High-Power Targets for ADS

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Scope of the current talk

- Safety Concepts in Nuclear Engineering
- Lessons Learnt in past targetry projects
- Proposed design of a high-power spallation source for ADS
- Concluding remarks

Safety Concepts
Deterministic vs. Probabilistic Analysis

- Deterministic safety analysis : all conceivable accidents are identified and grouped. For each accident category, “enveloping” scenarios are identified, taking into account the worst possible combinations. The precise radiological consequences are calculated. Beyond design basis accidents (DBA) are not necessarily considered. This is evolving.

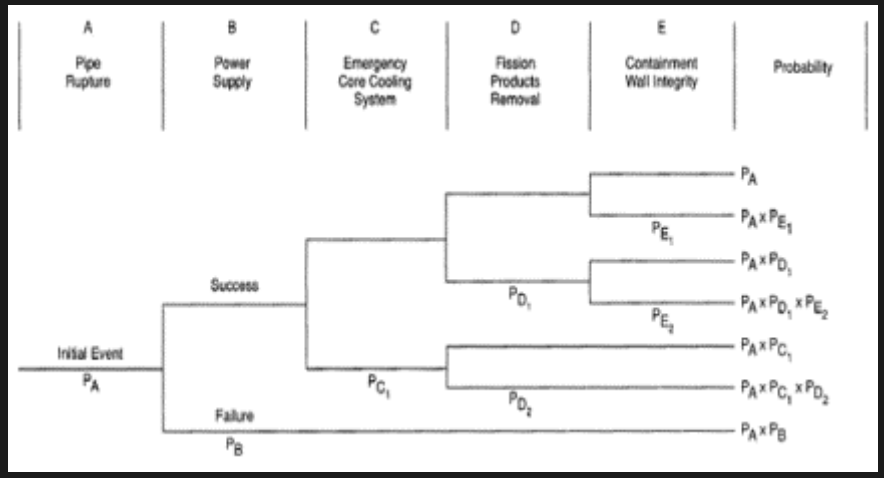
- Probabilistic safety analysis (PSA, PRA) assumes even rare events beyond DBA. Event trees describe the development of different scenarios that either lead to a successful mission or to core damage. A Level 1 PSA caculates the core damage frequency per reactor year. Level 2 PSA: release into the environment. Level 3 PSA: risk for the population

Safety Concepts
Deterministic vs. Probabilistic Analysis

- Deterministic safety analysis :

<table>
<tr><td colspan="2">Operational states</td><td colspan="3">Accident conditions</td></tr>
<tr><td rowspan="3">Normal operation</td><td rowspan="3">Anticipated operational occurrences</td><td rowspan="3">Design-basis accidents</td><td colspan="2">Beyond-design-basis accidents</td></tr>
<tr><td>Design-extension conditions</td><td>Practically eliminated conditions</td></tr>
<tr><td>No severe fuel degradation</td><td>Severe accidents</td></tr>
<tr><td colspan="3">Design basis</td><td>Design extension</td><td>Not considered as design extension</td></tr>
<tr><td colspan="5">Reducing frequency of occurrence ➔</td></tr>
</table>

- Probabilistic safety analysis

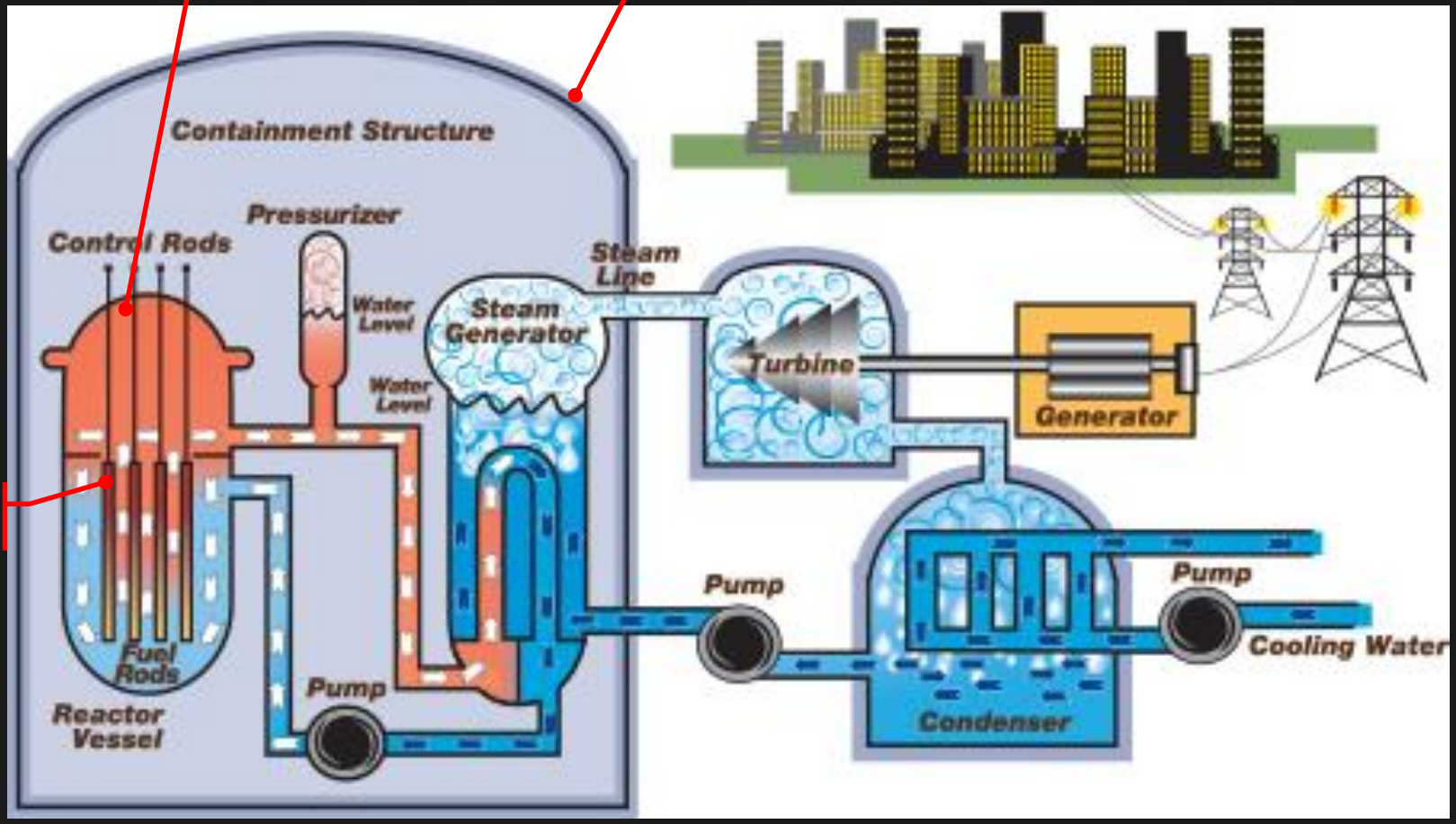


Safety Concepts
Pressurised Water Reactor Barriers

2. Primary Circuit

3. Containment Structure

1. Fuel rod

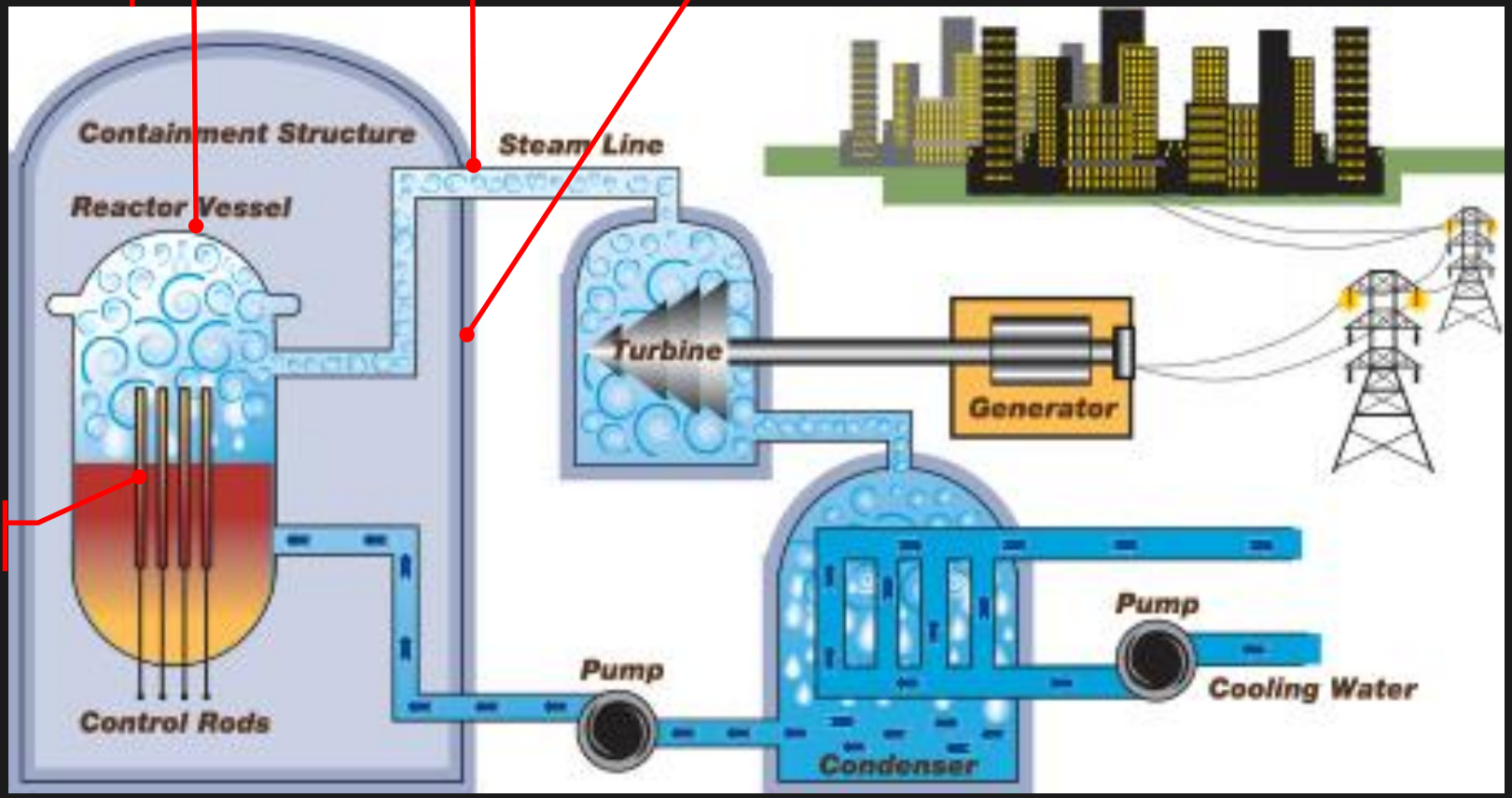


Safety
Pressurised Water Reactor Barriers

2½. Steam Lines

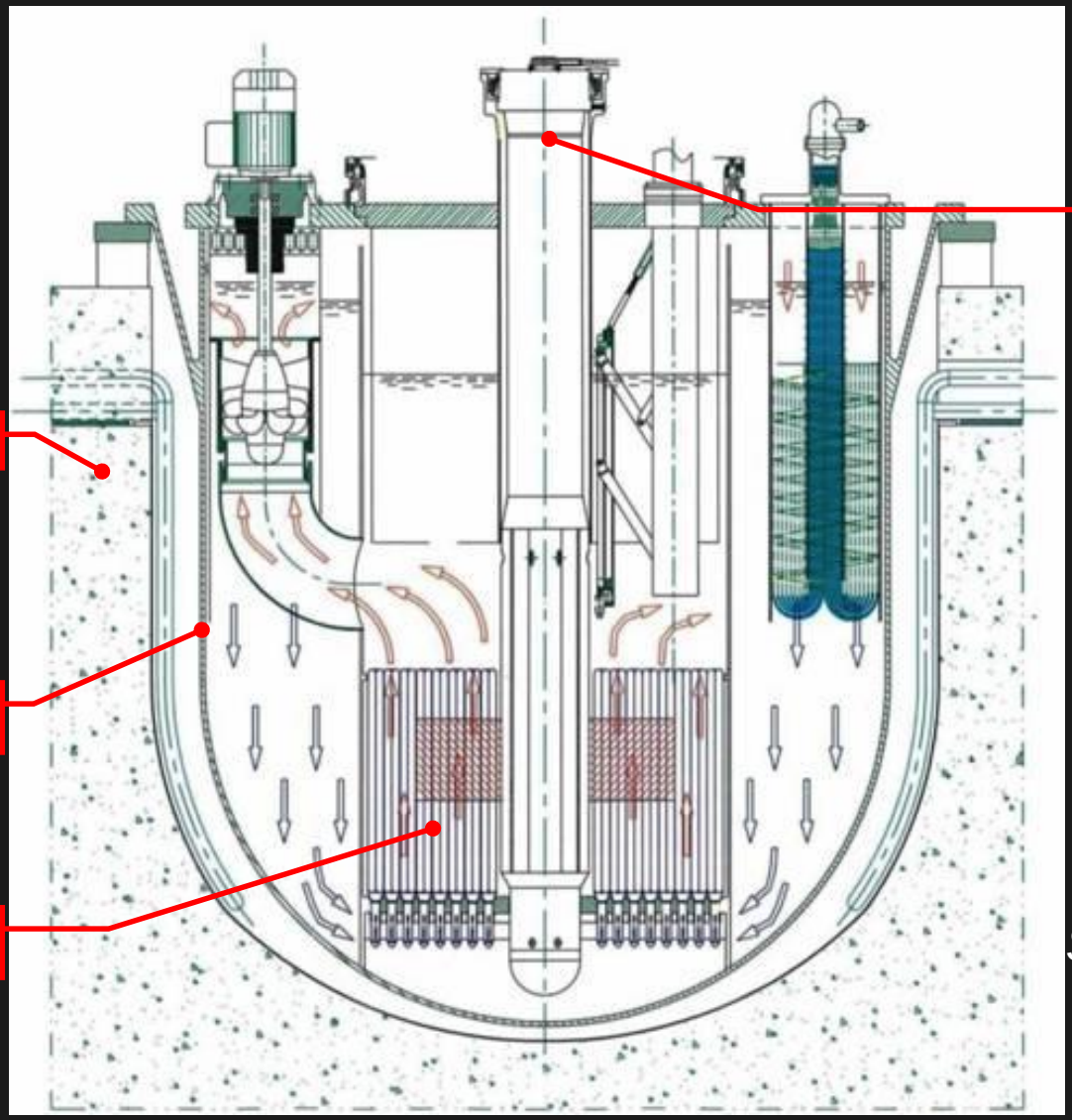
2. Primary Circuit

3. Containment Structure



1. Fuel rod

Safety
Accelerated Driven System Barriers



Source for the Graph: EFIT, KIT

Lessons learnt
Spallation source Projects Timeline

- 2006 MEGAPIE with irradiation
  - First Liquid Metal neutron source
  - Megawatt range
- 2009 EURISOL without iradiation
  - High speed compact Liquid metal source
  - 4 MW range
- 2011 ADS-compatible high power spallation source
  Proposal developped by Target Group at CERN

Lessons learnt
Spallation source Projects Achievements

- Main achievements
  - MEGAPIE with iradiation - 10^{14} n/cm^2/s
  - EURISOL without iradiation - 10^{15} n/cm^2/s (hydraulically tested)
- Target Group sought to apply this experience to a practical goal
  - MEGAPIE application of irradiation
  - EURISOL application of a compact design

Lessons Learnt
Megapie Irradiation Test

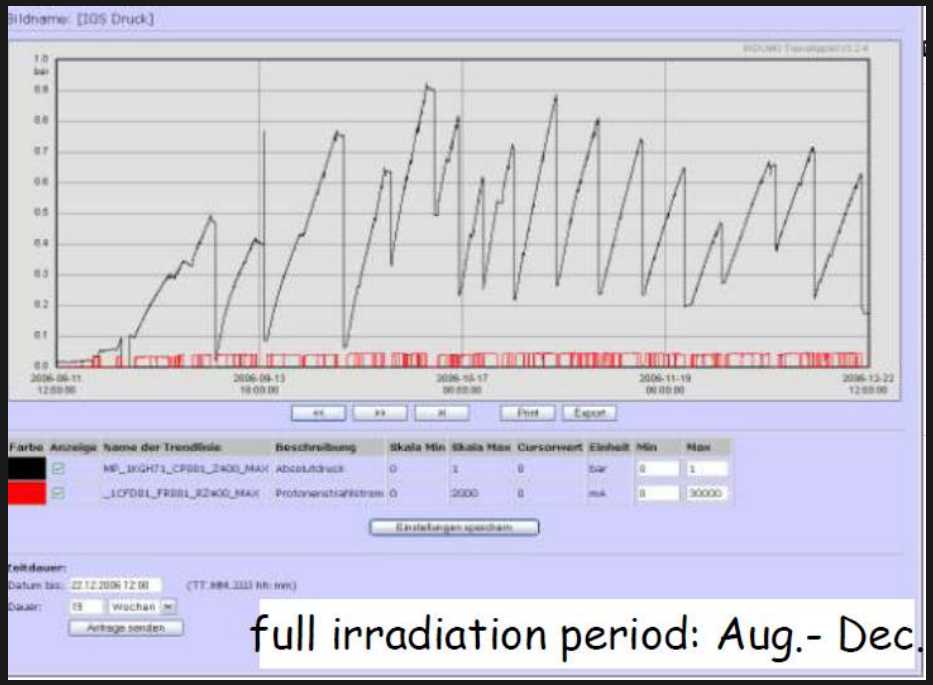
- Megawatt Pilot Experiment (MEGAPIE): world's first Megawatt-Class liquid metal spallation target, operated in SINQ at PSI.
- Goal: demonstrate safe operation of coupling an accelerator with a liquid metal target.
- Challenges :
- Vertical configuration in confined space.
  - Beam window able to withstand irradiation, liquid metal
- Decommissioning and waste management
- Provide scientific and engineering data

