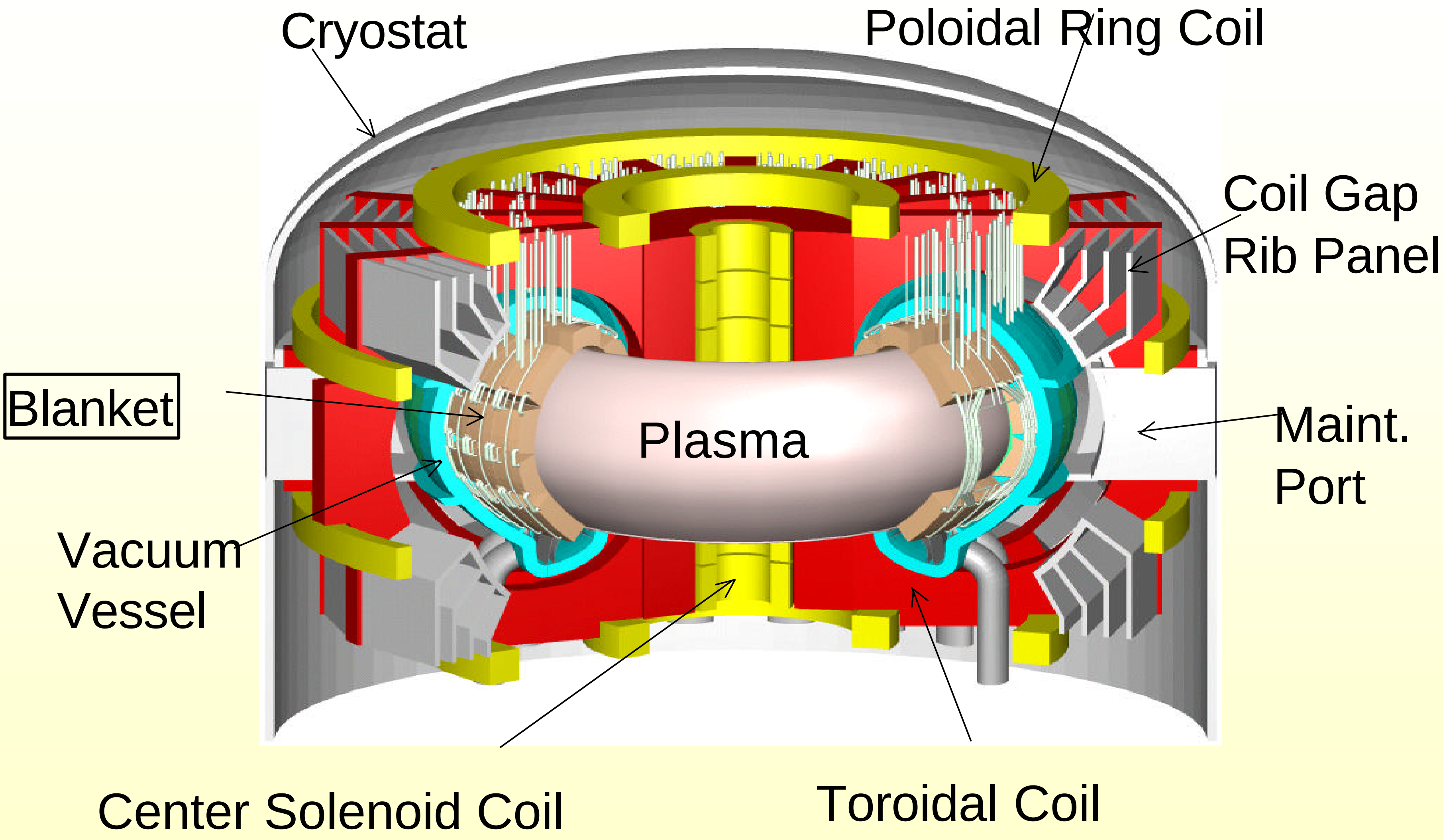
APPENDIX

JAERI DEMO Design



