



Neutron Streaming Through Divertor He-Access Pipes: 3-D Assessment and Recommendations

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ARIES-Pathways Project Meeting

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Georgia Tech

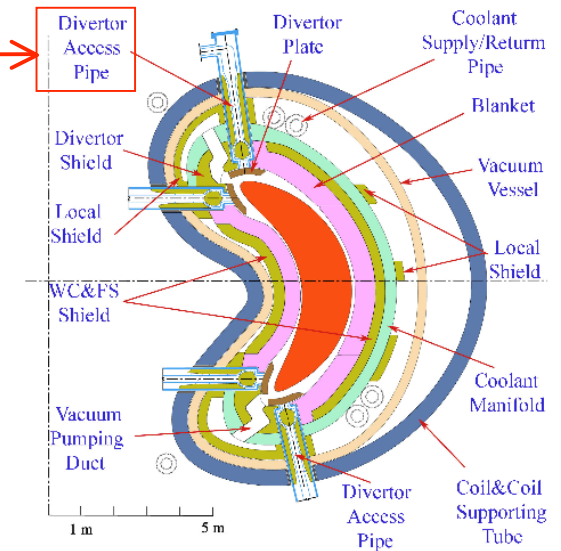
Background

- **Radial builds** and radiation levels are normally defined for perfect geometry without penetrations.
- **Penetrations** are necessary for vacuum pumping, coolant supply lines, plasma control, and maintenance ports.
- Such penetrations **compromise shielding performance** as streaming neutrons:
 - Enhance damage at surrounding components (shield, manifolds, VV, and magnet)
 - Increase flux and dose levels behind magnet.
- Unlike liquid-cooled system, **He coolant tubes/pipes** raise streaming concerns.
- Designing **penetration shields** for He system represents challenging task.
- **Example:** **ARIES-CS** dual-cooled LiPb/He/FS design.
- Results applicable to **ARIES-AT with DCLL system**.

ARIES-CS Penetrations

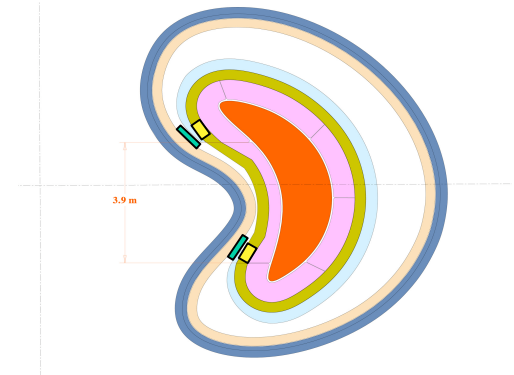
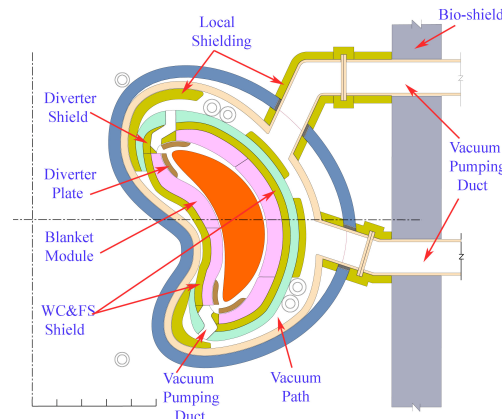
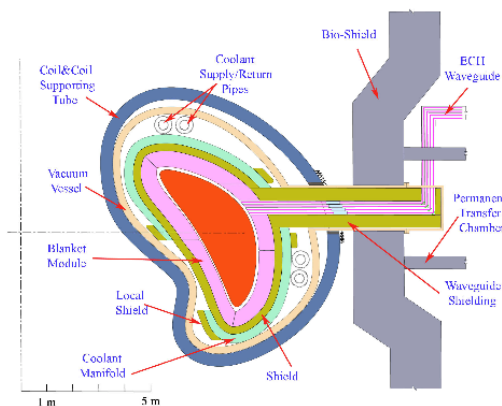
- Eight types of penetrations:**

- 198 He tubes for blanket (32 cm inner diameter (ID))
- **24 Divertor He access pipes (30-60 cm ID)**
- 30 Divertor pumping ducts (42 x 120 cm each)
- 12 Large pumping ducts (1 x 1.25 m each)
- 3 ECH ducts (24 x 54 cm each).
- 6 main He pipes connecting HX to blanket and shield (72 cm ID each)
- 6 main He pipes connecting HX to divertor (70 cm ID each)
- 4 access holes (3 cm diameter) for each blanket module.



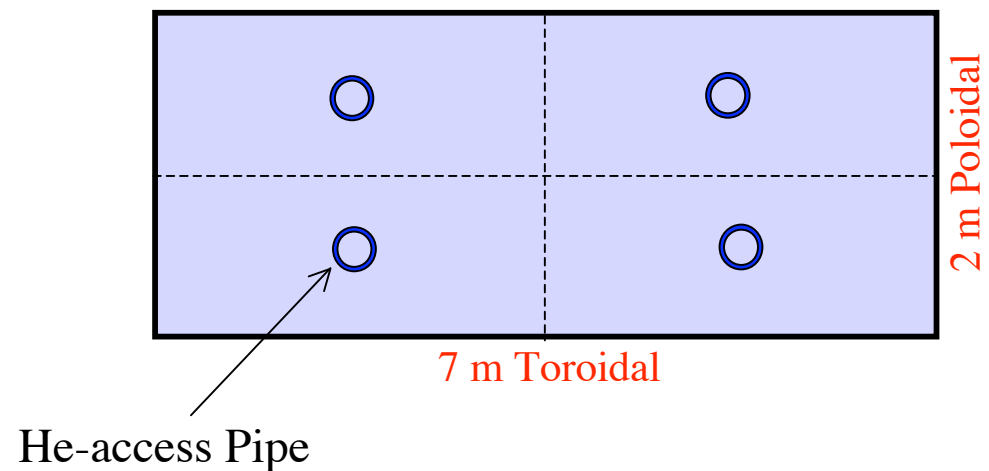
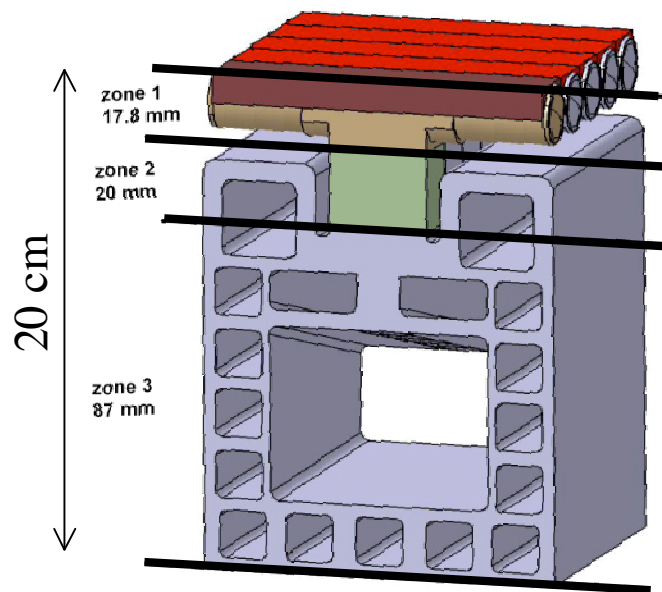
- Potential solutions:**