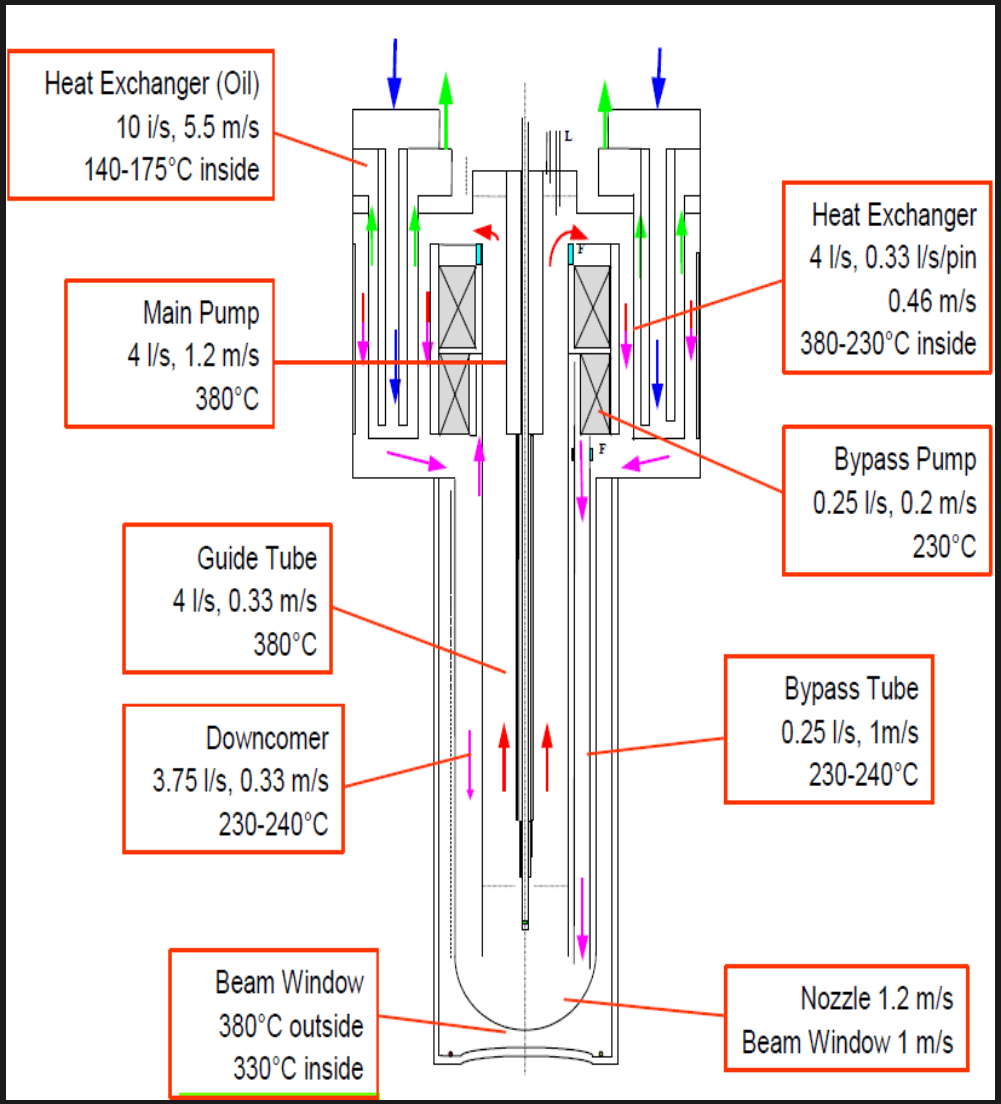

SINQ @ PSI

Lessons Learnt
Megapie Irradiation Test

Lesson 1
It's feasible

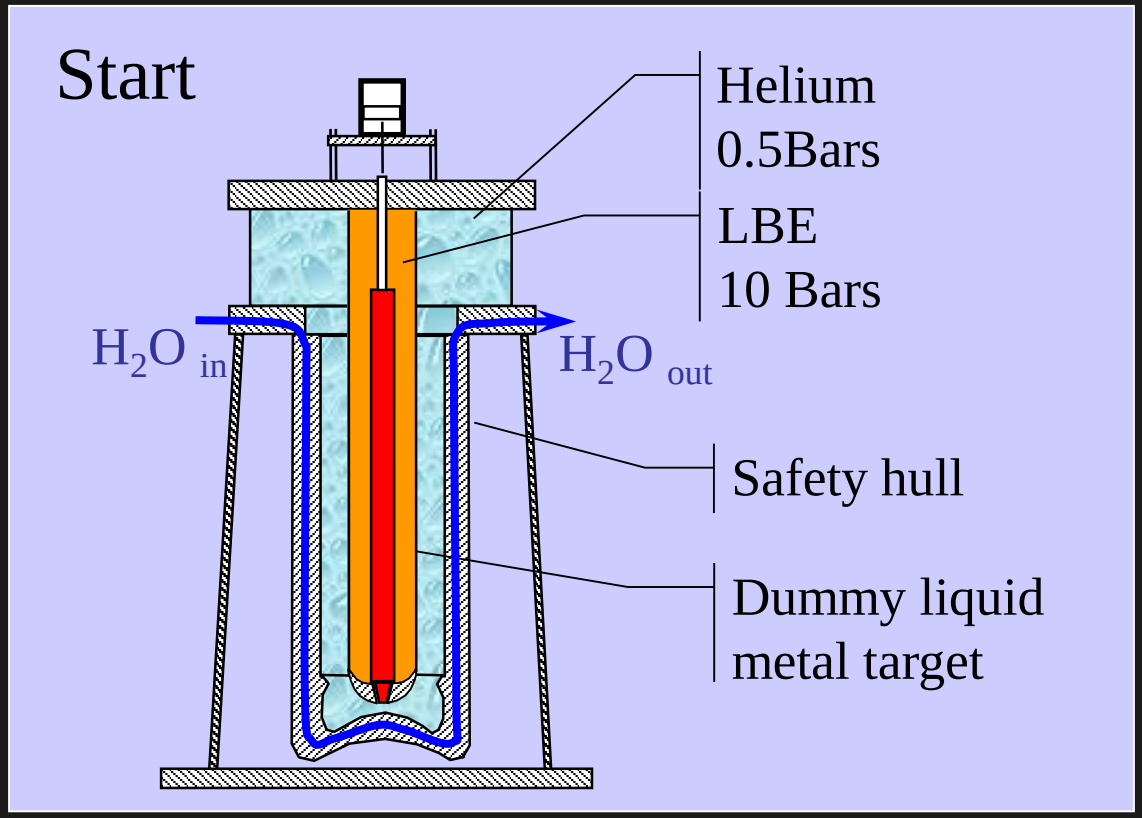
Lesson 2
Leaks are highly safety-relevant

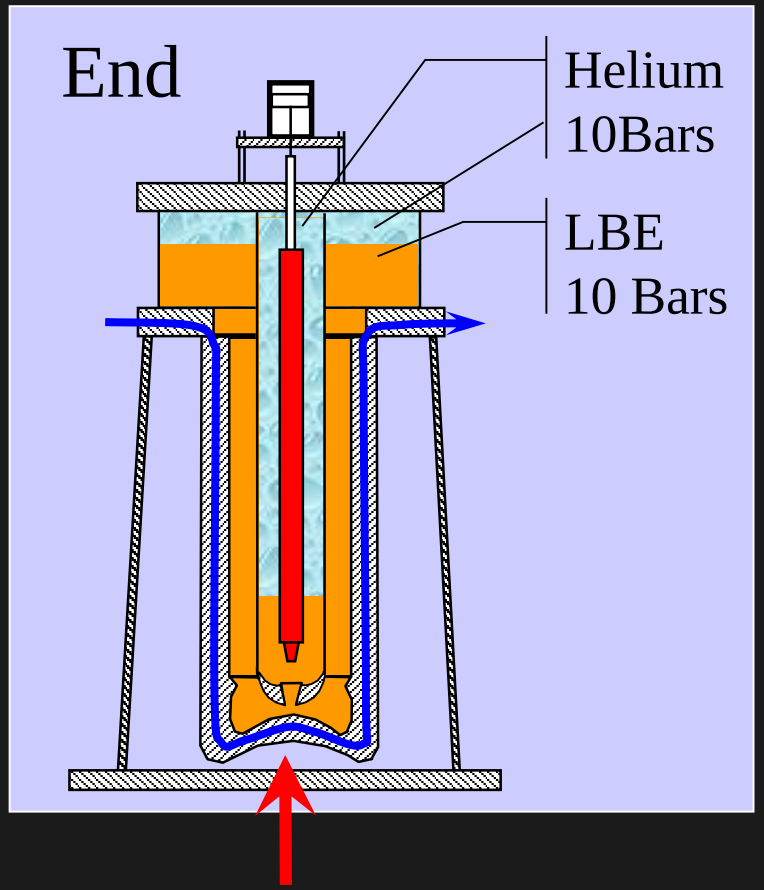




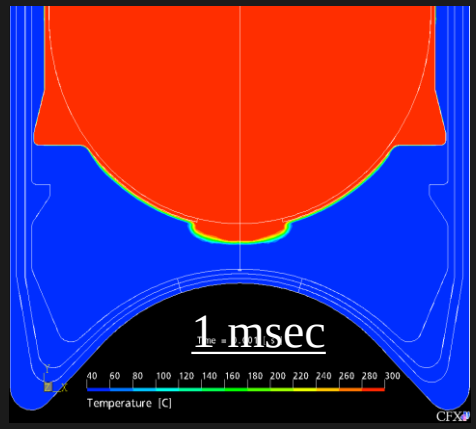
Lessons Learnt
Megapie Full-scale Safety Test

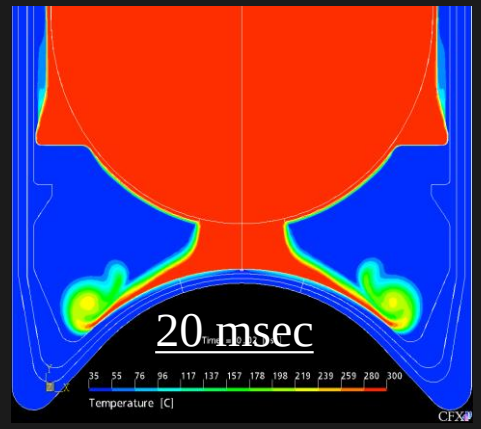
Full scale liquid metal leak test

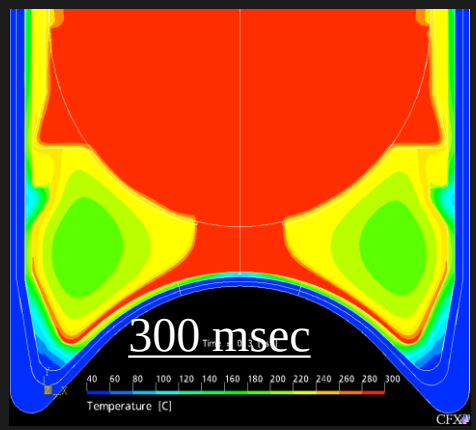


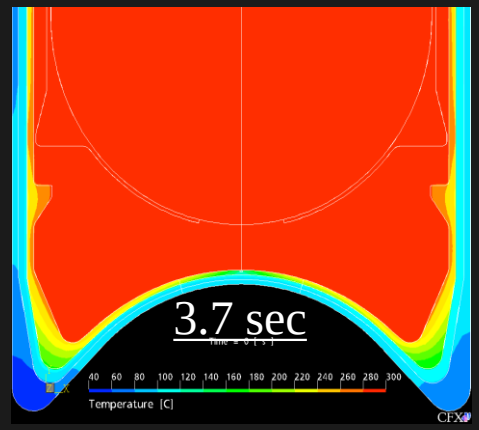


Lessons Learnt
Megapie Full-scale Safety Test



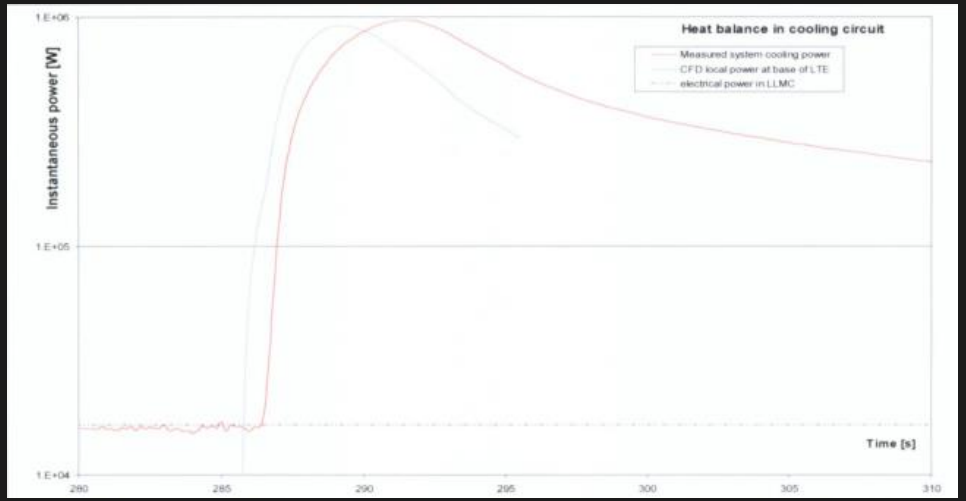


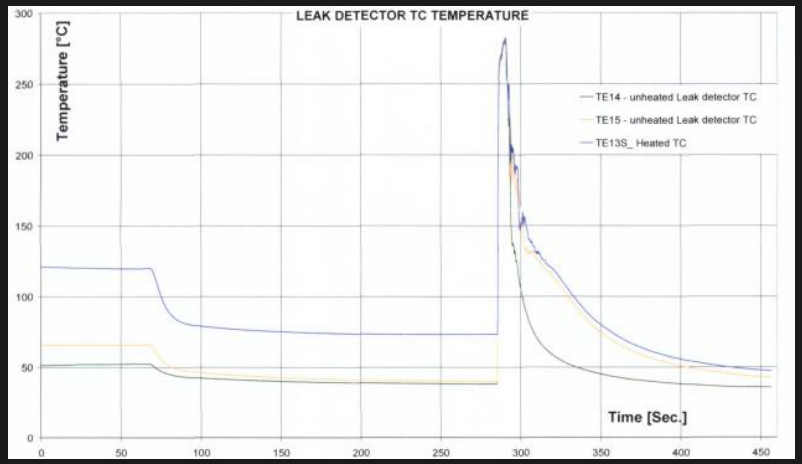


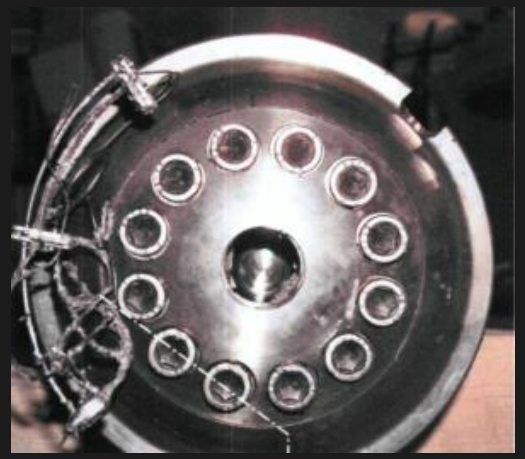


Lessons Learnt
Megapie Full-scale Safety Test

- Fully-instrumented pure aluminium containment hull survived the impact of envelope-case liquid metal leak at 10 Bar and > 300°C



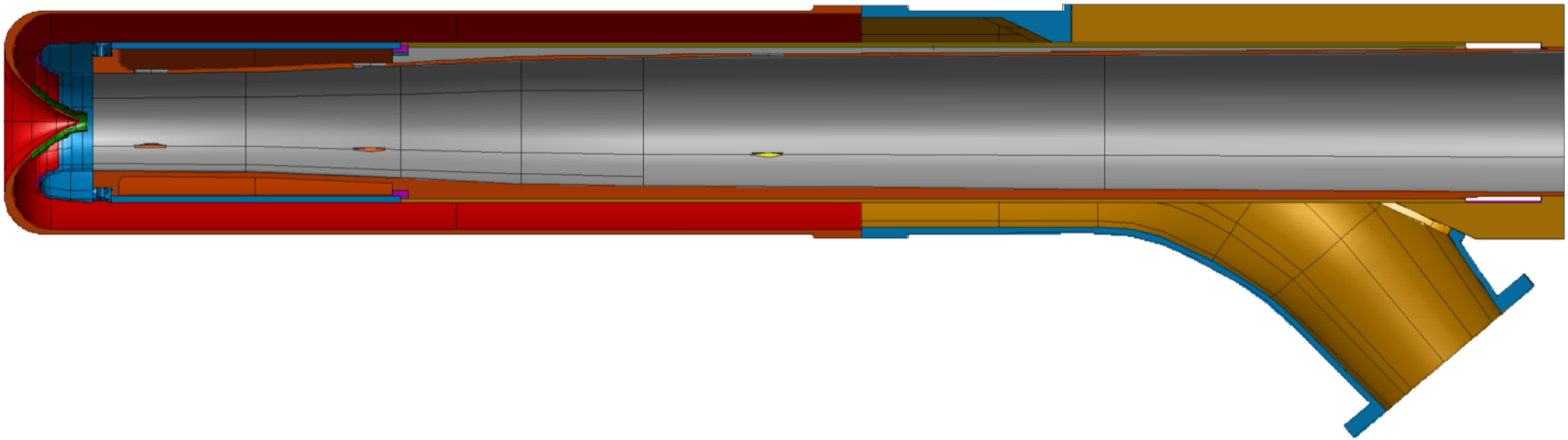




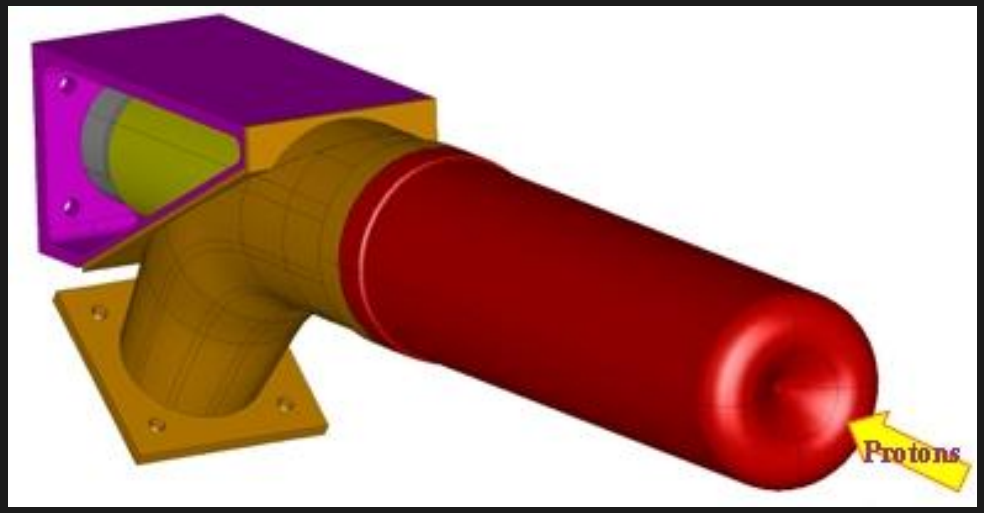
Source: *Full Scale Leak Test of the MEGAPIE Containment Hull, K. Samec, PSI-Bericht 06-02, ISSN 1019-0643*

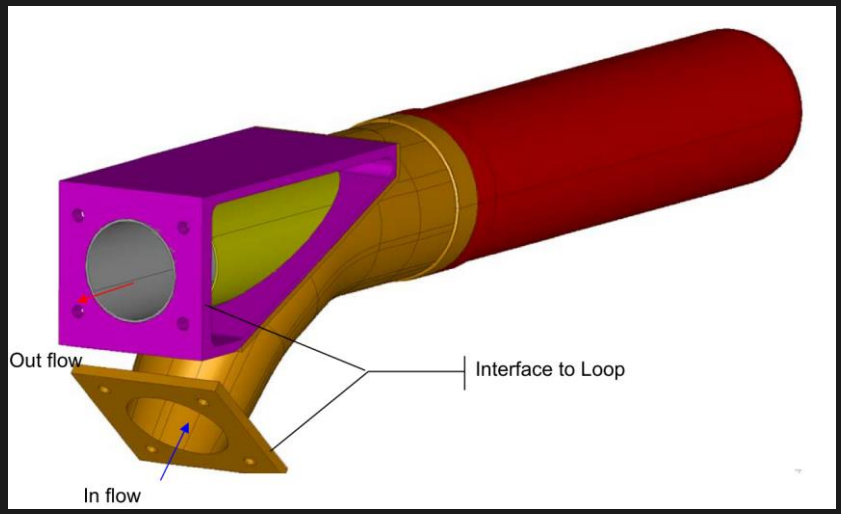
Lessons Learnt
Eurisol 4 MW Target Design

