

# **Maintainability and Availability Analyses**

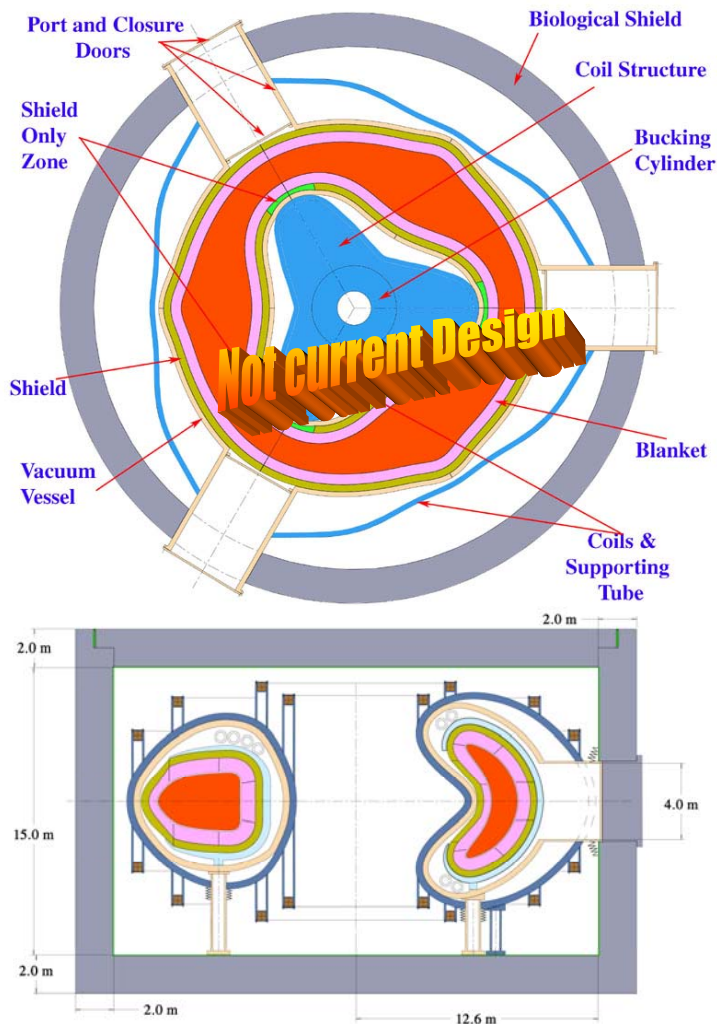
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**ARIES Meeting**  
**University of California, San Diego**  
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# **ARIES-CS Maintenance Approach**