- Local shield behind penetrations
- He tube axis oriented toward lower neutron source
- Penetration shield surrounding ducts
- Replaceable shield close to penetrations
- Avoid rewelding of manifolds and VV close to penetrations
- Several bends along penetration lines.



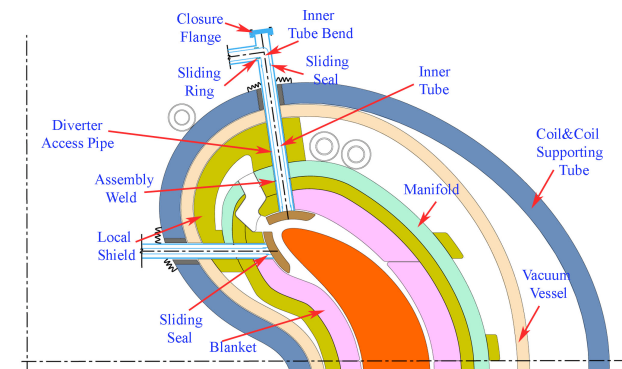
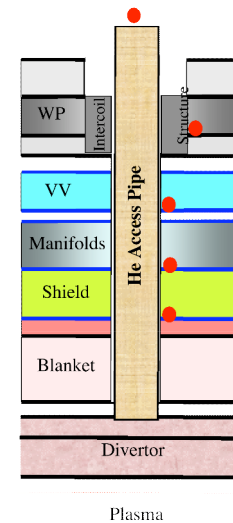
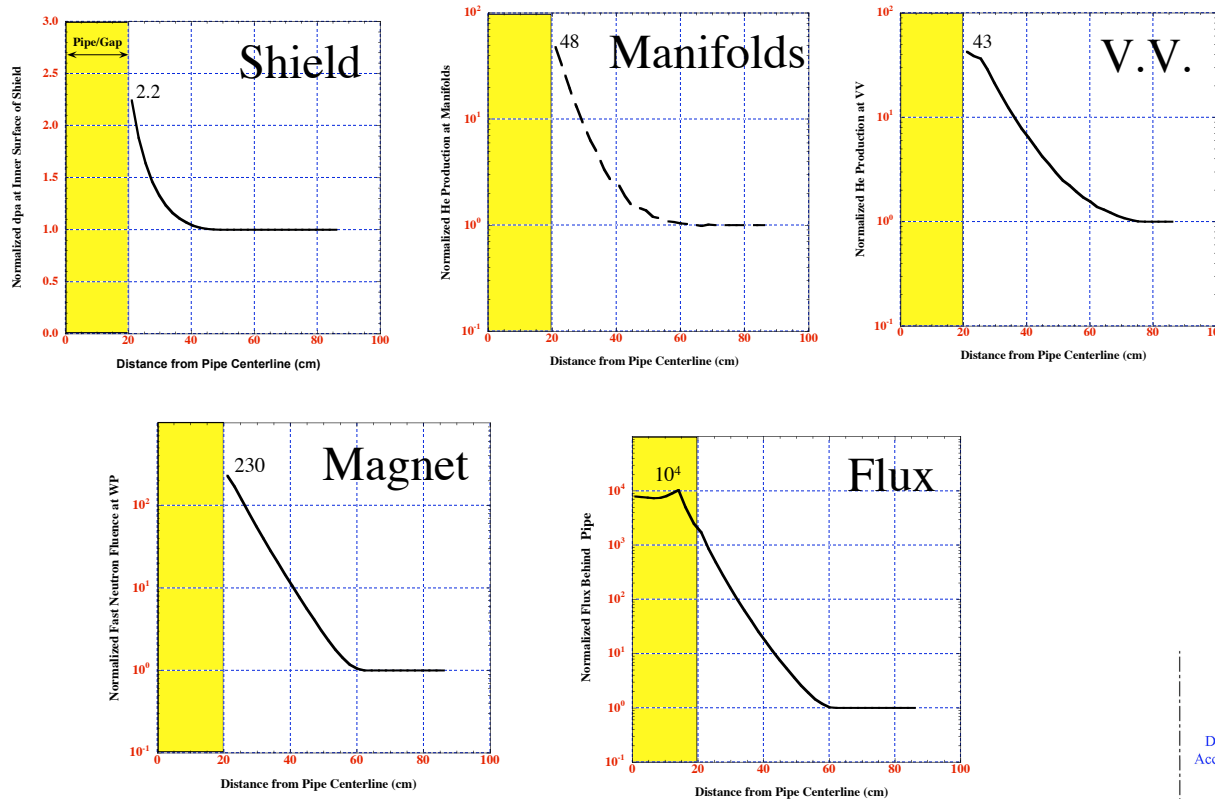
ARIES-CS Divertor System

Layout of Divertor System



- 2 divertor systems per field period
- 4 He-access pipes for each divertor system
- 24 He-access pipes in 3 FP of ARIES-CS

Preliminary 2-D Analysis Indicated Streaming Problems for He-Access Pipes (Simple Pipe with 30 cm ID)