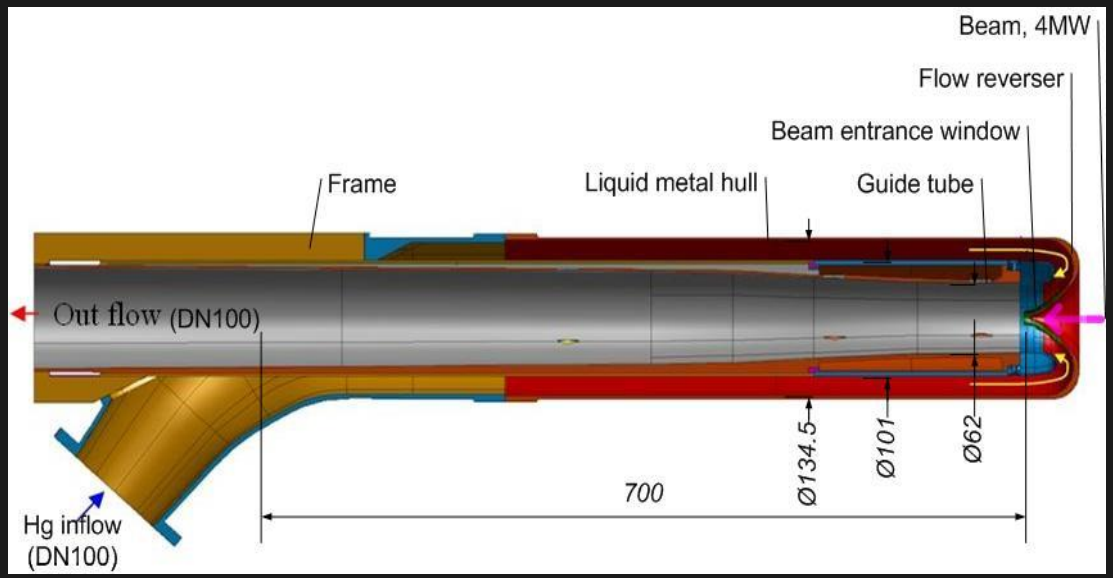
Design of Eurisol [2009]

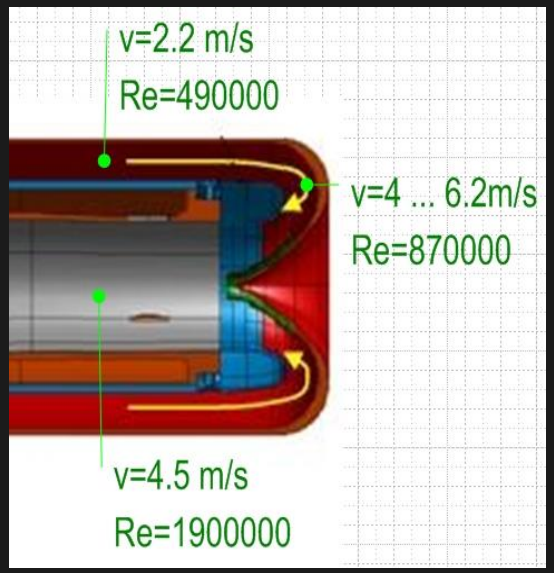


Lessons Learnt
Eurisol 4 MW Target Design

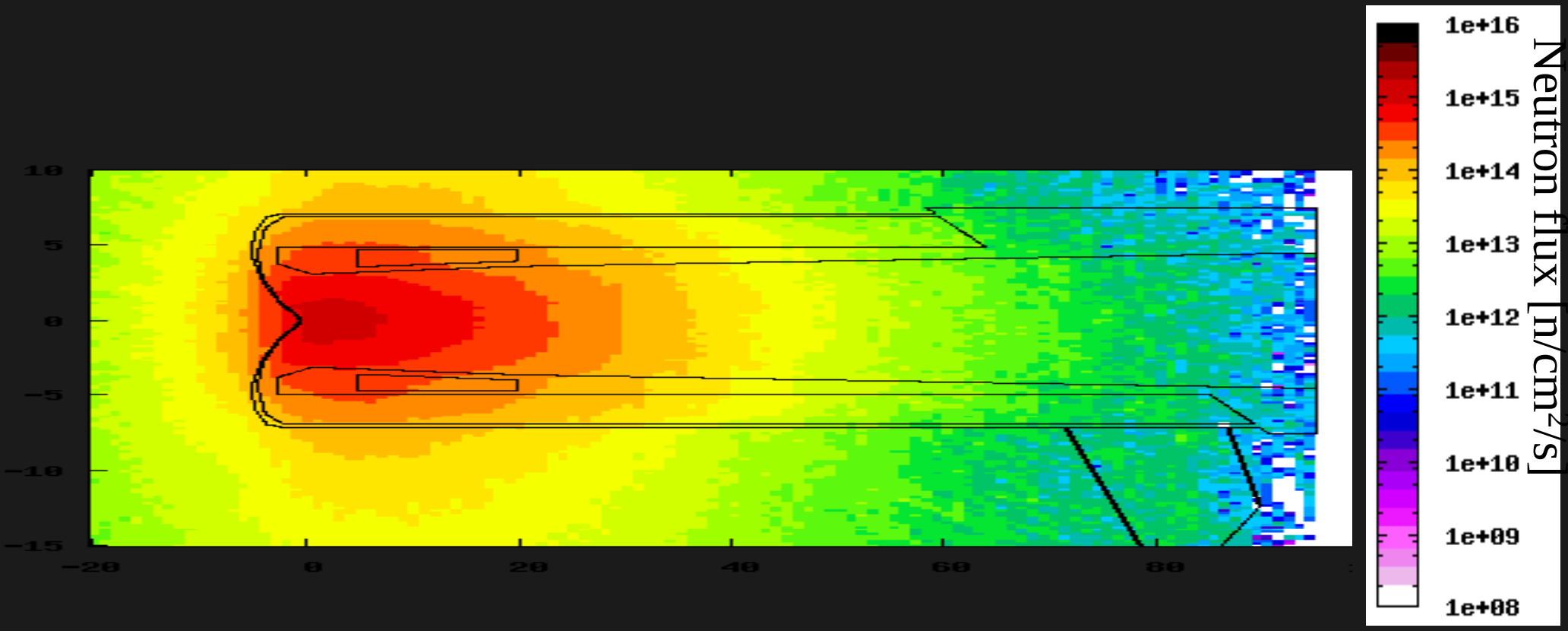




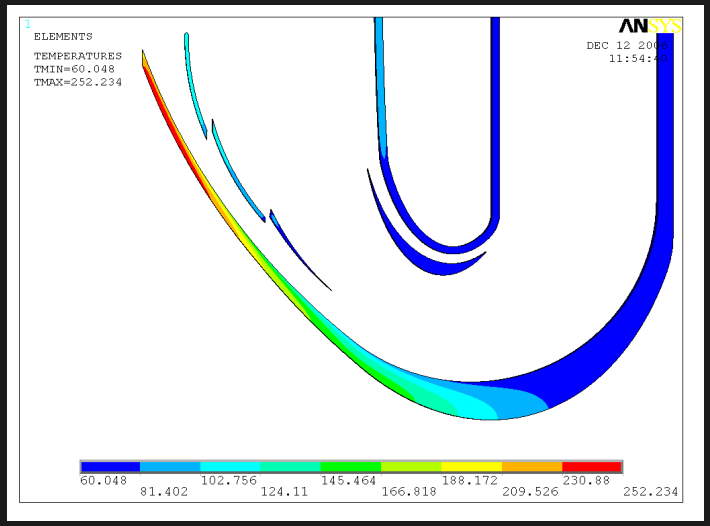


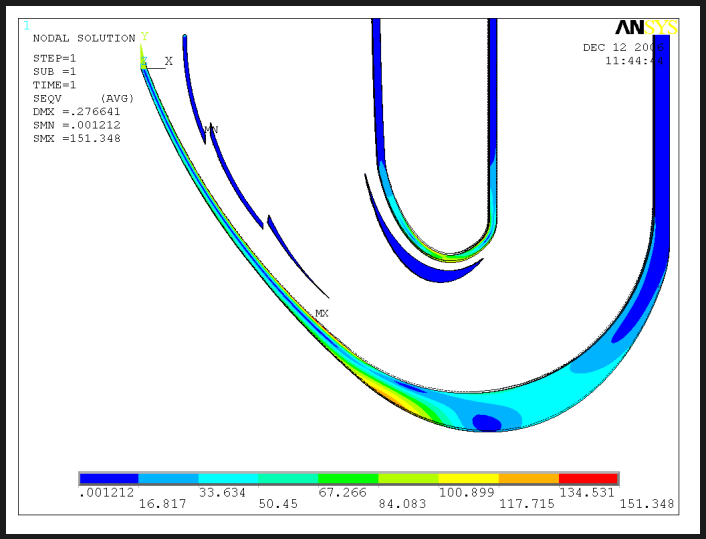


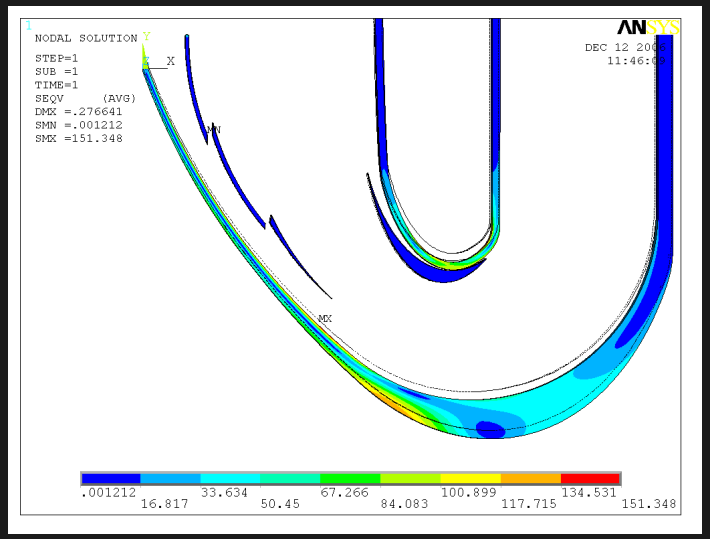
Lessons Learnt
Eurisol 4 MW Target Neutron Flux

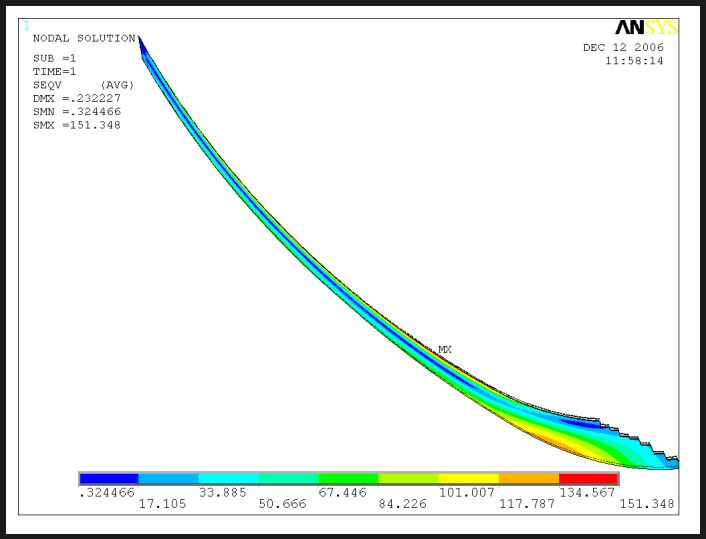


Lessons Learnt
Eurisol 4 MW Target Beam Window

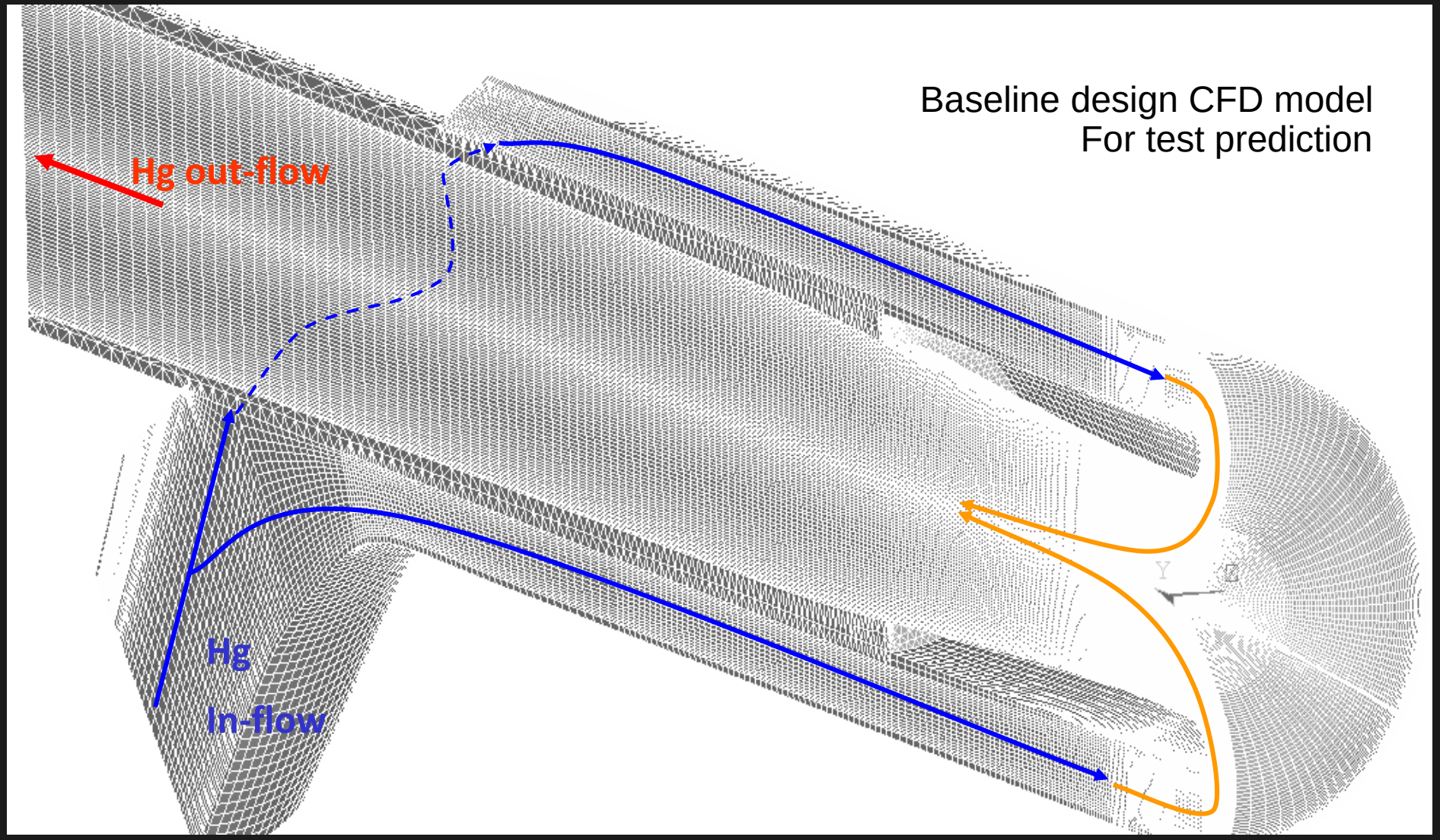








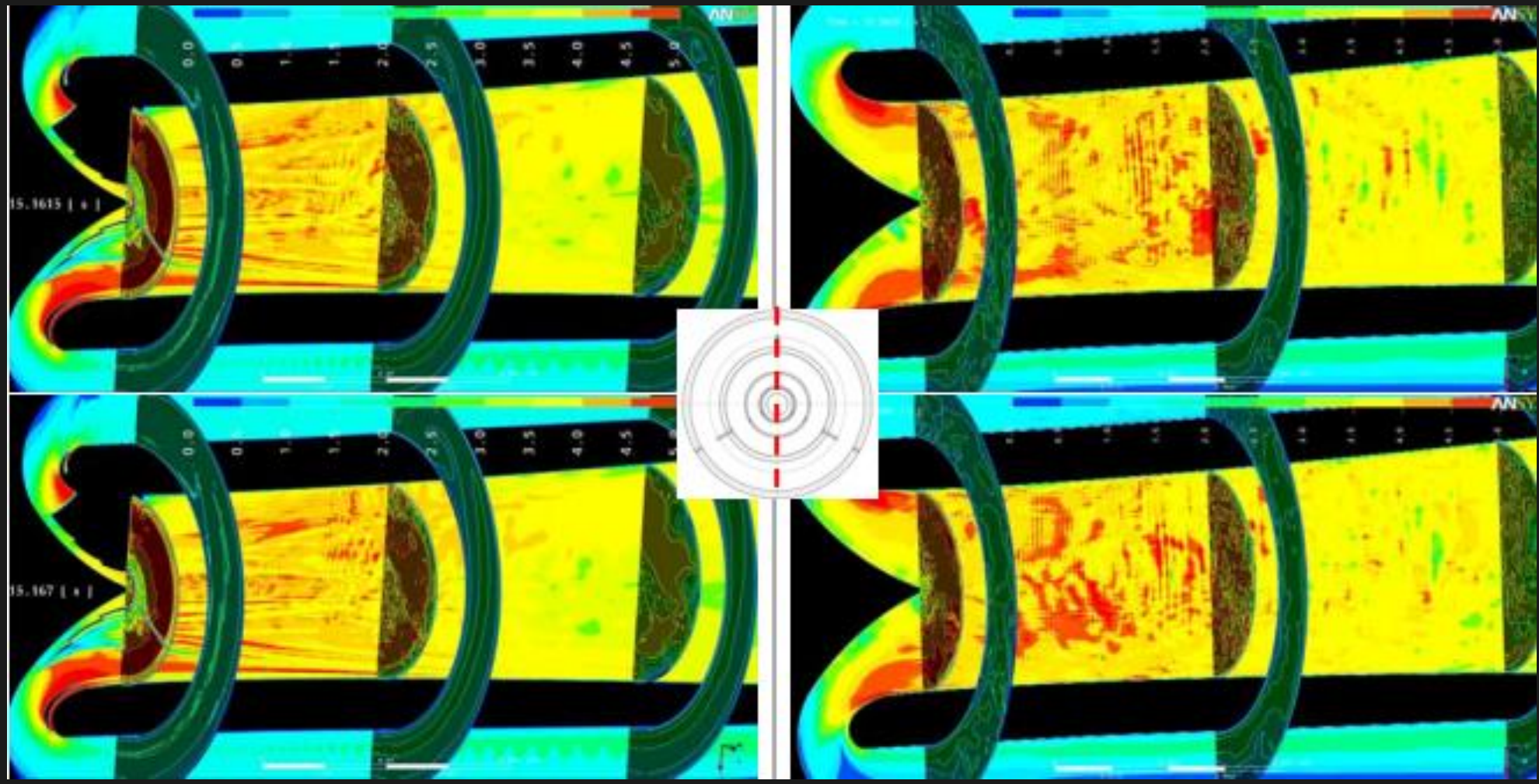
Lessons Learnt
Eurisol 4 MW 3D CFD Analysis



