IN-BORE TOOLS FOR BLANKET REPLACEMENT IN THE DEMO FUSION REACTOR

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Outline

- Overview of In-vessel Blanket, Shield and pipe integration
- Outboard and Inboard pipe requirements
- In-Bore Tool design tasks
- Overview of present and further R&D for join tool design
- Summary

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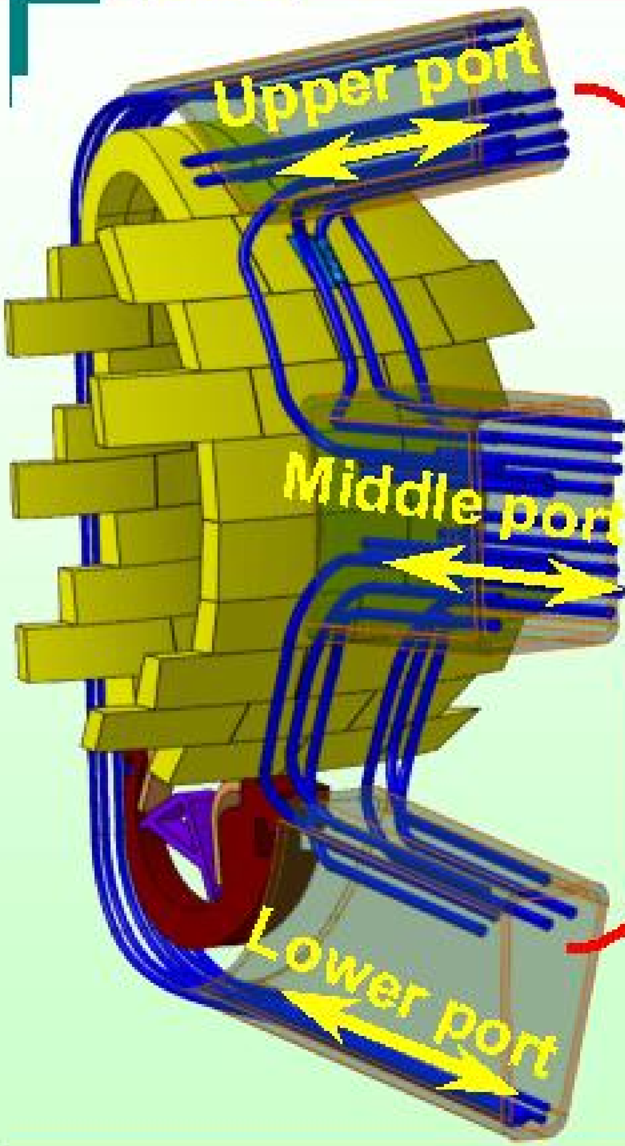


pipe operation data:

medium: He

max.temp.: 500°C

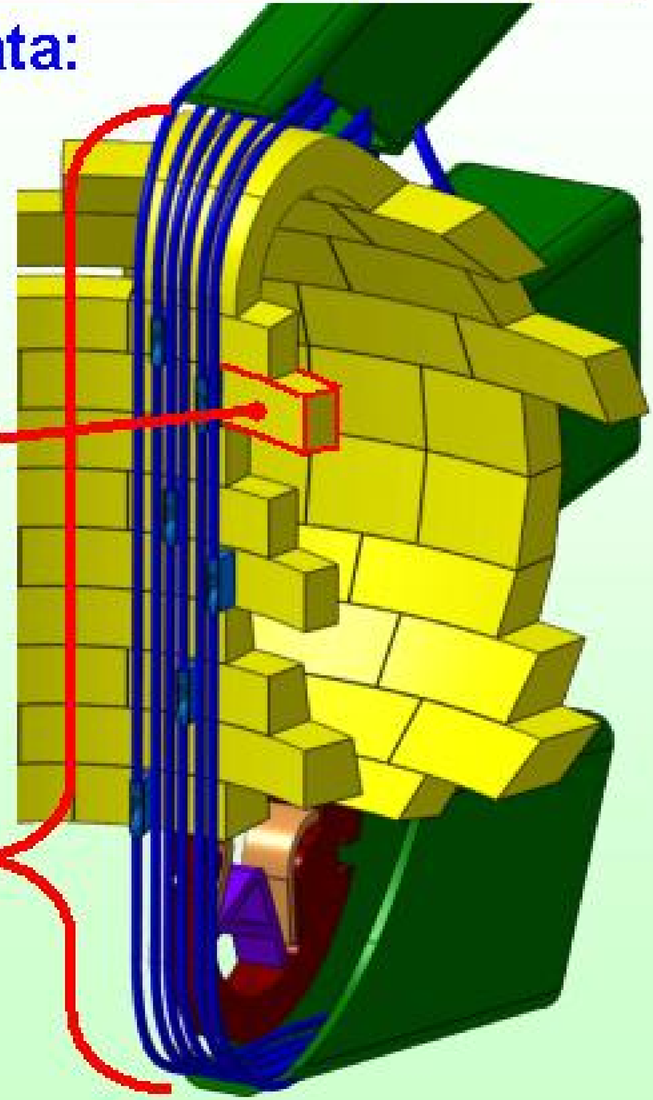
max.ΔT: 350°C

pressure: 80 bar

$\sum$ about 350 Blanket modules

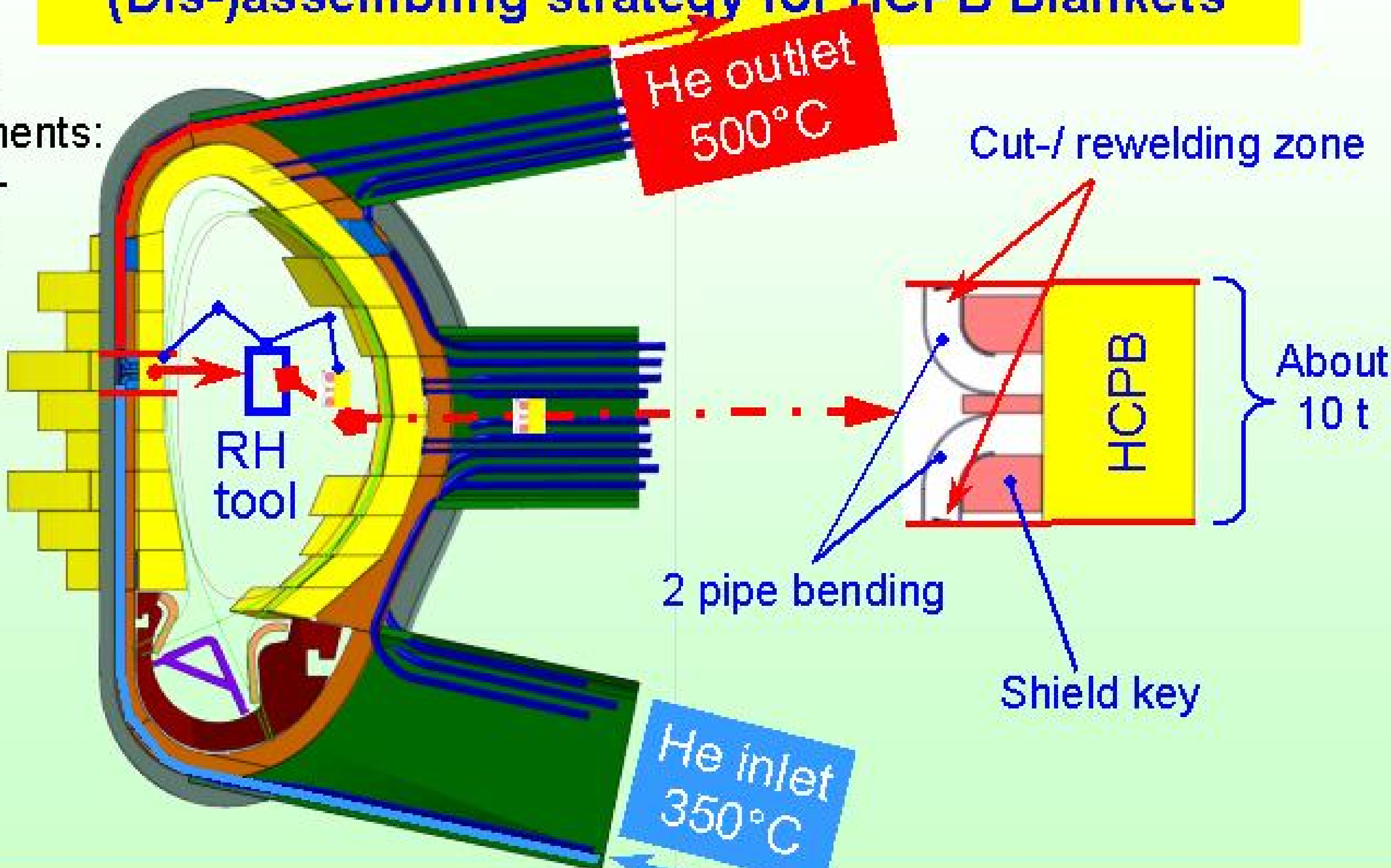
Outboard pipes:
$D_{internal}$ = 200 mm
s = 15 mm