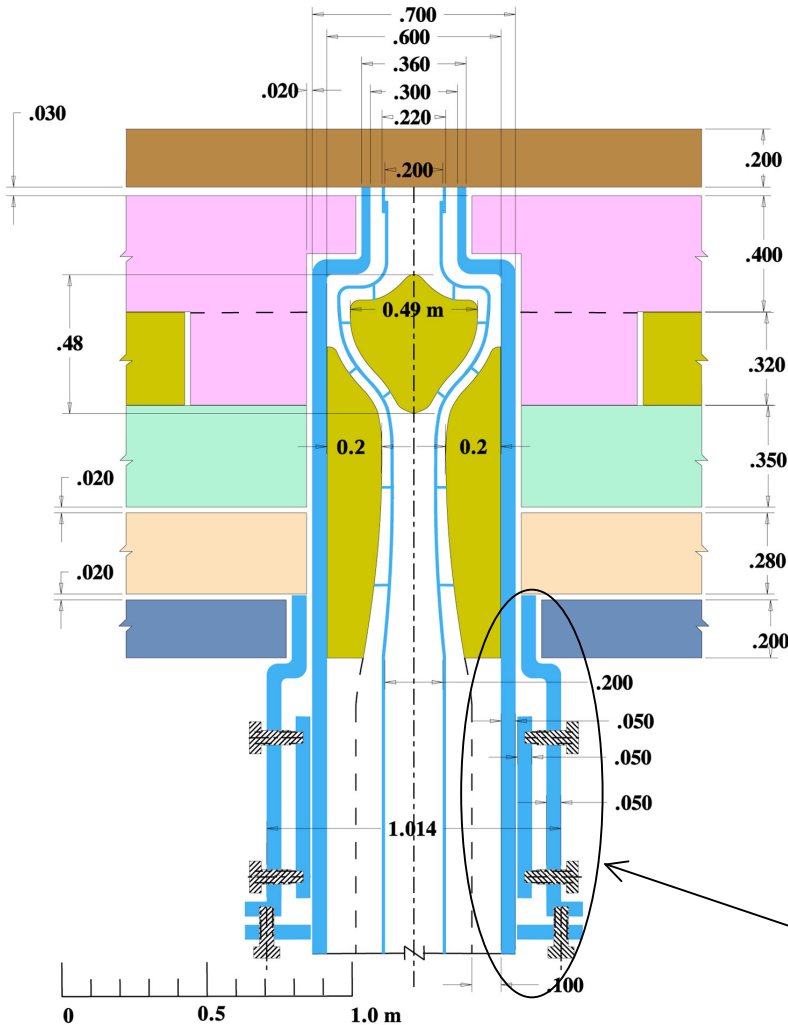


• Streaming problems:

- Shield surrounding pipe is not life-of-plant component
- Manifolds and VV close to pipe are not reweldable
- Winding pack should be 30-40 cm from pipe
- Inner part of pipe wall should be replaceable
- Pipe wall not reweldable
- Flux at end of pipe is excessive $\Rightarrow$ protect externals with local shields.



Selected Design for Streaming Analysis



WC Shielding Plug and Inserts

	1 Pipe	24 Pipes
Volume (m³)	0.05+0.4	11
Mass (tons)	7	170*

* 3 times total divertor mass (54 Tons).

Could this structure support 9-10 tons?
How to attach to VV?

3-D Neutronics Model

Purpose:

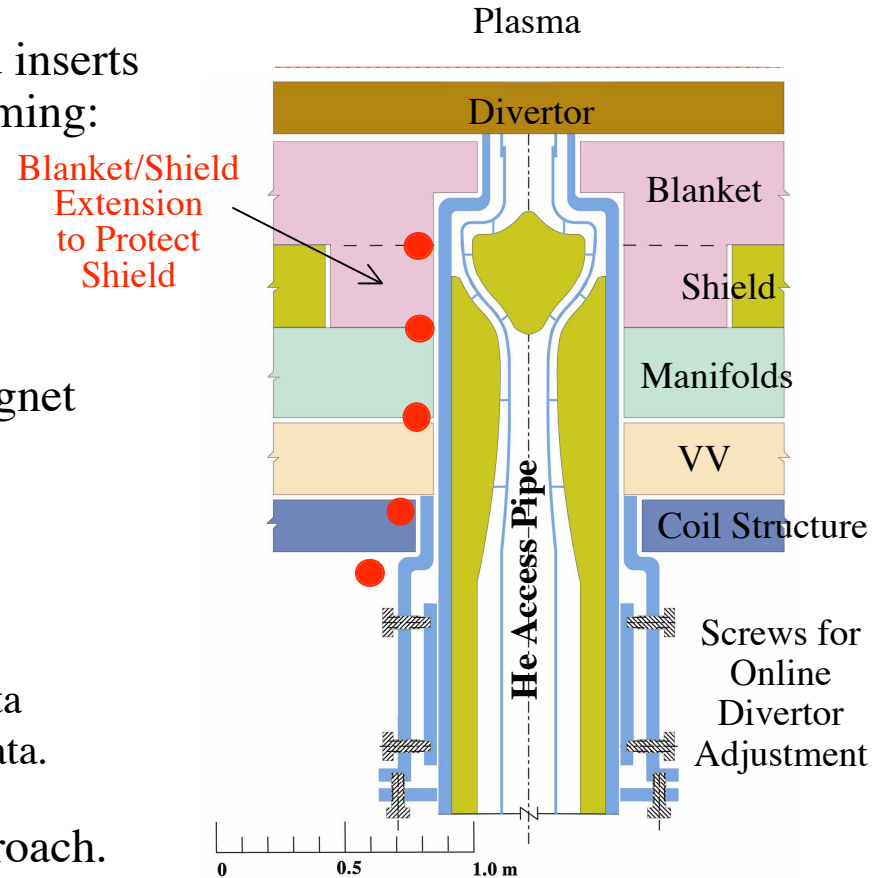
- Examine effectiveness of shield plug and inserts
- Estimate peaking in damage due to streaming:
 - dpa at shield
 - He production at manifolds
 - He production at VV
 - Fast neutron fluence at winding pack
 - dpa & He production along pipe wall
- Assess radiation environment behind magnet due to streaming.

Peak NWL @ divertor $\sim 2.7 \text{ MW/m}^2$.

3-D codes: Attila: discrete ordinates; 46 n + 21 γ group structure, FENDL-2.1 data
MCNPX: Monte Carlo; FENDL-2.1 data.

Direct **CAD/Attila and MCNPX** coupling approach.

