Three Dimensional Analysis of Radiation Streaming Through ARIES-CS He-access Pipes

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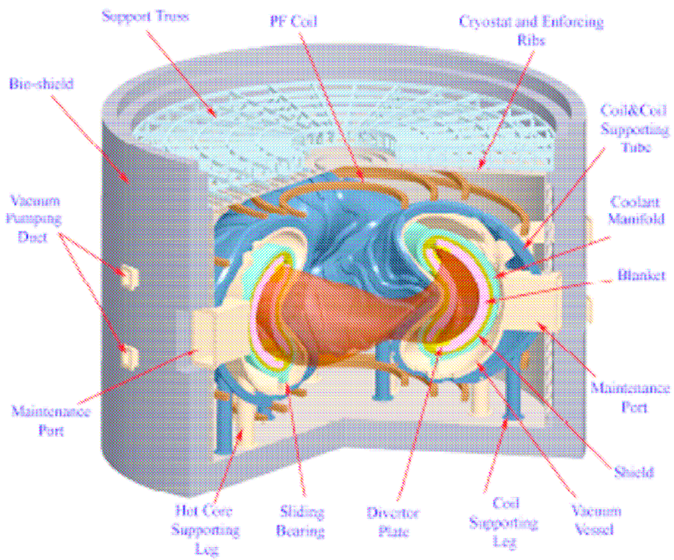
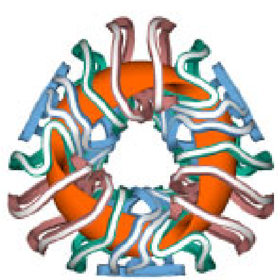
Outline

- Radial build of ARIES-CS
- 2-D analysis (simple straight pipe)
- 3-D analysis (pipe with shielding plug and inserts)
- Conclusions

ARIES- Compact Stellarator



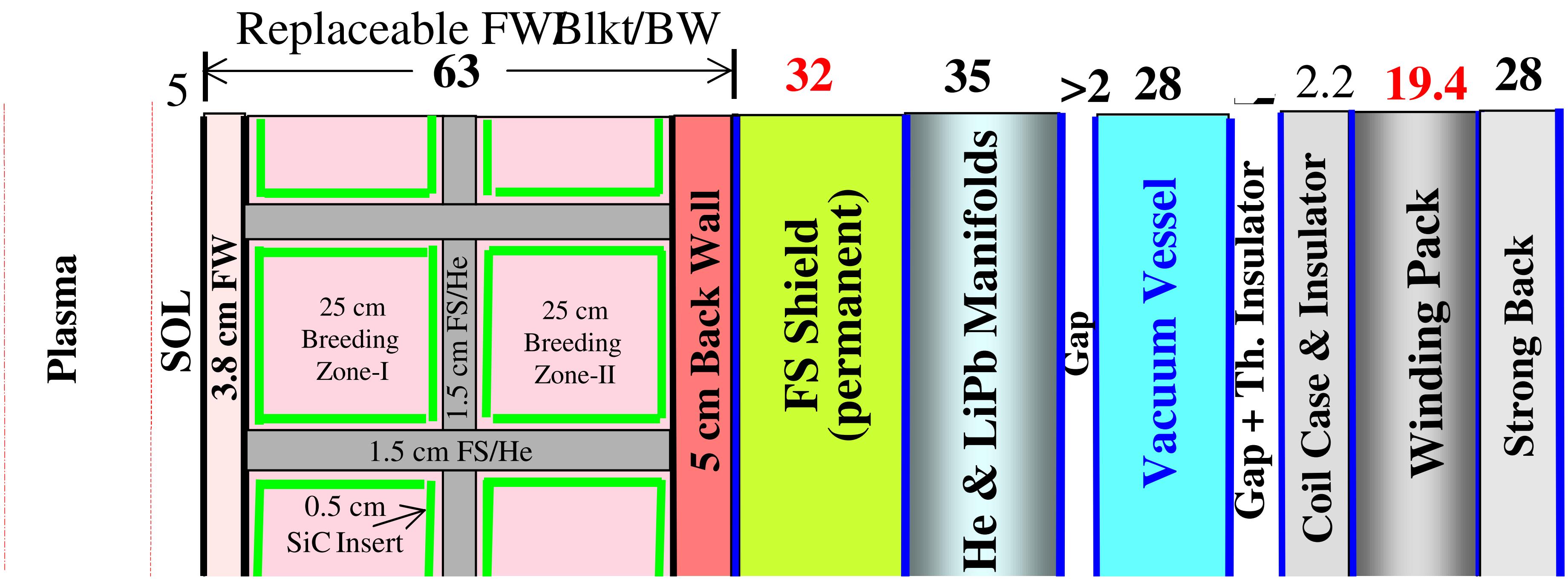


Plasma and poloidal coils

- ARIES-CS: a compact stellarator fusion power plant
- Parameters
  - 1000 MW net electrical power
  - 5.3 MW/m^2 Peak NWL
  - 40 FPY plant lifetime
- The device has a 120° symmetry in the toroidal direction

Radial build

Radial builds and radiation levels were defined in 1-D analysis without penetrations.



Fluxes and Damage Levels in Absence of Penetrations

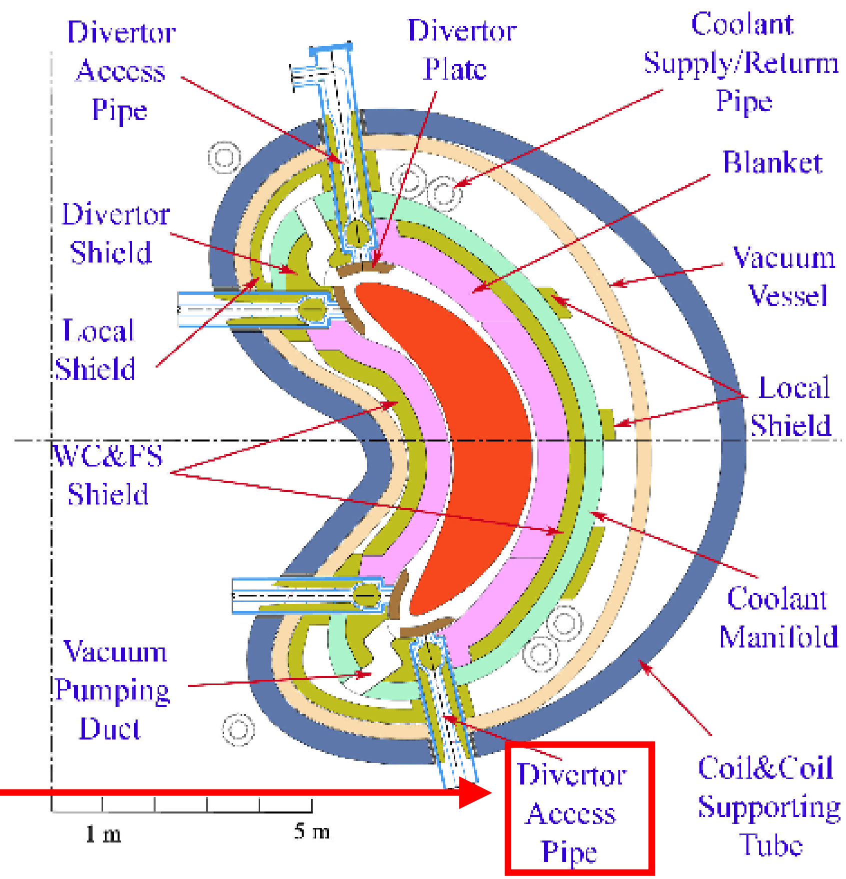
	Nominal Values (without pipes)	**Design Limits**	**Allowable Peaking Factor**
dpa at shield (dpa @ 40 FPY)	135	200	1.5
He production at manifolds (He appm @ 40 FPY)	**1**	1	1
He production at VV (He appm @ 40 FPY)	0.2	1	5
Fast neutron **fluence** @ magnet (n/cm^2 @ 40 FPY)	0.2×10^{19}	1×10^{19}	5
Total neutron flux outside magnet ($n/cm^2.s$)	10^7	5×10^7	5

Penetrations

- Necessary:
  - vacuum pumping
  - coolant supply lines
  - plasma control
  - maintenance ports.