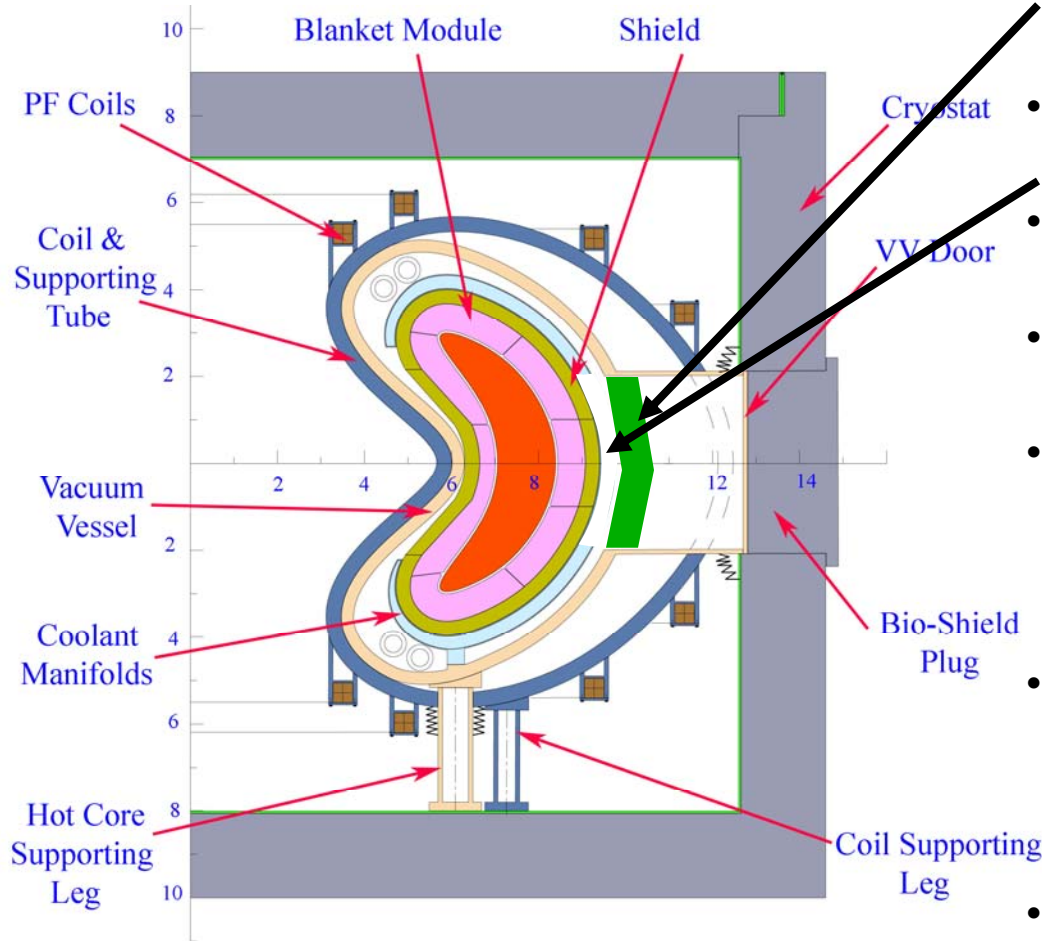
- **The Port Modular Maintenance Approach is preferred over the Field Period Approach**
- **At present, it does not appear to be a credible maintenance solution for the Field Period Approach**

# Maintenance Will Be Accomplished Through the Three Ports



- Ports are approximately 4 meters high and 1.9 meter wide, as limited by coil geometry and major radius
- The port height determines the poloidal segmentation (5 to 7 modules)
- The port width determines the toroidal segmentation (was 15° in the last meeting and will probably need to be 12°)
- This segmentation scheme creates about 60 modules per field period or about 180 total number of modules