Dimensions and compositions based on reference radial build: <http://fti.neep.wisc.edu/aries-cs/builds/build.html>



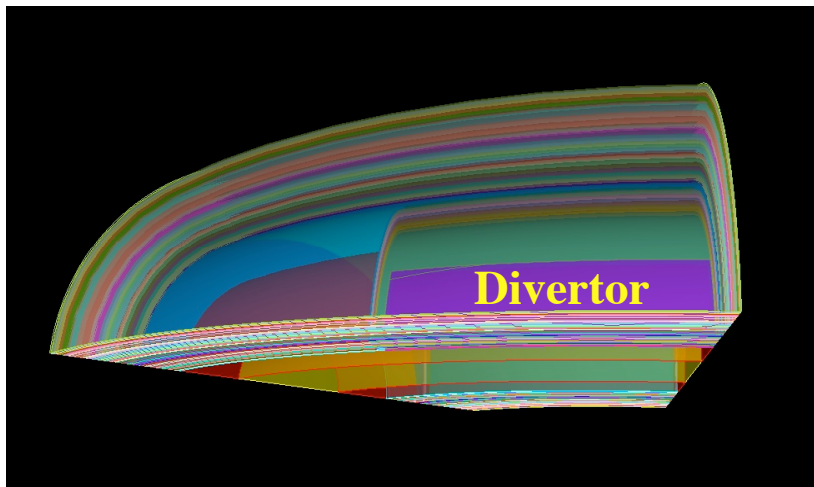


3-D Neutronics Model (Cont.)

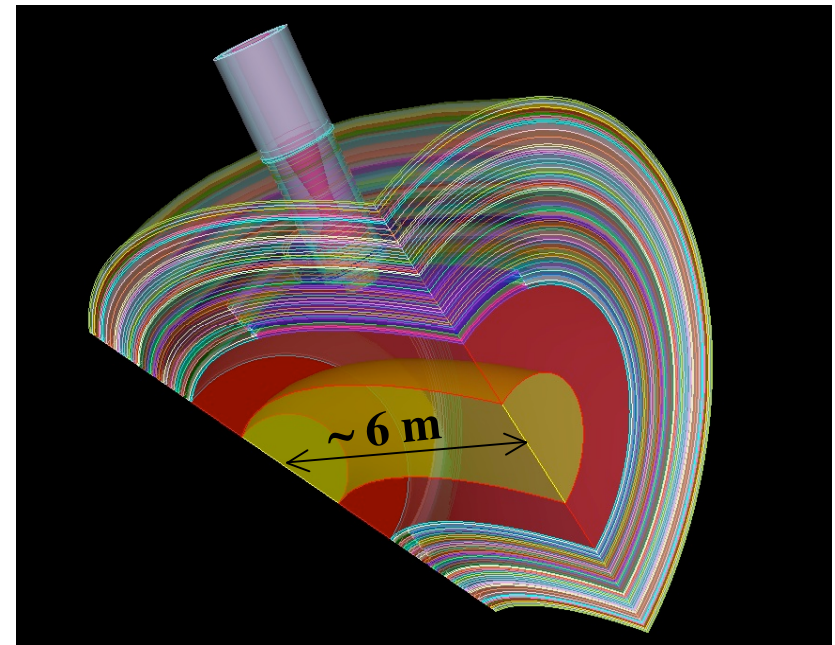
Peaking Factor due to streaming calculated by Attila/MCNPX codes relative to nominal values (away from pipe).

	Nominal Values	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)	0.2x10 ¹⁹	1x10 ¹⁹	5