Inboard pipes:
$D_{internal}$ = 150 mm
s = 10 mm



(Dis-)assembling strategy for HCPB Blankets

Lifetime Components: *shield* + polodial *pipes*



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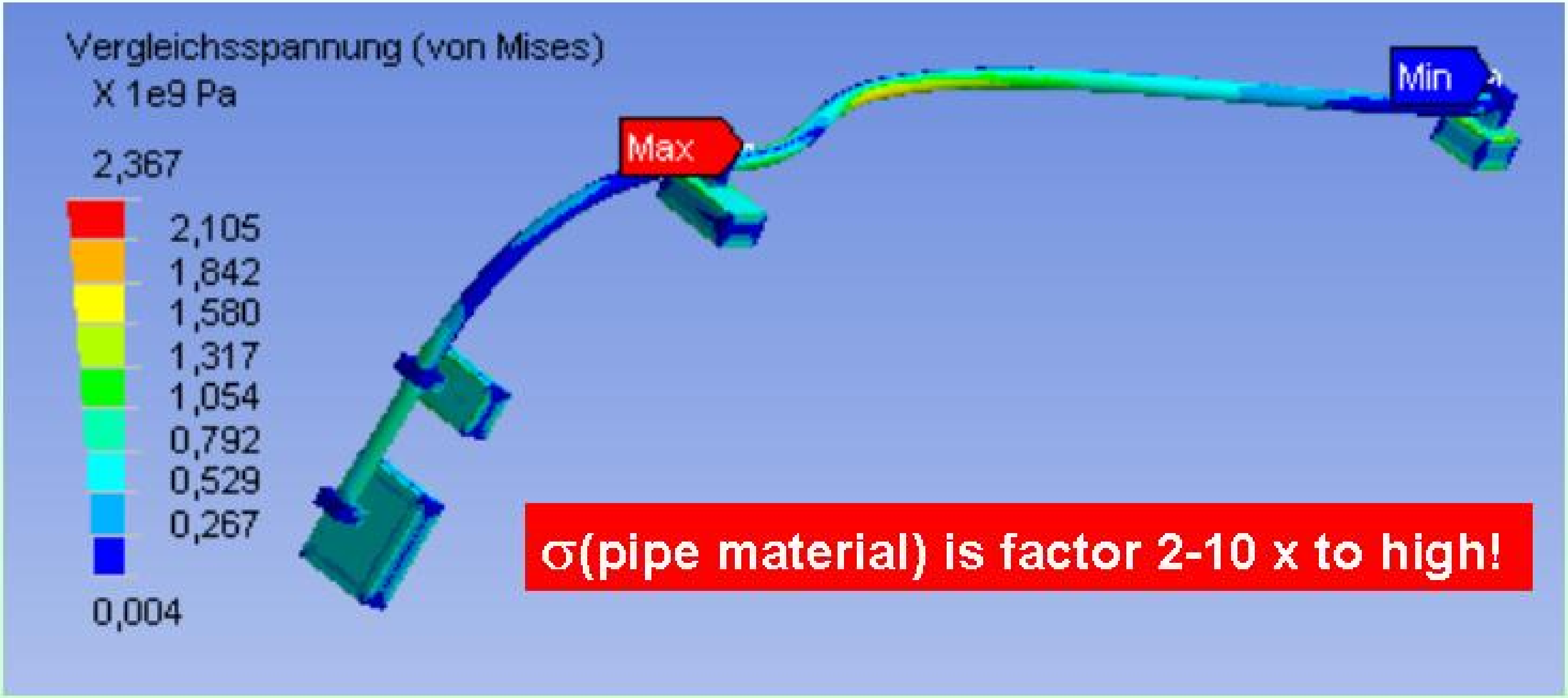
Inboard/outboard pipe design depends on

- General assembly strategy
- Operating and testing pressure
- Temperature gradient between shield ⇔ pipe
- *Modular* pipe compensation system

Inboard / outboard pipe stress analysis

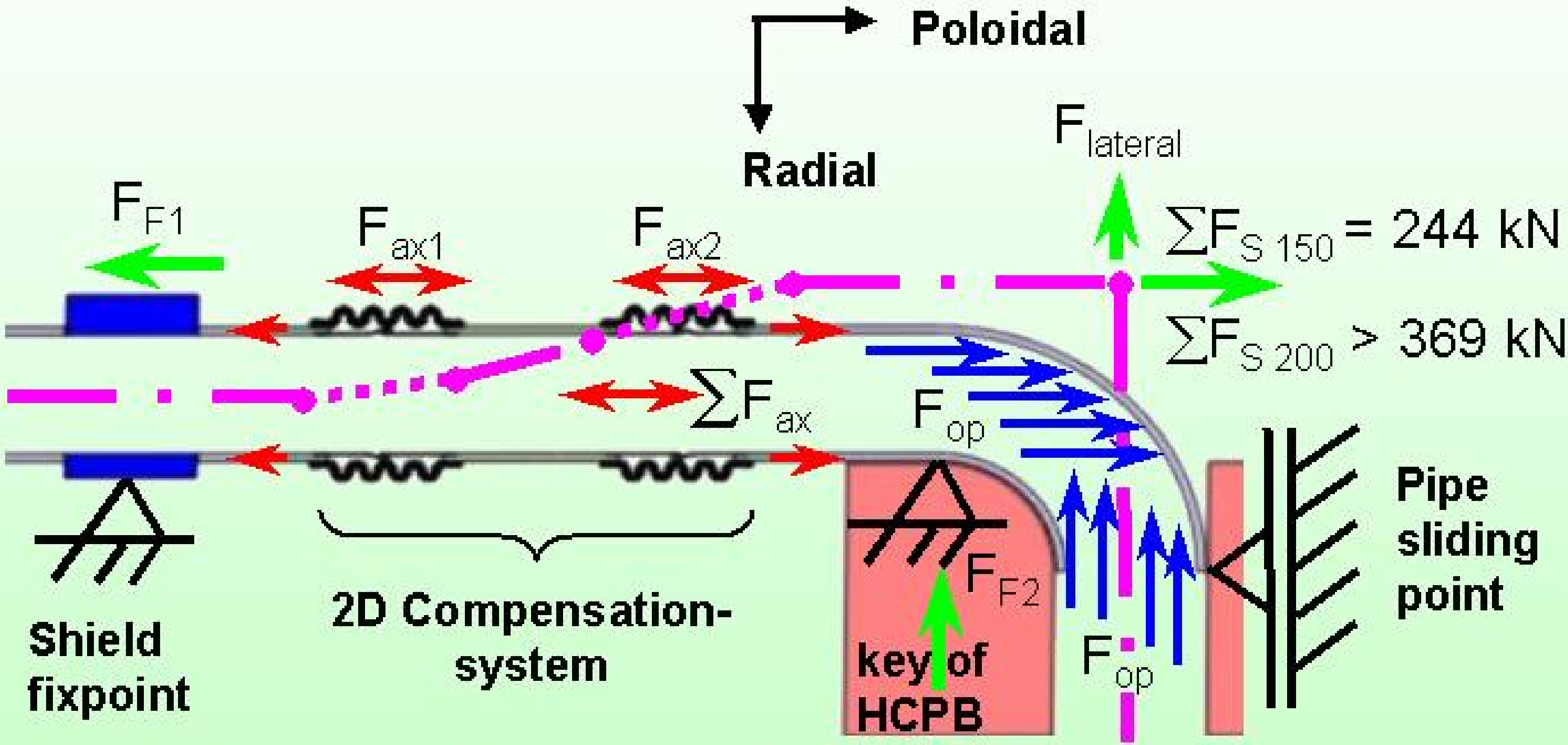


σ(pipe material) is factor 2-10 x to high!