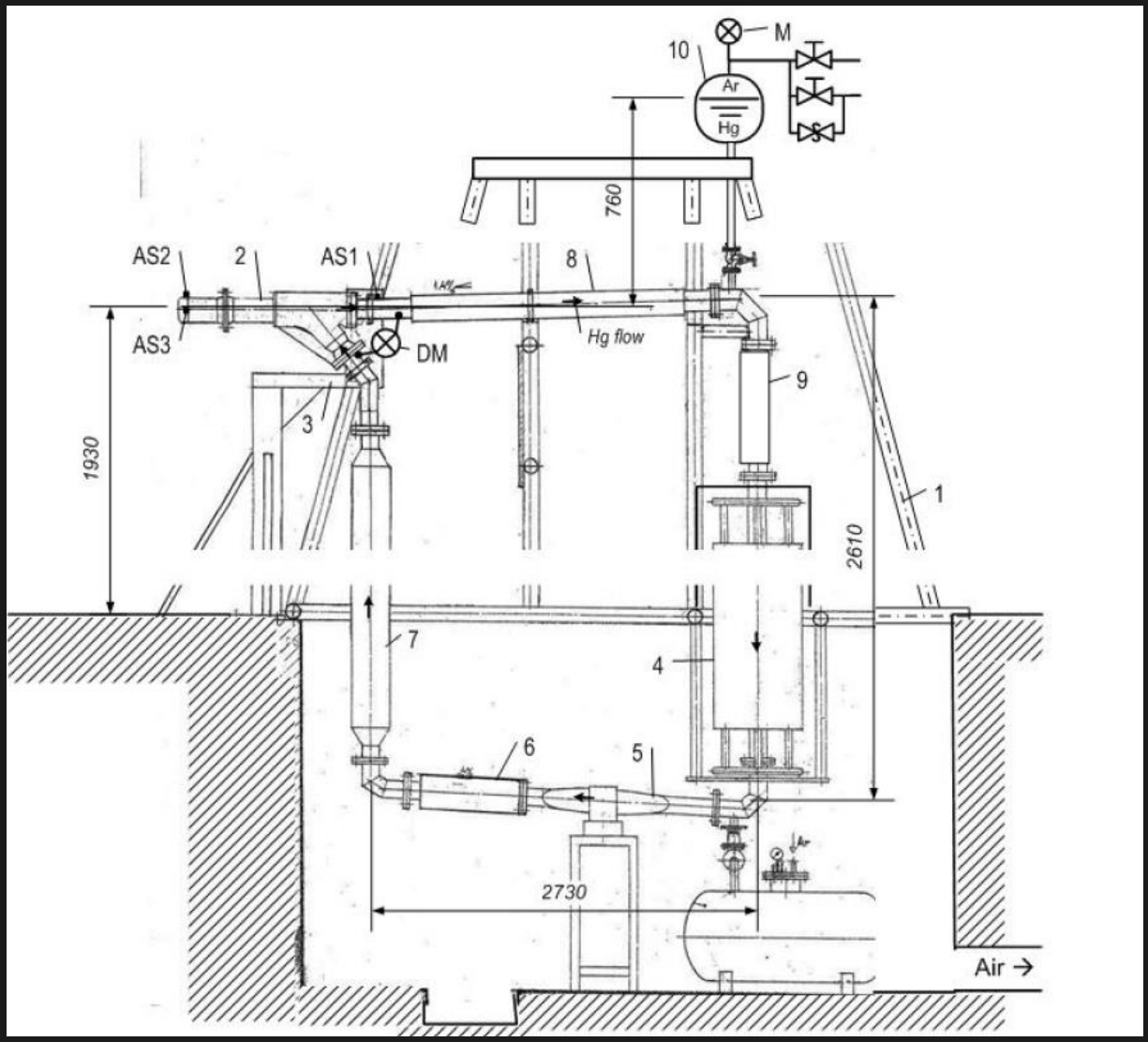
Lessons Learnt
Eurisol 4 MW 3D CFD Analysis of 2 versions

WITH vanes - cracked

WITHOUT vanes - survived

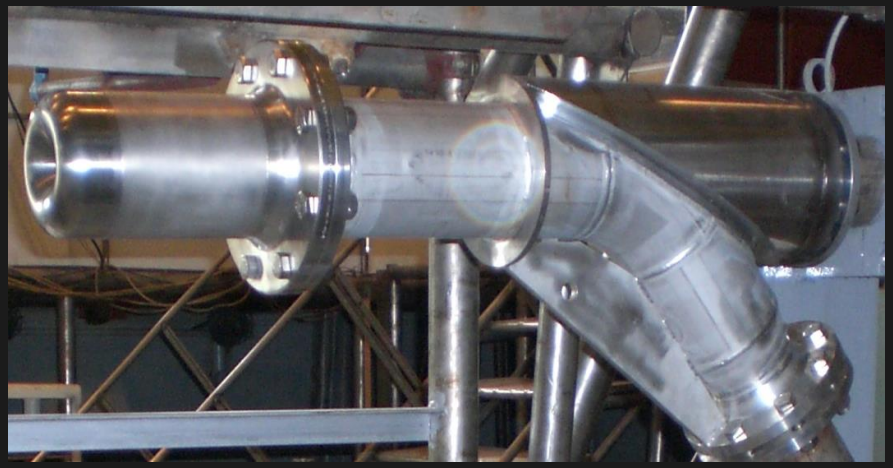


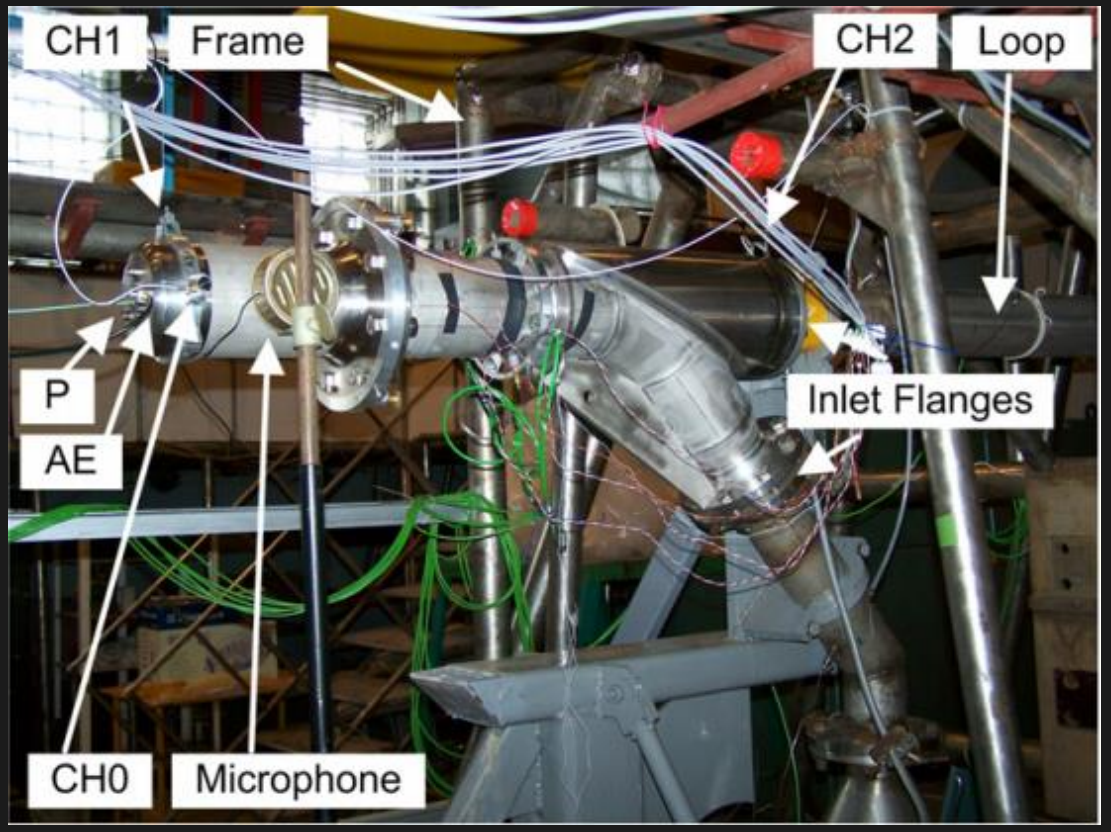
Lessons Learnt
Eurisol 4 MW Full-Scale Hydraulic Test



Lessons Learnt
Eurisol 4 MW Full-Scale Hydraulic Fest

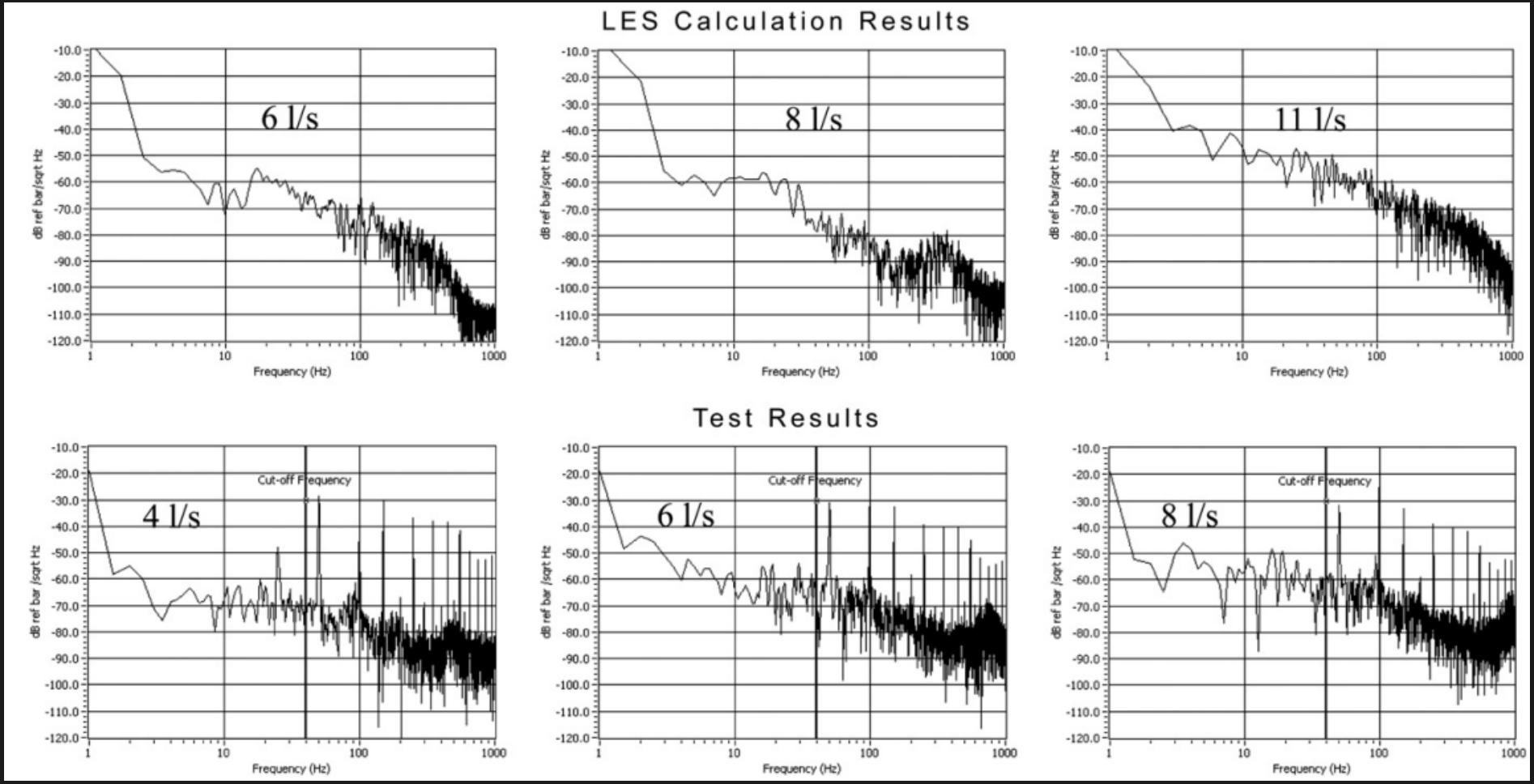
- Test at full flow rate 150 kg/s needed for absorbing 4 MW





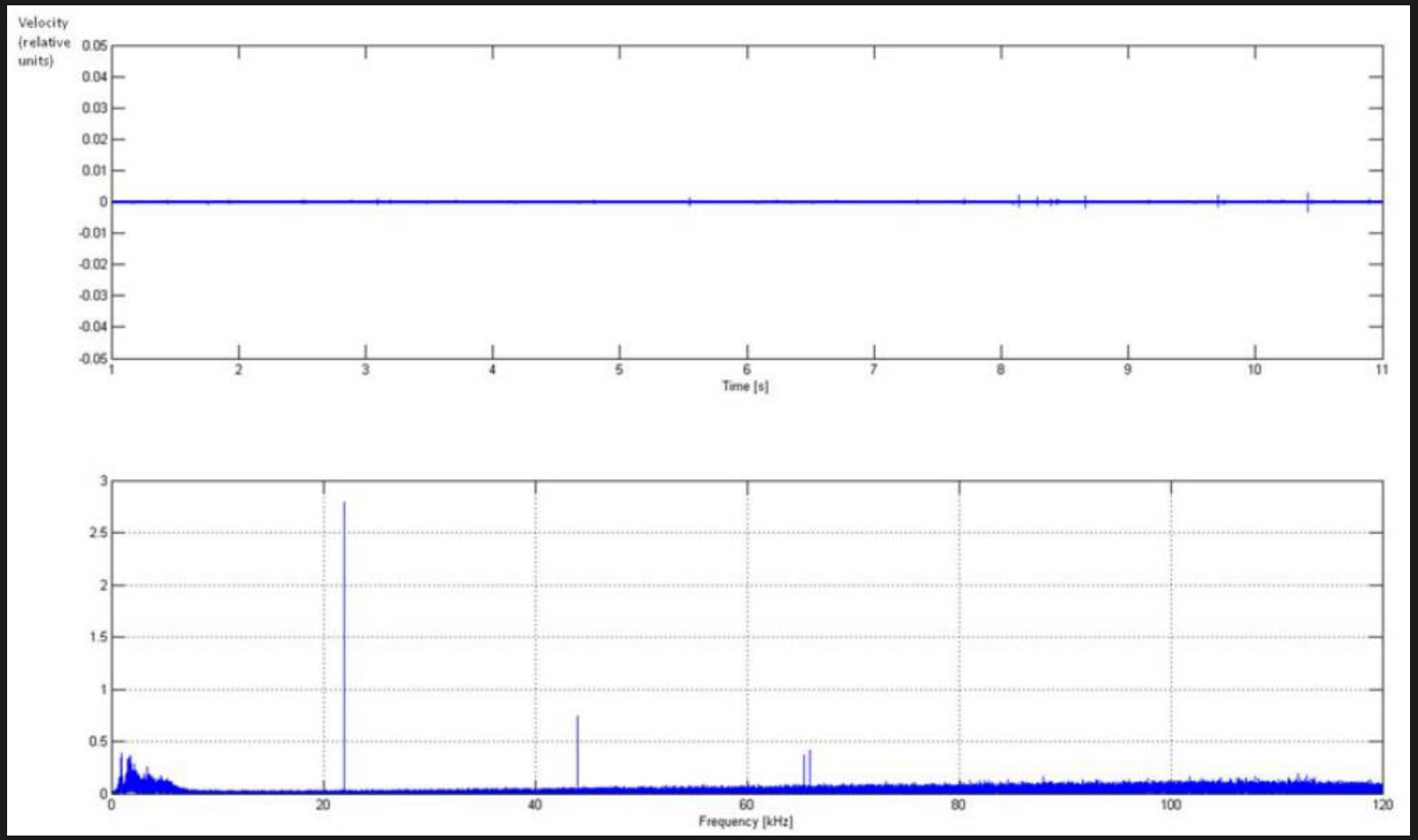
Lessons Learnt
Eurisol 4 MW Full-Scale Hydraulic Test

- Measured pressure fluctuations correlate well with CFD LES.



Lessons Learnt
Eurisol 4 MW Full-Scale Hydraulic Test

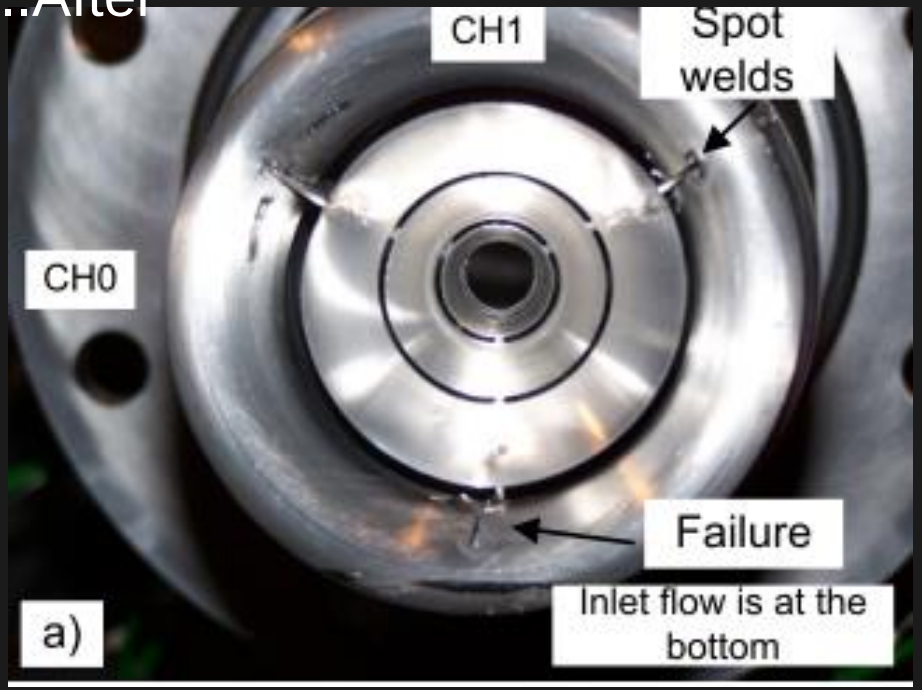
- LDV measurement of inner cavitation controlled by static pressure.



