB 4732	1.25*pd*Sm(Ttest)/Sm(Td)	1.1*pd*Sm(Ttest)/Sm(Td)		1.25*pd*Sm(Ttest)/Sm(Td)	1.1*pd*Sm(Ttest)/Sm(Td)	
NB/T 47003	Max(1.25*pd*Sm(Ttest)/Sm(Td), 0.05)	Max(1.15*pd*Sm(Ttest)/Sm(Td), 0.05)		Max(1.25*pd*Sm(Ttest)/Sm(Td), 0.05)	Max(1.15*pd*Sm(Ttest)/Sm(Td), 0.05)	
JB/T 4735	1.25*pd*Sm(Ttest)/Sm(Td)	pd*Sm(Ttest)/Sm(Td)		1.25*pd*Sm(Ttest)/Sm(Td)	pd*Sm(Ttest)/Sm(Td)	
GB/T 16702	1.25*ps					
NB/T 20407						
EJ/T 321						
EJ/T 322						
ASME BPVC III	1.25*pd	1.1*pd		1.25*pd		
ASME BPVC VIII	1.25*ps*Sm(Ttest)/Sm(Td)	1.15*ps*Sm(Ttest)/Sm(Td)		1.25*ps	1.15*ps	
EN 13445	Max(1.25*pd*Sm(Ttest)/Sm(Td), 1.43*ps)	Max(1.25*pd*Sm(Ttest)/Sm(Td), 1.43*ps)		1.25*pd	1.25*pd	
RCC-M	1.25*ps					
RCC-MR/MRx	Max(1.25*pd*Sm(Ttest)/Sm(Td), 1.43*ps)			Max(1.25*pd*Sm(Ttest)/Sm(Td), 1.43*ps)		
SDC-IC	Max(1.25*pd*Sm(Ttest)/Sm(Td), 1.43*pd)	1.15*pd*Sm(Ttest)/Sm(Td)				

Structural analysis criteria in different C&S

- **The basic structural analysis criteria is similar, with Sm for global membrane stress, 1.5*Sm for local membrane plus bending stress and 3*Sm for primary plus secondary stress.**