Principal design rules for inboard and outboard compensation

- Compensator load alternations: in present > 20.000
- Minimal radial and poloidal space
- Construction welds are never made in plies of waves
- Internal telescope pipe for in-bore tool necessary
- Defined fix- / sliding points for stress absorption

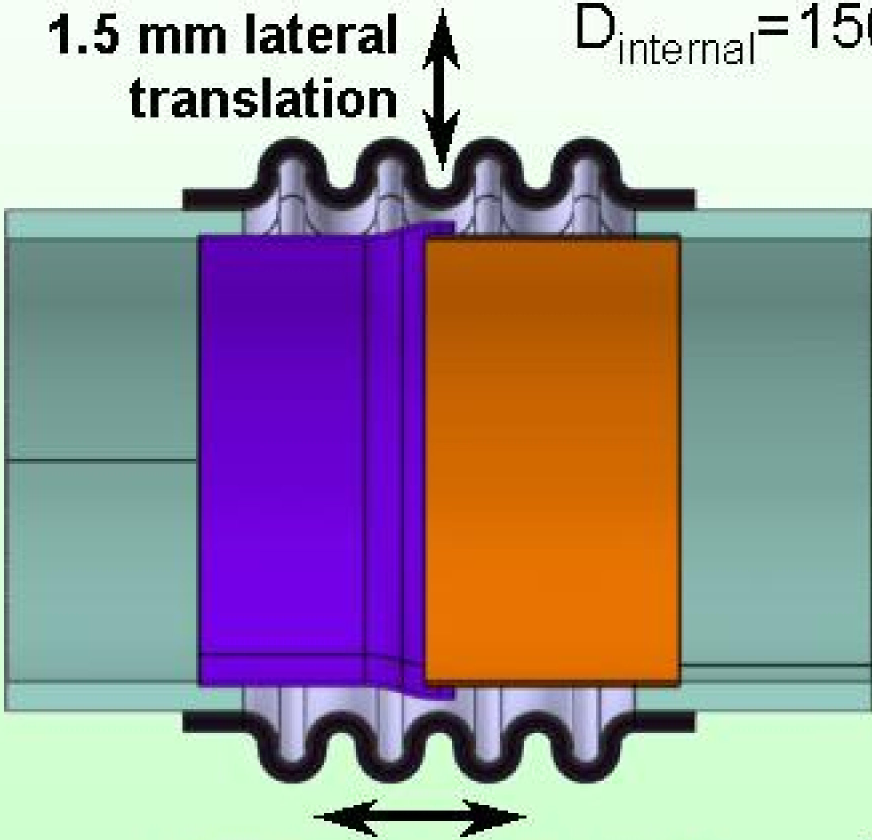