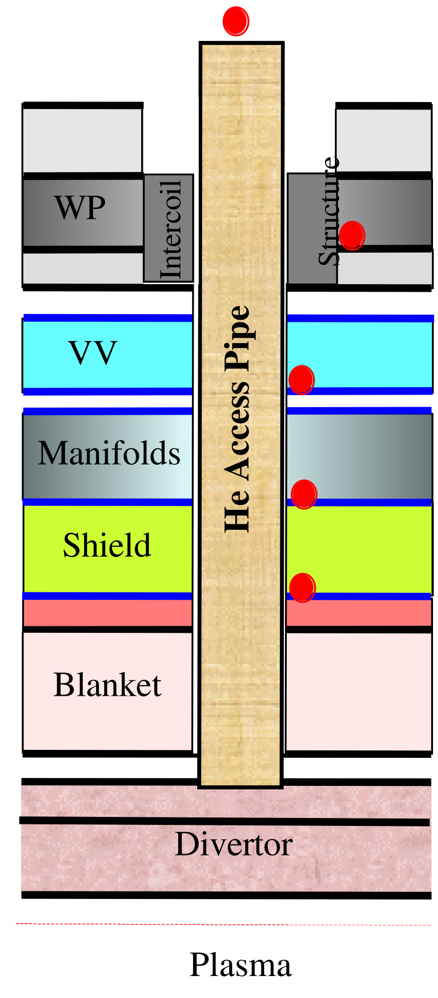
- Compromise shielding performance:
  - Enhance damage at surrounding components.
  - Increase dose levels behind magnet.

- Large divertor He-access pipe represents the most serious streaming issues.

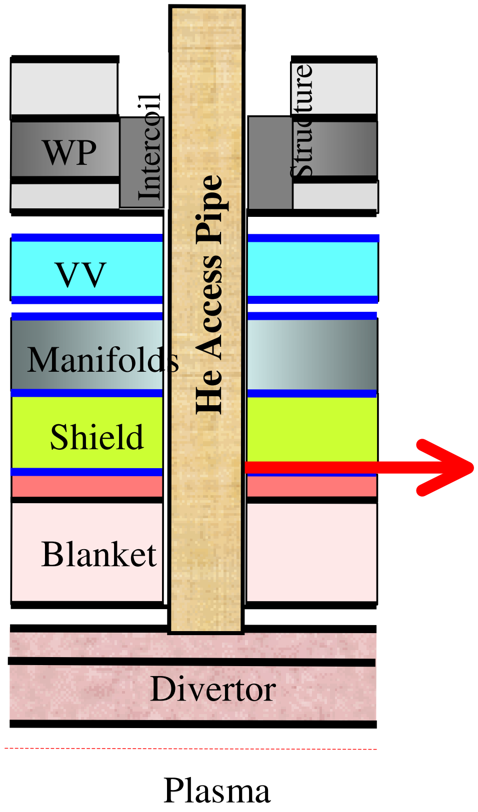


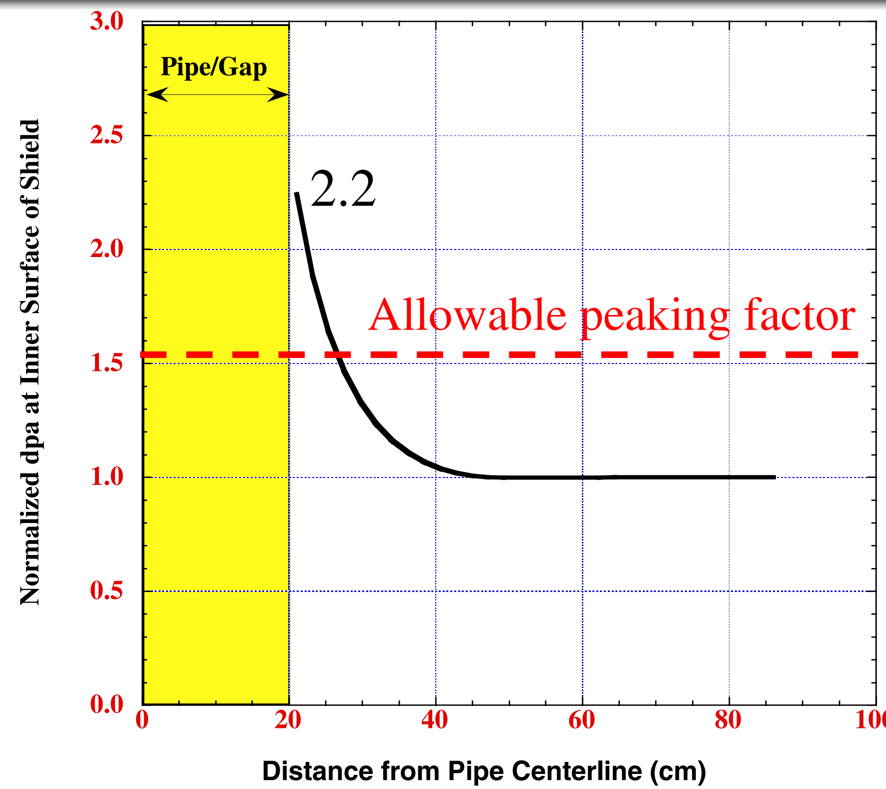
2-D Analysis (Simple Pipe with 30 cm ID)

- DANTSYS - a multi-dimensional, discrete ordinates transport code, developed by Los Alamos National Laboratory
- Data - FENDL2.1, 175n - 42g coupled cross section library



2-D Results (Shield)



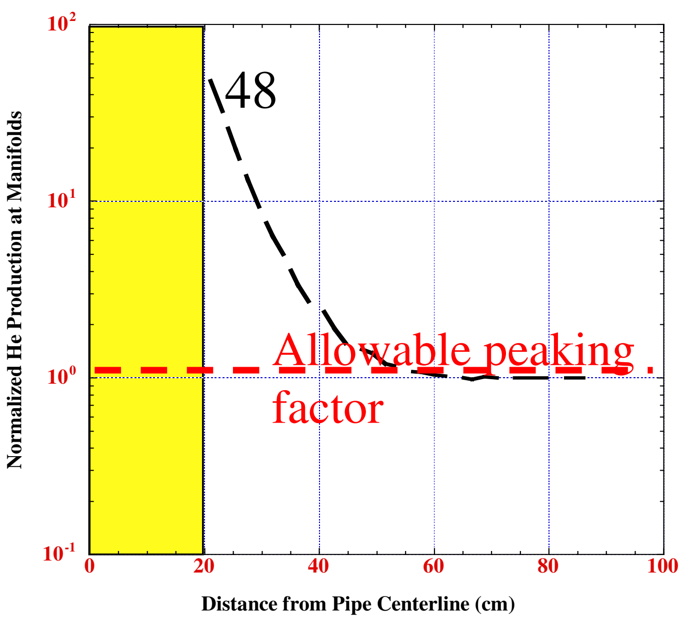


Nominal value: 135 dpa

Design Limit: 200 dpa

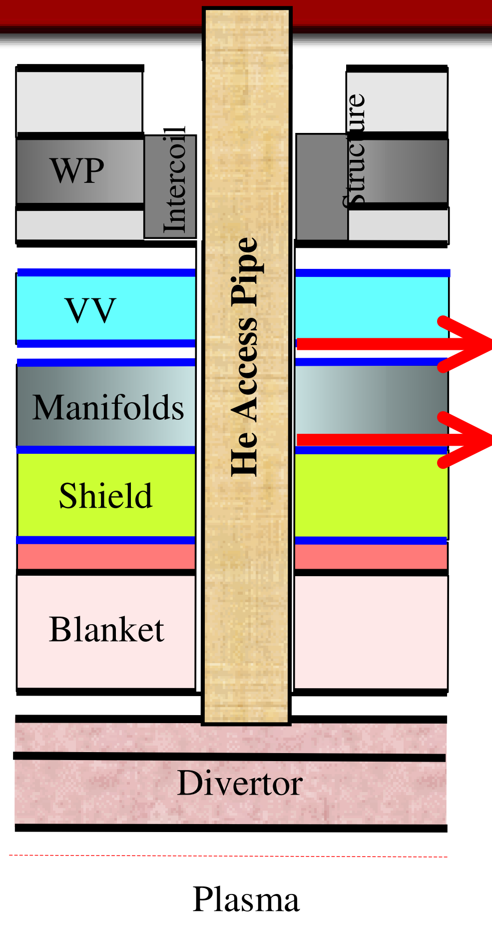
Shield surrounding pipe is not life-of-plant component