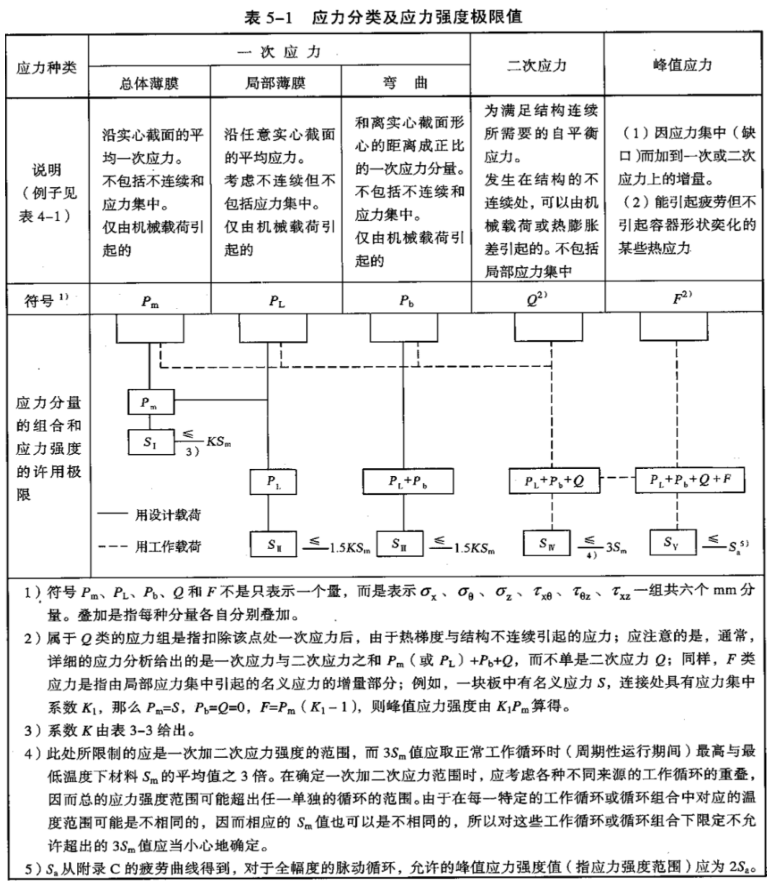


表 5–1　应力分类及应力强度极限值

应力种类	一次应力			二次应力	峰值应力
	总体薄膜	局部薄膜	弯　曲		
说明（例子见表 4–1）	沿实心截面的平均一次应力。不包括不连续和应力集中。仅由机械载荷引起的	沿任意实心截面的平均应力。考虑不连续但不包括应力集中。仅由机械载荷引起的	和离实心截面形心的距离成正比的一次应力分量。不包括不连续和应力集中。仅由机械载荷引起的	为满足结构连续所需要的自平衡应力。发生在结构的不连续处，可以由机械载荷或热膨胀差引起的。不包括局部应力集中	（1）因应力集中（缺口）而加到一次或二次应力上的增量。（2）能引起疲劳但不引起容器形状变化的某些热应力
符号[1]	P_m	P_L	P_b	Q[2]	F[2]

1）符号 P_m、P_L、P_b、Q 和 F 不是只表示一个量，而是表示 σ_x、σ_θ、σ_z、$\tau_{x\theta}$、$\tau_{\theta z}$、τ_{xz} 一组共六个 mm 分量。叠加是指每种分量各自分别叠加。

2）属于 Q 类的应力组是指扣除该点处一次应力后，由于热梯度与结构不连续引起的应力；应注意的是，通常，详细的应力分析给出的是一次应力与二次应力之和 P_m（或 P_L）$+P_b+Q$，而不单是二次应力 Q；同样，F 类应力是指由局部应力集中引起的名义应力的增量部分；例如，一块板中有名义应力 S，连接处具有应力集中系数 K_1，那么 $P_m=S$，$P_b=Q=0$，$F=P_m(K_1-1)$，则峰值应力强度由 K_1P_m 算得。

3）系数 K 由表 3–3 给出。

4）此处所限制的应是一次加二次应力强度的范围，而 $3S_m$ 值应取正常工作循环时（周期性运行期间）最高与最低温度下材料 S_m 的平均值之 3 倍。在确定一次加二次应力范围时，应考虑各种不同来源的工作循环的重叠，因而总的应力强度范围可能超出任一单独的循环的范围。由于在每一特定的工作循环或循环组合中对应的温度范围可能是不相同的，因而相应的 S_m 值也可以是不相同的，所以对这些工作循环或循环组合下限定不允许超出的 $3S_m$ 值应当小心地确定。