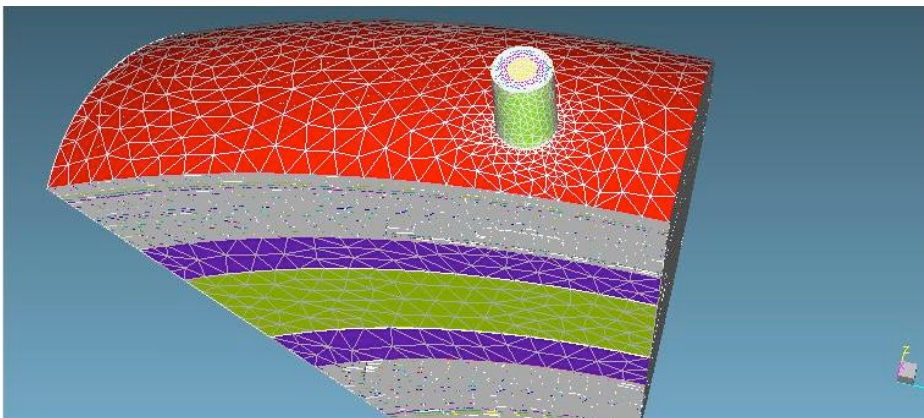
3-D Attila Model



1/4 Model of Divertor System w/o Pipe
in 45° Torus

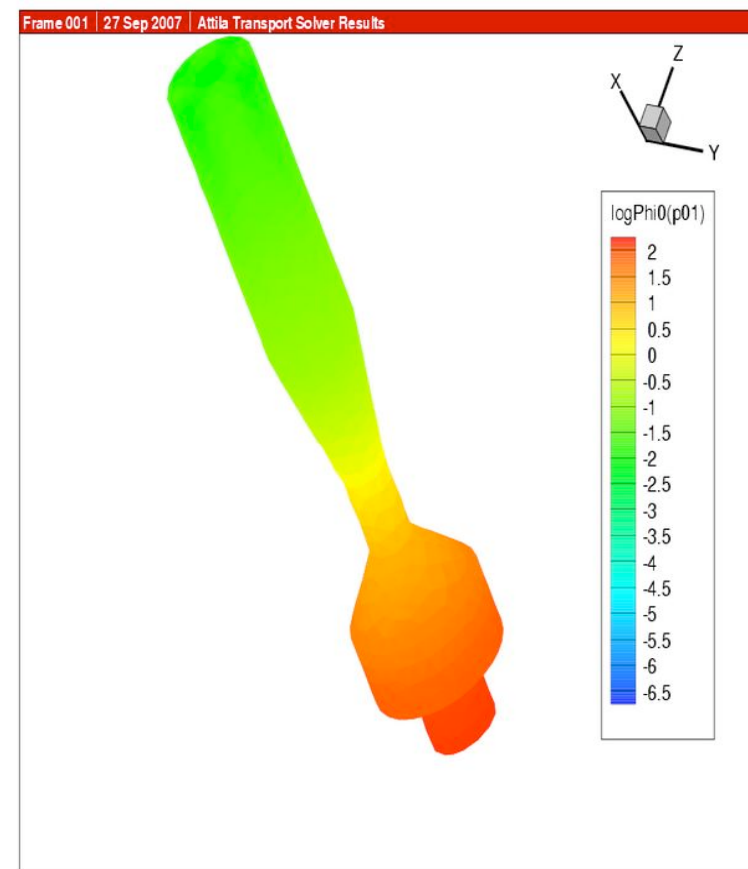
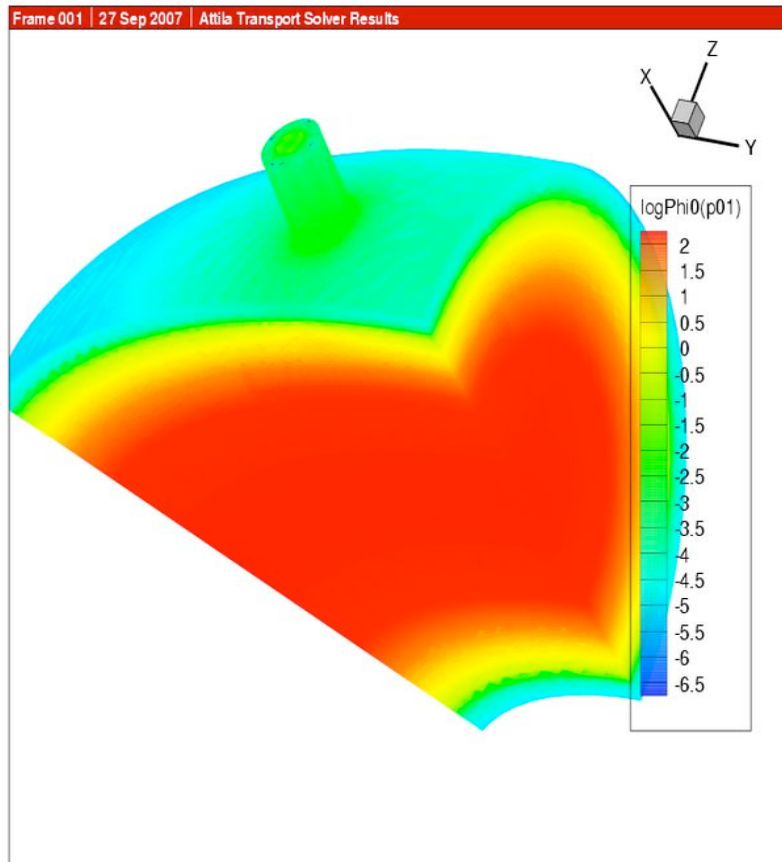


1/4 model of Divertor System w/ Pipe
in 45° Torus



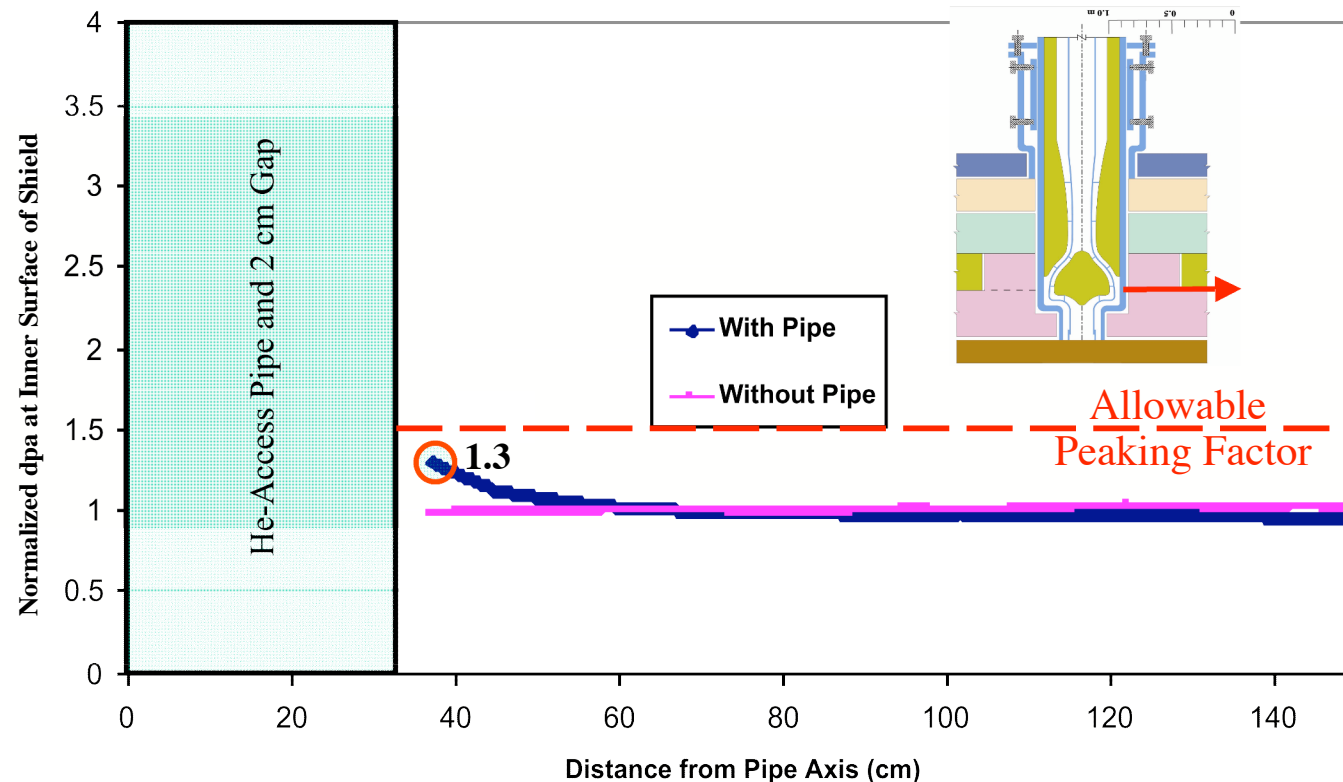
Tetrahedral mesh
representation

Attila Results: Neutron Flux Map (Relative values; Log scale)