Compensation and structural forces

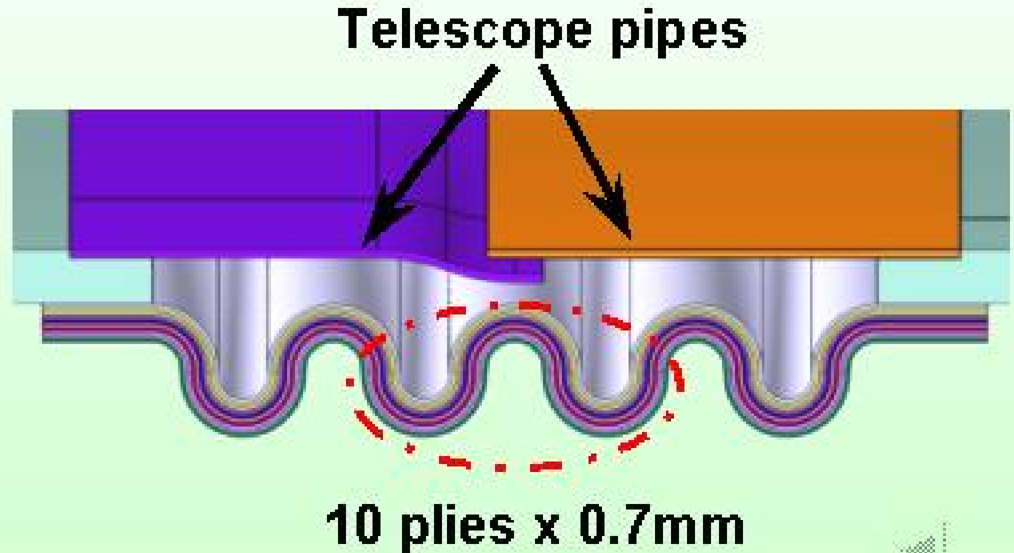


Lateral and axial compensation bending process

Modular axial and lateral wave movements

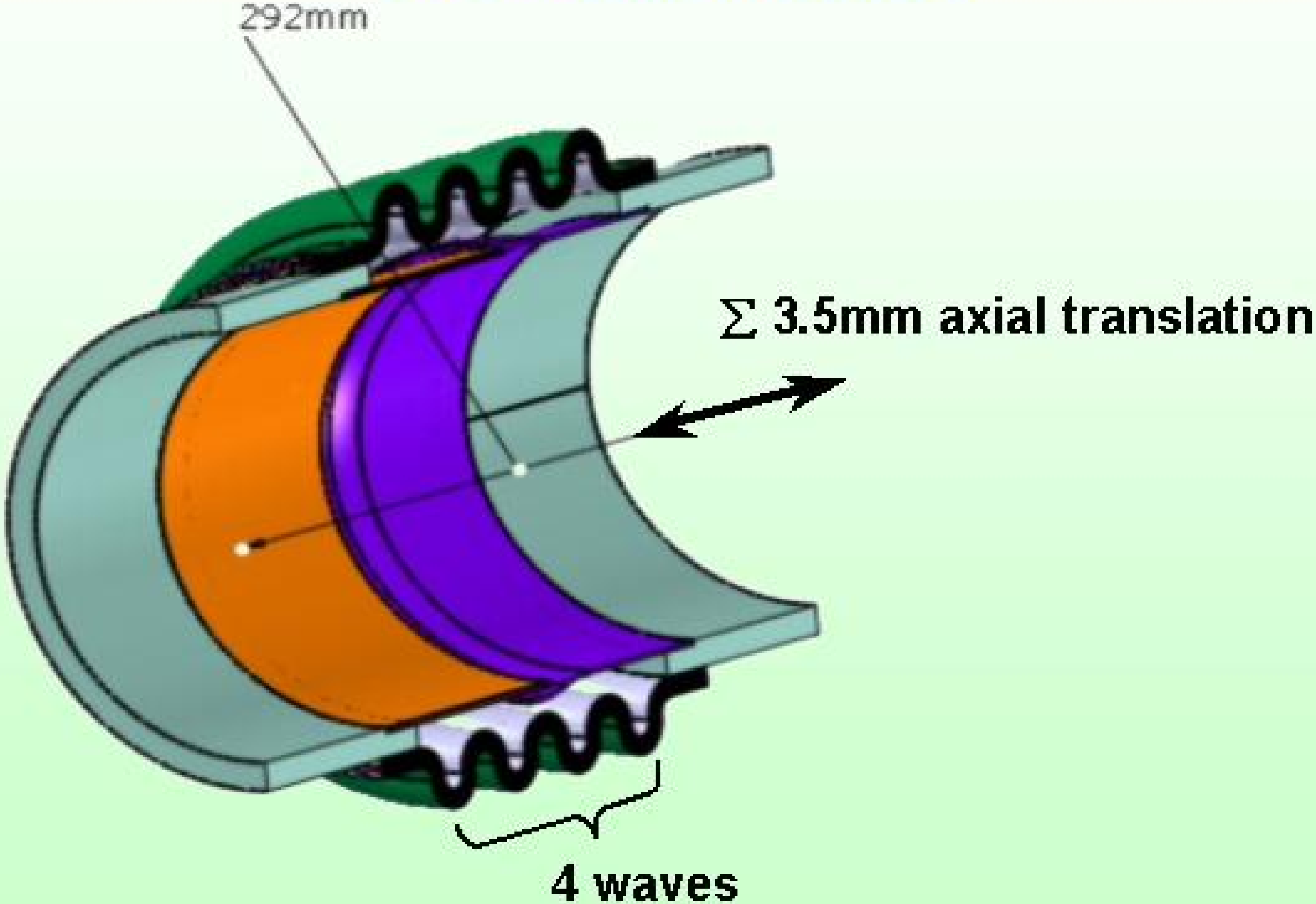
$D_{internal}$=150 mm, P_{Op}= 8 MPa



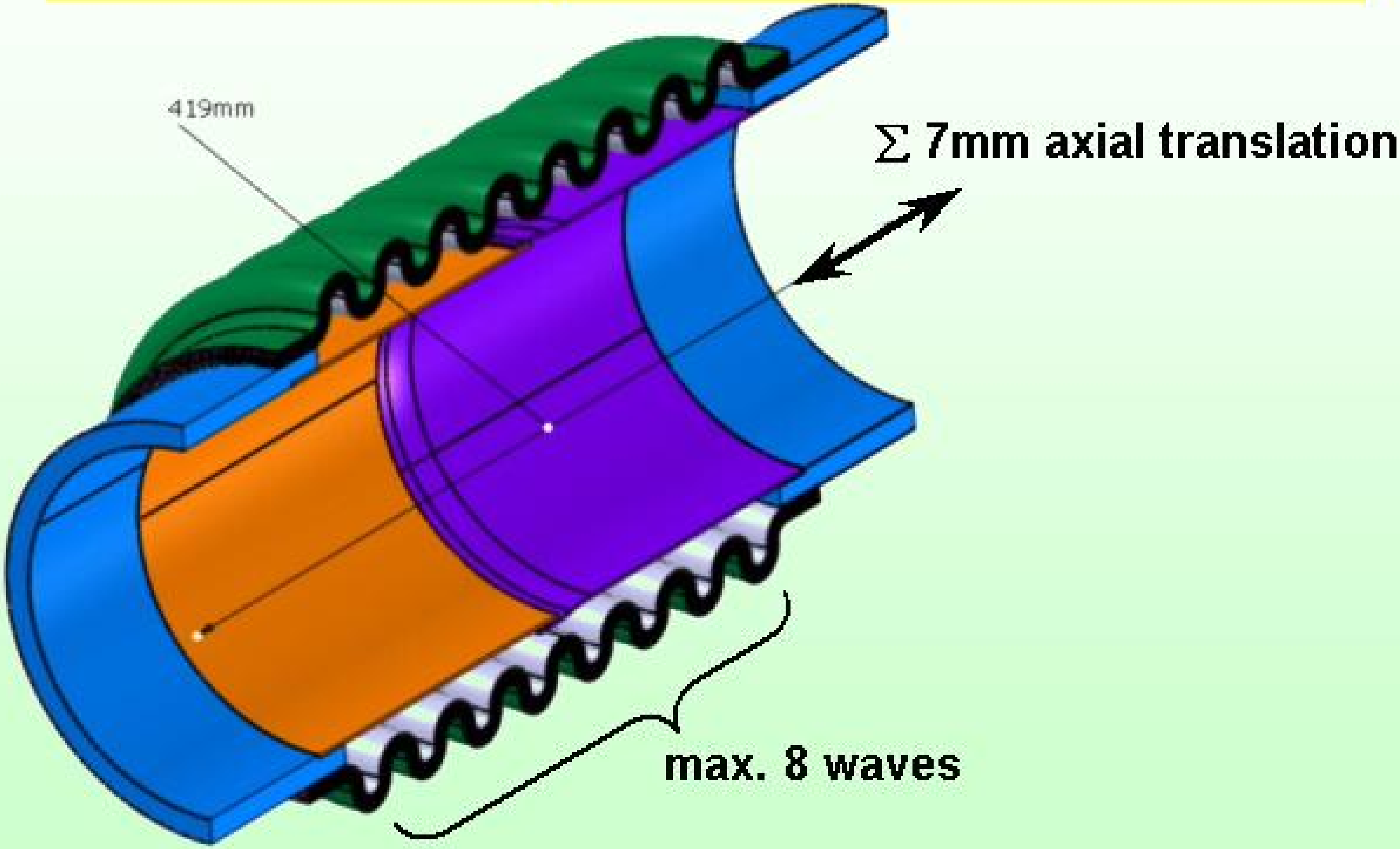


⇒ Goal of 4 waves *module* design!