5）S_a 从附录 C 的疲劳曲线得到，对于全幅度的脉动循环，允许的峰值应力强度值（指应力强度范围）应为 $2S_a$。

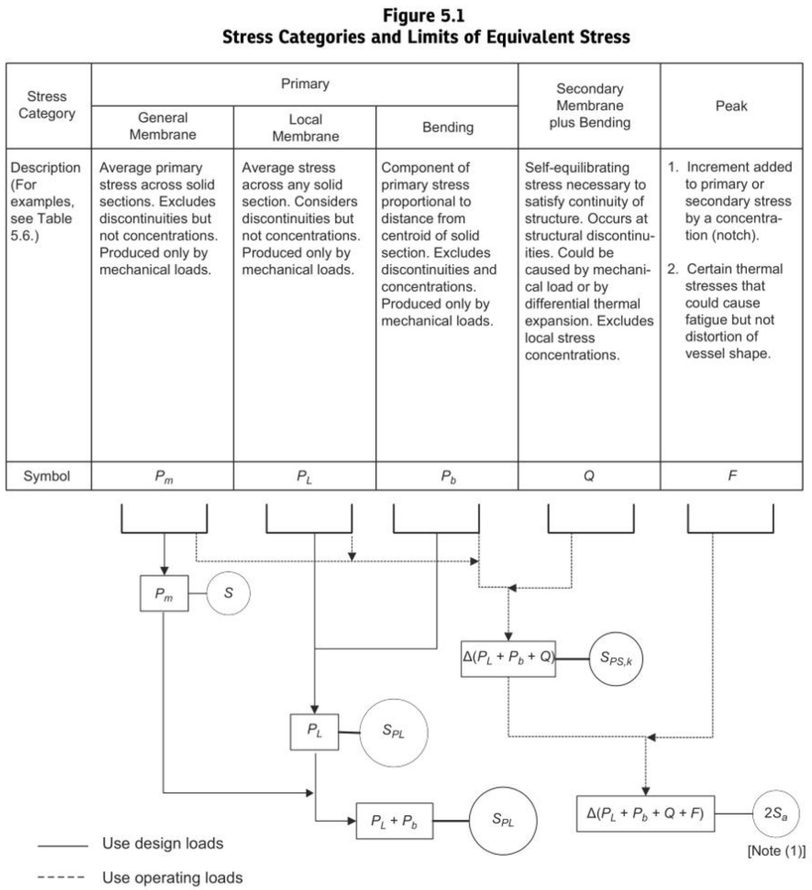


Figure 5.1
Stress Categories and Limits of Equivalent Stress

Stress Category	Primary			Secondary Membrane plus Bending	Peak
	General Membrane	Local Membrane	Bending		
Description (For examples, see Table 5.6.)	Average primary stress across solid sections. Excludes discontinuities but not concentrations. Produced only by mechanical loads.	Average stress across any solid section. Considers discontinuities but not concentrations. Produced only by mechanical loads.	Component of primary stress proportional to distance from centroid of solid section. Excludes discontinuities and concentrations. Produced only by mechanical loads.	Self-equilibrating stress necessary to satisfy continuity of structure. Occurs at structural discontinuities. Could be caused by mechanical load or by differential thermal expansion. Excludes local stress concentrations.	1. Increment added to primary or secondary stress by a concentration (notch). 2. Certain thermal stresses that could cause fatigue but not distortion of vessel shape.
Symbol	P_m	P_L	P_b	Q	F

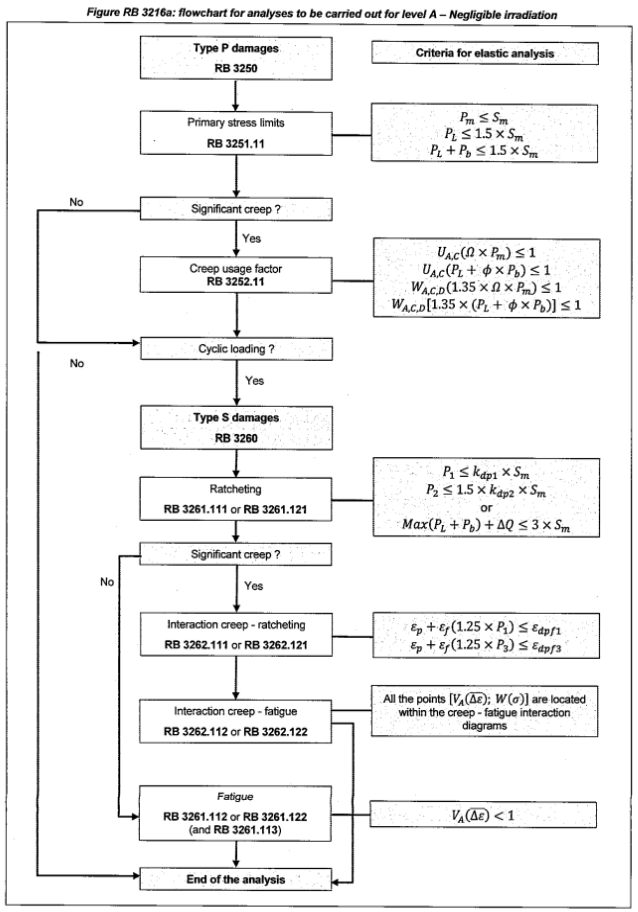


Figure RB 3216a: flowchart for analyses to be carried out for level A – Negligible irradiation