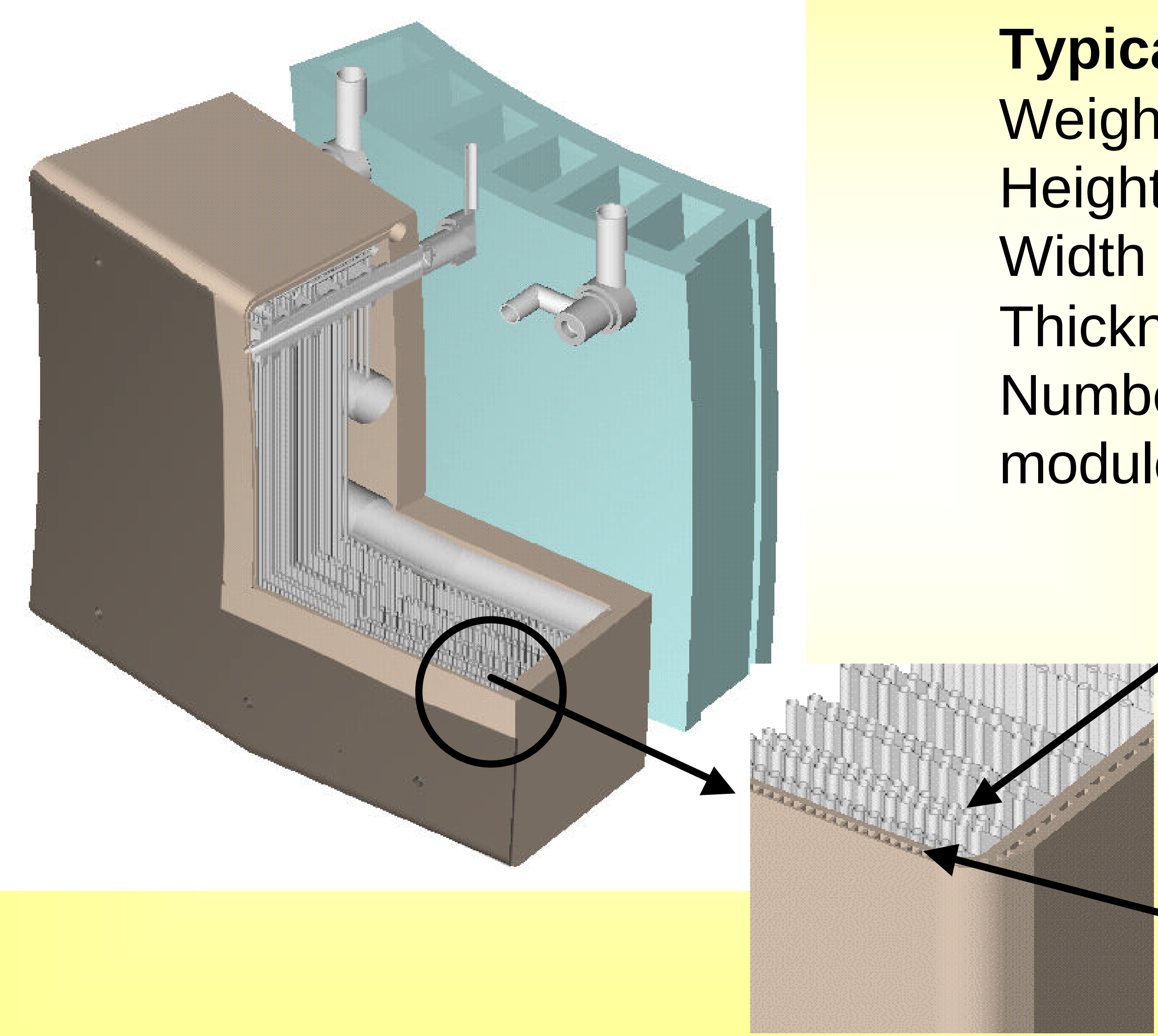
FNT: Components from Edge of Plasma to TFC.