Lessons Learnt
Eurisol 4 MW Full-Scale Hydraulic Fest

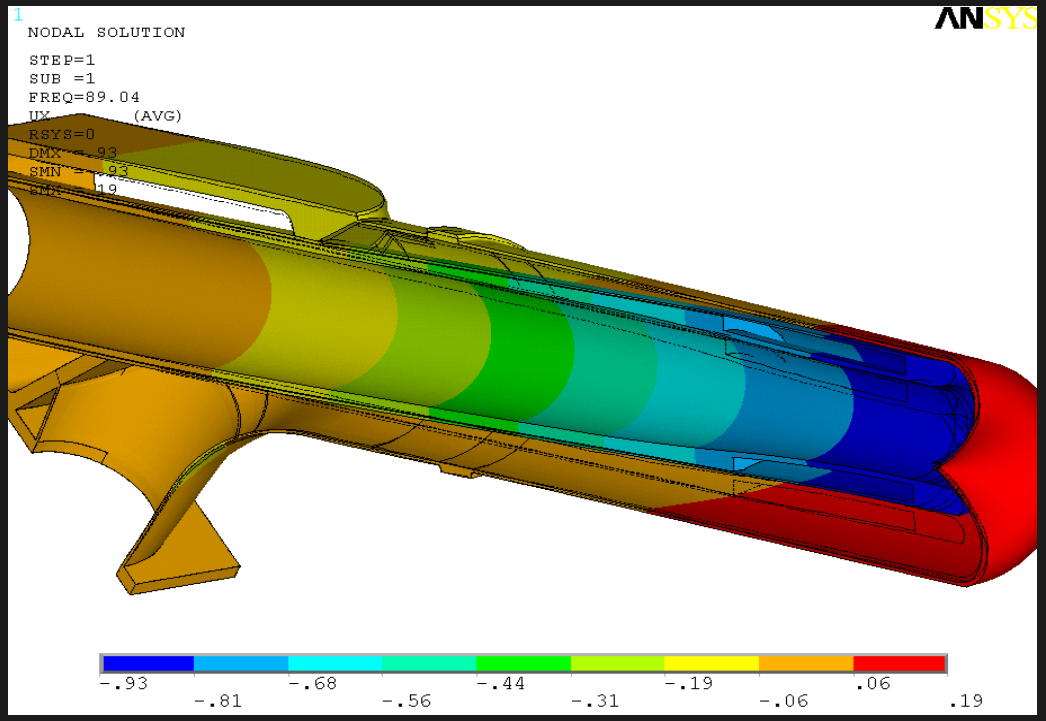
- Failure of the vane attachments

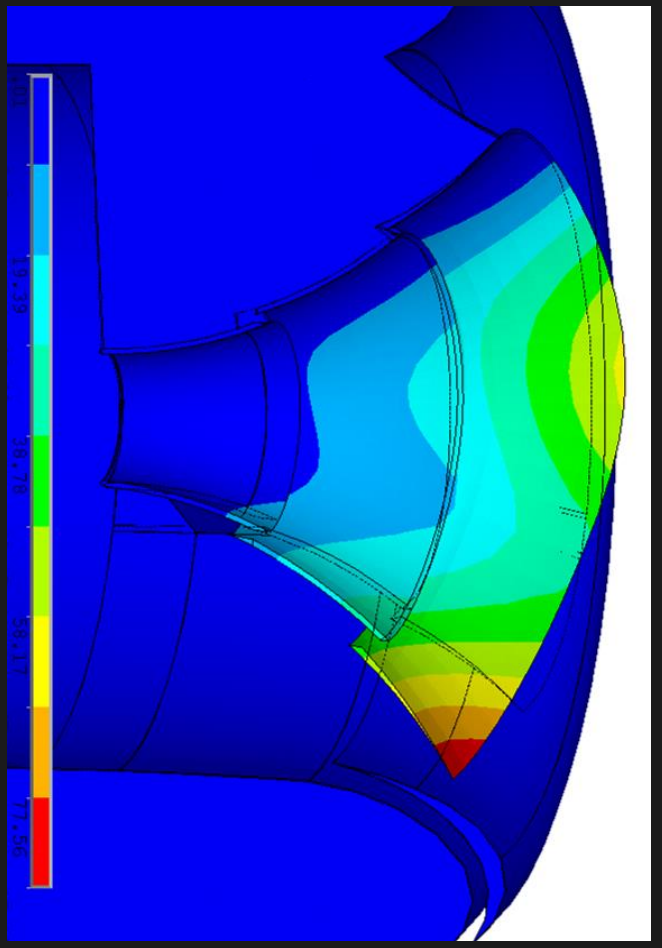
..After



Lessons Learnt
Eurisol 4 MW : Post Test Analysis

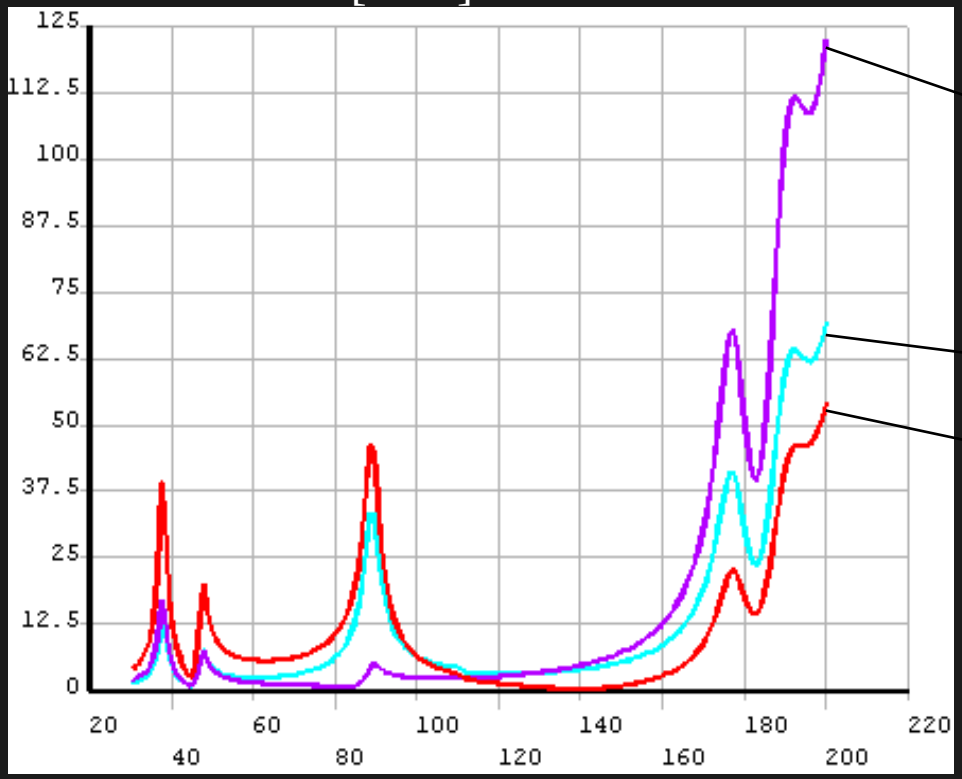
- Failure of the vane attachments : global / local modes

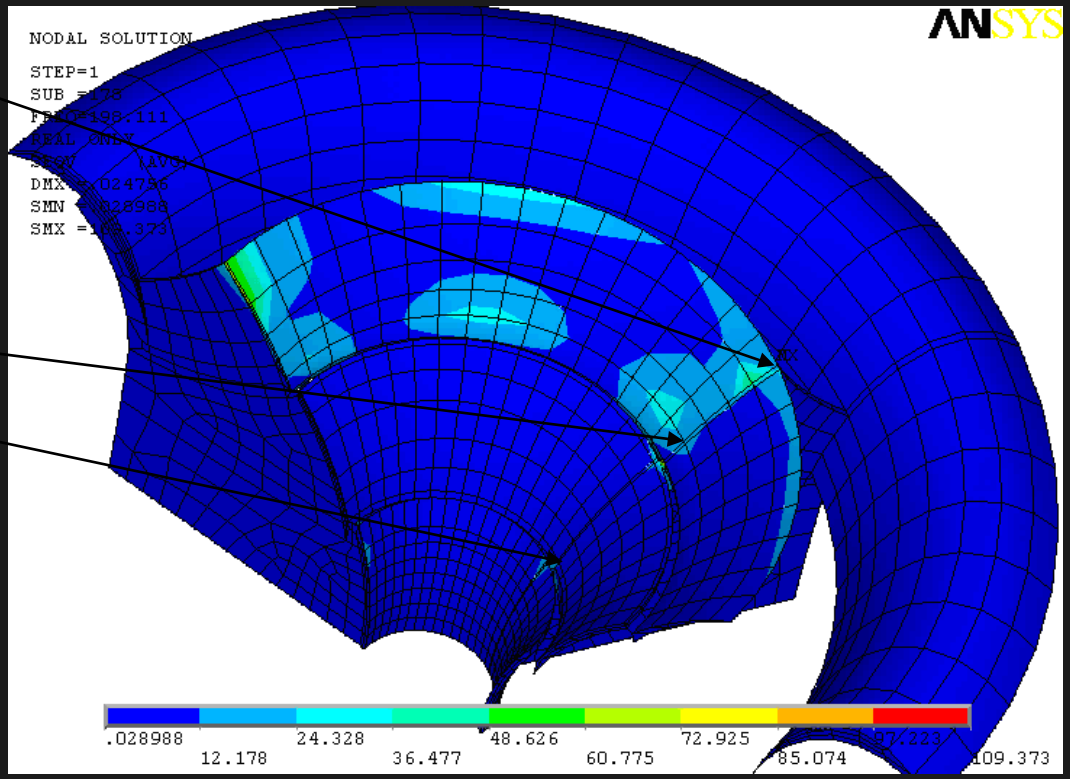




Lessons Learnt
Eurisol 4 MW : Post Test Analysis

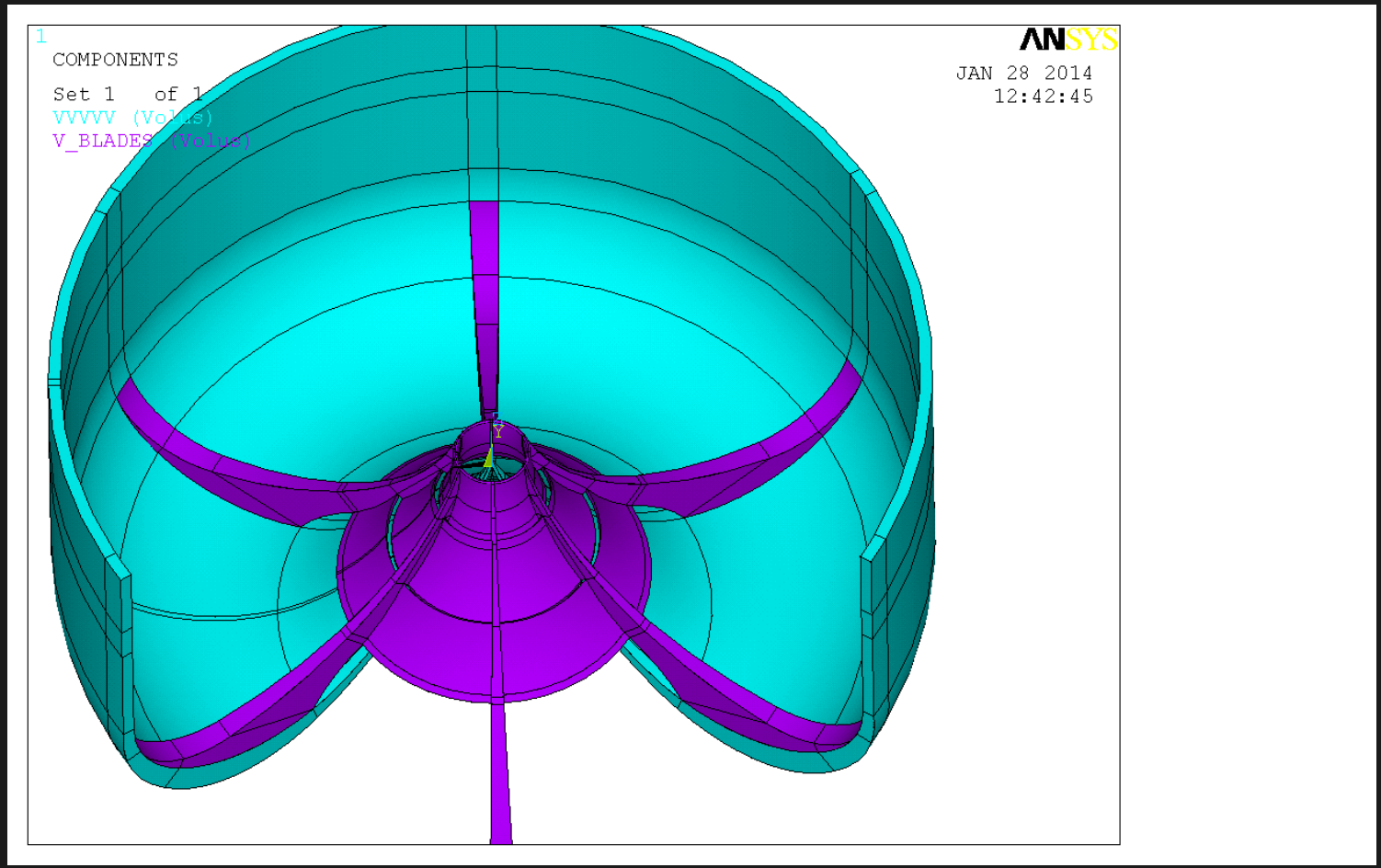
- Failure caused by high cycle fatigue





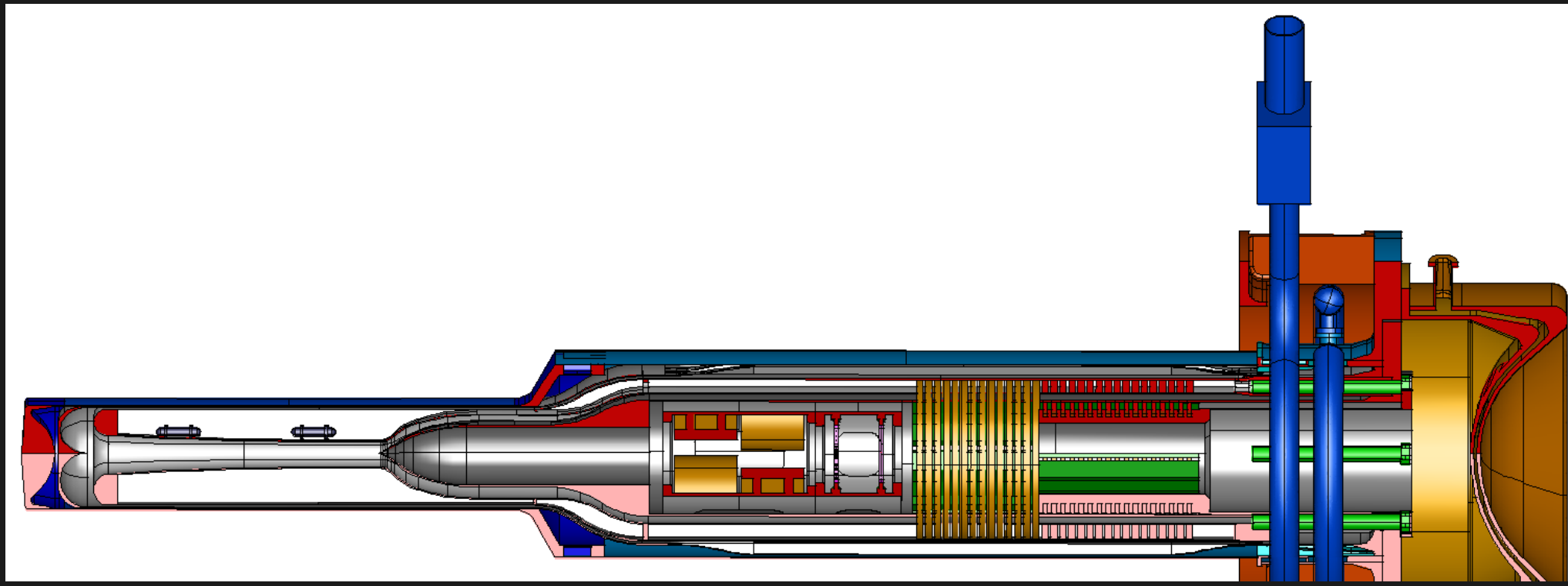
Lessons Learnt
Eurisol 4 MW : Post Test Analysis

- …to be cured by better design



Proposed design of a high-power spallation source for ADS

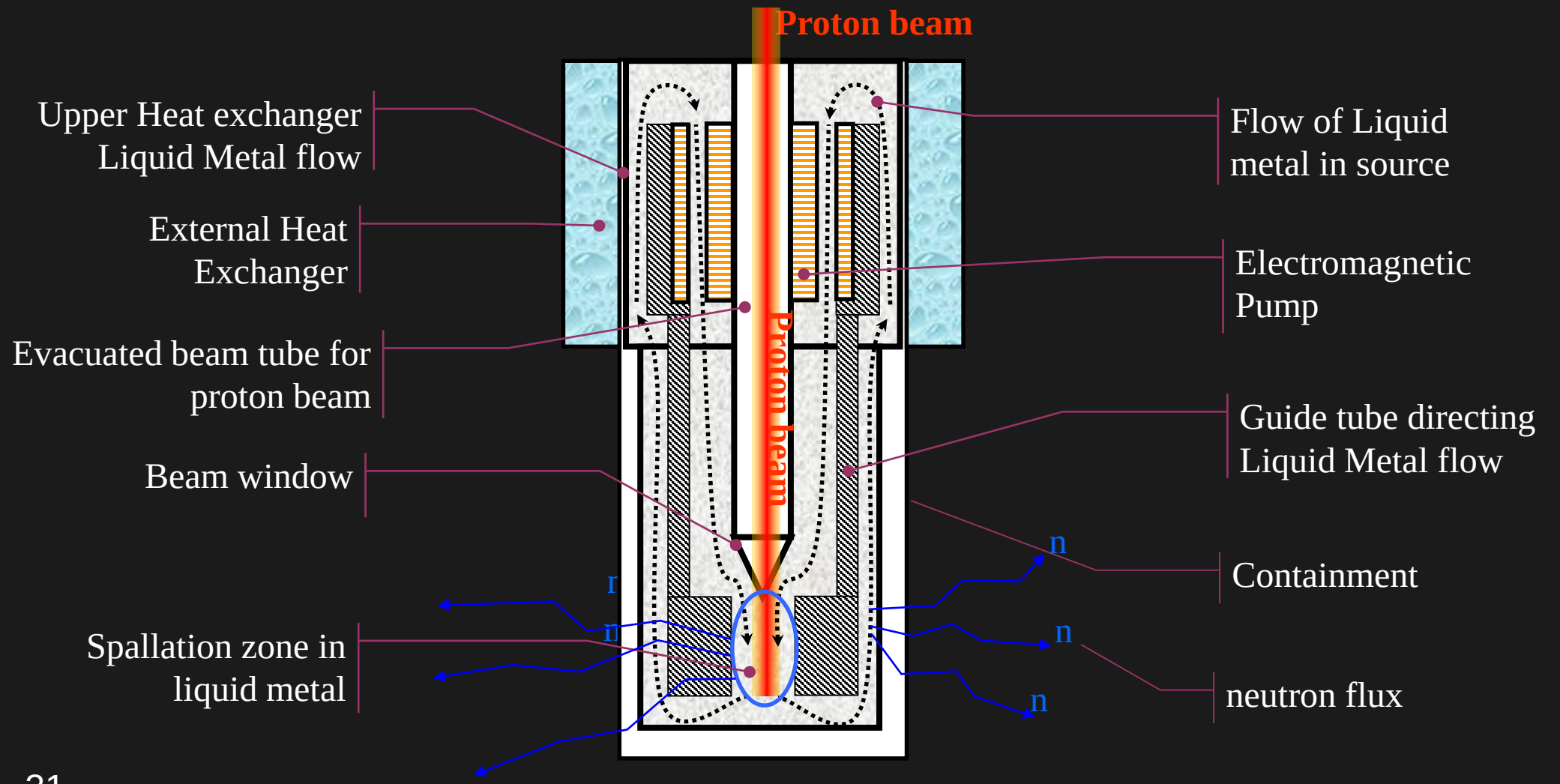
- Lessons learnt from developing neutron spallation sources flowing into a new design of a neutron spallation source adapted to the ADS