Structural analysis criteria in different C&S

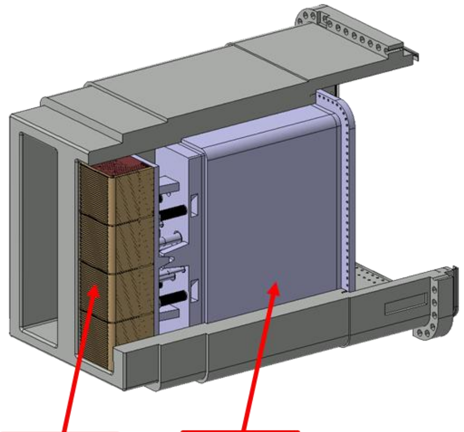
- **For standards related to equipment under high temperature or irradiation, more criteria for preventing creep or irradiation damage is added, i.e. RCC-MR/MRx, ITER SDC-IC.**

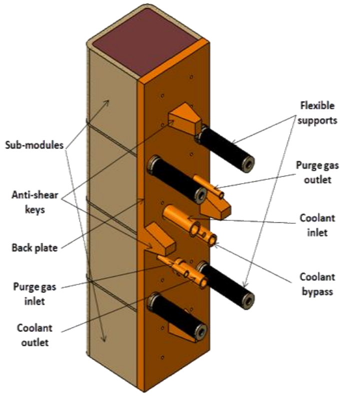
	JB 4732	GB/T 16702	NB/T 20407	EJ/T 321	EJ/T 322	ASME BPVC III	ASME BPVC VIII	EN 13445	RCC-M	RCC-MR/MRx	ITER SDC-IC
Pm	Sm	Sm	Sm	Sm	Sm	Sm	Sm	Sm	Sm	Sm	Sm
PL	1.5*Sm	1.5*Sm			1.5*Sm	1.5*Sm	Max(1.5*Sm, Sy)	1.5*Sm	1.5*Sm	1.5*Sm	Min(1.5*Sm, Sy)
PL+Pb	1.5*Sm	1.5*Sm	1.5*Sm	1.5*Sm	1.5*Sm	1.5*Sm	Max(1.5*Sm, Sy)	1.5*Sm	1.5*Sm	1.5*Sm	Keff*Sm
Pm+Qm										SemA	Se
PL+Pb+Q+F	2*Sa	2*Sa			2*Sa		2*Sa			SetA	Sd
Pe		3*Sm				3*Sm			3*Sm		
(PL+Pb+Q)/Sy	y’	y’			y’	y’	y’	y’	y’		
Max(Pm)/v1										1.3*Sm	1.3*Sm
Max(PL+Pb)/v2										1.3*1.5*Sm	1.3*1.5*Sm
Max(PL+Pb)+Q	3*Sm	3*Sm	3*Sm	3*Sm	3*Sm	3*Sm	Max(3*Sm, 2*Sy)	3*Sm	3*Sm	3*Sm	3*Sm
(PL+Pb/Kt)/Sy+(PL+Pb+Q)/Sy											Min(1.25*St, 2*Sy)/Sy
V(Δε)										1	1
V(N(Salt))	1	1	1	1		1	1	1	1		
U(Ω*Pm)										1	1
U(PL+Pb/Kt)										1	1
W(1.35*Ω*Pm)										1	
W(1.35*(PL+Pb/Kt)										1	1
C/CL	1/1.5	1/1.5				1/1.5	1/1.5	1/1.5	1/1.5	Sm/Sy	
C/CI		1/2.5							1/2.5	1/2.5	1/2.5
KI(PL+Q)											0.33*Kc
KI(PL+Pb+Q+F)		Kc/2							Kc/2		0.67*Kc