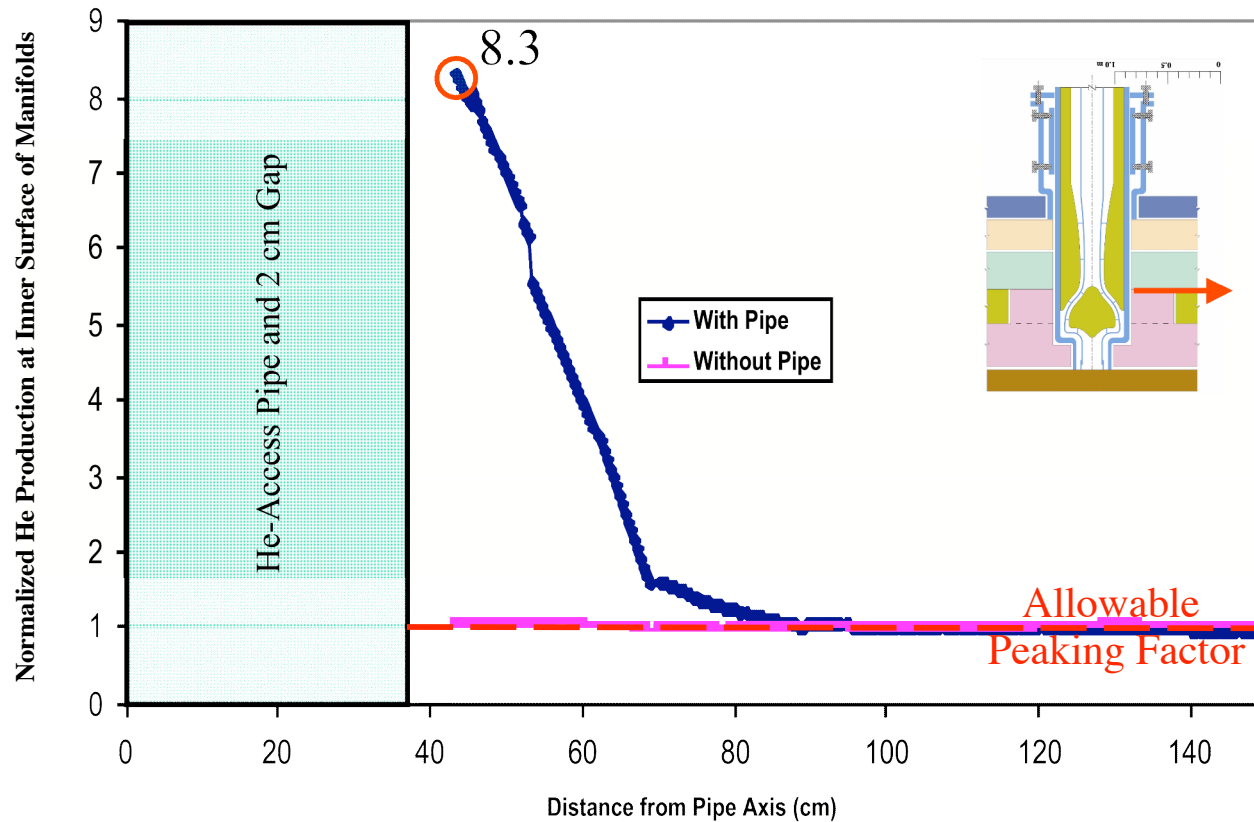
- Streaming causes 3-4 orders of magnitude increase in flux behind magnet.
- Shielding plug attenuates flux by 20 fold.

Shield Plug Helps Protect Bulk Shield



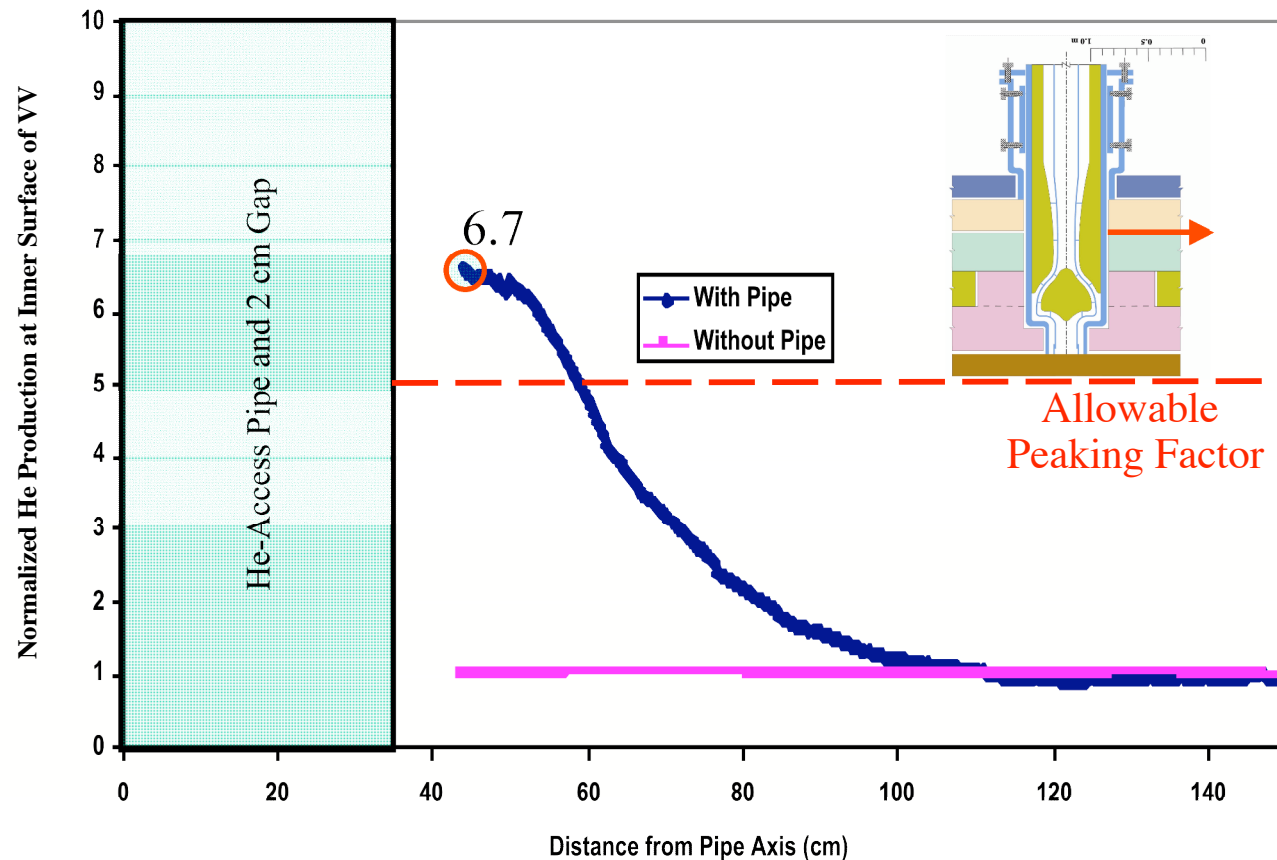
Peaking Factor = 1.3 $\Rightarrow$ ~ 175 dpa @ 40 FPY (< 200 dpa limit)
 $\Rightarrow$ Bulk shield is permanent component
 $\Rightarrow$ No need for blanket/shield extension.