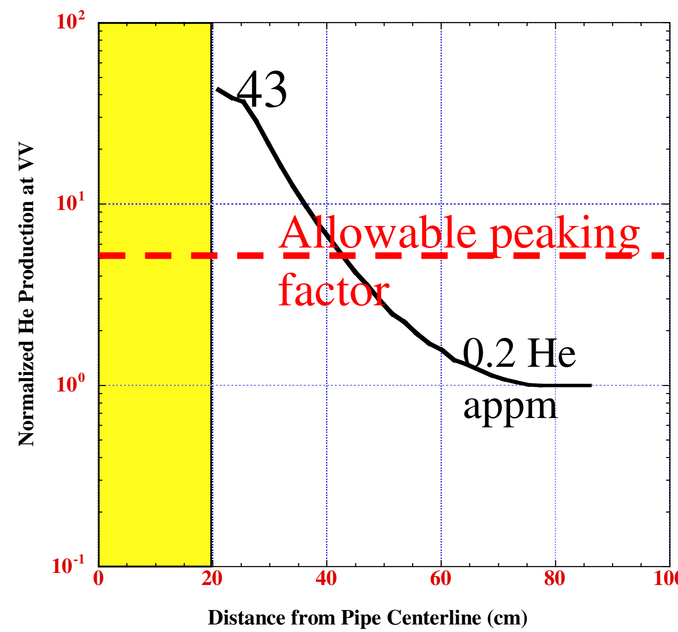
2-D Results (Manifold and Vacuum Vessel)



Nominal value: 0.9 appm

Design Limit: 1 appm



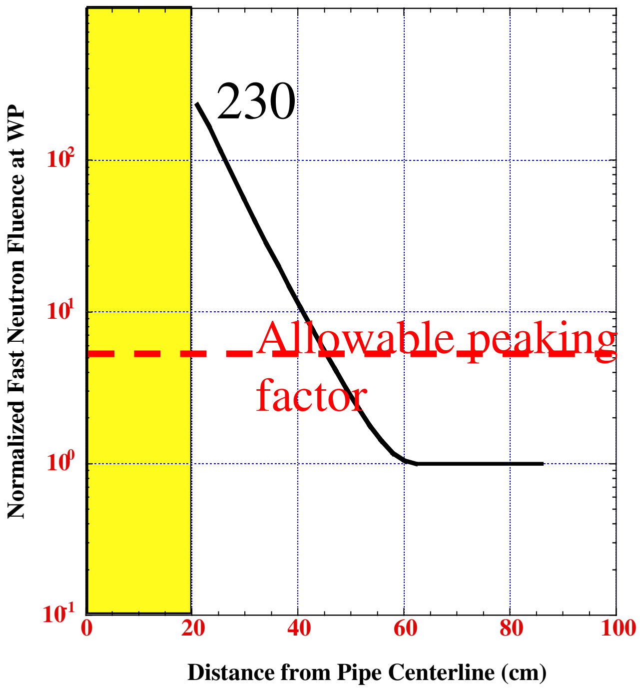


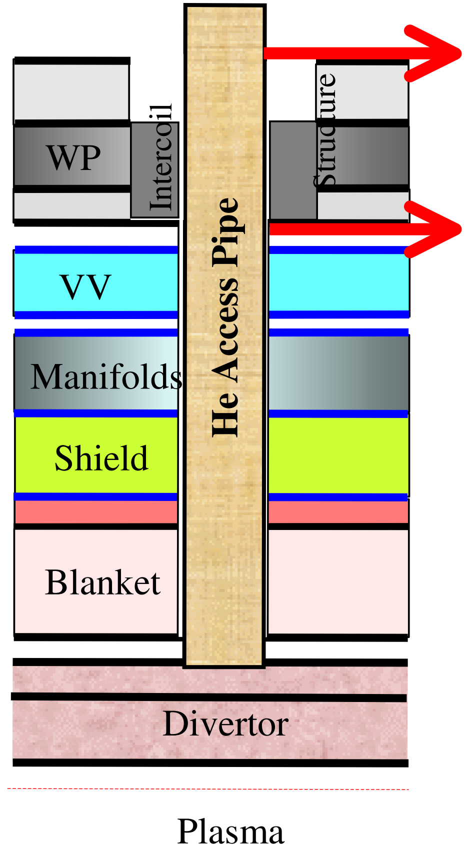
Nominal value: 0.2 appm

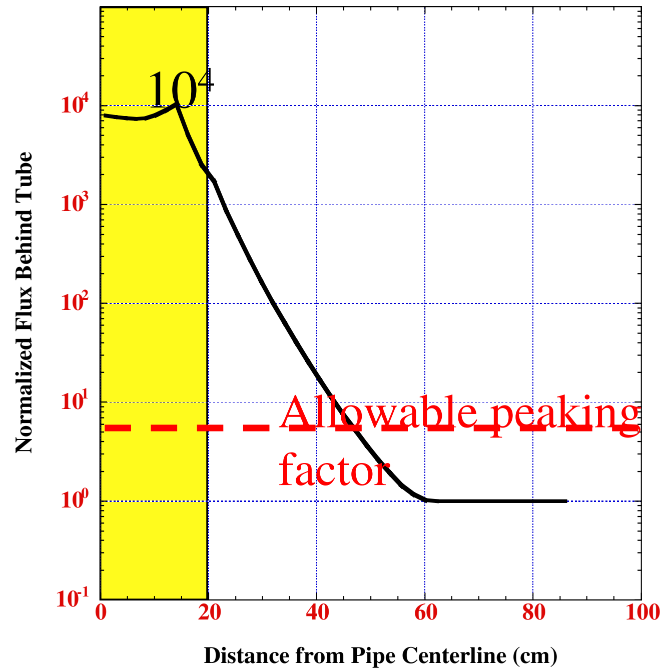
Design Limit: 1 appm

Parts of manifolds and vacuum vessel surrounding pipe cannot be rewelded

2-D results (Magnet)