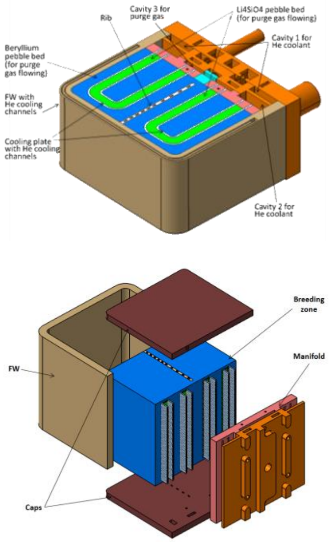
3 Application of RCC-MRx in CN ITER HCCB TBM-set

RCC-MR Application in CN TBM Program

- The "ITER TBM Program" foresees the simultaneous operation of 4 TBSs whose TBMs are located in the 2 ITER equatorial ports #16 and #18 (2 TBMs per port). in order to demonstrate that Tritium Breeding self-sufficiency can be achieved.
- CN HCCB TBM (Chinese Helium-Cooled Ceramic Breeder Test Blanket Module), developed by SWIP, will be installed and operated in the ITER equatorial port #18, together with JA WCCB TBM.







Parameter	Design value
Neutron wall loading	0.78 MW/m^2
Surface heat flux	0.3 MW/m^2
Structural material	CLF-1/CLAM (~1.1 t, <550 ºC)
Tritium breeder	Li_4SiO_4 pebble bed (<900 ºC)
Neutron multiplier	Be pebble bed (<650 ºC)
Coolant	He (8 MPa, 1.04 kg/s) FW (300 ºC/390 ºC) BU (390 ºC/500 ºC)
Purge gas	He+0.1%H_2 (0.3 MPa, 0.3 g/s, 20 ºC/400 ºC)

RCC-MR Application in CN TBM Program

中核集团 CNNC

- **Requirement from SRD-56 (Test Blanket Modules System) from DOORS (ITER_D_28B3A7 v 5.2)**

[56s686-R;Defined Requirement] RCC-MR Edition 2007 shall be used for components providing first confinement barrier of the plasma chamber. Any deemed necessity to use a subsequent edition of RCC-MR, such as RCC-MRx Edition 2015 or future ones, has to be proposed to the ITER Organization for acceptance. Such proposal is to include an exhaustive demonstration how that the used edition is enveloping the previous RCC-MR 2007 requirements and prescriptions, or alternatively, how this equivalence is reached.

- The **RCC-MRx 2018 standard** is currently selected as the design and manufacturing Codes for HCCB TBM-Set.
  - The RCC-MRx class of HCCB TBM-set is supposed to be **N2$_{\mathbf{Rx}}$**.
  - According to Section III - Tome 1 - Subsection C of RCC-MRx 2018, the size of different pipes crossing TBM shield will follow the suggested codes **EN 10206-5**.

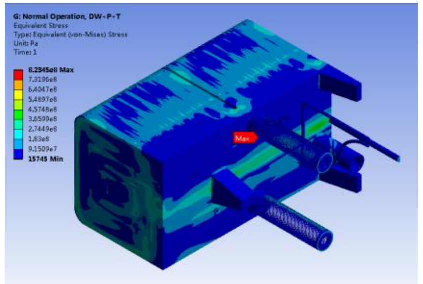
Table RB 3615.1: list of dimensional standards used