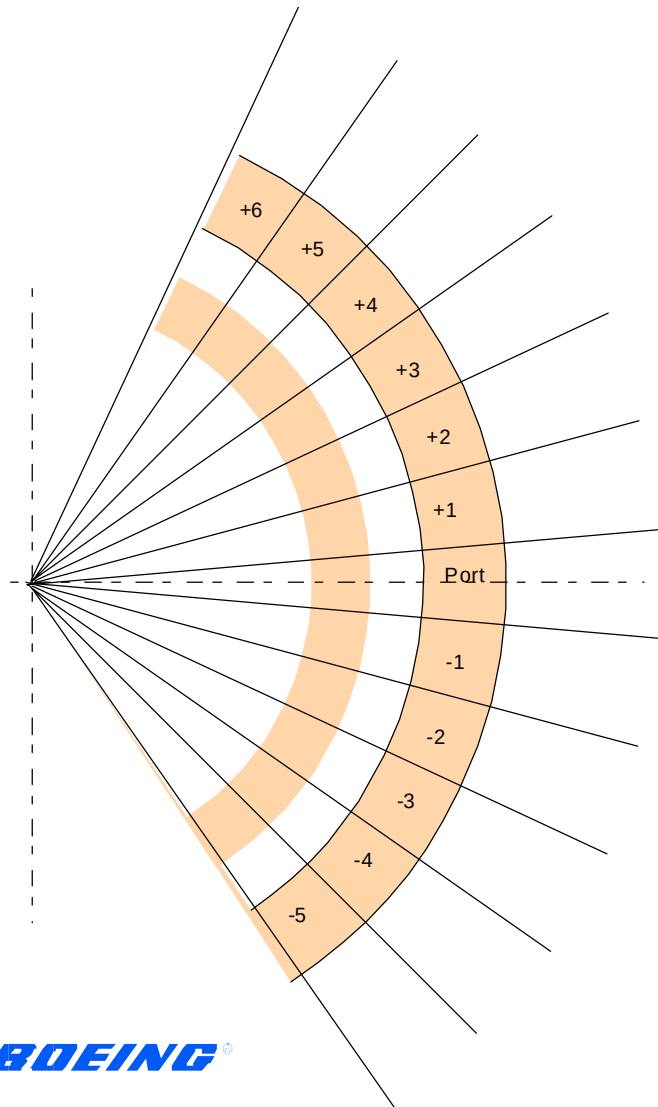
# Sequence of Blanket Removal



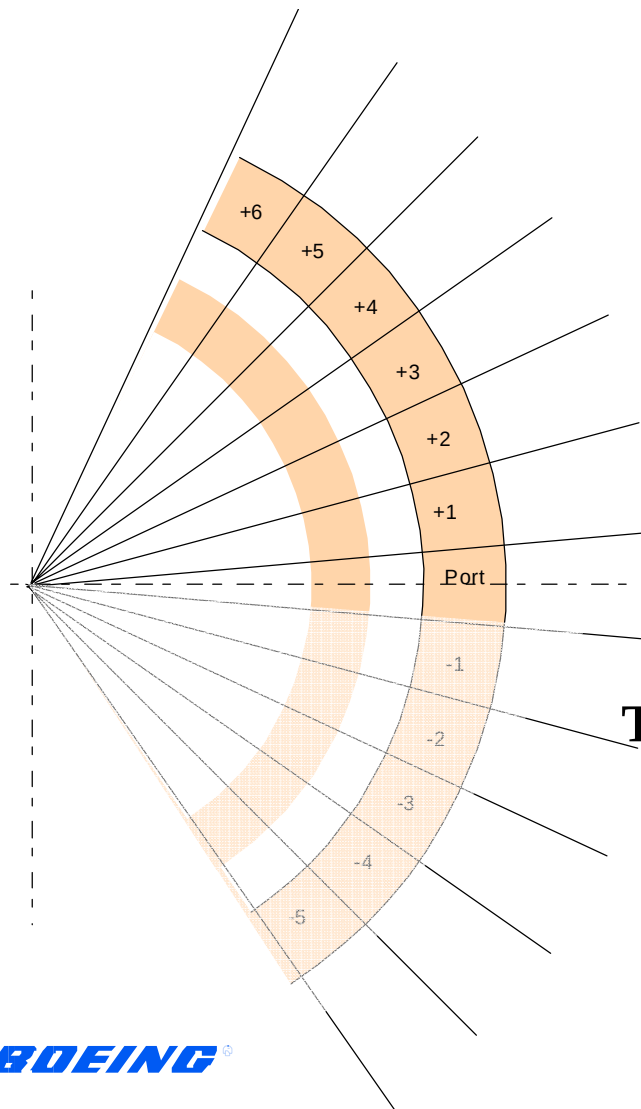
- Another shield plug is required inside the VV port to provide for missing shielding in the port
- There should not be any hot structure behind the port blanket module
- The port blanket and shield should be separate modules
- The size of the port module will have to be increased to port size
- After the removal of the Bioshield plug and port shielding, the port shield module is removed, followed by the port blanket module
- Then the remainder of the blanket modules within the port segment will be removed by separating from shield
- CAD definition will be utilized to determine clearances and removal sequence (not important for conceptual design.)

# Scheduled Replacement with Three Ports

- If 1/3 of the power core is replaced per 1.3 year (3.9 FPA), then one port would be exclusively used for maintenance on one field period. However, the other two ports could also be accessed at the same time to replace the other two field periods. This would result in a much higher overall average availability over the blanket lifetime. Full blanket replacement every 3.9 FPY.



# Scheduled Replacement with Three Ports (Cont.)



- Another strategy would be to replace one half the modules at a time at all the ports simultaneously removing the zero degree modules and all those on the right (or left). Then the zero degree modules would either be replaced with the same modules (if not at the end of life) or new modules. This is not quite a good availability due to the duplication of removal of the port modules. However it results in a maintenance period that is about  $\frac{1}{2}$  as long and twice as frequent. Half blanket replacement every 1.95 FPY.

The same number of maintenance equipment and people are needed in both scenarios. Because of the slightly better availability value, the first approach will be adopted.