Proposed design of a high-power spallation source for ADS

Relevance	Relevant Safety Guideline
System	Multiple containment strategy is vital
	Natural circulation is of little value
	Leaks must not flow into the path of the beam
	Leak analysis and mitigation strategy in place
	No organic cooling liquid inside source
	Development using multi-physics analysis
Component	Calibrated electro-magnetic pumps are reliable
	High-grade finishes reduce drag losses
	T91 /316 stainless steel are an appropriate choice
Signal	Diversify flow-meter instrumentation
	Instruments in- and outside of source (beam)
	Ensure leak detection using diverse sensors
	Pressure transducers and TCs are resilient

Proposed design of a high-power spallation source for ADS



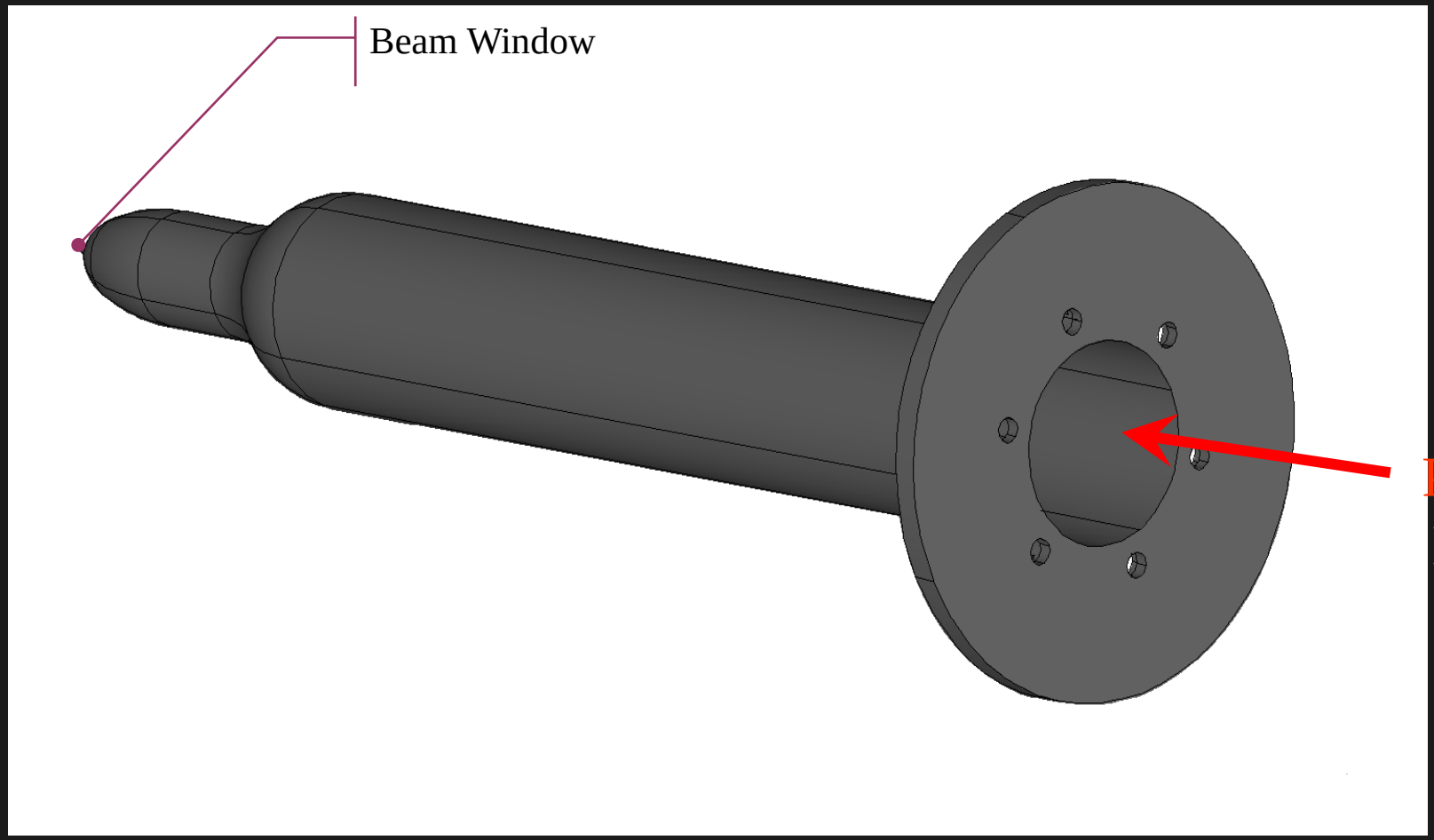
Proposed design of a high-power spallation source for ADS

Engineering Concept

Innovative Design of a compact target

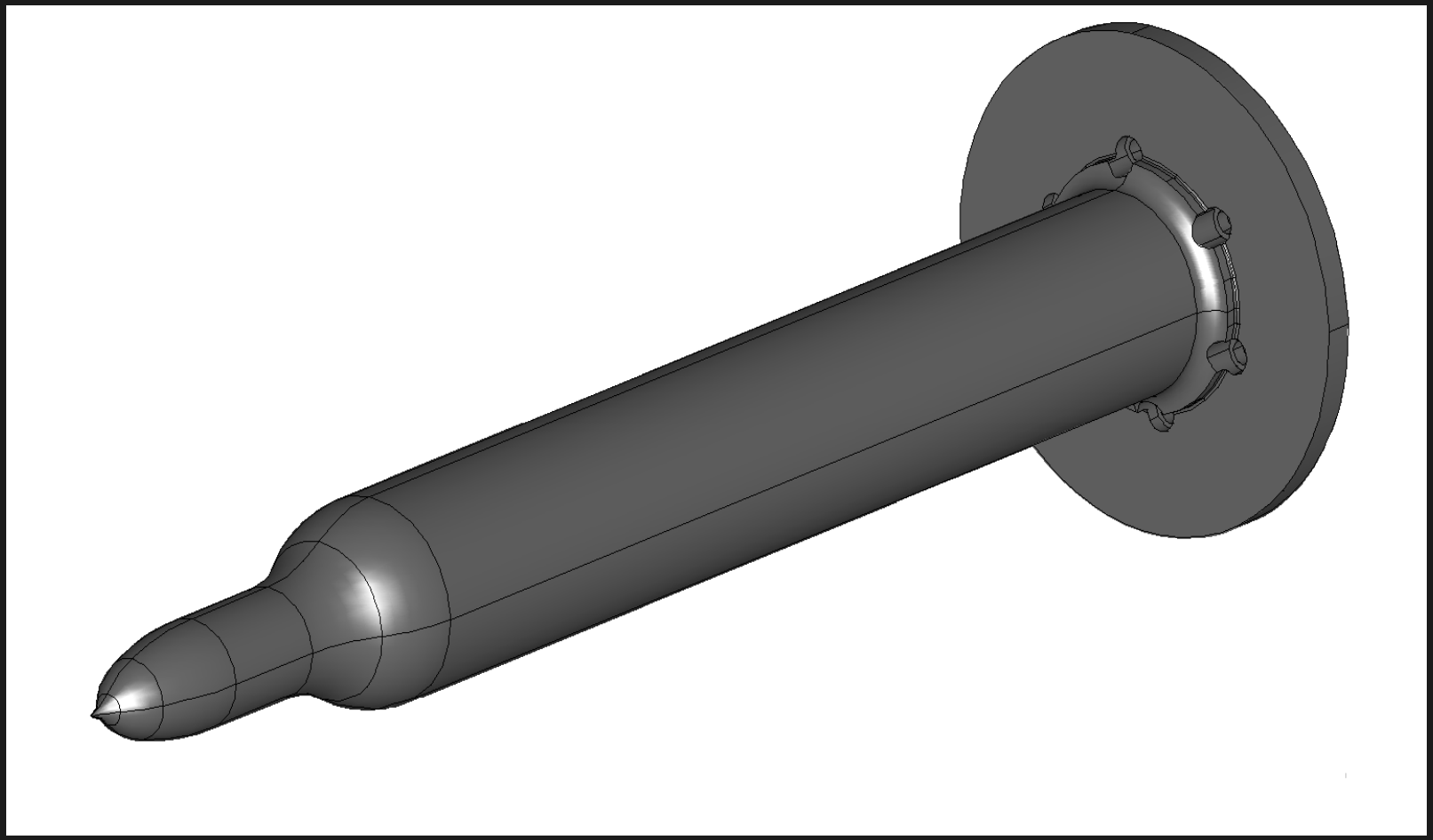
Illustrations of the assembly procedure

Proposed design of a high-power spallation source for ADS



Inner Beam Tube

Proposed design of a high-power spallation source for ADS



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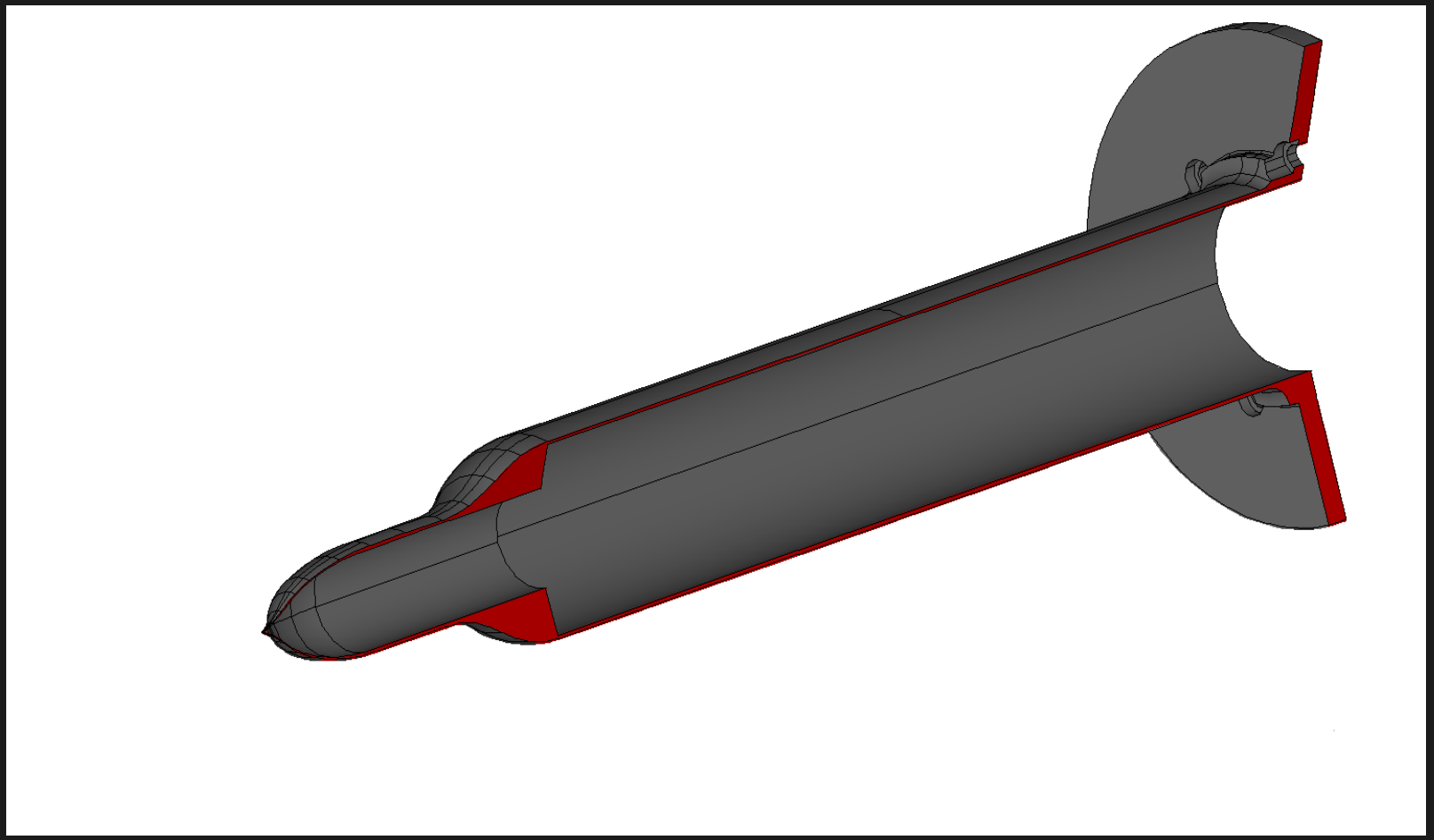

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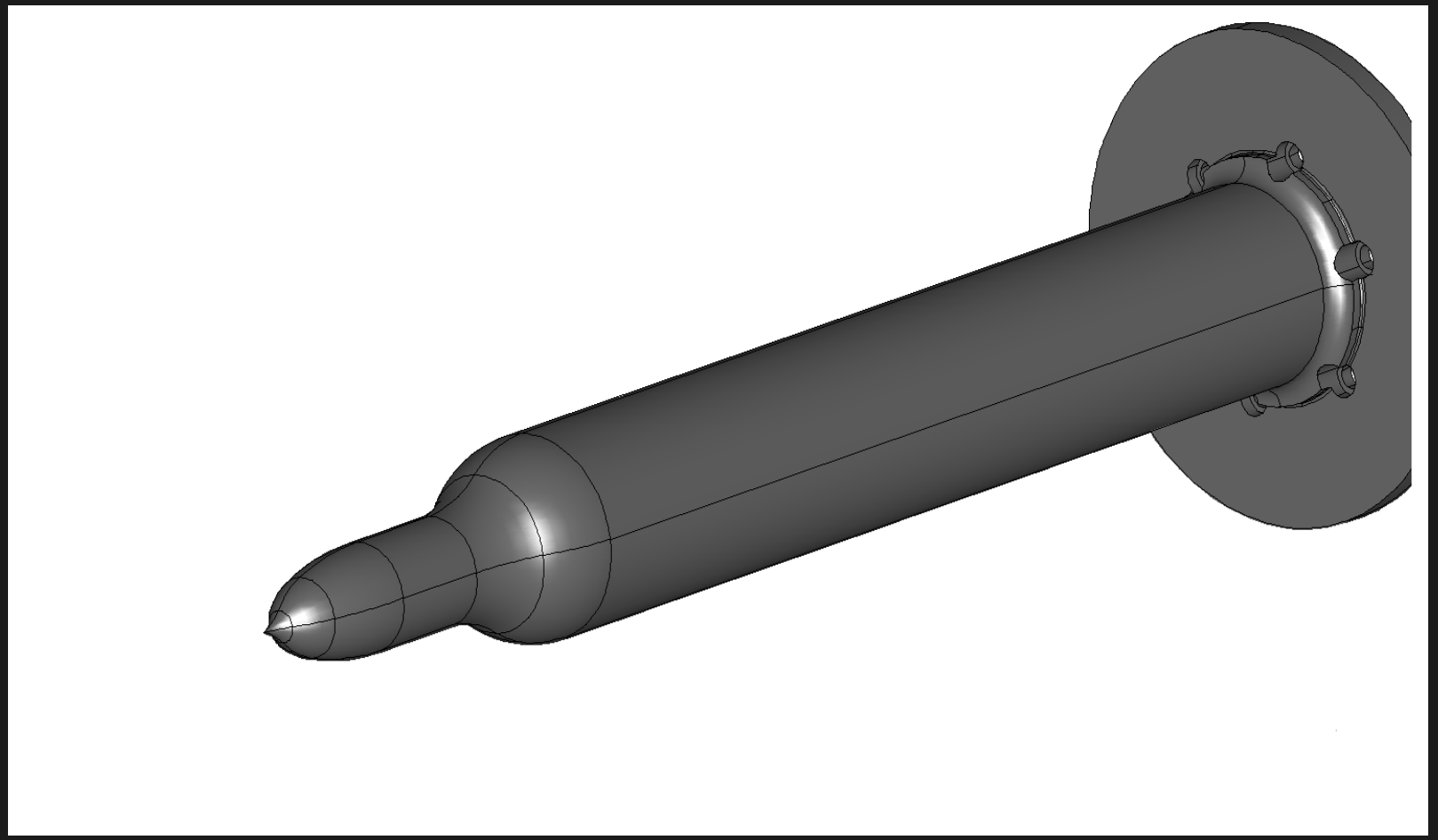

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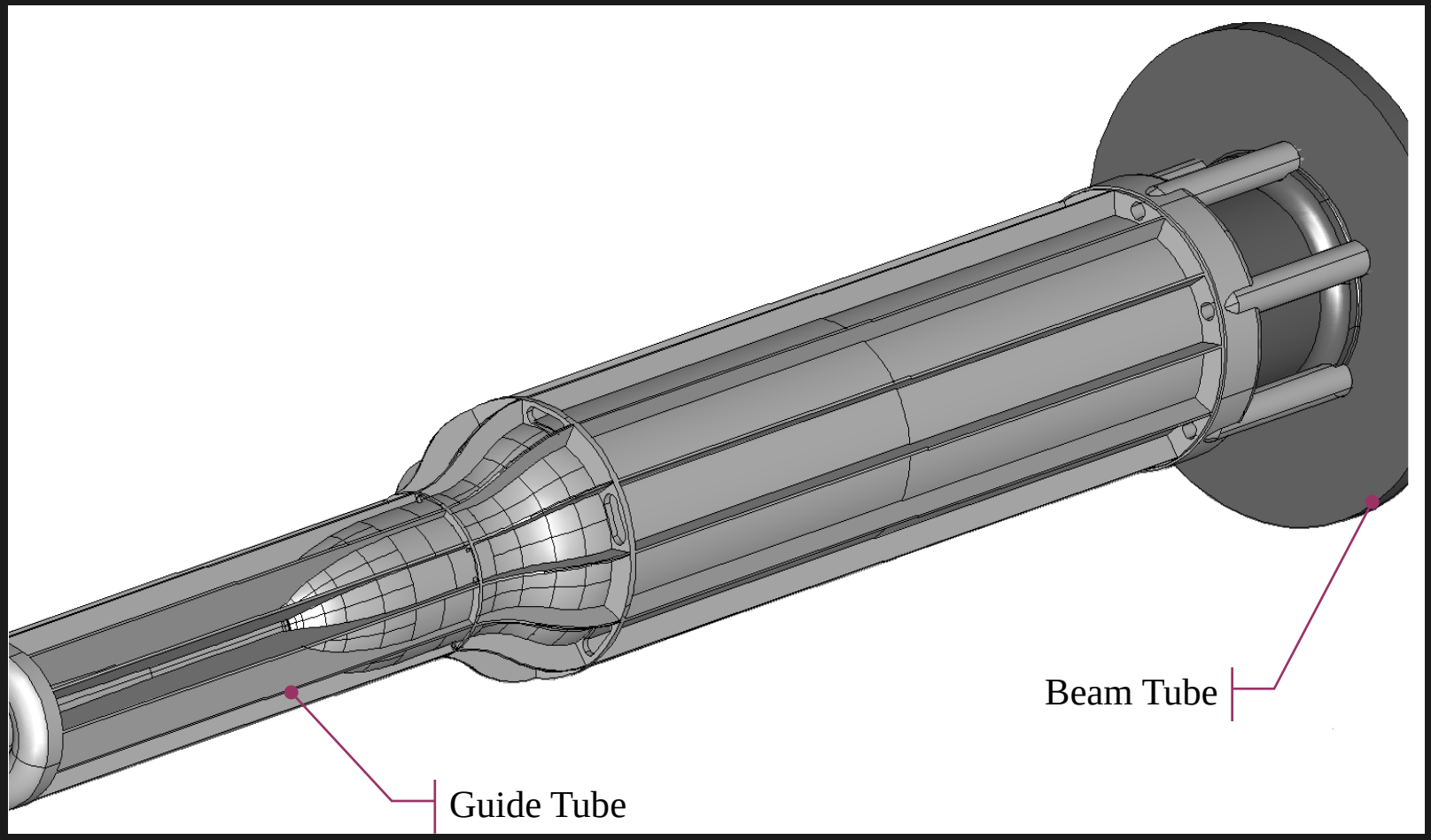