Blanket / Divertor immediately circumscribe the plasma (often called Chamber Technology)

From Akiba, Japan: Typical Blanket Module in DEMO

Schematic of Test Blanket Module

Typical Blanket Module	
Weight	4 ton
Height	1 m
Width	2 m
Thickness	0.6 m
Number of modules	256



Breeder and Multiplier Pebble bed layers

First Wall with embedded Cooling Channels

Tests for Thermomechanics Interactions of Be/Breeder/He-purge/Structure require “volumetric” heating in complex geometry (fission then fusion)

<u>A Case Study</u> ➡ HICU Project: A High Fluence Irradiation on Ceramic Breeder Pebble Beds with Mechanical Constraints in Fission Reactor

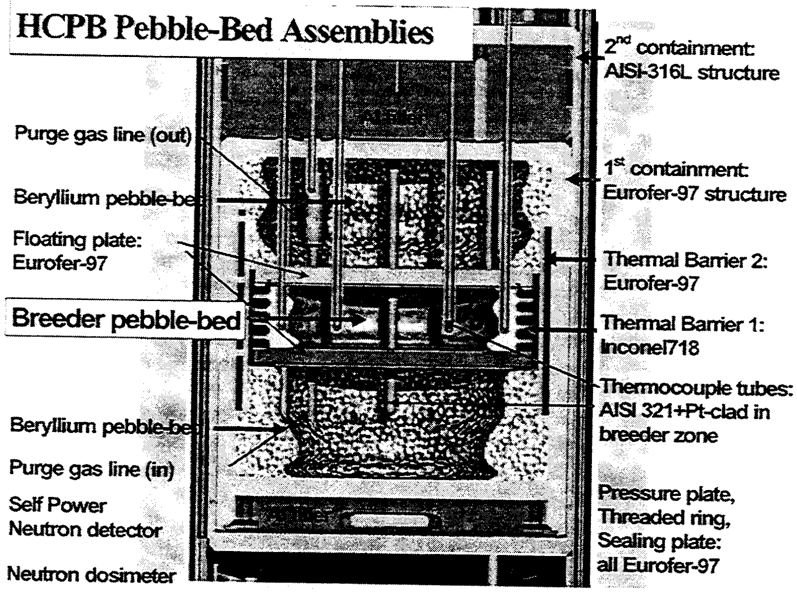
Project goals:

“the investigation of the impact of neutron spectrum and the influence of constraint conditions on the thermo-mechanical behavior of breeder pebble-beds in a high fluence irradiation”

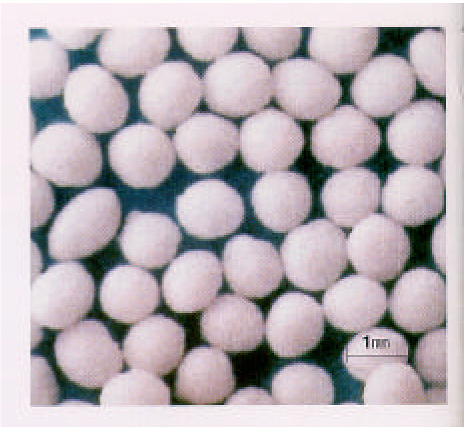
Main critical issues for the “project” concern the specimen size and the geometry(limited test volume in fission reactor)

Instrumentation

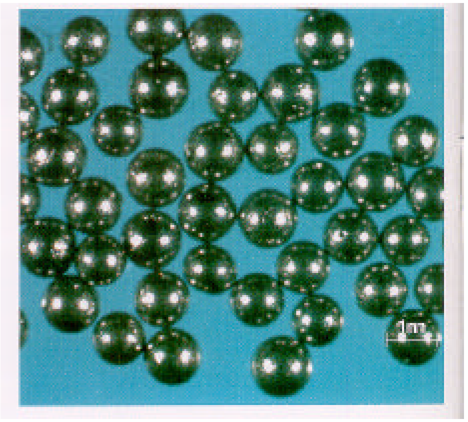
(neutron dosimeter, thermocouples, tritium monitor)



Schematic view of pebble-bed assembly, showing cross-section of test-element, second containment and instrumentation