Nominal value: 0.2×10^{19} n/cm^2

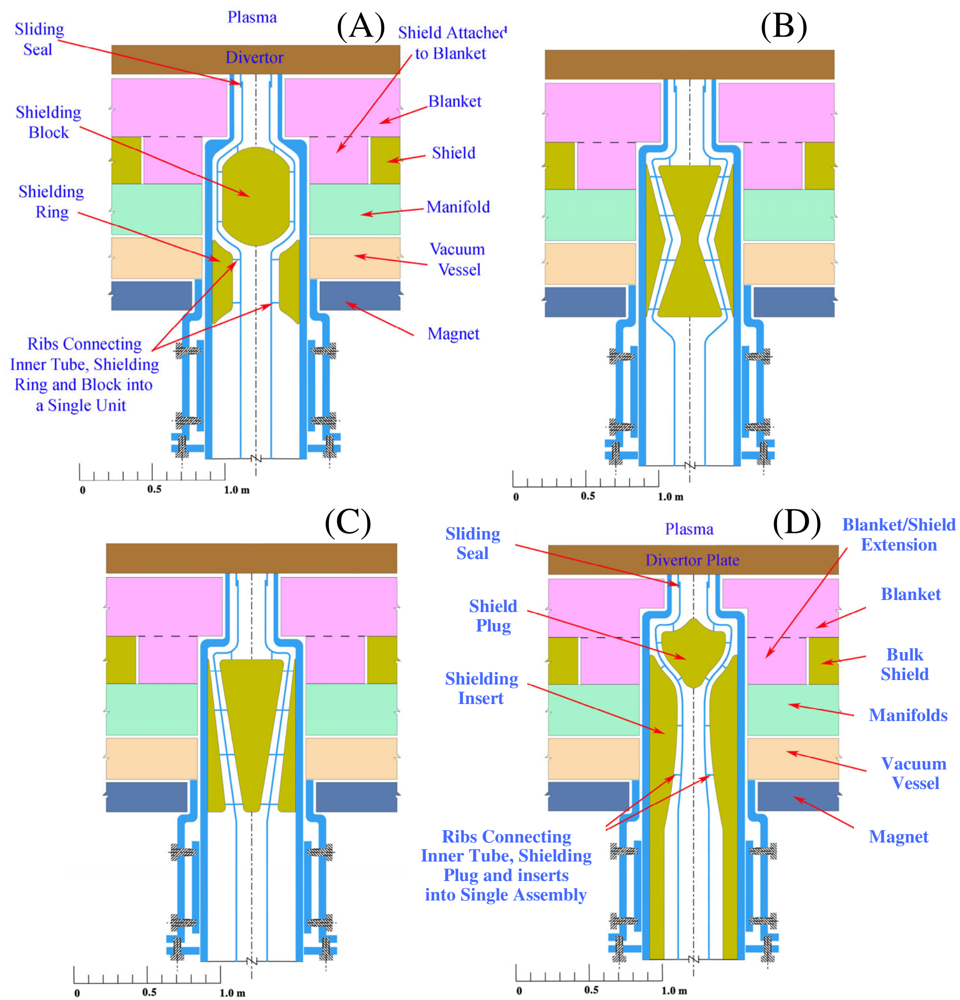
Design Limit: 10^{19} n/cm^2

Nominal value: 10^7 n/cm^2.s

Design Limit: 5×10^7 n/cm^2.s

- Winding pack should be placed 30-40 cm from pipe
- Flux at end of pipe is excessive $\Rightarrow$ protect externals with local shields.

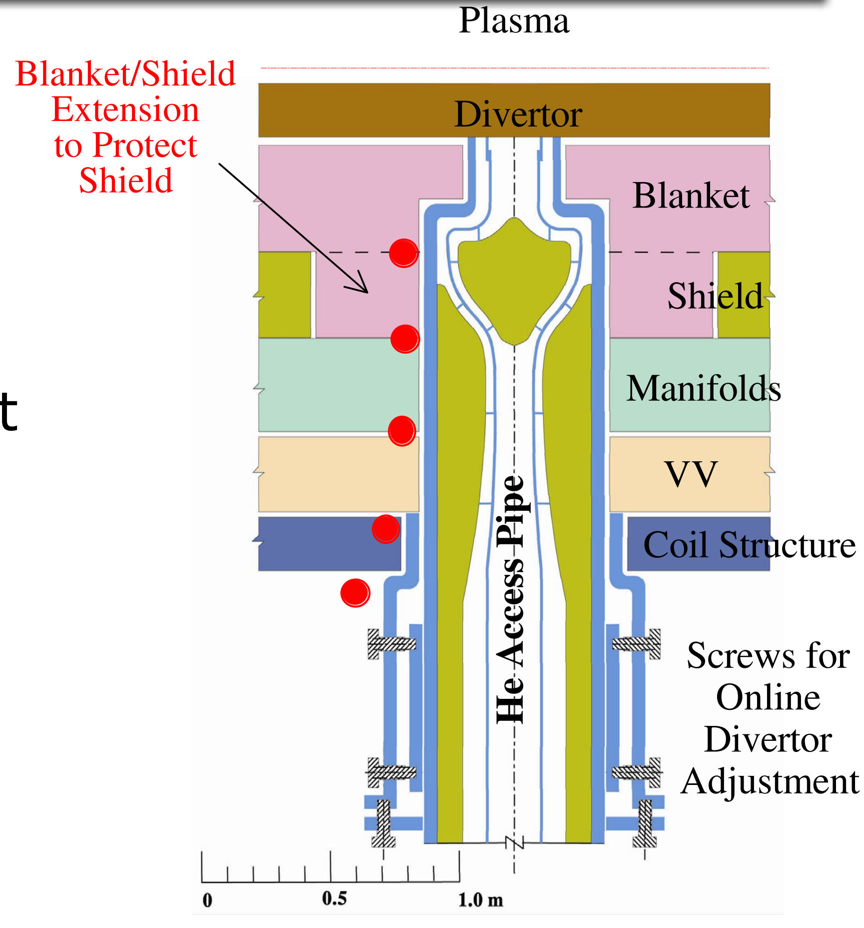
3-D Model



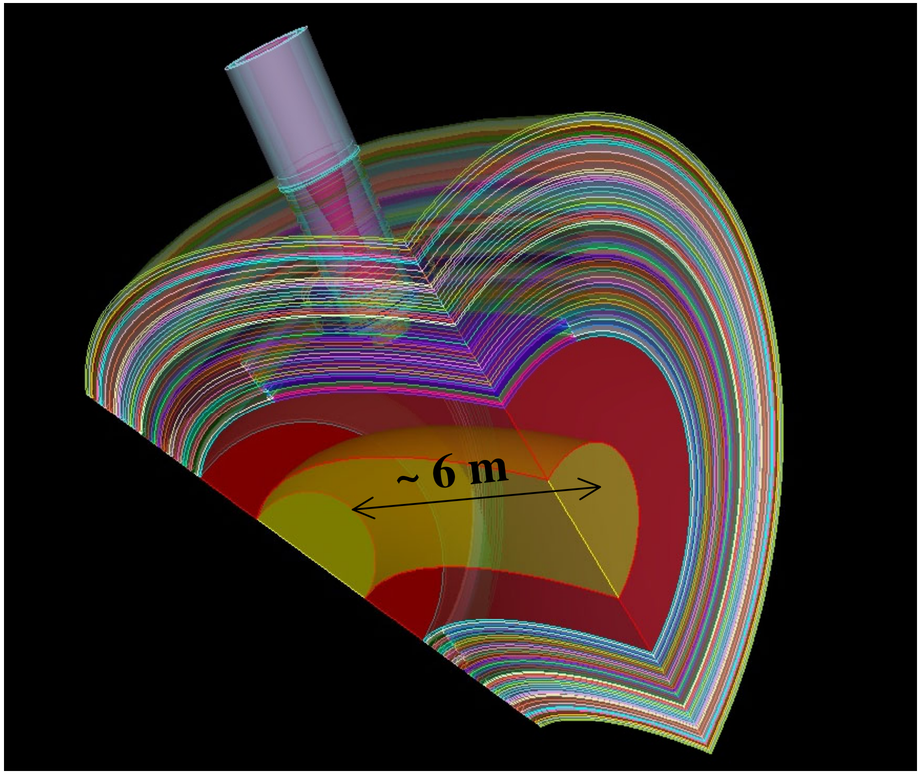
(A)
Plasma
Sliding
Seal
Divertor
Shield Attached
to Blanket
Blanket
Shielding
Block
Shield
Shielding
Ring
Manifold
Vacuum
Vessel
Magnet
Ribs Connecting
Inner Tube, Shielding
Ring and Block into
a Single Unit
0
0.5
1.0 m
(B)
0
0.5
1.0 m
(C)
0
0.5
1.0 m
(D)
Plasma
Sliding
Seal
Divertor Plate
Blanket/Shield
Extension
Blanket
Shield
Plug
Bulk
Shield
Shielding
Insert
Manifolds
Vacuum
Vessel
Magnet
Ribs Connecting
Inner Tube, Shielding
Plug and inserts
into Single Assembly
0
0.5
1.0 m