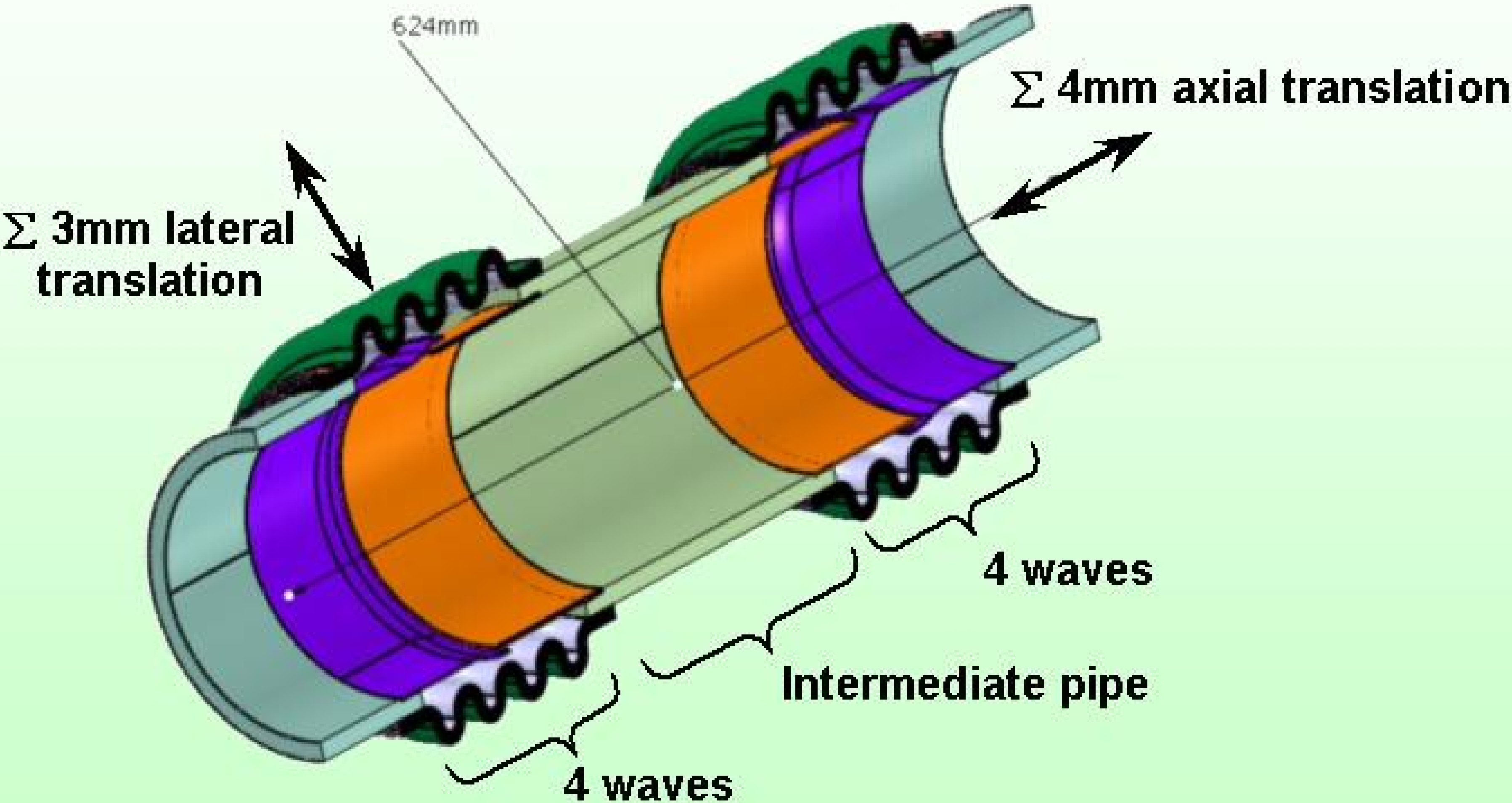
Short axial module I



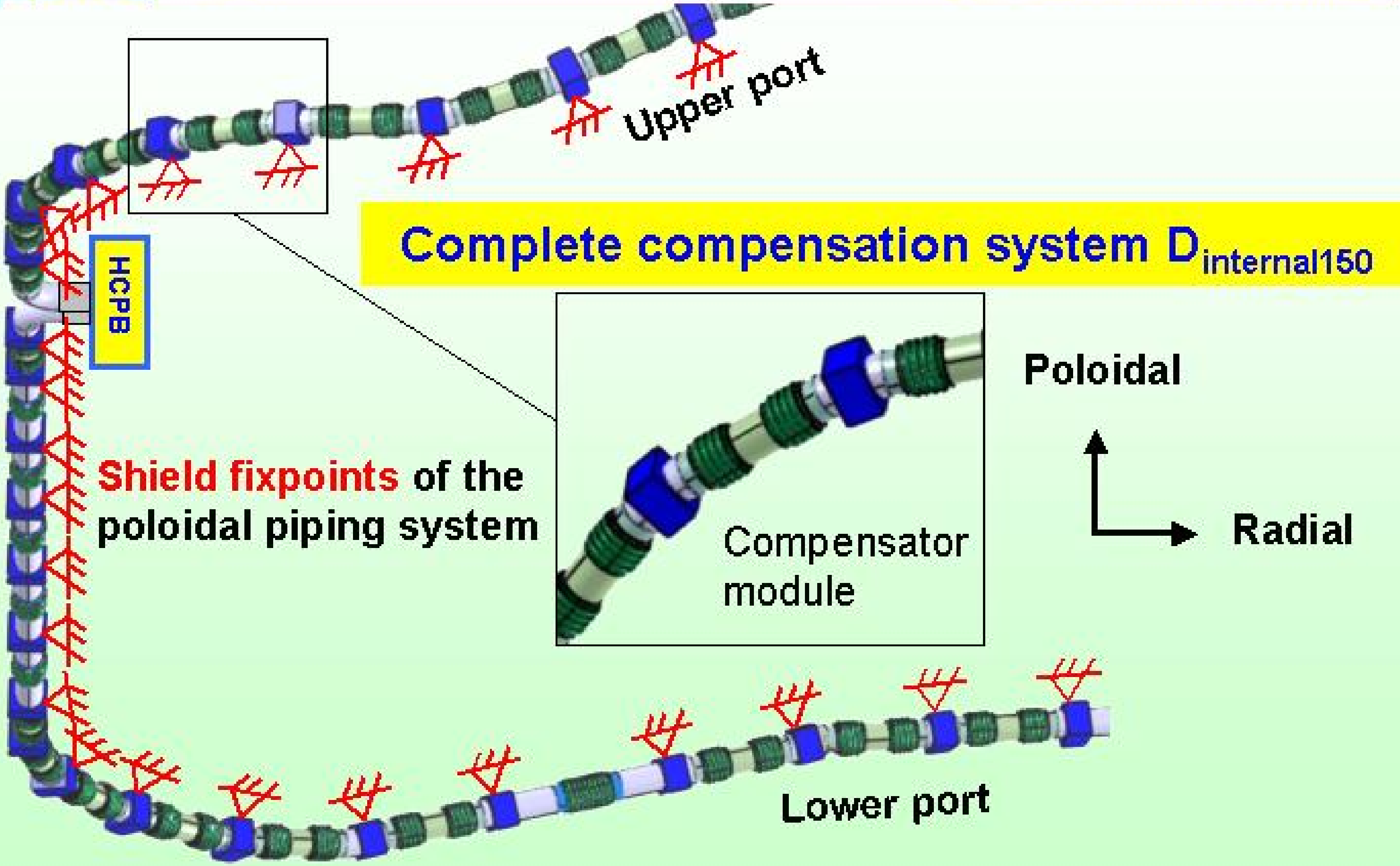
Long axial module II



Axial / lateral module III



Complete compensation system $D_{internal150}$



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First step to solve the problem of limited space:

Separation of the different tool tasks

A) Path reference → **In *all* operations required!**

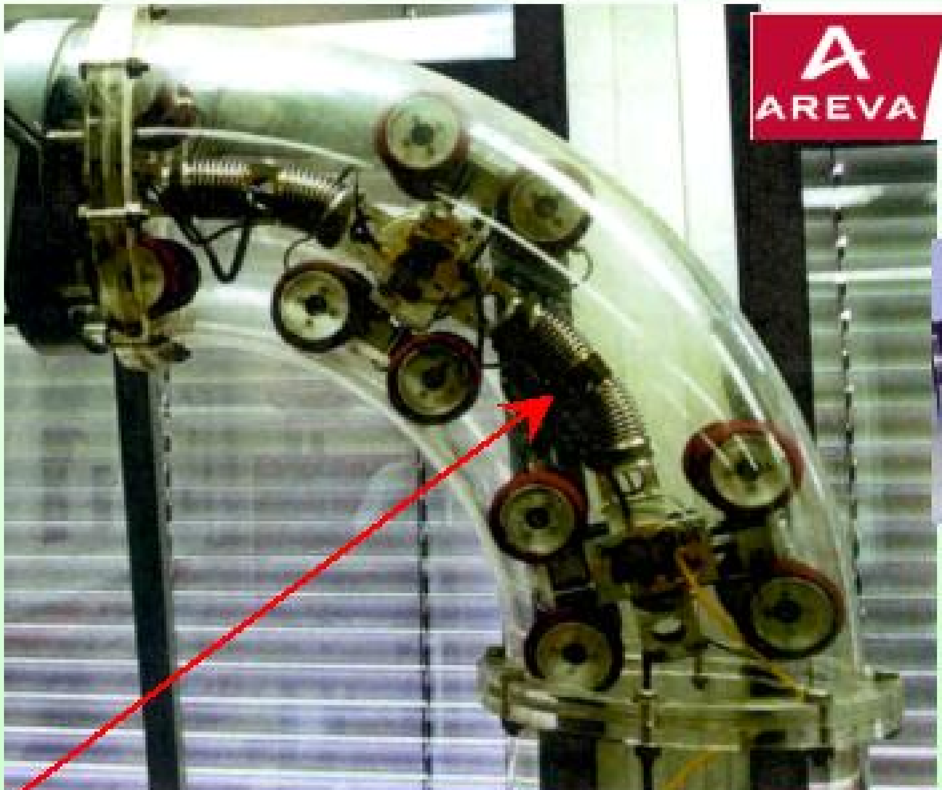
B) Cutting

C) (*Re-*)welding

D) Inspection

(B–D:) **All tasks in head position!**
3x different tools required

What is the possible path bending radius for in-bore tools?