Li_2O ceramic breeder



Beryllium pebble

Table XX.*

Characteristic Time Constants in Solid Breeder Blankets

Process	Time Constant
Flow	
Solid breeder purge residence time	6 s
Coolant residence time	1 to 5 s
Thermal	
Structure conduction (5-mm metallic alloys)	1 to 2 s
Structure bulk temperature rise	
5 mm austenitic steel / water coolant	~1 s
5 mm ferritic steel / helium coolant	5 to 10 s
Solid breeder conduction	
Li_2O (400 to 800°C)	
10 MW/m^3	30 to 100 s
1 MW/m^3	300 to 900 s
$LiAlO_2$ (300 to 1000°C)	
10 MW/m^3	20 to 100 s
1 MW/m^3	180 to 700 s
Solid breeder bulk temperature rise	
Li_2O (400 to 800°C)	
10 MW/m^3	30 to 70 s
1 MW/m^3	80 to 220 s
$LiAlO_2$ (300 to 1000°C)	
10 MW/m^3	10 to 30 s
1 MW/m^3	40 to 100 s
Tritium	
Diffusion through steel	
300°C	150 days
500°C	10 days
Release in the breeder	
Li_2O 400 to 800°C	1 to 2 h
$LiAlO_2$ 300 to 1000°C	20 to 30 h

** From Fusion Technology, Vol. 29, pp 1-57, January 1996*

Table XXI.*

Characteristic Time Constants in Liquid-Metal Breeder Blankets

Process	Time Constant
Flow	
Coolant residence time	
First wall (V=1 m/s)	~30 s
Back of blanket (V=1 cm/s)	~100 s
Thermal	
Structure conduction (metallic alloys, 5mm)	1 to 2 s
Structure bulk temperature rise	~4 s
Liquid breeder conduction	
Lithium	
Blanket front	1 s
Blanket back	20 s
LiPb	
Blanket front	4 s
Blanket back	300 s
Corrosion	
Dissolution of iron in lithium	40 days
Tritium	
Release in the breeder	
Lithium	30 days
LiPb	30 min
Diffusion through:	
Ferritic Steel	
300°C	2230 days
500°C	62 days
Vanadium	
500°C	47 min
700°C	41 min