3-D Neutronics Model

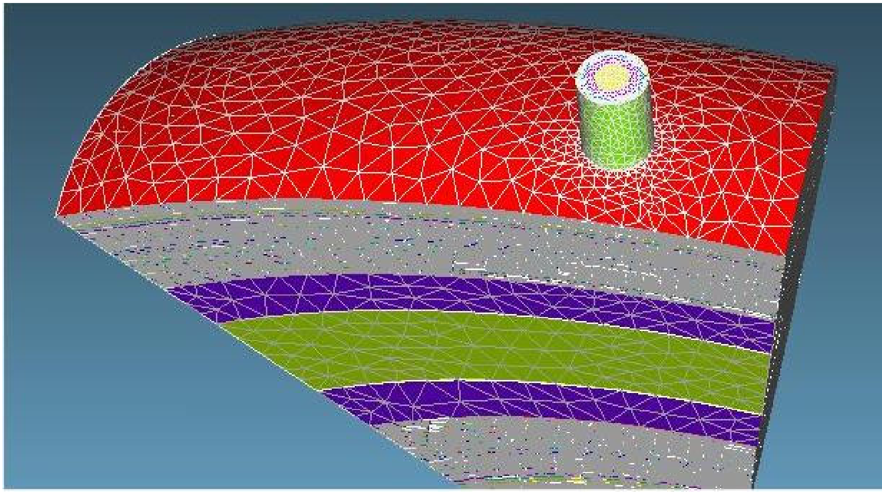
- **Purpose**:
  - Examine effectiveness of shield plug and inserts
  - Estimate peaking in damage due to streaming
  - Assess radiation environment behind magnet due to streaming
- **3-D codes**:
  - Attila: discrete ordinates
  - DAG-MCNPX: Monte Carlo



3D CAD Models

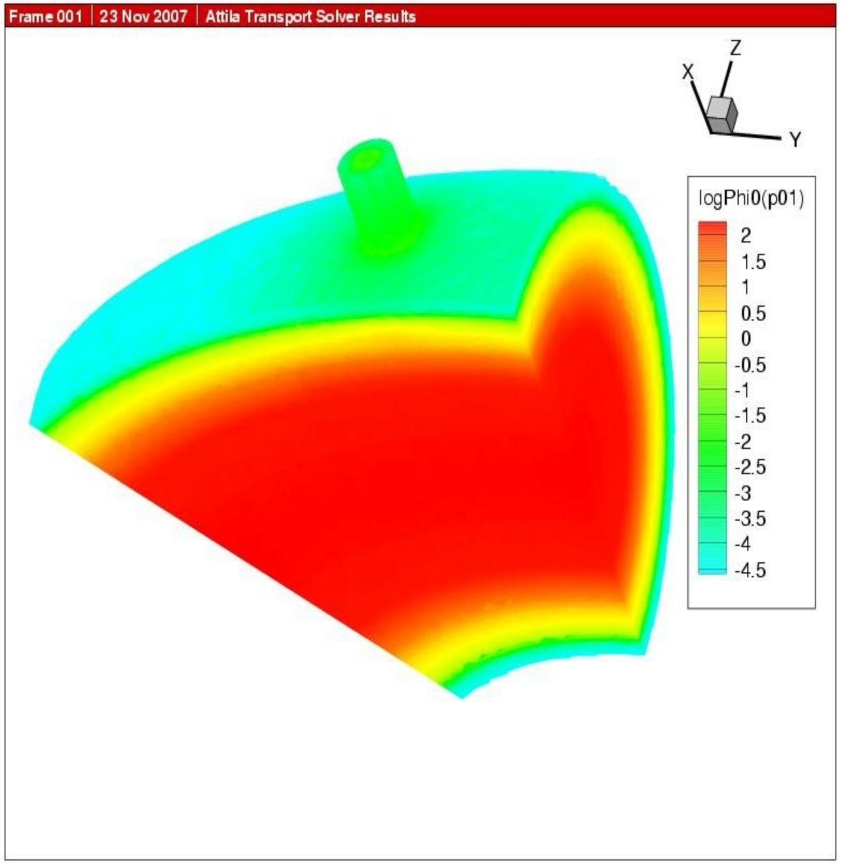


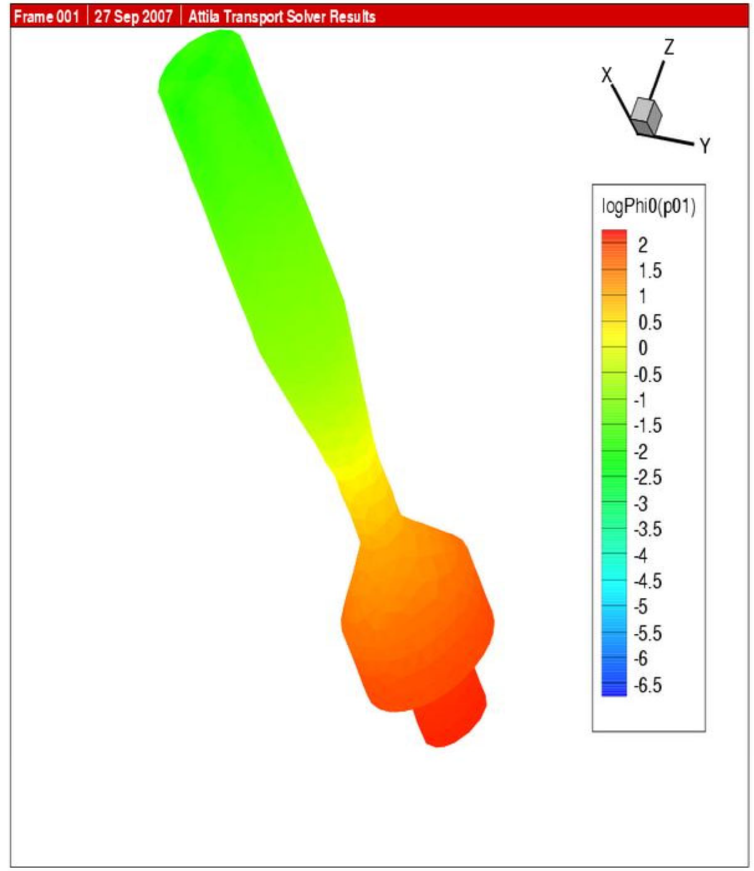
CAD model



Tetrahedral mesh representation (Attila)