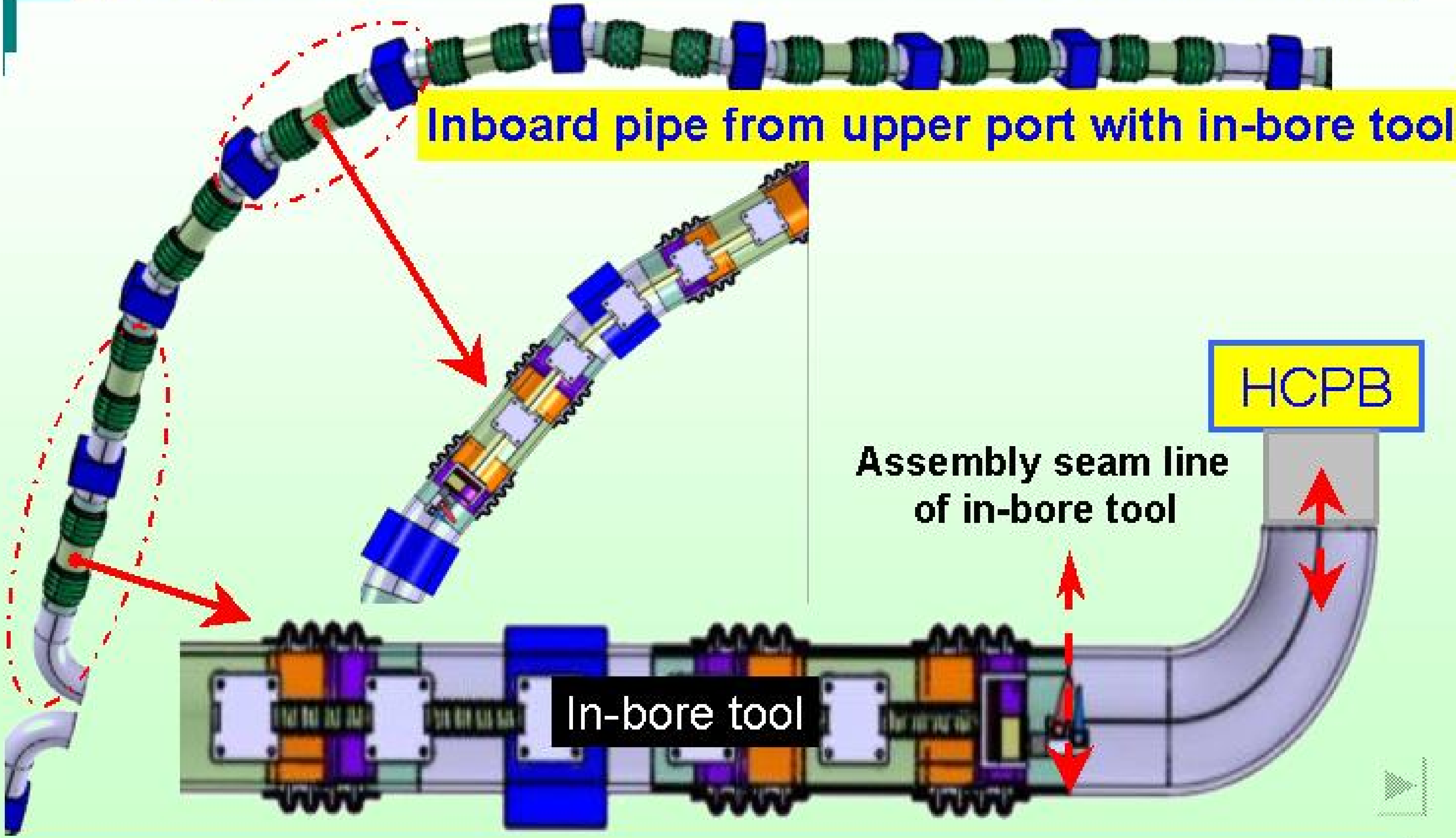


≈ 1.2 m

$r \geq 1.5 \times D_{internal}$

$D_{internal}$

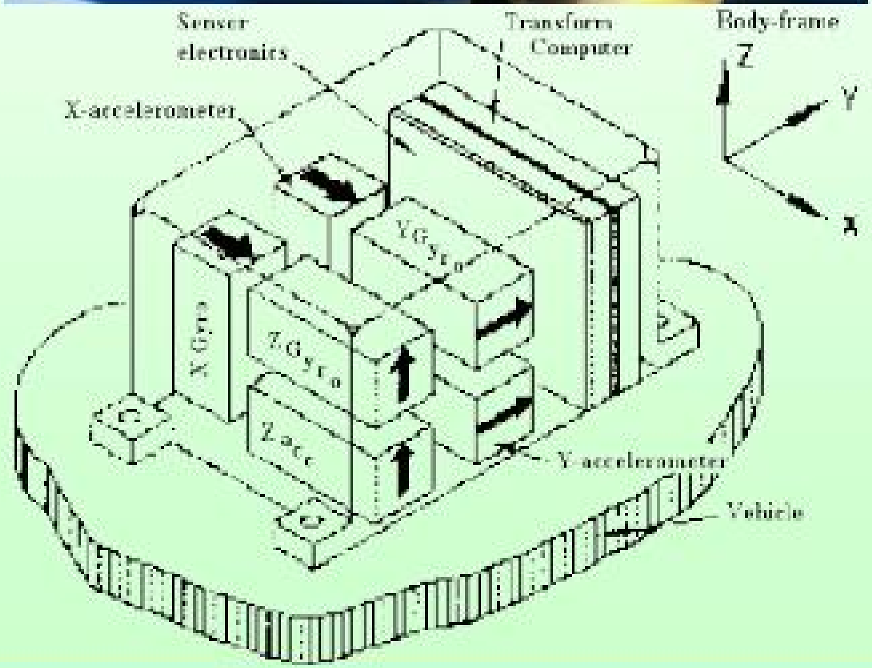
Further research for 3D welding torch necessary!


Inboard pipe from upper port with in-bore tool
HCPB
Assembly seam line
of in-bore tool
In-bore tool

A) Realisation of path reference

- Optical detection
- Detection by 1D tire roll motion
- Detection with 3D gyroscopic system
- Detection with 3D LASER scanner system

In-bore 3D Gyroskop modul



B) Realisation of pipe cutting

- Because of internal dust only LASER torch system
- With inertgas radial dust blow-out
- Internal vacuum system for dust reduction
- Lifetime component with minimal joining seam design

C) (*Re*-)welding of He pipe system

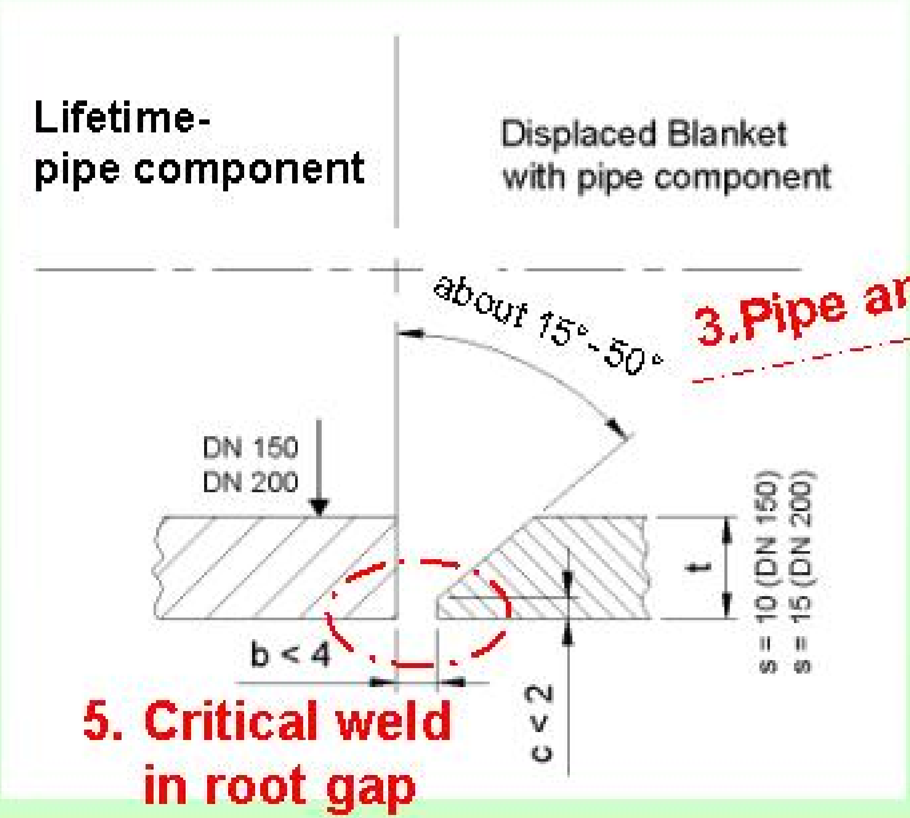
What are the *essential* joining aspects?

- Only in-bore tooling possible
- Because of He leak tightness max. seam quality
- Simulation of test- and operation pressure
- Axial, radial and angle pipe tolerances ⇒ seam design
- (Re-)weldability with gap bridging ⇒ weld techniques