# Estimated Maintenance Times

| Maintenance Action                               | Duration of Serial Operations, Hr | Subtotal for Set of Operations, hr | Duration of Parallel Operations, hr |
|--------------------------------------------------|-----------------------------------|------------------------------------|-------------------------------------|
| <b>Shutdown and preparation for maintenance</b>  |                                   |                                    |                                     |
| Cooldown of systems, afterheat decay             | 24.0                              |                                    |                                     |
| De-energize coils, keep cryogenic                |                                   |                                    | 2.0                                 |
| Pressurize power core with inert gas             |                                   |                                    | 2.0                                 |
| Drain Coolants, fill with inert gas              | 6.0                               |                                    |                                     |
| Open transfer chamber outer main isolation door  |                                   |                                    | 0.1                                 |
| Move maintenance machine into transfer chamber   |                                   |                                    | 0.2                                 |
| Close transfer chamber outer main isolation door |                                   |                                    | 0.1                                 |
|                                                  |                                   | 30.0                               |                                     |

These nominal values are multiplied by a productivity factor

**These times are consistent with ARIES  
RS and AT maintenance Analyses**

# Estimated Maintenance Times

| Maintenance Action                                                | Duration of Serial Operations, Hr | Subtotal for Set of Operations, hr | Duration of Parallel Operations, hr |
|-------------------------------------------------------------------|-----------------------------------|------------------------------------|-------------------------------------|
| <b>Removal Maintenance Tasks</b>                                  |                                   |                                    |                                     |
| Remove and set aside port bio shield door                         | 0.5                               |                                    |                                     |
| Disconnect vacuum seals around vacuum vessel door                 | 2.0                               |                                    |                                     |
| Remove and set aside vacuum vessel door                           | 0.3                               |                                    |                                     |
| Disconnect primary coolant plumbing connections                   |                                   |                                    |                                     |
| Introduce robotic cutting machine into plumbing system            |                                   |                                    | 0.2                                 |
| Move cutting machine into position at first removable joint       |                                   |                                    | 0.4                                 |
| Cut plumbing joint for revmoval of port shield                    |                                   |                                    | 0.2                                 |
| Continue cutting for blanket removal (in parallel with removal)   |                                   |                                    | as required                         |
|                                                                   |                                   | 2.8                                |                                     |
| Move Maint Machine into port postion and secure                   | 0.1                               |                                    |                                     |
| Move boom forward and position over shield for blanket module     | 0.1                               |                                    |                                     |
| Disengage shield for port blanket module                          | 0.2                               |                                    |                                     |
| Retract boom with shield for port blanket module                  | 0.2                               |                                    |                                     |
| Retract Maint Machine into transfer chamber with shield module    | 0.1                               |                                    |                                     |
| Place shield module into transfer airlock and close airlock       | 0.1                               |                                    |                                     |
|                                                                   |                                   | 0.8                                |                                     |
| Move Maint Machine into port postion and secure                   | 0.1                               |                                    |                                     |
| Move boom forward and position over back of blanket module        | 0.1                               |                                    |                                     |
| Disengage first blanket module                                    | 0.2                               |                                    |                                     |
| Retract boom with port blanket module                             | 0.2                               |                                    |                                     |
| Retract Maint Machine into transfer chamber with blanket module   | 0.1                               |                                    |                                     |
| Place blanket module into transfer airlock and close airlock      | 0.1                               |                                    |                                     |
| May need to remove additional shields for access                  |                                   | 0.8                                |                                     |
| Move Maint Machine into port postion and secure                   | 0.1                               |                                    |                                     |
| Move boom forward and position over blanket module inside chamber | 0.2                               |                                    |                                     |
| Disengage blanket module to be replaced                           | 0.2                               |                                    |                                     |
| Retract boom with removed blanket module                          | 0.2                               |                                    |                                     |
| Retract Maint Machine into transfer chamber with blanket module   | 0.1                               |                                    |                                     |
| Place blanket module into transfer airlock and close airlock      | 0.1                               |                                    |                                     |
|                                                                   | 0.9                               |                                    |                                     |
| Repeat above sequence of steps for 60 blanket modules             |                                   |                                    |                                     |
| Total repetitive time = 60 modules x 0.9 hr                       | 54.0                              |                                    |                                     |
|                                                                   |                                   | 54.0                               |                                     |