Part of Manifolds Surrounding Pipe Cannot be Rewelded after 0.5 FPY



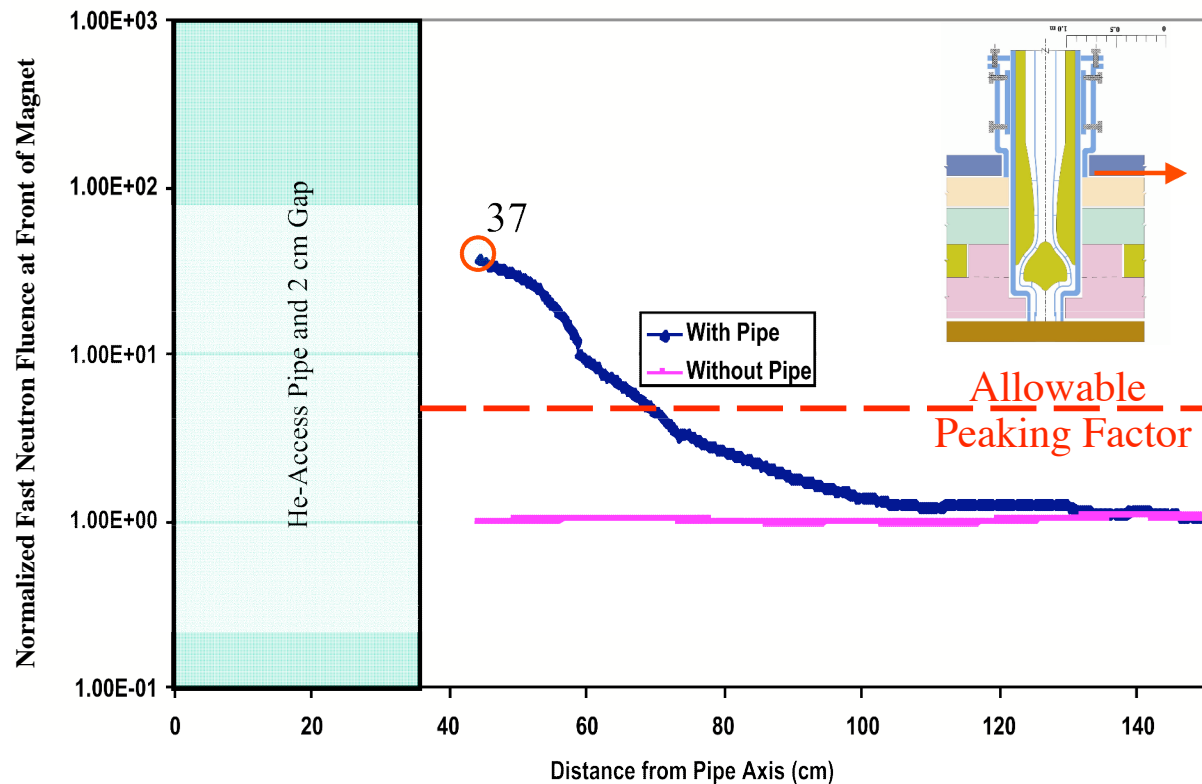
Peaking Factor = 8.3 $\Rightarrow$ ~ 8 He appm @ 40 FPY (> 1 appm limit)
 $\Rightarrow$ Avoid rewelding 40 cm thick manifolds surrounding pipe

Part of VV Surrounding Pipe Cannot be Rewelded after 30 FPY



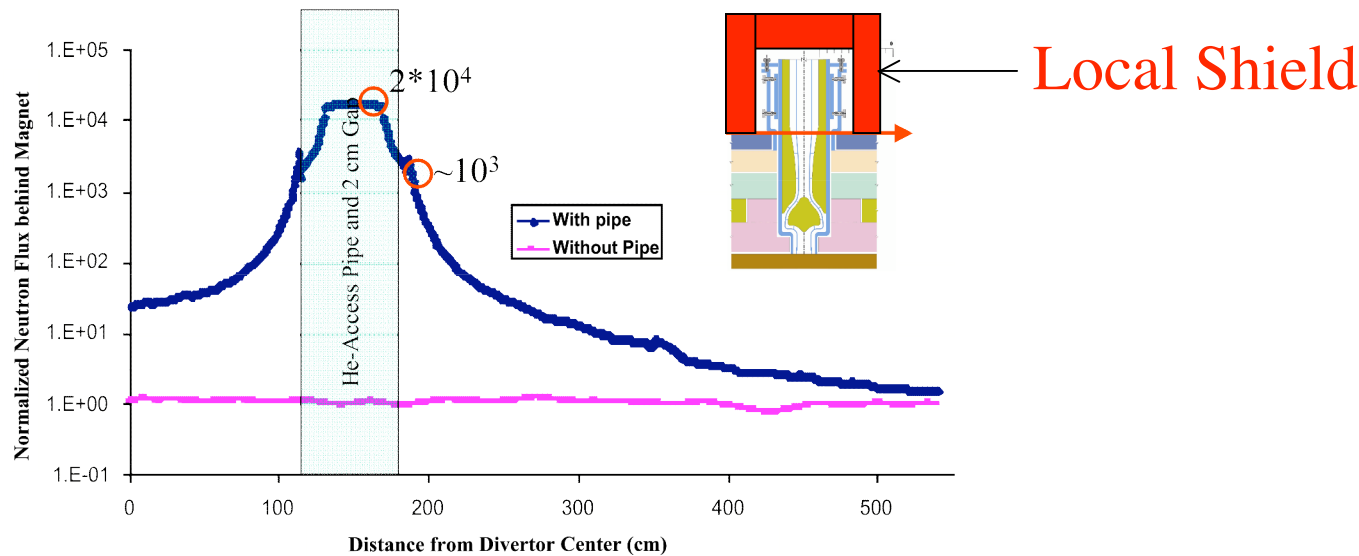
Peaking Factor = 6.7 $\Rightarrow$ ~ 1.3 He appm @ 40 FPY (> 1 appm limit)
 $\Rightarrow$ Avoid rewelding 20 cm thick VV surrounding pipe