** From Fusion Technology, Vol. 29, pp 1-57, January 1996*

- **To Achieve DEMO Availability = 48%**

	Required Blanket Availability
R. Buende (1989)	97%
IEA-VNS (1996)	90%

- **To Achieve DEMO Availability = 30%**

J. Sheffield (2002): Required blanket availability = 88%
(Assuming Major MTTR = 800 h, Minor MTTR = 100 h)

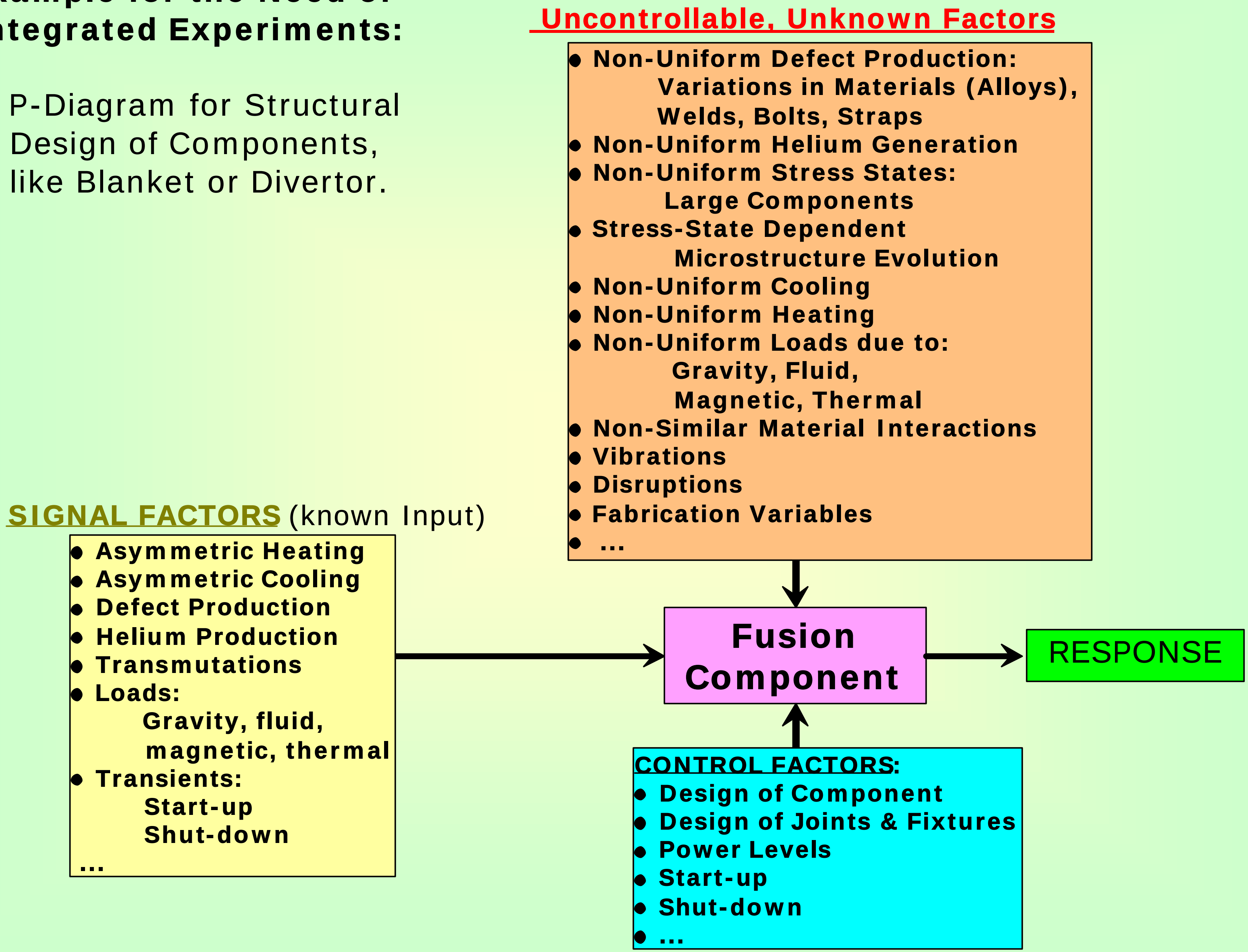
Required MTBF for DEMO Blanket

Depends on availability requirements and MTTR

DEMO Availability	Required Blanket Availability	Required MTBF for a Blanket Module (100 modules, MTTR=1 month)
30%	**88%**	**60 yr**
48%	**90%**	**75 yr**

Example for the Need of Integrated Experiments:

P-Diagram for Structural Design of Components, like Blanket or Divertor.



Uncontrollable, Unknown Factors

- **Non-Uniform Defect Production:**
  Variations in Materials (Alloys), Welds, Bolts, Straps
- **Non-Uniform Helium Generation**
- **Non-Uniform Stress States:**
  Large Components
- **Stress-State Dependent**
  Microstructure Evolution
- **Non-Uniform Cooling**
- **Non-Uniform Heating**
- **Non-Uniform Loads due to:**
  Gravity, Fluid,
  Magnetic, Thermal
- **Non-Similar Material Interactions**
- **Vibrations**
- **Disruptions**
- **Fabrication Variables**
- **...**

SIGNAL FACTORS (known Input)

- **Asymmetric Heating**
- **Asymmetric Cooling**
- **Defect Production**
- **Helium Production**
- **Transmutations**
- **Loads:**
  Gravity, fluid,
  magnetic, thermal
- **Transients:**
  Start-up
  Shut-down

...