These nominal values are multiplied by a productivity factor

Repetitive actions



# Estimated Maintenance Times

| Maintenance Action                                                                             | Duration of Serial Operations, Hr | Subtotal for Set of Operations, hr | Duration of Parallel Operations, hr |
|------------------------------------------------------------------------------------------------|-----------------------------------|------------------------------------|-------------------------------------|
| <b>Shield and Support System Inspection and Repair</b>                                         |                                   |                                    |                                     |
| Inspection of shield for damage and displacement, record data                                  | 12.0                              |                                    |                                     |
| Allocated time for potential repair of fasteners, alignment features, and plumbing connections | 24.0                              |                                    |                                     |
| Repair inspection                                                                              | 2.0                               |                                    |                                     |
|                                                                                                |                                   | 38.0                               |                                     |

*These nominal values are multiplied by a productivity factor*

# Estimated Maintenance Times

| Maintenance Action                                                                                                           | Duration of Serial Operations, Hr | Subtotal for Set of Operations, hr | Duration of Parallel Operations, hr |
|------------------------------------------------------------------------------------------------------------------------------|-----------------------------------|------------------------------------|-------------------------------------|
| <b>Replacement Maintenance Tasks</b>                                                                                         |                                   |                                    |                                     |
| Retrieve new blanket module from transfer airlock and close airlock                                                          | 0.1                               | } Repetitive actions               |                                     |
| Move Maint Machine into port position and secure                                                                             | 0.1                               |                                    |                                     |
| Move boom forward and position blanket module over shield inside chamber                                                     | 0.2                               |                                    |                                     |
| Engage and secure new blanket module                                                                                         | 0.2                               |                                    |                                     |
| Retract boom                                                                                                                 | 0.1                               |                                    |                                     |
| Retract Maint Machine into transfer chamber                                                                                  | 0.1                               |                                    |                                     |
|                                                                                                                              | 0.8                               |                                    |                                     |
| Repeat above sequence of steps for 60 additional blanket modules                                                             |                                   |                                    |                                     |
| Total repetitive time = 60 modules x 0.8 hr                                                                                  | 48.0                              |                                    |                                     |
|                                                                                                                              |                                   | 48.0                               |                                     |
| Re-connect primary coolant plumbing connections                                                                              |                                   |                                    |                                     |
| Introduce robotic welding machine into plumbing system                                                                       |                                   |                                    | 0.2                                 |
| Move welding machine into position at furthest removable joint                                                               |                                   |                                    | 0.4                                 |
| Reweld plumbing joints and inspect joints                                                                                    |                                   |                                    | 0.2                                 |
| Continue welding and inspections for all blankets and shield plumbing in parallel with installation of blanket installation. |                                   |                                    | as required                         |
| Retrieve new port blanket module from transfer airlock and close airlock                                                     | 0.1                               |                                    |                                     |
| Move Maint Machine into port position and secure                                                                             | 0.1                               |                                    |                                     |
| Move boom forward and position port blanket module                                                                           | 0.2                               |                                    |                                     |
| Engage and secure port blanket module                                                                                        | 0.2                               |                                    |                                     |
| Retract boom                                                                                                                 | 0.1                               |                                    |                                     |
| Retract Maint Machine into transfer chamber                                                                                  | 0.1                               |                                    |                                     |
|                                                                                                                              |                                   | 0.8                                |                                     |
| Retrieve new port shield from transfer airlock and close airlock                                                             | 0.1                               |                                    |                                     |
| Move Maint Machine into port position and secure                                                                             | 0.1                               |                                    |                                     |
| Move boom forward and position port shield module                                                                            | 0.2                               |                                    |                                     |
| Engage and secure port shield                                                                                                | 0.2                               |                                    |                                     |
| Retract boom                                                                                                                 | 0.1                               |                                    |                                     |
| Retract Maint Machine into transfer chamber                                                                                  | 0.1                               |                                    |                                     |
|                                                                                                                              |                                   | 0.8                                |                                     |