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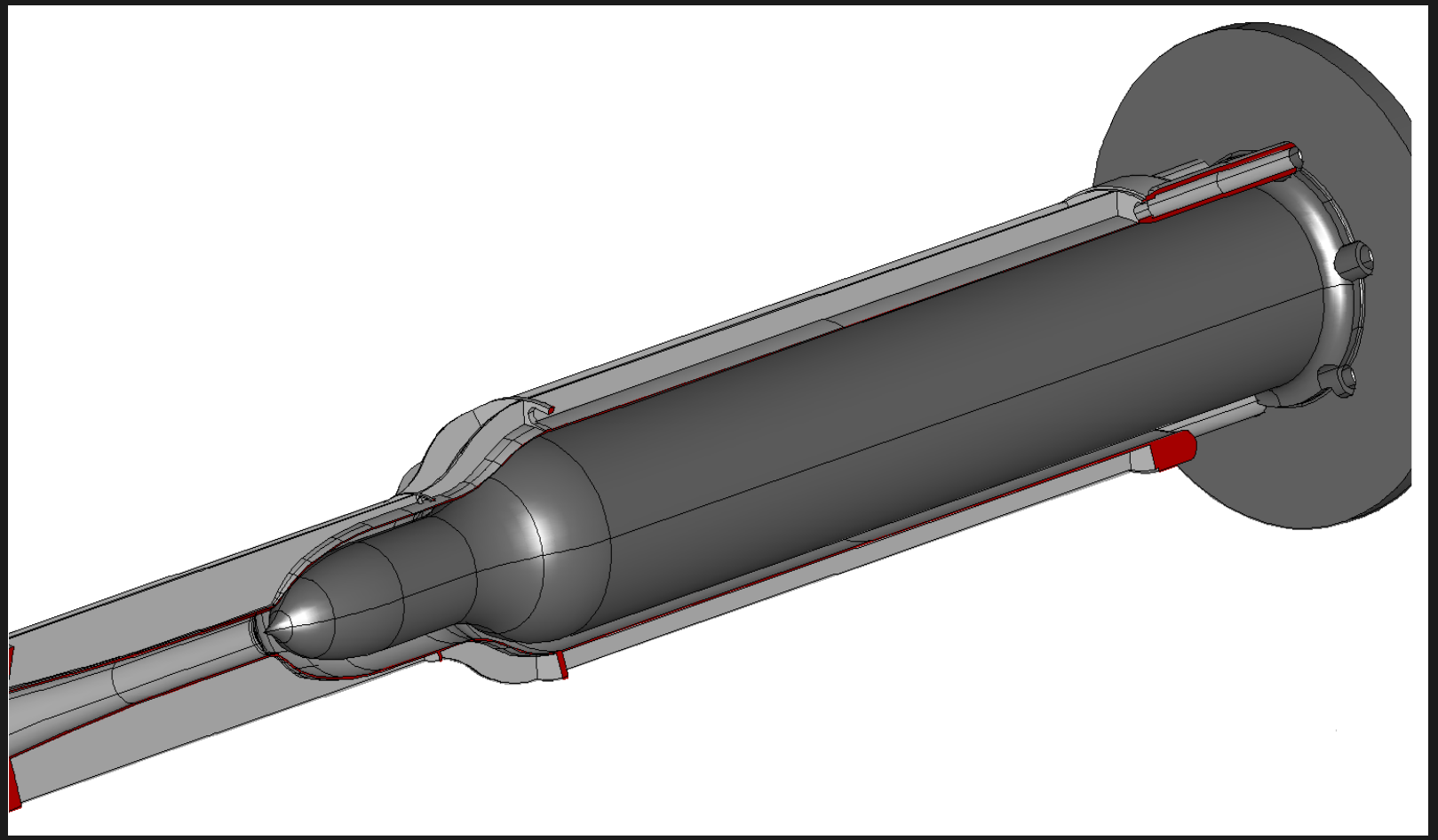

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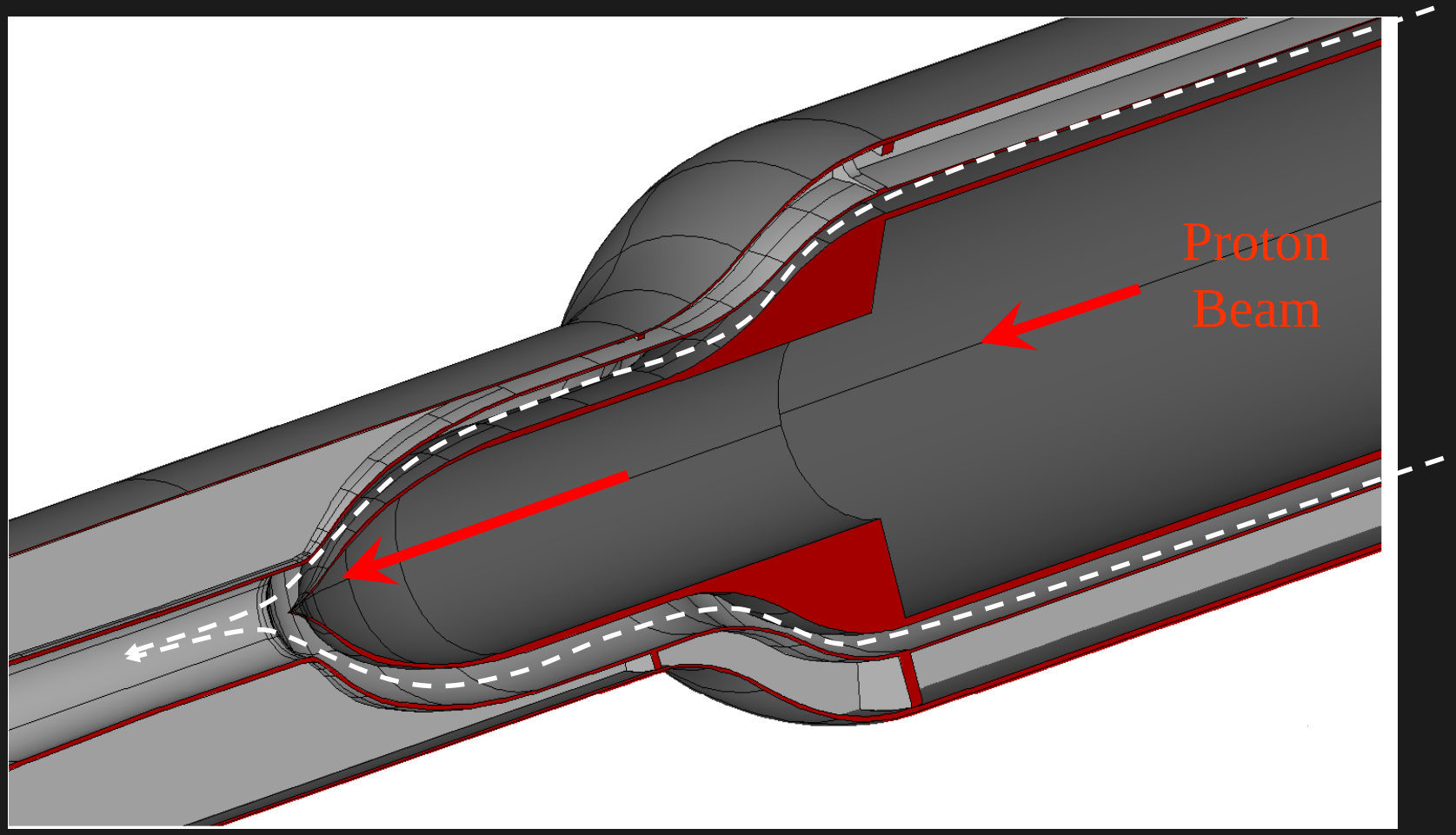

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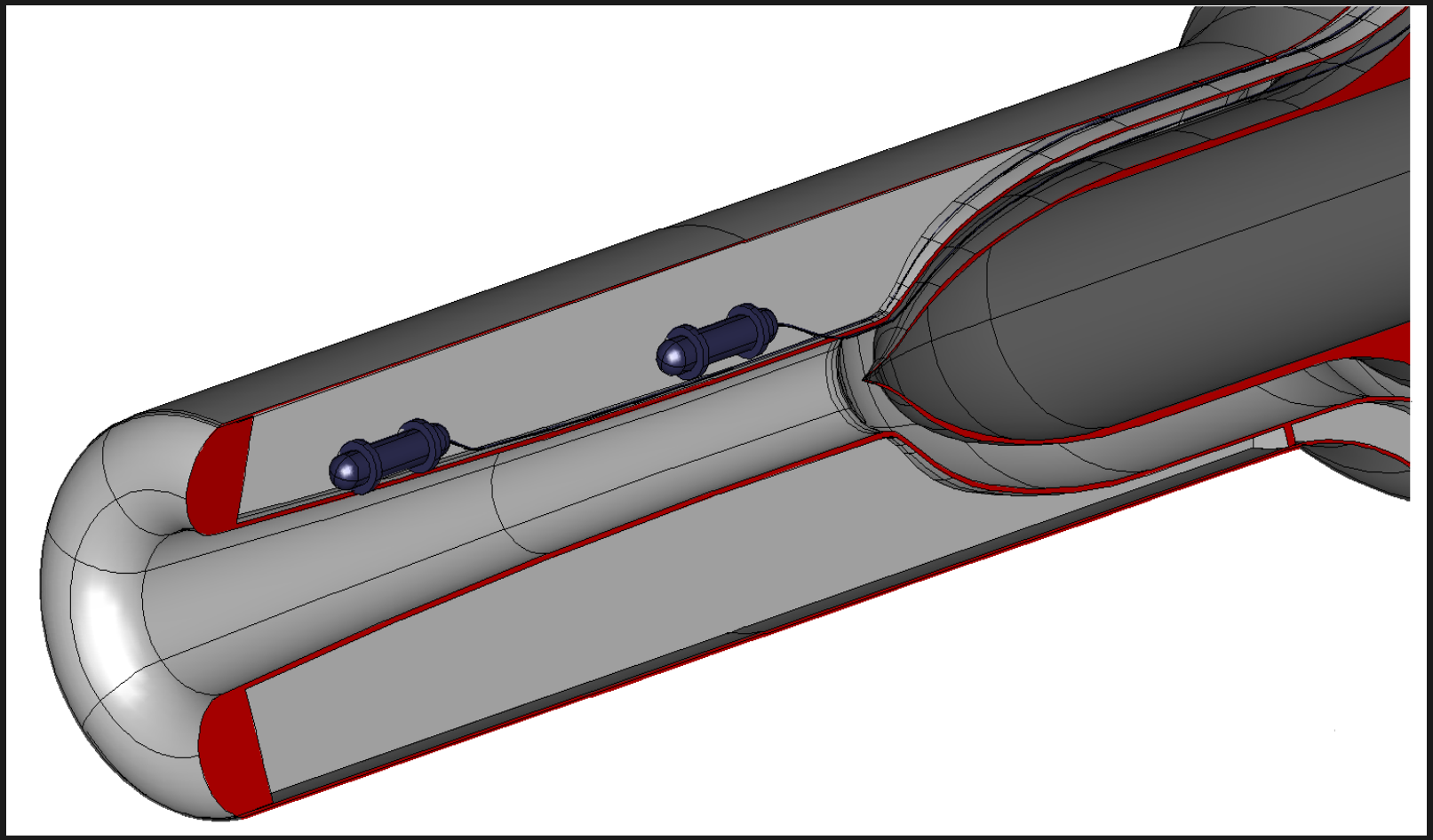
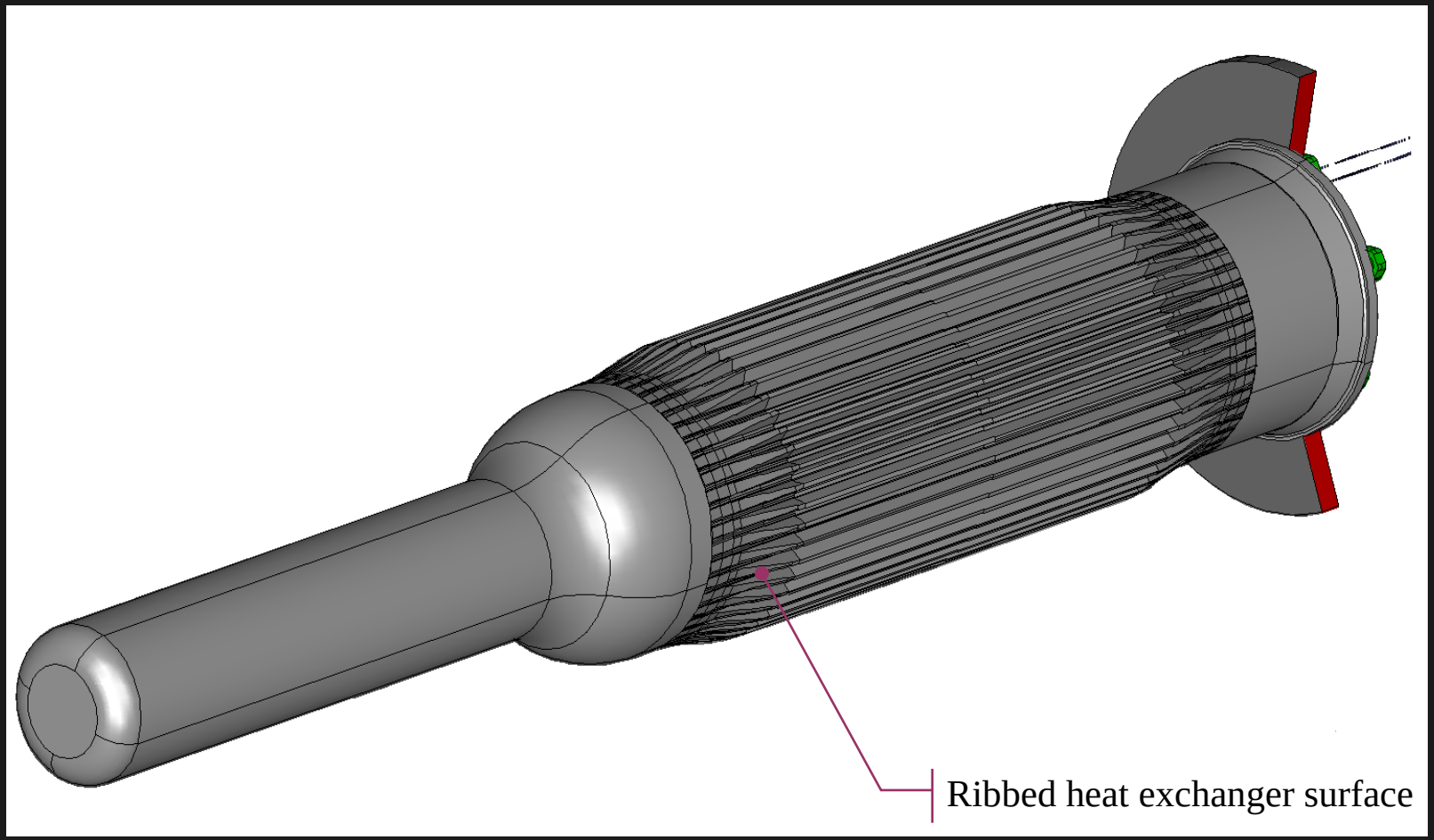
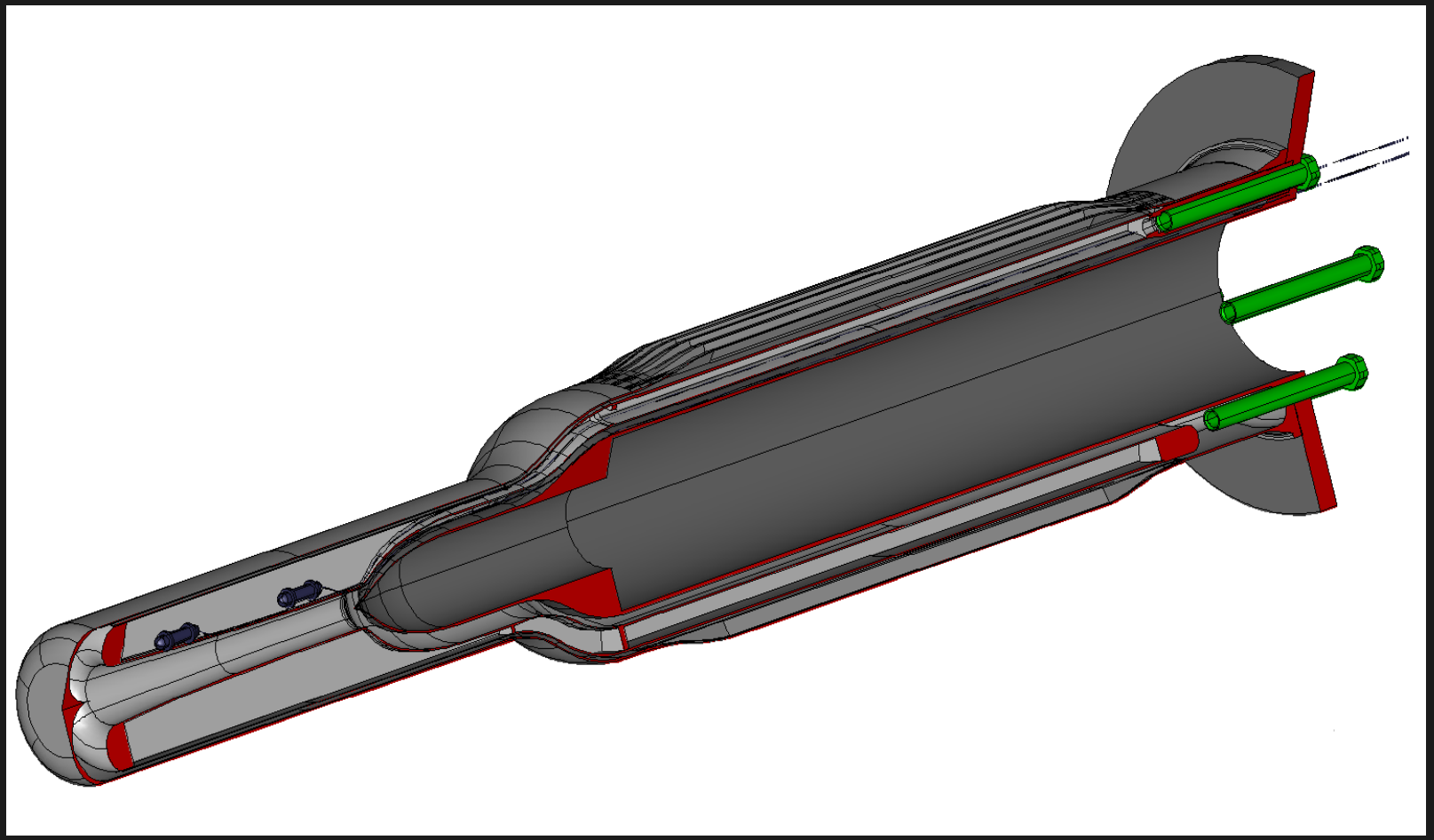