Fusion Component

RESPONSE

CONTROL FACTORS:

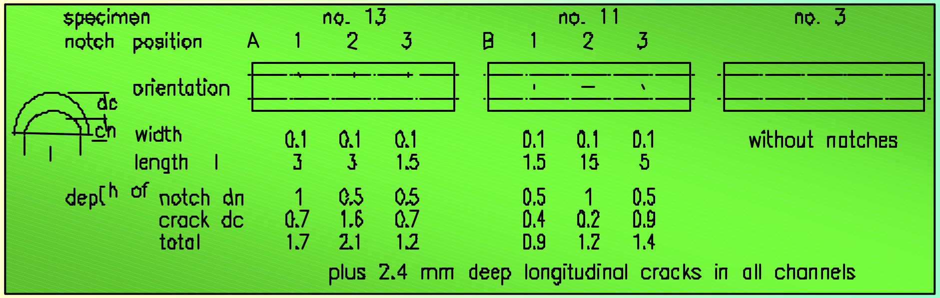
- **Design of Component**
- **Design of Joints & Fixtures**
- **Power Levels**
- **Start-up**
- **Shut-down**
- **...**

FW-Mock Up Fatigue Testing at FZK

Shows an example of unexpected failure modes that cannot be predicted by models.

(Information from Eberhard Diegele at FZK)

- Thermo-mechanical fatigue test were performed for FW-mock ups from SS 316 L.
  - Loading conditions: about 0.7 MW/m2 heat flux (Fig. 1)
- The specimens were pre-cracked (notched) perpendicular to the coolant tubes at different locations with different sizes (Fig. 2)
- After 75,000 cycles the notched cracks grew to the sizes as indicated.
- **However, unexpectedly there were longitudinal cracks that were initiated in *every channel* - and these cracks grow under fatigue and would have led to failure if the experiment continued.**



specimen	no. 13			no. 11			no. 3
notch position	A 1	2	3	B 1	2	3	
orientation							
width	0.1	0.1	0.1	0.1	0.1	0.1	without notches
length l	3	3	1.5	1.5	15	5	
depth of notch dn	1	0.5	0.5	0.5	1	0.5	
crack dc	0.7	1.6	0.7	0.4	0.2	0.9	
total	1.7	2.1	1.2	0.9	1.2	1.4	