These nominal values are multiplied by a productivity factor

# Estimated Maintenance Times

| Maintenance Action                                               | Duration of Serial Operations, Hr | Subtotal for Set of Operations, hr | Duration of Parallel Operations, hr |
|------------------------------------------------------------------|-----------------------------------|------------------------------------|-------------------------------------|
| <b>Inspection, Diagnostics and Preparation for Operations</b>    |                                   |                                    |                                     |
| Pressurize coolant systems and test with test gas for leaks      | 4.0                               |                                    |                                     |
| Evacutate power core interior                                    | 10.0                              |                                    |                                     |
| Initiate trace or helium heating                                 |                                   |                                    | 10.0                                |
| Pick up VV door, move into position, and secure                  |                                   |                                    | 0.3                                 |
| Reestablish vacuum door seal                                     |                                   |                                    | 2.0                                 |
| Acquire port bio shield door, align, and move into position      |                                   |                                    | 0.5                                 |
| Remove maintenance machine from transfer chamber                 |                                   |                                    | 0.2                                 |
| Close transfer chamber outer main isolation door                 |                                   |                                    | 0.1                                 |
| Fill power core coolants                                         | 8.0                               |                                    |                                     |
| Bake out (clean) power core chamber                              | 12.0                              |                                    |                                     |
| Check out and power up systems                                   | 4.0                               |                                    |                                     |
|                                                                  |                                   | 38.0                               |                                     |
| Total Maintenance Time for three field periods, port maintenance | 214.0                             | 214.0                              |                                     |

*These nominal values are multiplied by a productivity factor*

# Availability Analysis

This is the analysis for the replacement of the blanket modules. The replacement period is 3.9 full power years plus the replacement time. Scheduled other plant equipment replacement that requires the plant shutdown should be accomplished at this same time. More frequent replacements should be accommodated with redundant systems.

|                                                                                 |         |              |
|---------------------------------------------------------------------------------|---------|--------------|
| Full power years                                                                | 3.9     |              |
| Number of Total Available Days                                                  | 1424.5  |              |
| Number of Total Available Hours                                                 | 34187.4 |              |
| Nominal hours to replace three field periods                                    | 214.0   | ← Aggressive |
| Inherent availability (total avail hours)/(total avail hours+sched maint hours) | 99.38%  |              |
| Annualized scheduled maintenance period, days                                   | 2.29    |              |

These maintenance estimates result in very optimistic inherent availability for the scheduled maintenance periods. As the basis for a more conservative estimate, the in-vessel time durations are multiplied by factor to the right

|                                                                                 |        |                |
|---------------------------------------------------------------------------------|--------|----------------|
|                                                                                 | 4.0    |                |
| Conservative estimate of time (hr) to replace three field periods               | 856.0  | ← Conservative |
| Inherent availability (total avail hours)/(total avail hours+sched maint hours) | 97.56% |                |
| Scheduled Blanket Maintenance days/FPY                                          | 9.15   |                |

## Unscheduled Maintenance for Removal of Failed Blanket Module

The unscheduled blanket maintenance time is related to the scheduled blanket maintenance time because of the maintenance actions to access the failed modules are identical. However, an unscheduled failure of a blanket module will likely be random. A good assumption would be that half the blanket modules on one side of the port will have to be removed to access the failed module.

Unscheduled Maintenance time is equal to the scheduled one-time actions plus 1/4 the repetitive actions to replace all the modules.  
Conservative estimate with multiplying factor

The reliability of the blanket modules are completely unknown at this time. But a reasonable estimate might be that a single blanket module would fail each year (assume 1 FPY). Inherent availability would be

## One Failure/FPY

|        |                |
|--------|----------------|
| 137.50 | ← Aggressive   |
| 550.00 | ← Conservative |
| 94.10% |                |

# Availability Analysis

## Unscheduled In Situ Maintenance of a Plumbing Leak

There is another class of blanket failures (small leaks) that would require shutting down the power core. These failures could be a leak in the primary piping, which would require draining the fluids and putting the cutting/welding machines in the piping. Another failure might be a small leak within the blanket itself. Small autonomous robot repair machines would be dispatched to the leak site and repair the leak. Repair time would involve shutting down the power core, draining fluids, making the repairs, systems checks, refilling fluids, and start up sequence.