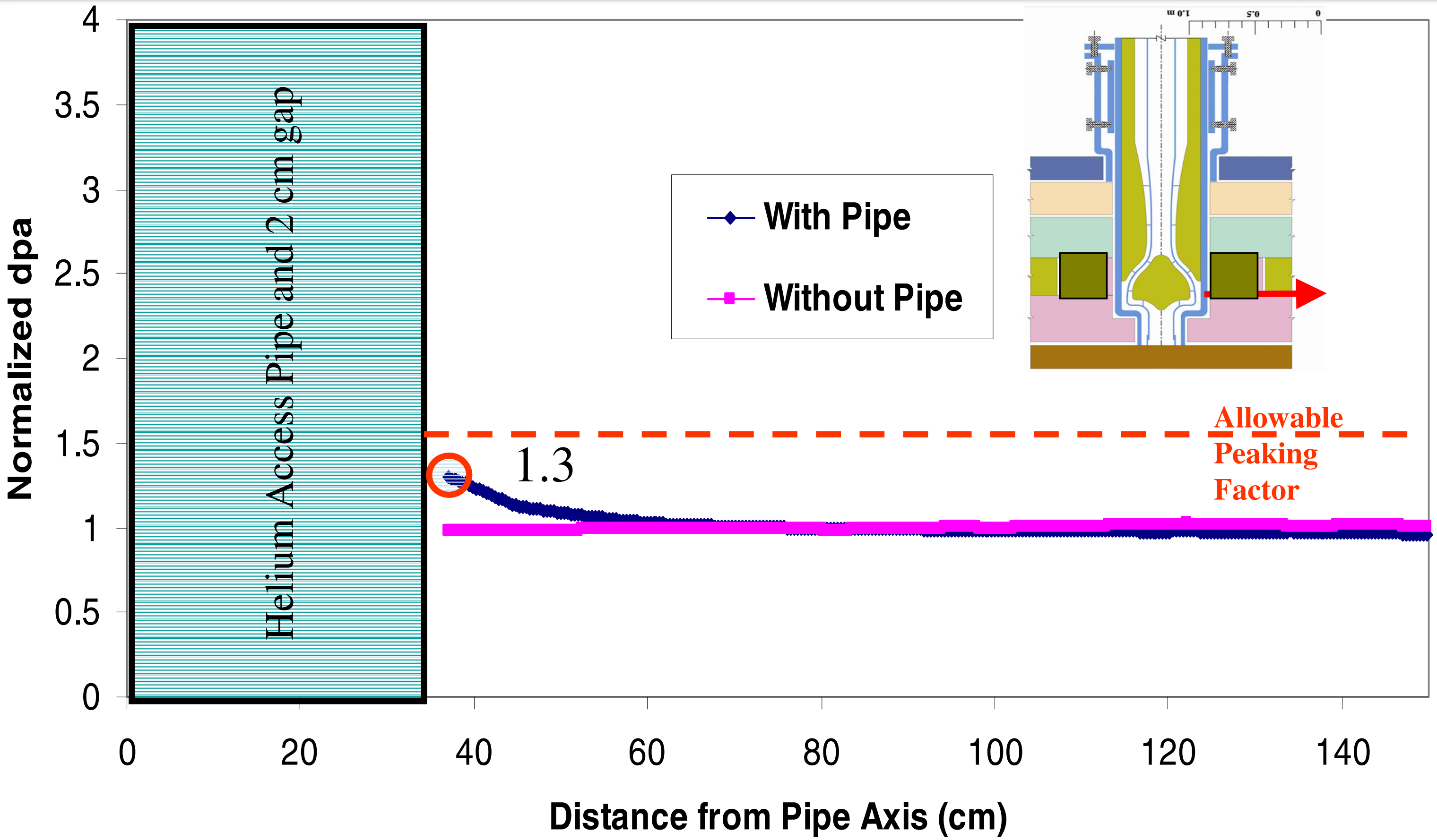
3-D Results: Neutron Flux Map





- Streaming causes 3-4 orders of magnitude increase in flux behind magnet.
- Shielding plug attenuates flux by a factor of 20.

3-D Results: Shield

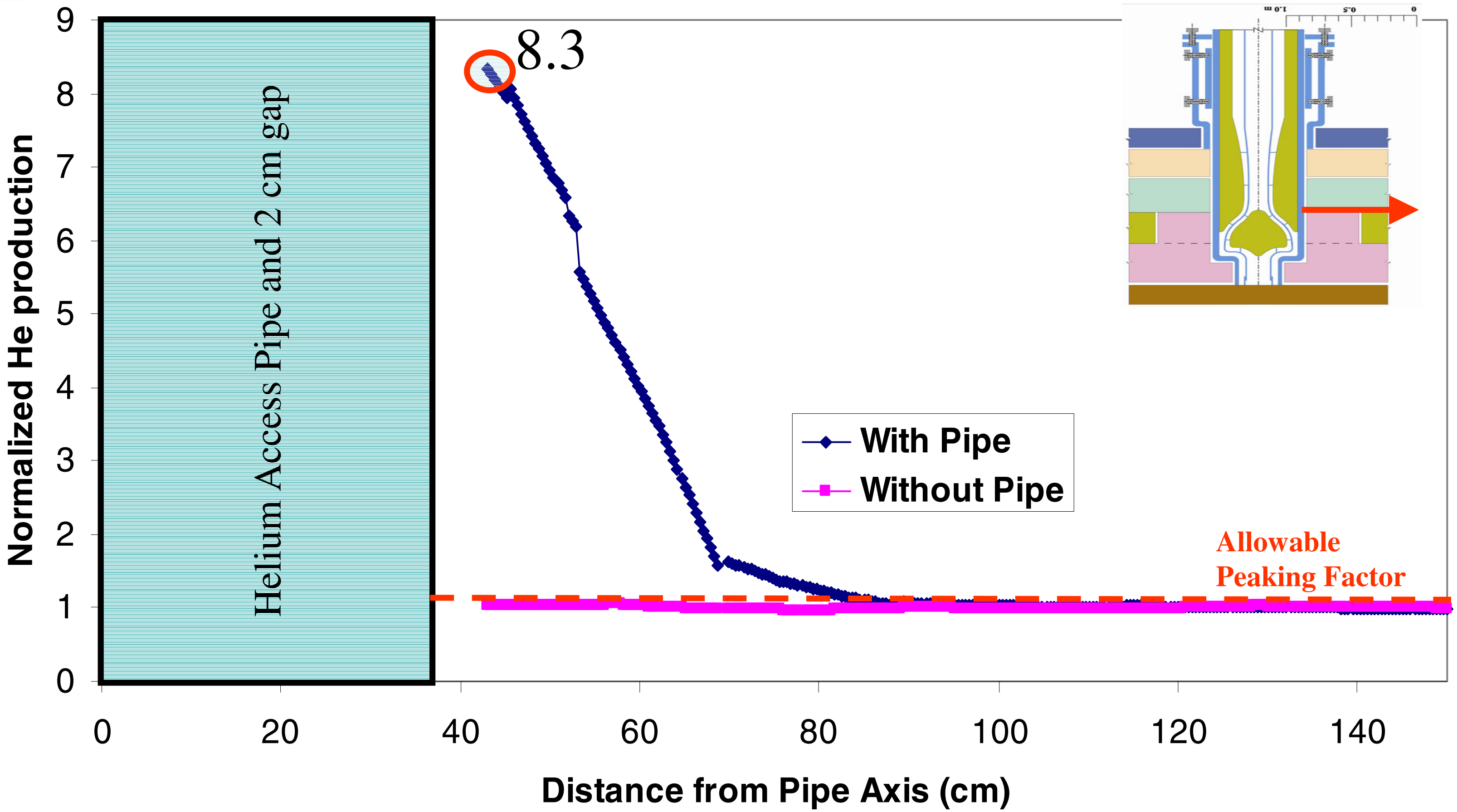


Peaking Factor = 1.3 ⇒ ~ (< 200 dpa limit)

⇒ Bulk shield is permanent component

⇒ No need for blanket/shield extension.