plus 2.4 mm deep longitudinal cracks in all channels

Fig.2:Spark eroded notches and cracks after 75,000 cycles

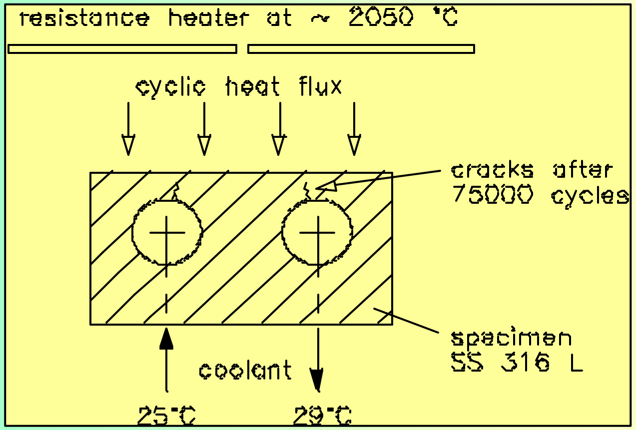


Fig.1: Schematic of FW-Mock Up

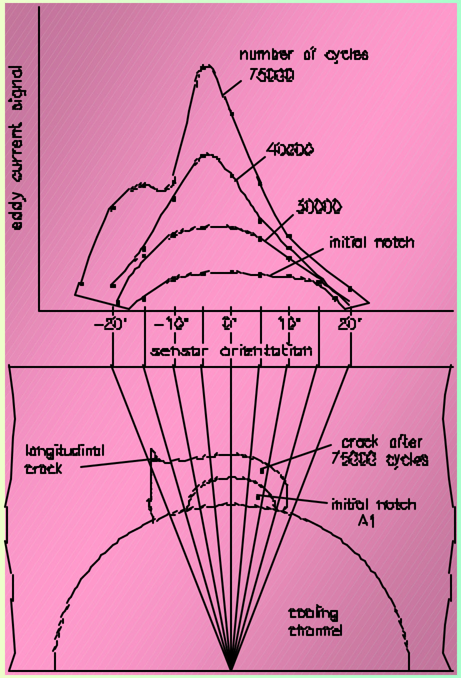


Fig.3: Crack measurements

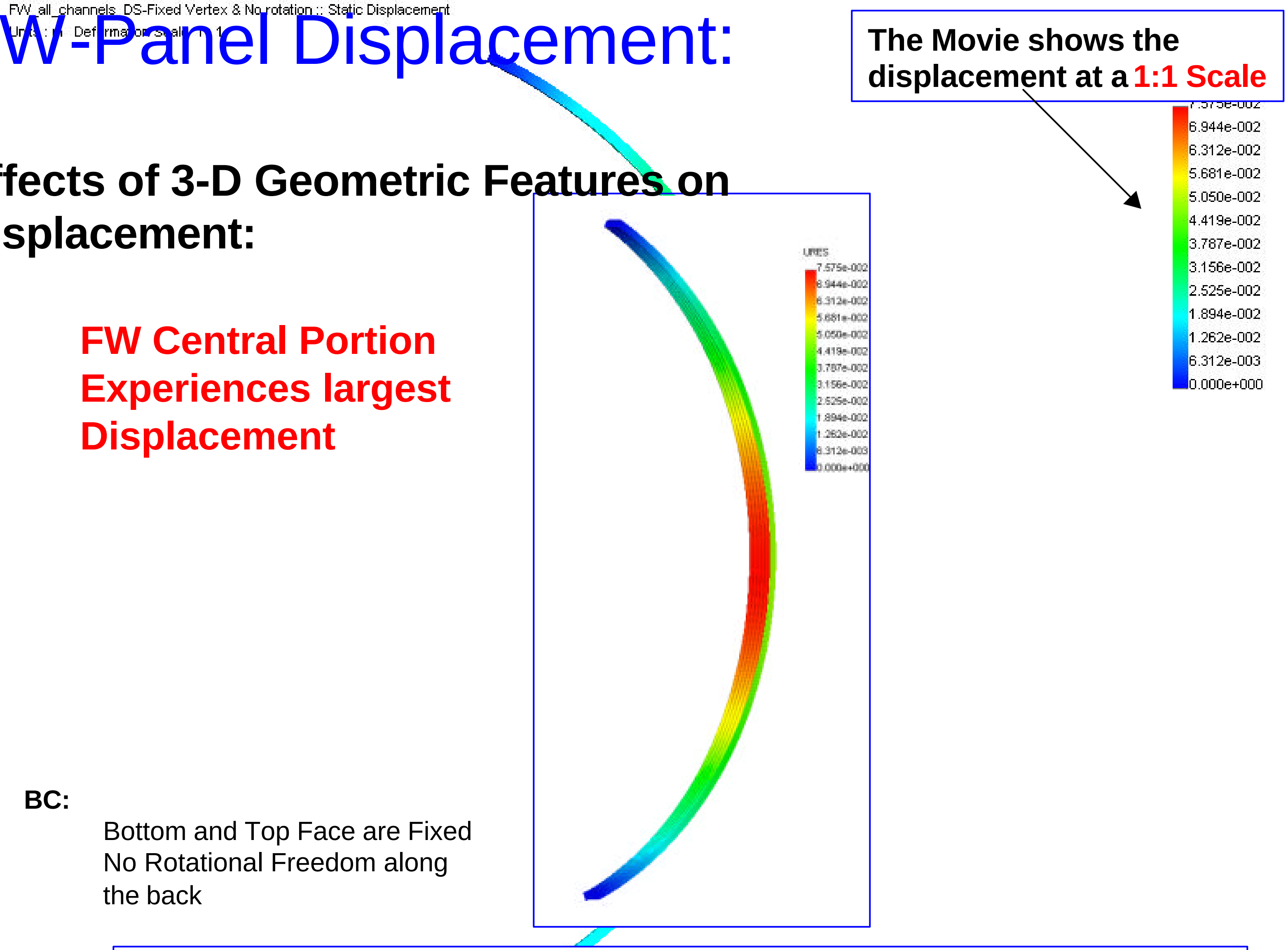
From elastic-plastic fracture mechanics modeling:

- **Expected the large pre-cracks at the crown of the channel to fail.**
- **Initiation and growth of the longitudinal cracks were not and can not be predicted by models.**

FW-Panel Displacement:

The Movie shows the displacement at a 1:1 Scale

Effects of 3-D Geometric Features on Displacement:



FW Central Portion Experiences largest Displacement

BC:

Bottom and Top Face are Fixed
No Rotational Freedom along the back

Max Displacement at Center ~ 7.3 cm with no back support. With back support, these displacements must be accommodated through higher stresses

Notes from M. Abdou and D. Sze in response to a question received on 10/25/2002.