|                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |        |                                     |
|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------|-------------------------------------|
| Shutdown and preparation for maintenance                                                                                                                                                                                                                                                                                                                                                                                                                         | 30.00  | <b>One Plumbing Failure/3.9 FPY</b> |
| Introduce robotic repair machine into plumbing system                                                                                                                                                                                                                                                                                                                                                                                                            | 0.20   |                                     |
| Traverse plumbing to leak site                                                                                                                                                                                                                                                                                                                                                                                                                                   | 1.00   |                                     |
| Repair leak                                                                                                                                                                                                                                                                                                                                                                                                                                                      | 6.00   |                                     |
| Pressurize system and verify integrity of repair                                                                                                                                                                                                                                                                                                                                                                                                                 | 2.00   |                                     |
| Traverse plumbing to entry site                                                                                                                                                                                                                                                                                                                                                                                                                                  | 1.00   |                                     |
| Remove robotic repair machine from the plumbing system                                                                                                                                                                                                                                                                                                                                                                                                           | 0.20   |                                     |
| Pressurize coolant systems and test with test gas for leaks                                                                                                                                                                                                                                                                                                                                                                                                      | 4.0    |                                     |
| Evacuate power core interior                                                                                                                                                                                                                                                                                                                                                                                                                                     | 10.0   |                                     |
| Initiate trace or helium heating                                                                                                                                                                                                                                                                                                                                                                                                                                 |        |                                     |
| Fill power core coolants                                                                                                                                                                                                                                                                                                                                                                                                                                         | 8.0    |                                     |
| Bake out (clean) power core chamber                                                                                                                                                                                                                                                                                                                                                                                                                              | 12.0   |                                     |
| Check out and power up systems                                                                                                                                                                                                                                                                                                                                                                                                                                   | 4.0    |                                     |
| Unscheduled of small leaks with in-situ repair, hrs                                                                                                                                                                                                                                                                                                                                                                                                              | 78.4   | <b>Aggressive<br/>Conservative</b>  |
| Conservative estimate with multiplying factor                                                                                                                                                                                                                                                                                                                                                                                                                    | 313.60 |                                     |
| The reliability of the modules for small insitu repairable leaks is unknown. However, this is a 10th of a kind power plant and any design-inherent reliability problems probably have been addressed. There are around 600 modules with two heat transfer fluids. I would estimate reliability would be 0.9999/yr or 1 failure in 10,000/yr. A conservative estimate would be one failure per 3.9 FPY. Inherent availability for the small leak repair would be: |        | 99.09%                              |

The availability of the Reactor Plant Equipment (RPE), other than the power core components, does not have a substantial database upon which to draw. But these systems are separate from the core and can have redundant subsystems and components to bring the availability as high as necessary. It is judged that the RPE would also have a combined availability of 97.5%.

Balance of Plant Availability assumed in ARIES-AT was assumed to be consistent with the improving trends in the power generating industry.

97.50%

# Availability Analysis

## ARIES-CS Conservative Estimate

| Summary of Maintenance Actions                                   | Availability | Maint Days/FPY |
|------------------------------------------------------------------|--------------|----------------|
| Scheduled Blanket and Divertor Maintenance                       | 97.56%       | 9.15           |
| Unscheduled Blanket and Divertor Maintenance, Major              | 94.10%       | 22.92          |
| Unscheduled Blanket and Divertor Maintenance, In situ repairable | 99.09%       | 3.35           |
| Other Reactor Plant Equipment                                    | 97.50%       | 9.37           |
| Balance of Plant                                                 | 97.50%       | 0.98           |
| Total Plant Availability                                         | 86.47%       | 57.14          |

### This compares to the ARIES-AT Availability Analysis

|                                |        |       |
|--------------------------------|--------|-------|
| Power Core, Major, Scheduled   | 98.90% | 4.23  |
| Power Core, Minor, Scheduled   | 98.40% | 6.05  |
| Power Core, Unscheduled        | 94.70% | 20.56 |
| RPE, Scheduled and Unscheduled | 97.50% | 9.37  |
| BOP, Scheduled and Unscheduled | 97.50% | 9.37  |
| Total                          | 87.60% |       |

**Used 85%**

# Summary

**This analysis should be considered preliminary. Additional details on number of modules and maintenance actions will be added. The Factor of 4 seems a little too conservative, but maybe that is OK.**

**For the moment, continue to assume an availability of 85%.**