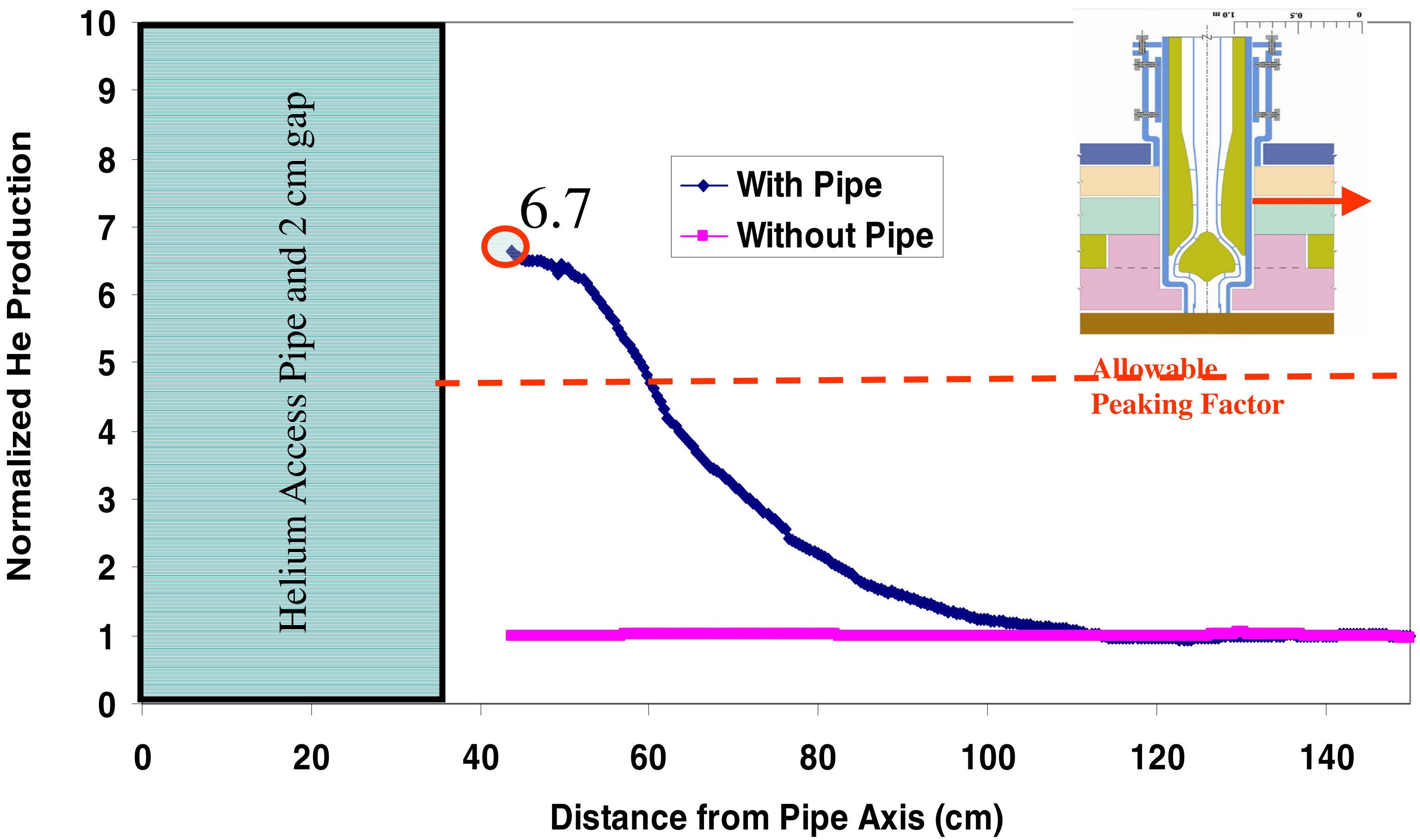
3-D results: Manifold



Peaking Factor = 8.3 $\Rightarrow$ ~ 8 He appm @ 40 FPY (> 1 appm limit)

$\Rightarrow$ Avoid rewelding 40 cm thick manifolds surrounding pipe

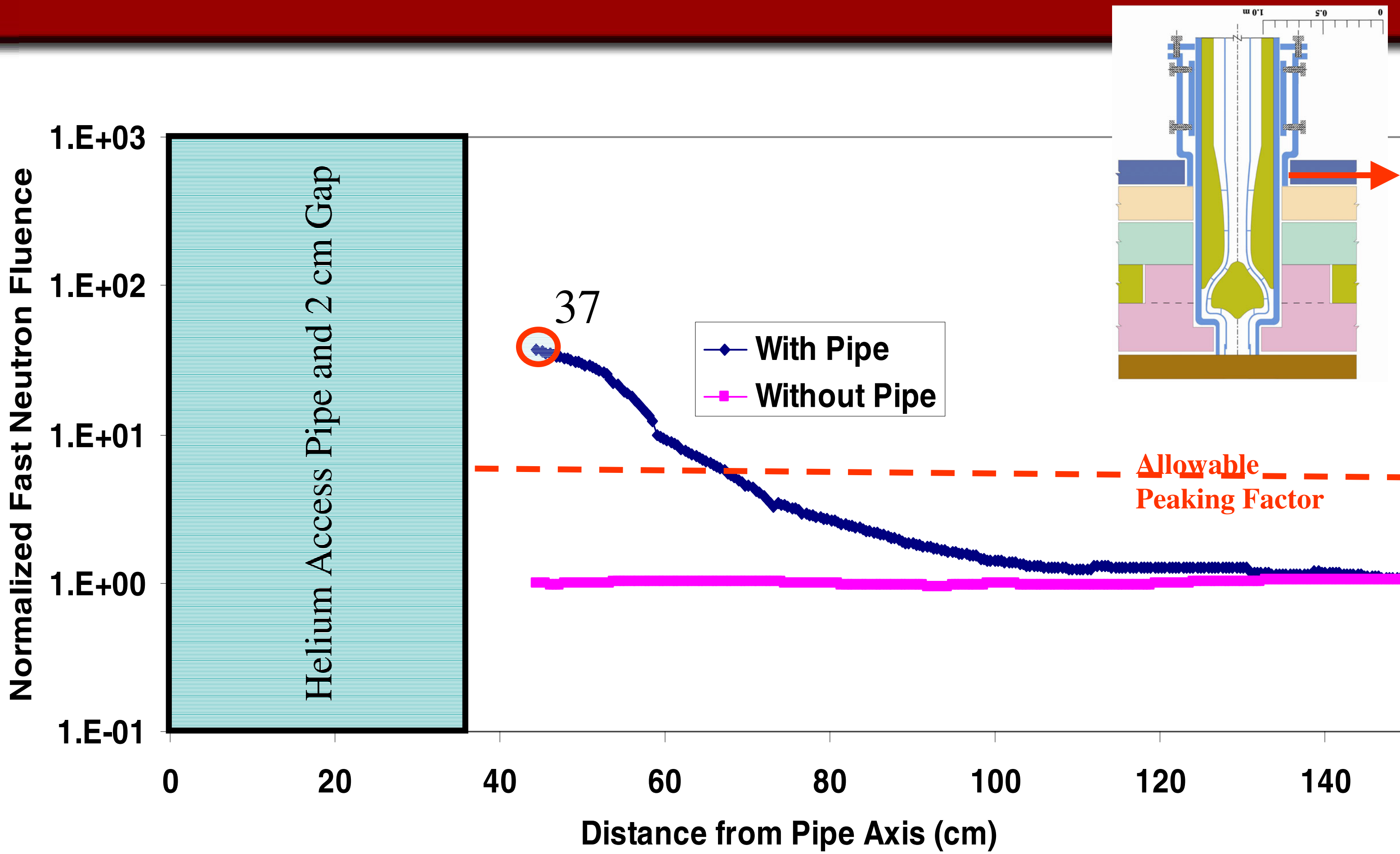
3-D Results: VV



Peaking Factor = 6.7 ⇒ ~ 1.3 He appm @ 40 FPY (> 1 appm limit)