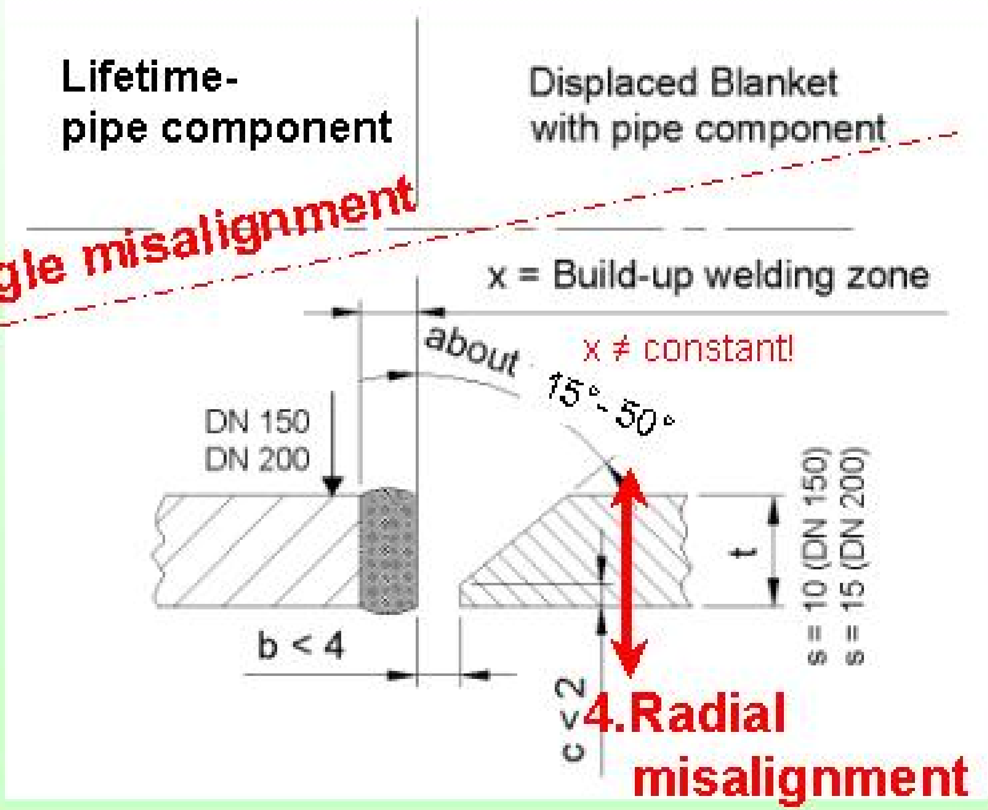
What are possible seam scenarios

1.Standard TIG HV-seam

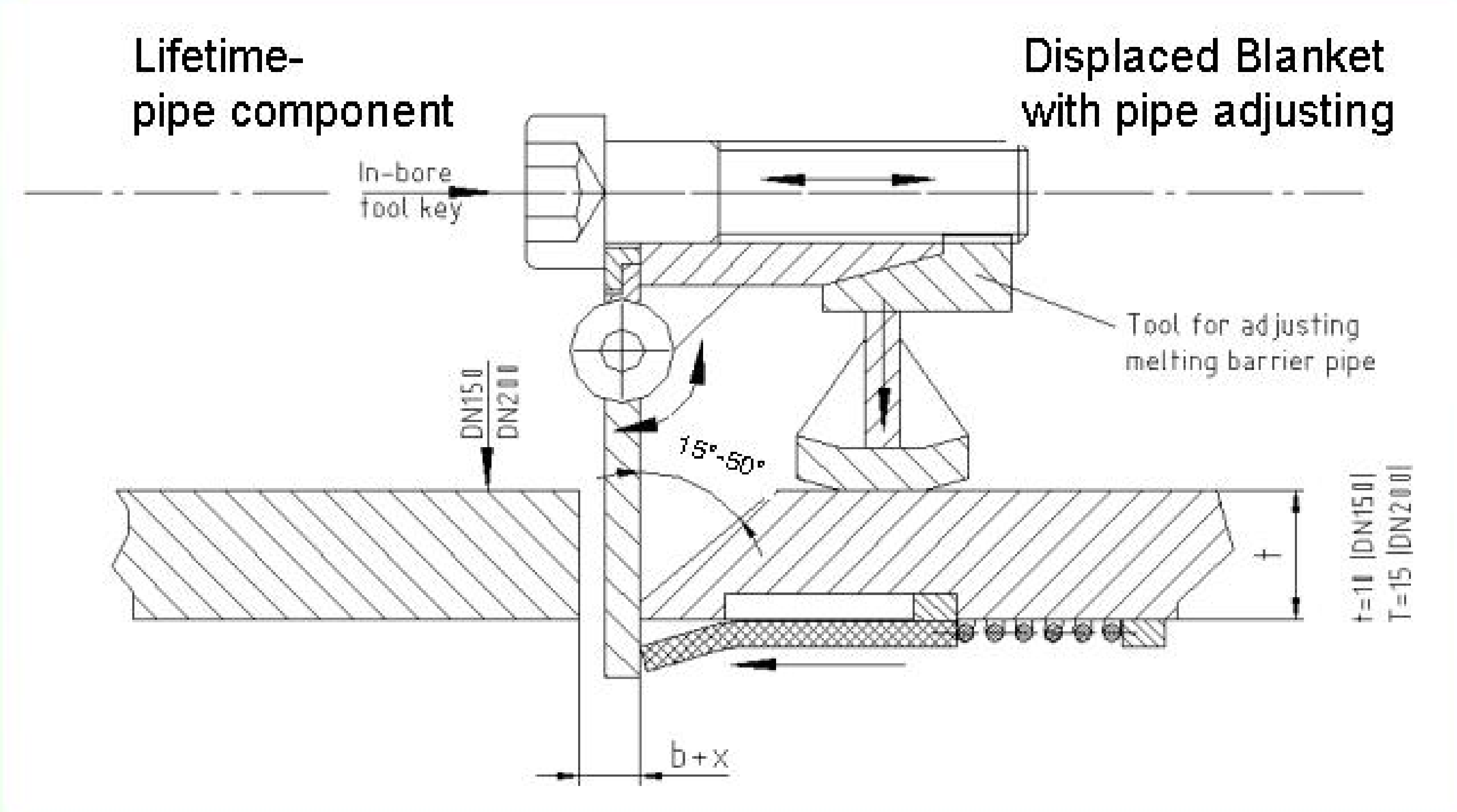
2.TIG HV-seam + X-gap



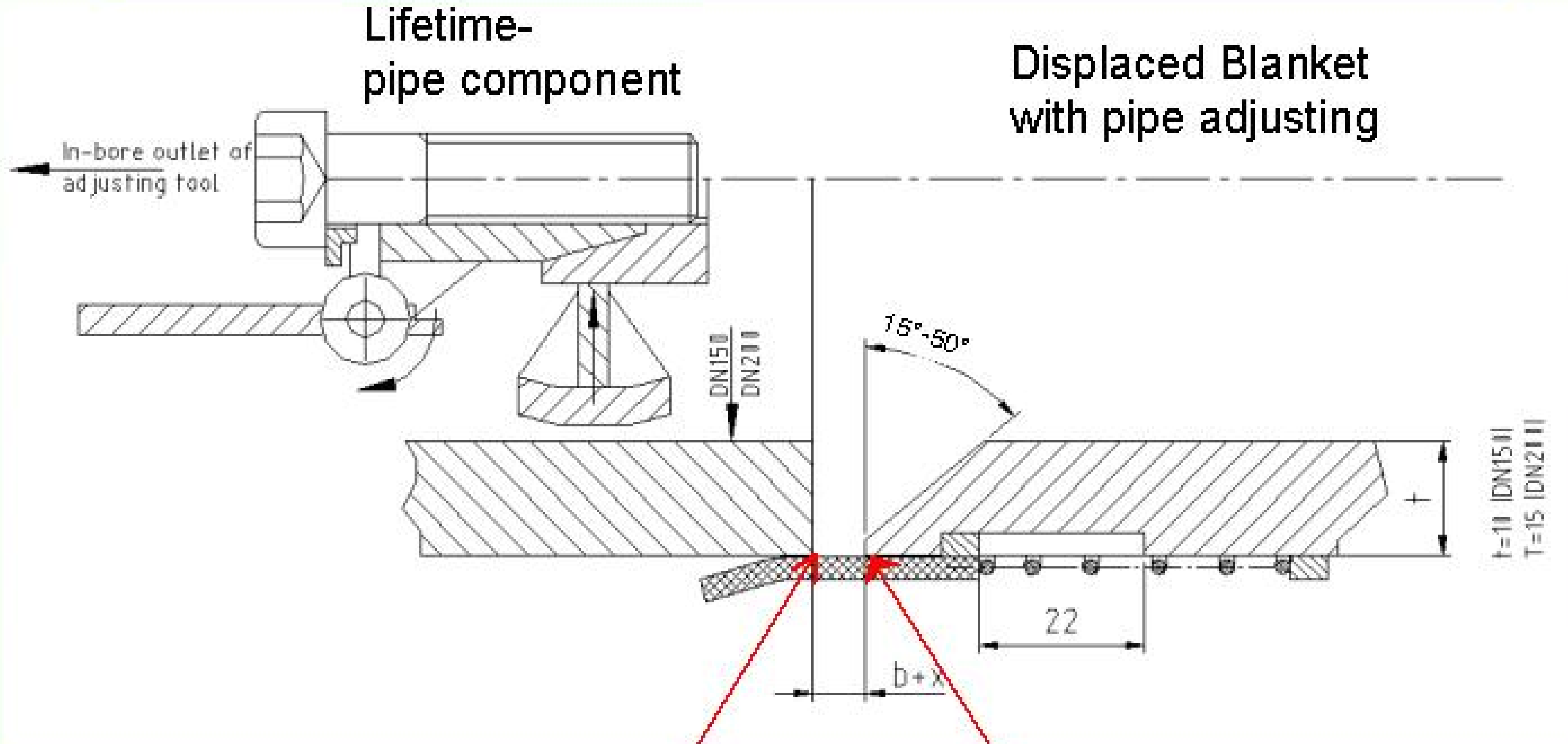
3.Pipe angle misalignment



Possible in-bore pipe assembly scenario



Adjusted seam root and tool outlet



Critical: root corners ⇒ **ceramic barrier**

Thermal In-bore arc welding seam composition aspects

Inboard data: $D_{internal}$= 150 mm, s = 10 mm, material: 1.4919,

TIG weld, about 12 plies

- **Welding root seam about 3 plies in *short* time**
- **> 4 plies limit of the local temperature less than 150°C - 200°C**