Is "Batch" Processing together with "low temperature blanket" a good "transition" option?

Batch Processing

--Evaluated in the 1970s

--Conclusion: Not Practical for the "complex" fusion devices

1. In large systems like a tokamak: It takes a long time to remove/reinsert blankets. You still have to go through the vessel, the shield, and the magnet support. (for example: several months in ITER); therefore you cannot do it frequently (once every two years?!).
2. In 1000 MW Fusion Power Device, the tritium consumption is 55.8 kg per full power year. So, for 20% availability, tritium inventory accumulated in 2 years is >22 kg (in addition to the "hold up" inventories in PFCs and other in-vessel components).
3. Safety experts have suggested much lower targets for tritium inventory (~2 kg). Note also that tritium will decay at 5.47%/year and you will have to provide external start up inventory, plus inventory for duration of "first batch".
4. And "there is really no effective way to recover tritium from the blanket using a batch process."

Low-Temperature Blanket?

Evaluated during INTOR, ITER-CDA, ITER-EDA

Assessment:

-- It is still high risk because we use technologies unvalidated in the fusion environment.

-- There is no good low-temperature breeding blanket option. You can have only “partly” low-temperature.

-- “Partly” low-temperature breeding blankets have their added complications and issues for which an additional R&D program is needed.

Options for Low-Temperature Blanket?

- **All self-cooled liquid metal options require high temperature (>300°C) because of high melting point. We do not know if any of them are feasible in the fusion environment because of issues such as insulators, tritium barriers, etc.**

- **Separately-cooled LiPb requires either Helium or water, both above 300°C. Practically all feasibility issues for “reactor-type” blankets are the same and must be resolved by extensive testing first in the fusion environment.**

Options for Low-Temperature Blanket? (cont'd)

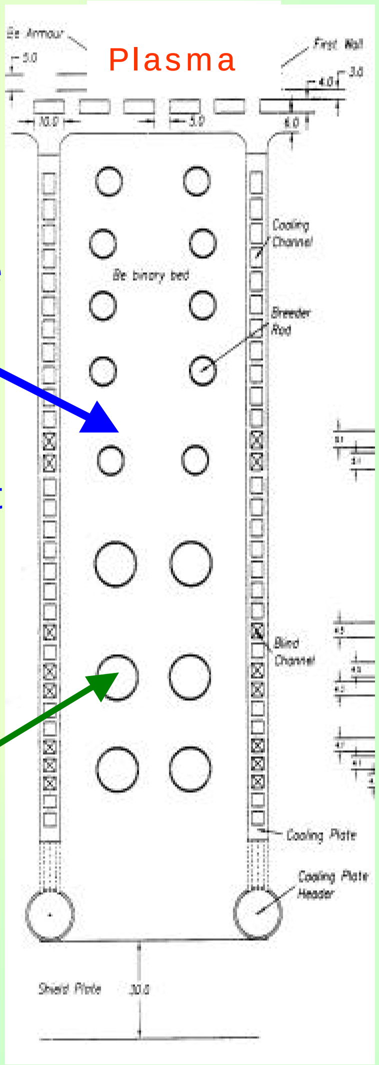
- **Solid Breeder Options were evaluated in INTOR, and ITER-CDA, ITER-EDA**

-- Breeder must run at high temperature

-- Only the coolant can be low temperature

-- All the feasibility issues with the breeder and multiplier are essentially the same as those for reactor-type blanket. But with the added complexity of providing "thermal resistance" between the low-temperature coolant and the hot solid breeder.

-- Both stainless steel and ferritic steel have severe embrittlement problems at low-temperature (ITER can use low-temperature coolant in the present non-breeding design only because of the very low fluence).



Beryllium pebble bed is used as a temperature barrier in a low temperature breeding blanket design

Breeder pebble bed rod