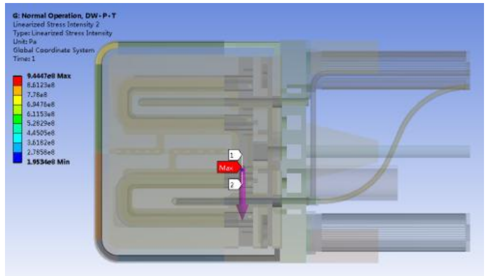
Designation	Reference
Dimensional standards for piping products	
Carbon steel or low alloy steel pipes	ASME B36.10M
Carbon steel or low alloy steel pipes without welds	EN 10216-1, EN 10216-2
Carbon steel or low alloy steel welded pipes	EN 10217-1, EN 10217-2
Stainless steel pipes	ASME B36.19M, *EN 10216-5 (that refers to EN ISO 1127 for the dimensional parts)*
Dimensional standards for fittings	
Steel flanges and flanged fittings	ASME B16.5 or EN 1759-1 or EN 1092-1
Butt welded steel fittings	ASME B16.9, EN 10253-2 or EN 10253-4
Short radius butt welded steel elbows	EN 10253-2 or EN 10253-4

RCC-MR Application in CN TBM Program

Application of rules for design:

- Reference: Section II
  - Hydrostatic test pressure and allowable stress (REC 3257.4)
- Reference: Section III Tome 1 Subsection B&C
  - Neglect creep or not (RB 3216)
  - Minimum distance of welded joints (RC 3834.2)
  - Types of authorized welded joints (RC 3834.3)
  - Weld joint coefficient (RC 3851)
  - Allowable stresses for P-type damage (RB 3250)
  - Allowable stresses for S-type damage (RB 3260)
  - Allowable stresses for bolts (RB 3280)
  - Rules for prevention of fast fracture (RB 32100)
- Reference: Section III Tome 1 Subsection Z
  - Recommendation of size of bolts (A6.2800)
  - Guide for prevention of fast fracture, Leak Before Break analysis and defect assessment (A16)





Assessment of P-type damage

Load condition	Pm		PL		PL+Pb	
	Maximum	Allowable	Maximum	Allowable	Maximum	Allowable
Normal operation	≤179.9MPa	211MPa@200℃	179.9MPa	316.5MPa@200℃	281MPa	316.5MPa@200℃
	≤54.3MPa	163MPa@500℃	54.3MPa	244.5MPa@500℃	110.7MPa	244.5MPa@500℃
Baking	≤63.6MPa	199.3MPa@300℃	63.6MPa	299MPa@300℃	128MPa	299MPa@300℃
Hydrostatic test	≤165.1MPa	284.9MPa@20℃	165.1MPa	427.3MPa@20℃	332.5MPa	427.3MPa@20℃
In-box LOCA	≤378.8MPa	308MPa@450℃	378.8MPa	462MPa@450℃	437.3MPa	462MPa@450℃

Assessment of S-type damage

Load condition	PL+Pb+ΔQ	
	Maximum	Allowable
Normal operation	485.9MPa	489MPa@500℃
Baking	128MPa	597.9MPa@300℃

Load condition	Fatigue usage fraction	
	Calculation	Allowable
Normal operation	0.82	1
Baking	<5e-4	1

RCC-MR Application in CN TBM Program

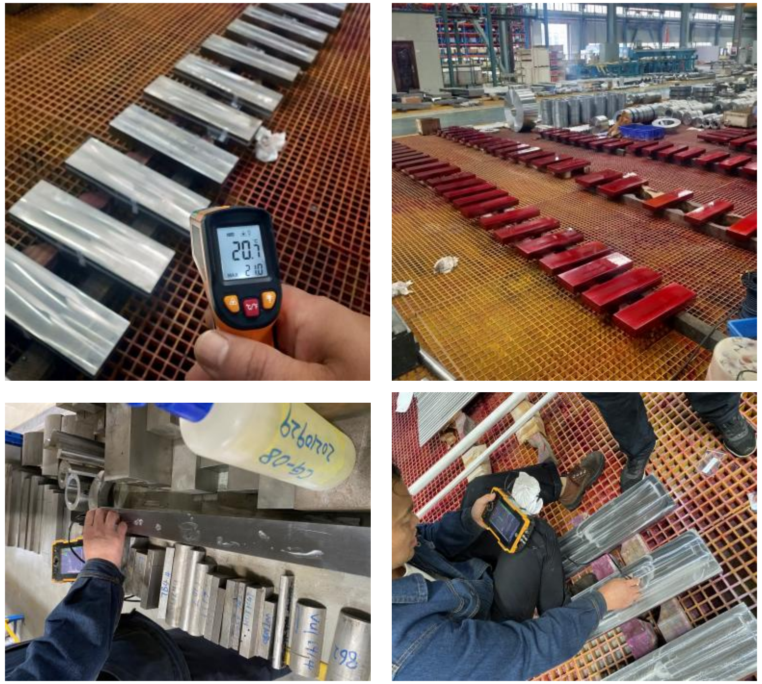
Application of rules for material:

- Reference: Section III Tome 2
  - Common general provisions (RM 010-0)
  - Procurement provisions as per reference standards (RM 030-0)
  - RPS Austenitic stainless steels (RM 330-0)

Development of Chinese Low-activation Ferritic-martensitic No.1 steel (CLF-1)

- Special procurement specification(S-SPS): **RM 0111.1, RM 0330, RM 0350, RM 0120**
- Fabrication: **RMC 1000, RMC 7100, RMC 2000, RMC 4000, RF 2000, RF 3000, RA 3900**
- Material testing and database: **RPP4-2012-EUROFER**

UT and PT of CLF-1 steel(50mm)



UT and PT of CLF-1 steel(30mm)

RCC-MR Application in CN TBM Program

Application of rules for manufacturing:

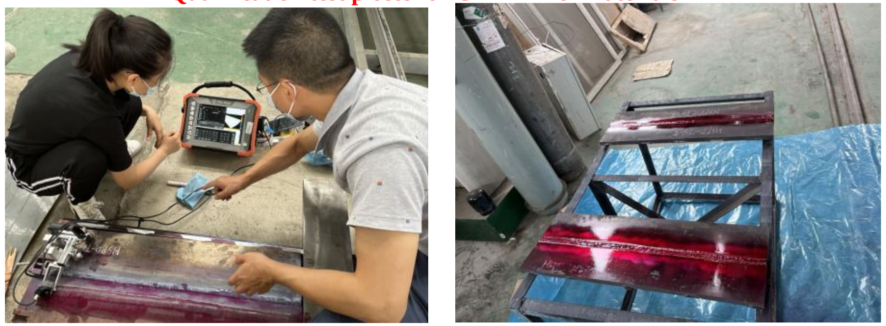
Reference: Section III Tome 4

- Acceptance of filler materials（RS 2000）
- Welding procedure qualification（RS 3000）
- Qualification of welders and operators（RS 4000）
- Qualification of filler materials（RS 5000）
- Welding operations of production welds（RS 7000）
- Destructive tests and examinations on welds（RS 9000）

Reference: Section III Tome 5

- Cutting - repair without welding（RF 3000）
- Forming and dimensional tolerances（RF 4000）
- Surface treatment（RF 5000）
- Cleanliness（RF 6000）
- Heat treatments（parts and components）（RS 8000）

Qualification test pieces for CLF-1 filler materials



Non-destructive examinations of qualification test pieces

Forming of double-layer pipe assembly mockup

4 Conclusion and remark

Conclusion and remark

- Tritium breeding blanket is one of the key components in fusion reactor, with functions of tritium breeding, heat extraction and radiation shielding.
- Different C&Ss were developed for nuclear industry and pressure equipment. The current C&Ss are not fully compliable to tritium breeding blanket, covering both nuclear safety and pressure-bearing requirements.
- For CN HCCB TBM-set, RCC-MR/MRx is adopted due to IO design requirement for 1st confinement boundary.
- Specific standards still need to be developed for tritium breeding blanket of fusion reactor in future.

Thanks for listening!