40 cm Inter-coil Structure around Pipe Helps Protect Winding Pack



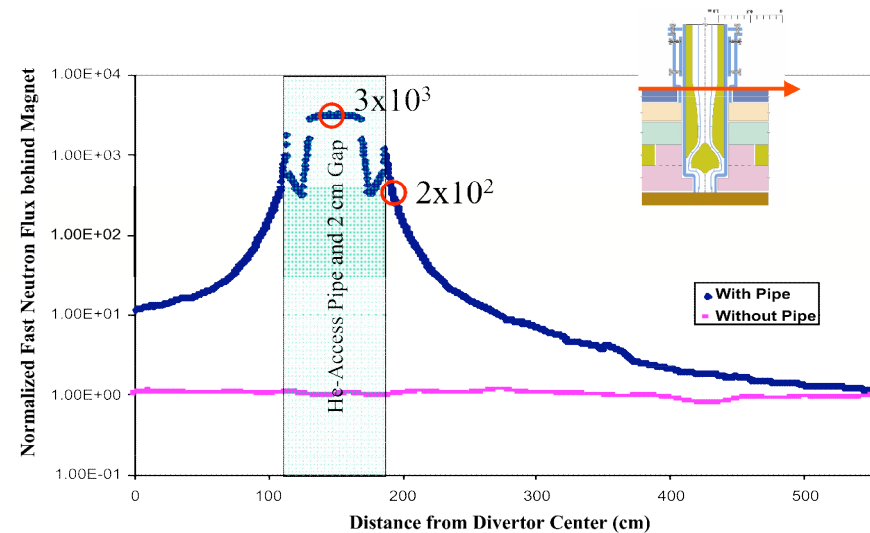
Peaking Factor = 37 $\Rightarrow \sim 9 \times 10^{19} \text{ n/cm}^2 \text{ @ } 40 \text{ FPY}$ ($> 10^{19} \text{ n/cm}^2$ limit)
 $\Rightarrow$ Winding pack should be placed 40 cm away from pipe

Excessive Neutron Flux Behind Pipe Calls for Local Shield to Protect Externals

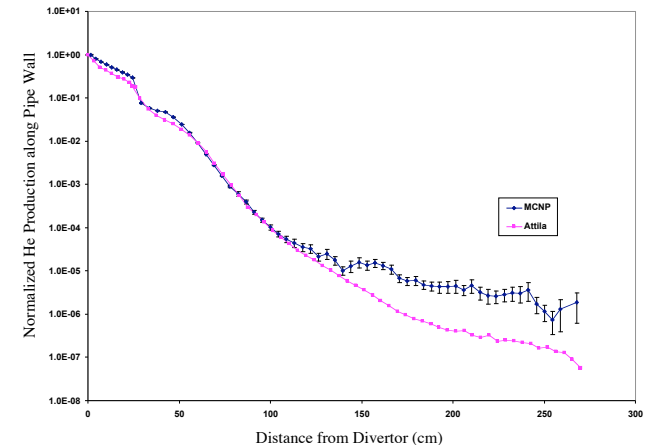
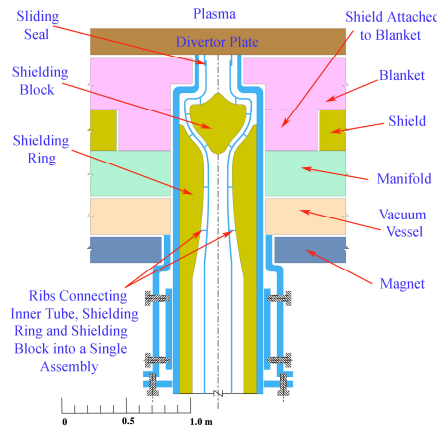
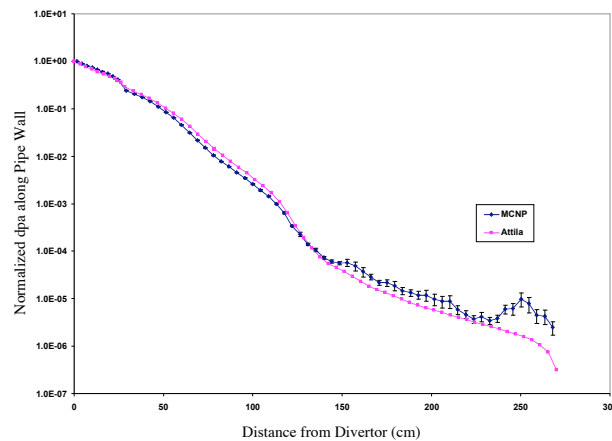


Behind magnet:

- High flux covers large area
- Around pipe, fast flux ($E_n > 0.1$ MeV) comprises 20% of total flux.



Damage to Pipe Wall and Screws



Pipe wall lifetime ~ 4.5 FPY,
exceeding divertor lifetime (3 FPY)

Damage to **screws** (at ~2 m) will not exceed
10 dpa @ 40 FPY
⇒ **< 0.05% n-induced swelling** at screws,
causing no problem, per Malang.

- Front **60 cm of pipe wall is not reweldable after 3 FPY** and should be replaced with divertor
- **End of pipe (> 120 cm) can be reused repeatedly during 40 FPY**
- Middle of pipe (60-120 cm) reaches 1 appm limit gradually at various times, ranging between 3 and 40 FPY.

Concluding Remarks and Recommendations

- **3-D results indicate:**
 - Bulk shield is well protected $\Rightarrow$ no need for blanket/shield extension
 - Peaking in damage is more pronounced at magnet than at shield
 - 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
 - Neutron-induced swelling in screws (that adjust divertor plates during operation) is negligible ($< 0.05\%$)
 - Front 60-120 cm of pipe wall is not reweldable and should be replaced along with divertor system every 3 FPY.
- Final ARIES-CS design accords with these recommendations.
- 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.
- 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).



Publications

- D. Henderson presented preliminary results at **SOFE** meeting - June 07, Albuquerque, NM.
- **UWFDM-1331** report published:
A. Ibrahim, D.L. Henderson, L. El-Guebaly, and P.P.H. Wilson,
“Analysis of Radiation Streaming Through ARIES-CS He-Access Pipes using Attila and DAG-MCNPX 3-D Neutronics Codes,”
University of Wisconsin Fusion Technology Institute Report,
UWFDM-1331 (Dec. 2007).
Available at: <http://fti.neep.wisc.edu/pdf/fdm1331.pdf>.
- Presentation will be given by A. Ibrahim at **2008 ANS Student Conference**, Feb 28 - March 1, 2008, College Station, TX.
- Abstract and full paper will be submitted to **18th TOFE**, October 08, San Francisco.