⇒ **Therefore *recooling* in Heat Affected Zone (HAZ) necessary**

- **Upper plies additional cooling time schedule in range of 2 x *t (join)***

⇒ **Therefore welding time depends also mainly from recooling time**

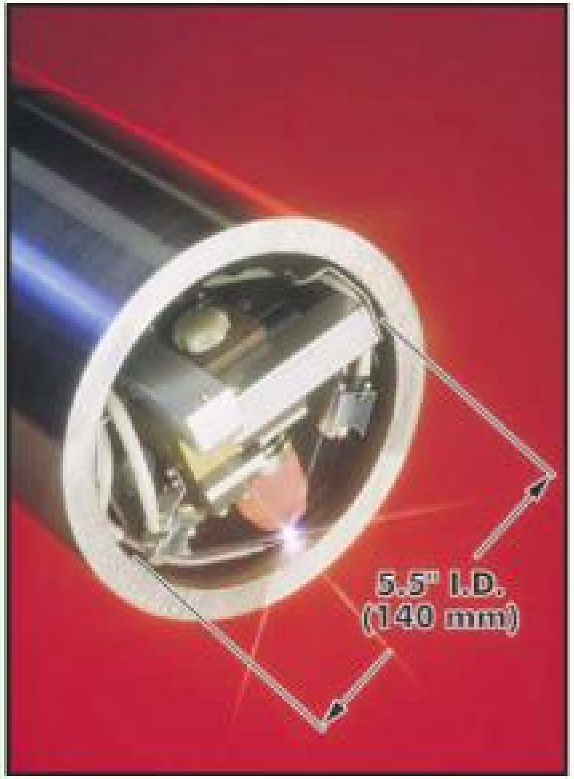
Total welding process time

Inboard data: $D_{internal}$ = 150 mm, s = 10 mm, material: 1.4919, TIG weld, about 12 plies

Process	Tool velocity	process time [min]	Remarks
In-bore module positioning	≈ 200 [m / h]	2 x 10 + 10 = 30	path detection inclusive, without tool reference
Join process	≈ 6 [min / ply]	≈ 72	without cooling sequence
Recooling	—	2 x f (join) = 144	accompanying to the join process, depending from number of plies

Total process time is f (material) ⇔ For 1 join: > 4 hours!

3-D TIG in-bore welding torch



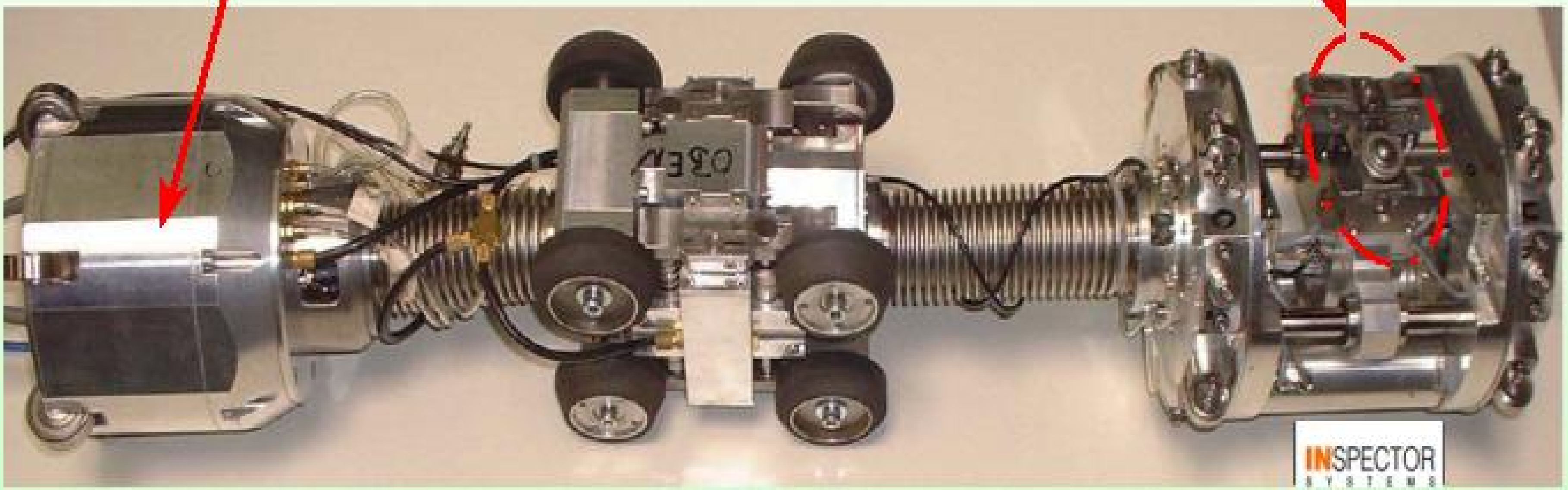
D) In-bore tool inspection systems

- **Visual with micro camera Test (VT)** $\Rightarrow$ **surface defects**
- **Eddy current Test (ET)** $\Rightarrow$ **internal surface cracks**
- **Ultrasonic Test (UT)** $\Rightarrow$ **internal join defects**

In-bore ultrasonic inspection modul

Plunger module

US torch



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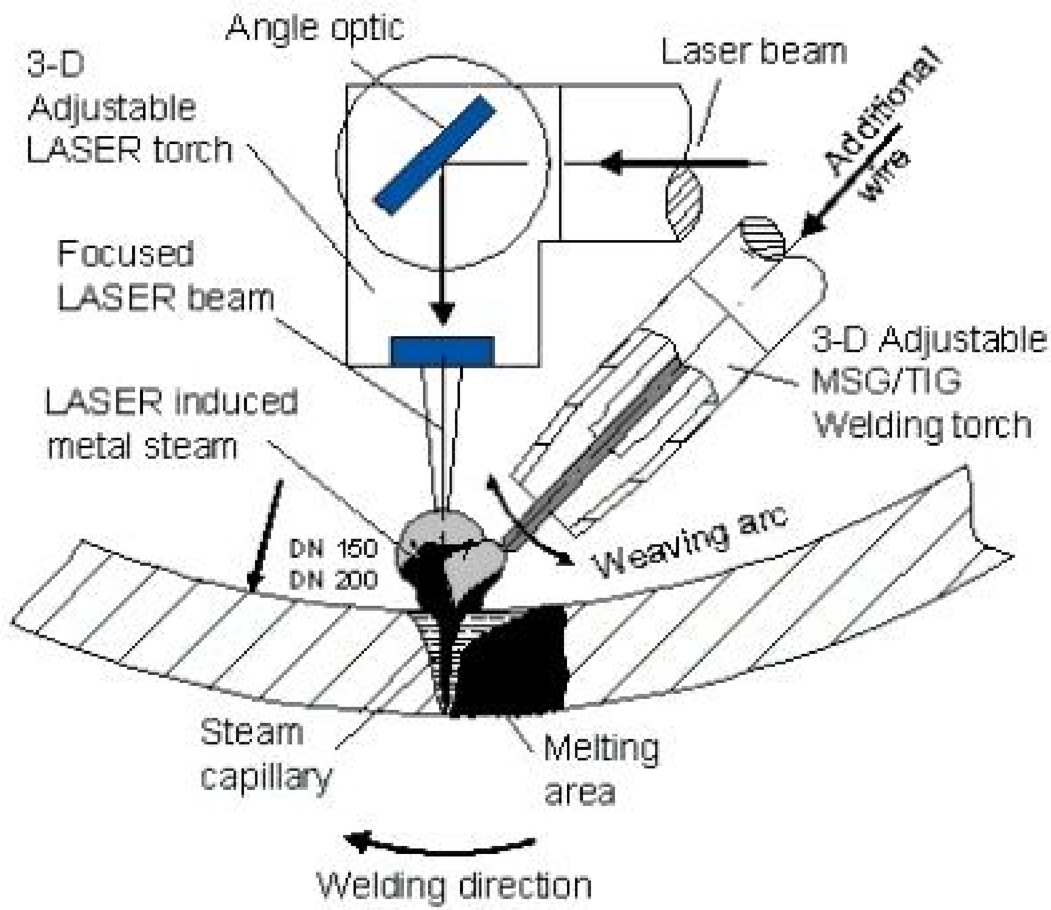
In-bore LASER Hybrid technique

Further R&D measures:

- **Gap bridging >1mm**
- **More flexible control for arc construction welds**



➢Summary

- Poloidal in-bore pipe tools are realistic
- Path reference with LASER or gyroscope head + R&D
- *Segmentation* of pipes with compensation
- Joining aspects: root quality and recooling of HAZ
- Pipe bending aspect makes welding torch R&D necessary

Acknowledgments for the realization of this presentation

Fa. ARC Machines AMI (in-bore welding tools)

Fa. Framatome ANP (in-bore modules)

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Fa. Witzenmann (compensator techniques)

FZK-IAI (3D gyroscopic system)

Any further questions?