⇒ Avoid rewelding 20 cm thick VV surrounding pipe

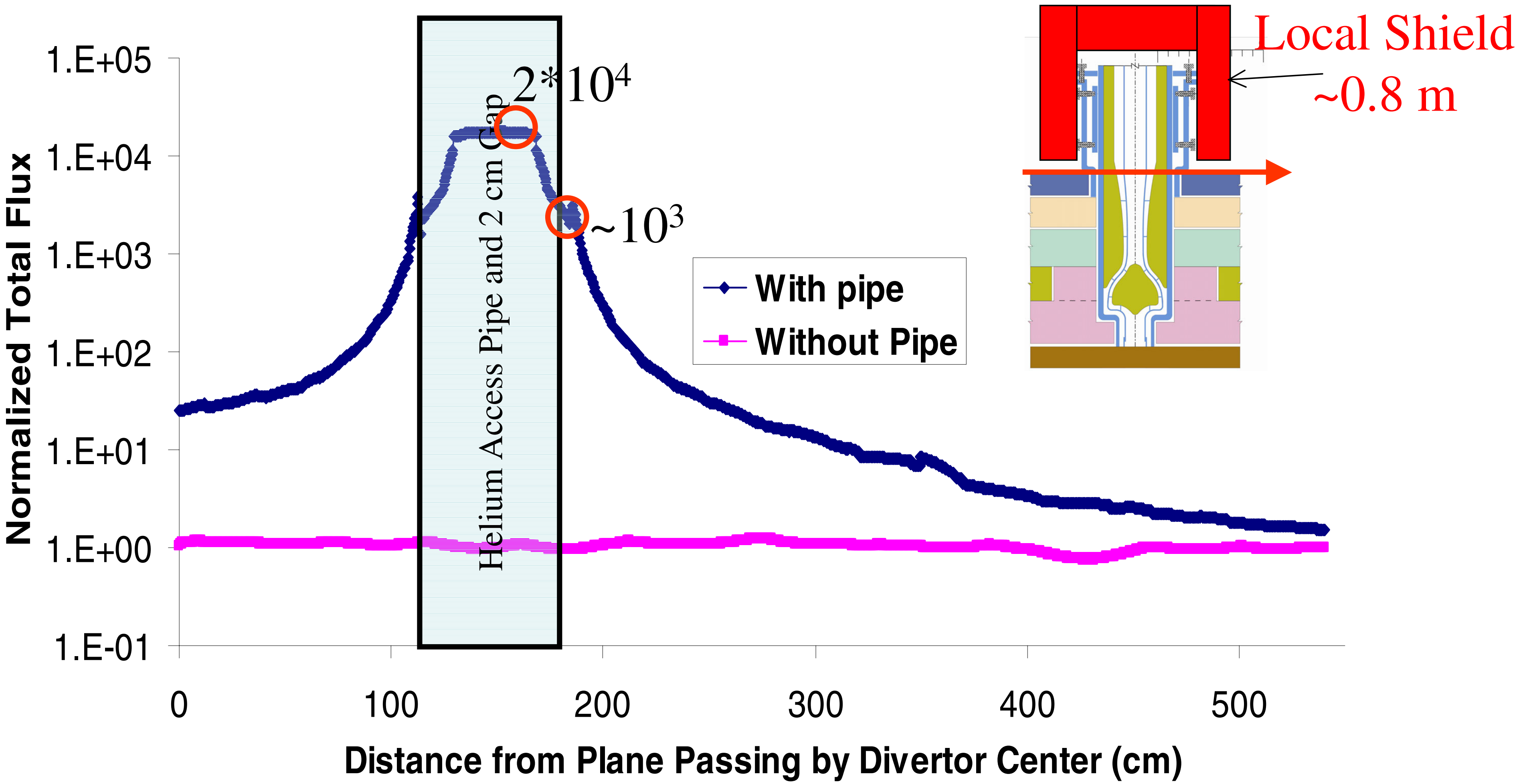
3-D Results: Magnet



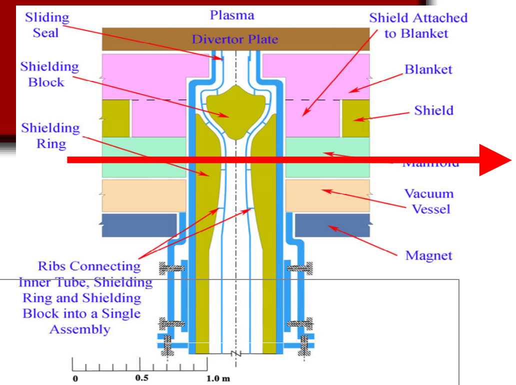
Peaking Factor = 37 $\Rightarrow$ ~ 9 x 10^{19} n/cm^2 @ 40 FPY (> 10^{19} n/cm^2 limit)

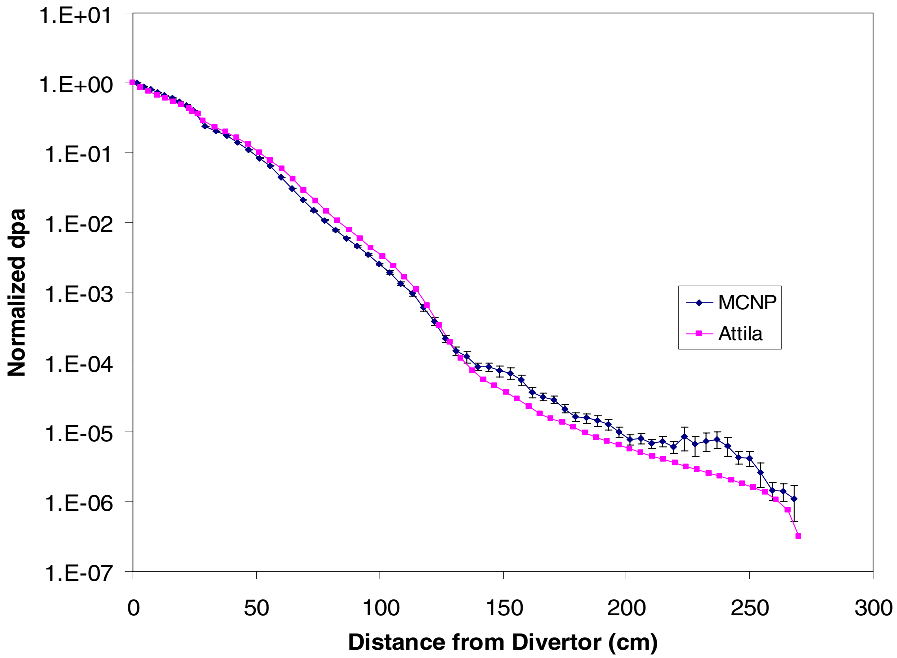
$\Rightarrow$ Winding pack should be placed 40 cm away from pipe

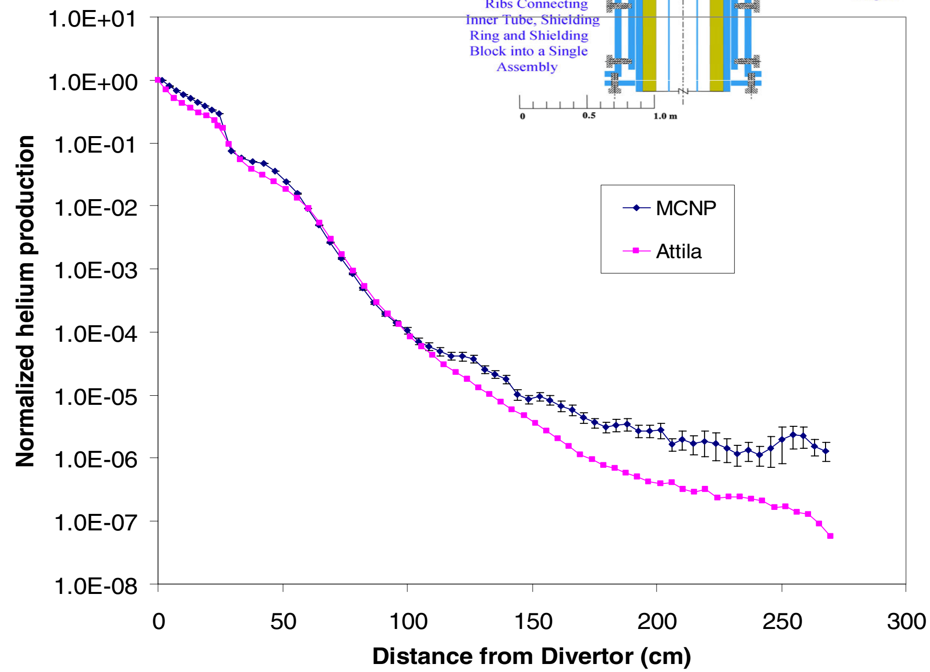
3-D Results: Magnet



3-D Results: Pipe







- Pipe wall lifetime ~ 4.5 FPY, exceeding divertor lifetime (3 FPY)
- Front 60 cm of pipe wall is not reweldable after 3 FPY and should be replaced with divertor
- Damage to screws (at ~2 m) is negligible

Conclusions

- **3-D results indicate**:
  - No need for blanket/shield extension.
  - Helium production at manifolds and VV exceeds reweldability limit by 2-8 fold

    $\Rightarrow$ avoid rewelding within 20-40 cm from pipe.
  - Winding pack should be placed at least 40 cm from pipe.
  - Front 60-120 cm of pipe wall is not reweldable and should be replaced along with divertor system every 3 FPY.
  - Neutron-induced swelling in screws is negligible (< 0.05%).

- Neutron flux behind pipe is excessive, calling for 60-80 cm thick local shield to protect externals.

- Neutron attenuation through shielding plug and inserts is not sufficient to eliminate streaming problems entirely.

Recommendations

- Future studies could develop more effective scheme(s) to attenuate streaming neutrons and reduce flux outside pipes. For example, simple pipe with smaller diameter (< 60 cm) and several right-angle bends represents a better approach, eliminating the need for massive shielding plug and inserts (170 tons for 24 pipes of ARIES-CS).

Questions

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