Proposed design of a high-power spallation source for ADS

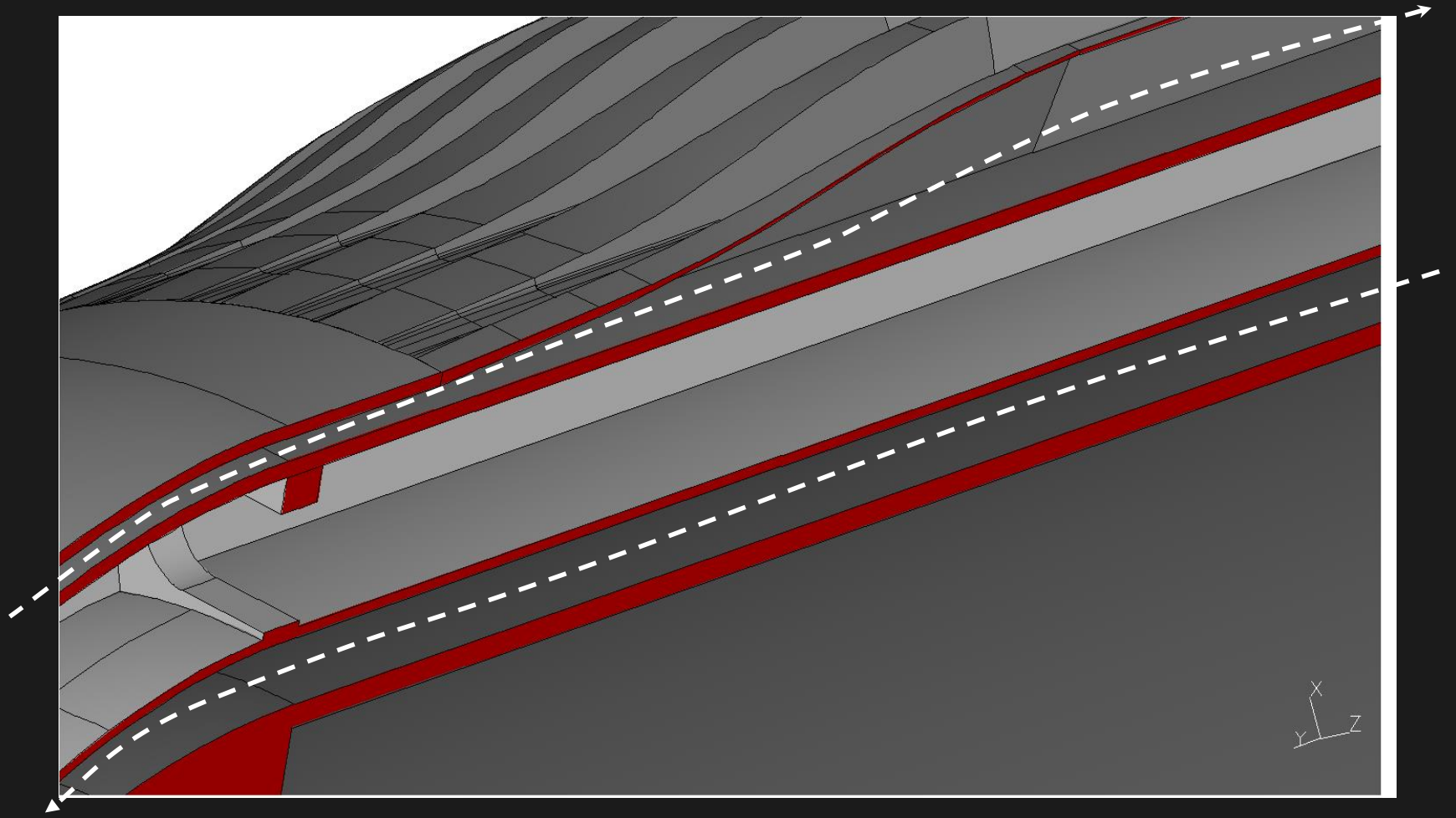


Outer shell of target

Proposed design of a high-power spallation source for ADS

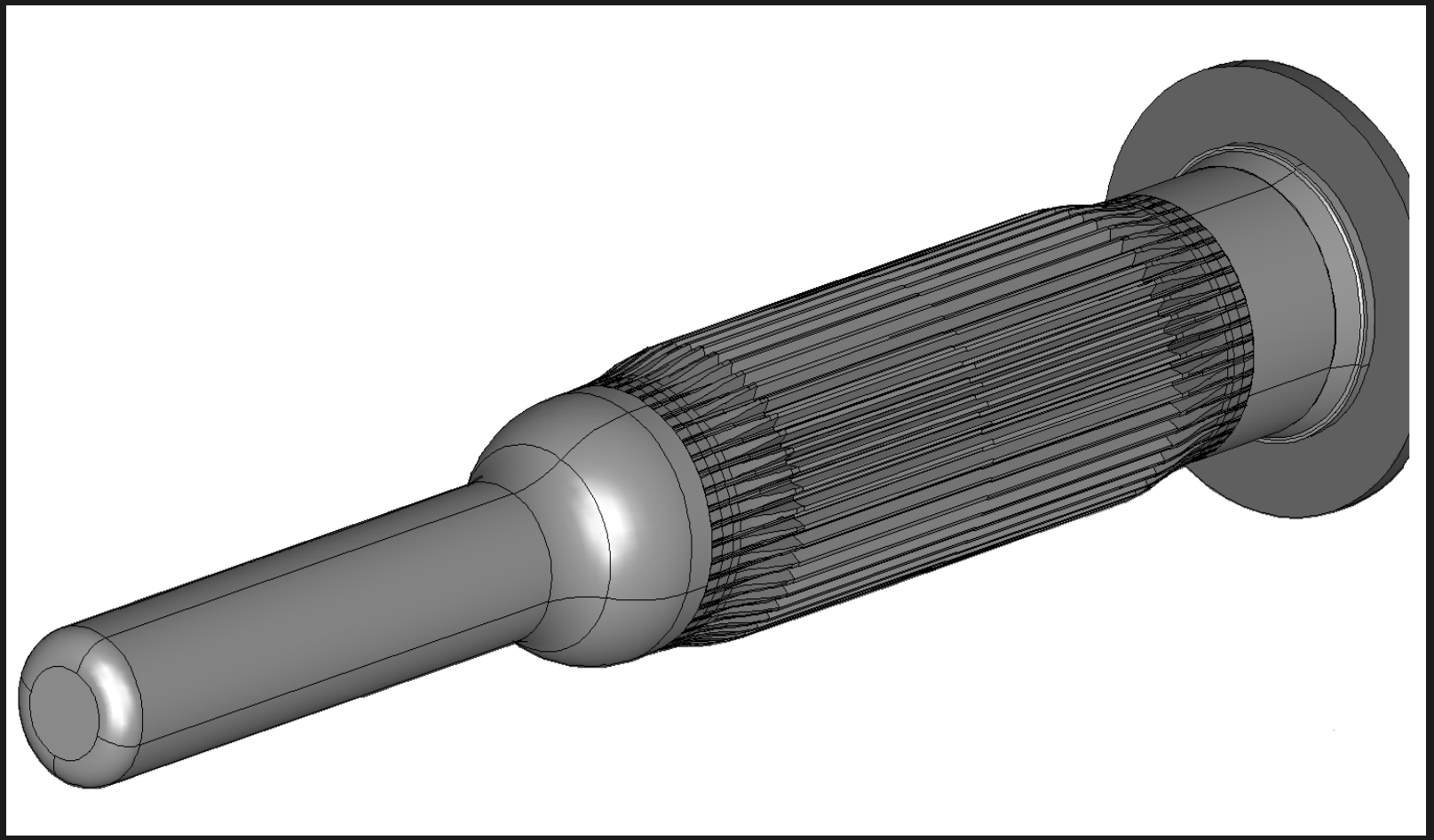


Proposed design of a high-power spallation source for ADS

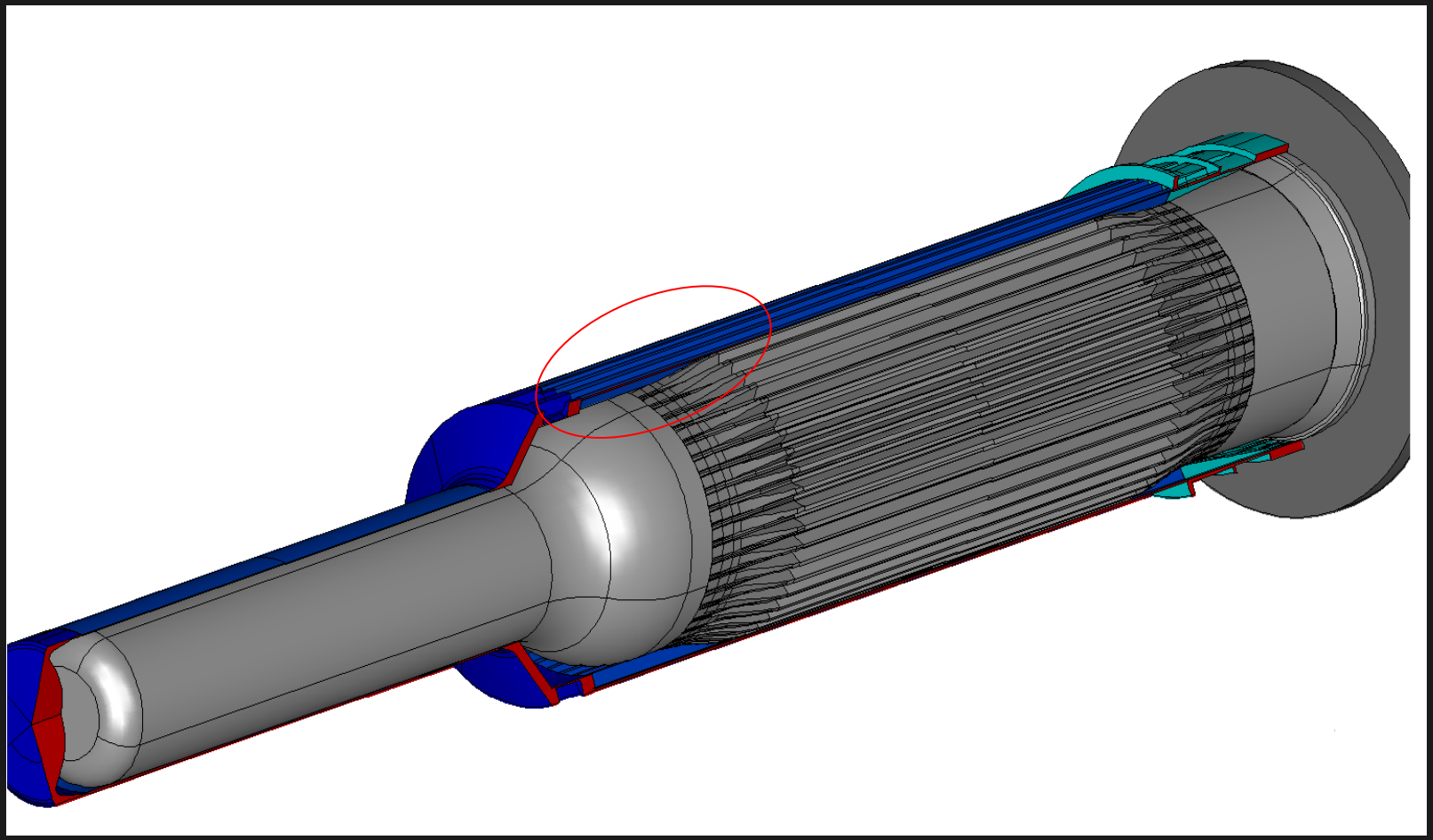


Liquid metal flow

Proposed design of a high-power spallation source for ADS

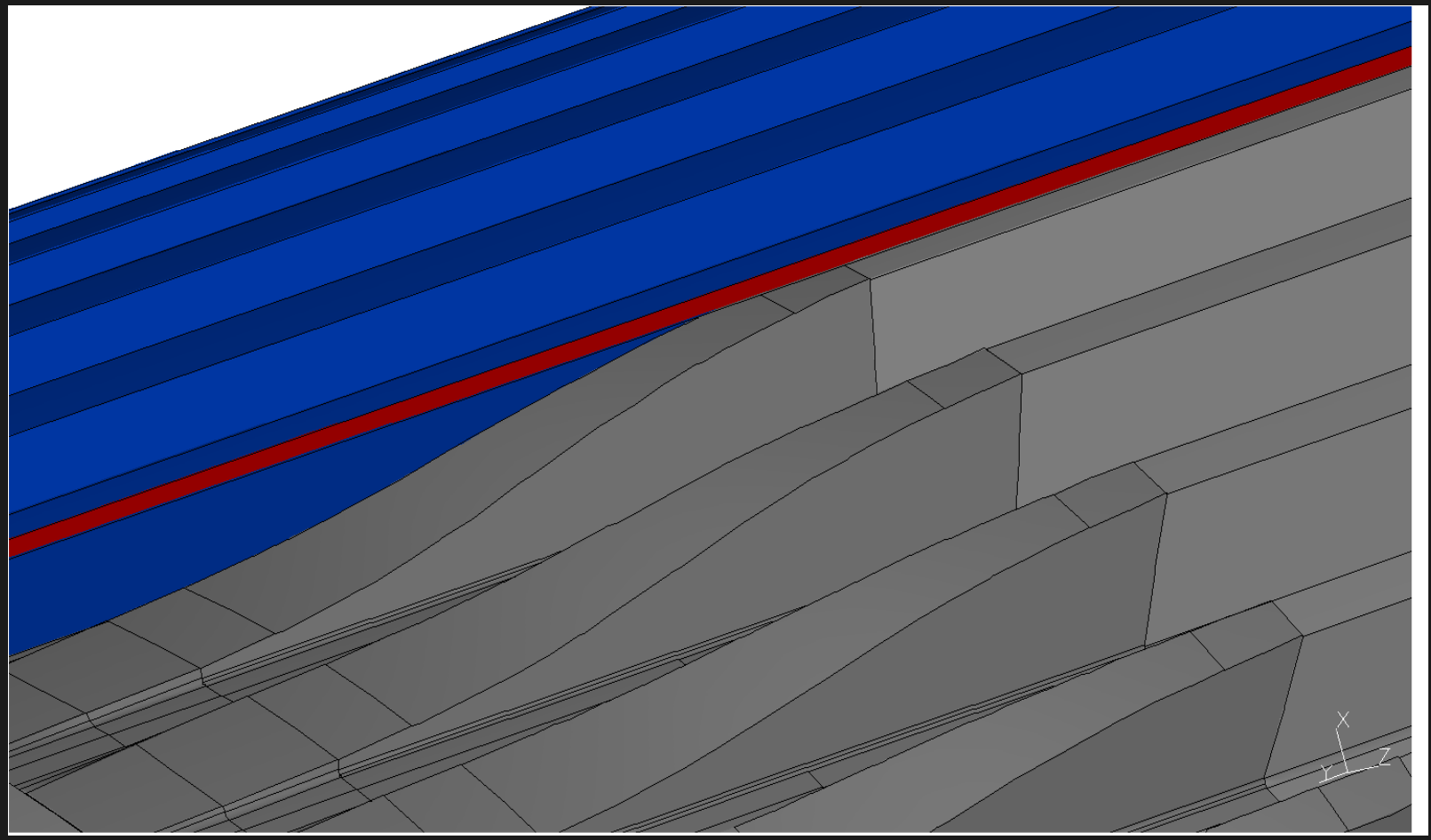


Proposed design of a high-power spallation source for ADS

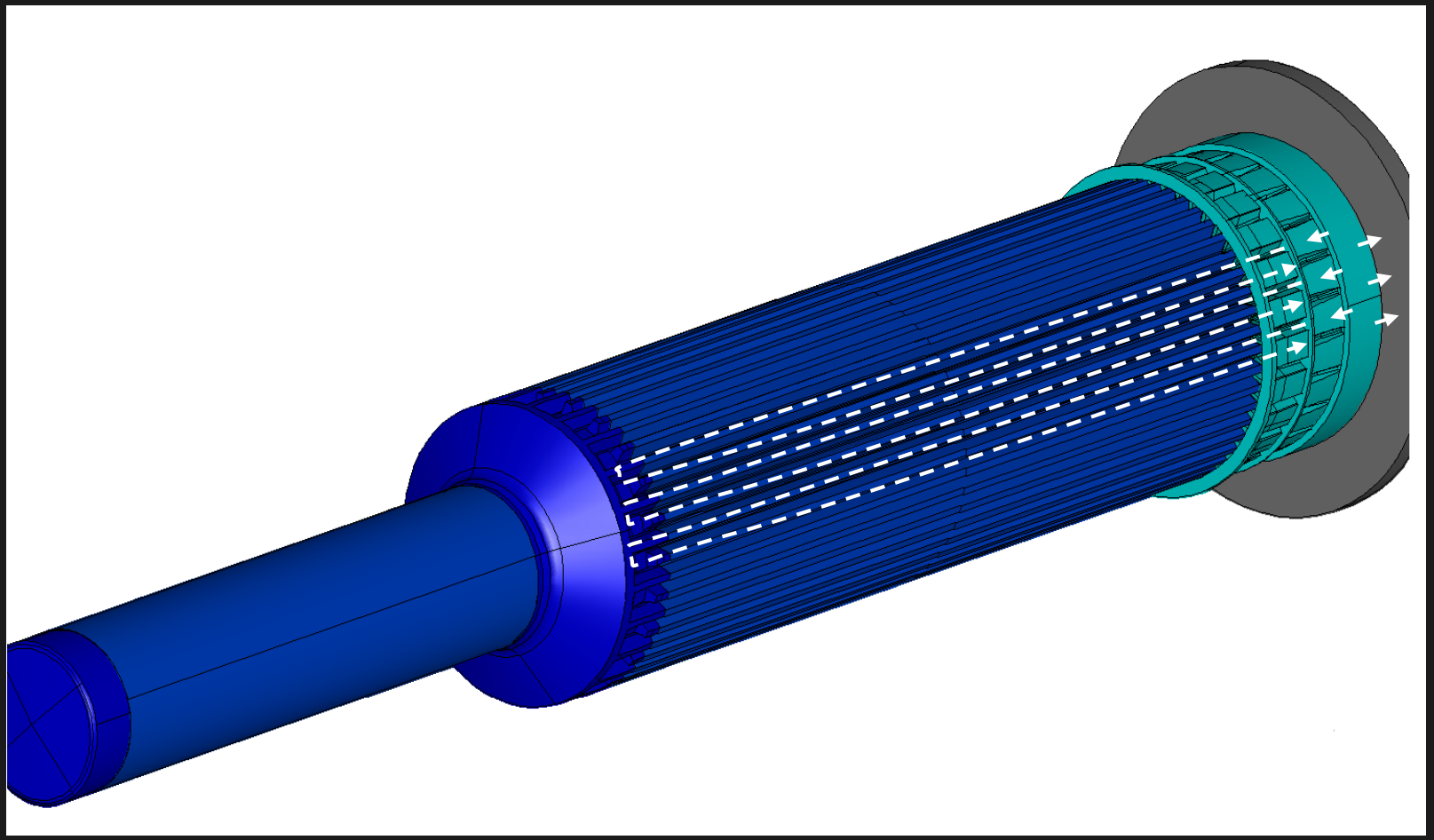


Outer containment serves as a heat exchanger

Proposed design of a high-power spallation source for ADS

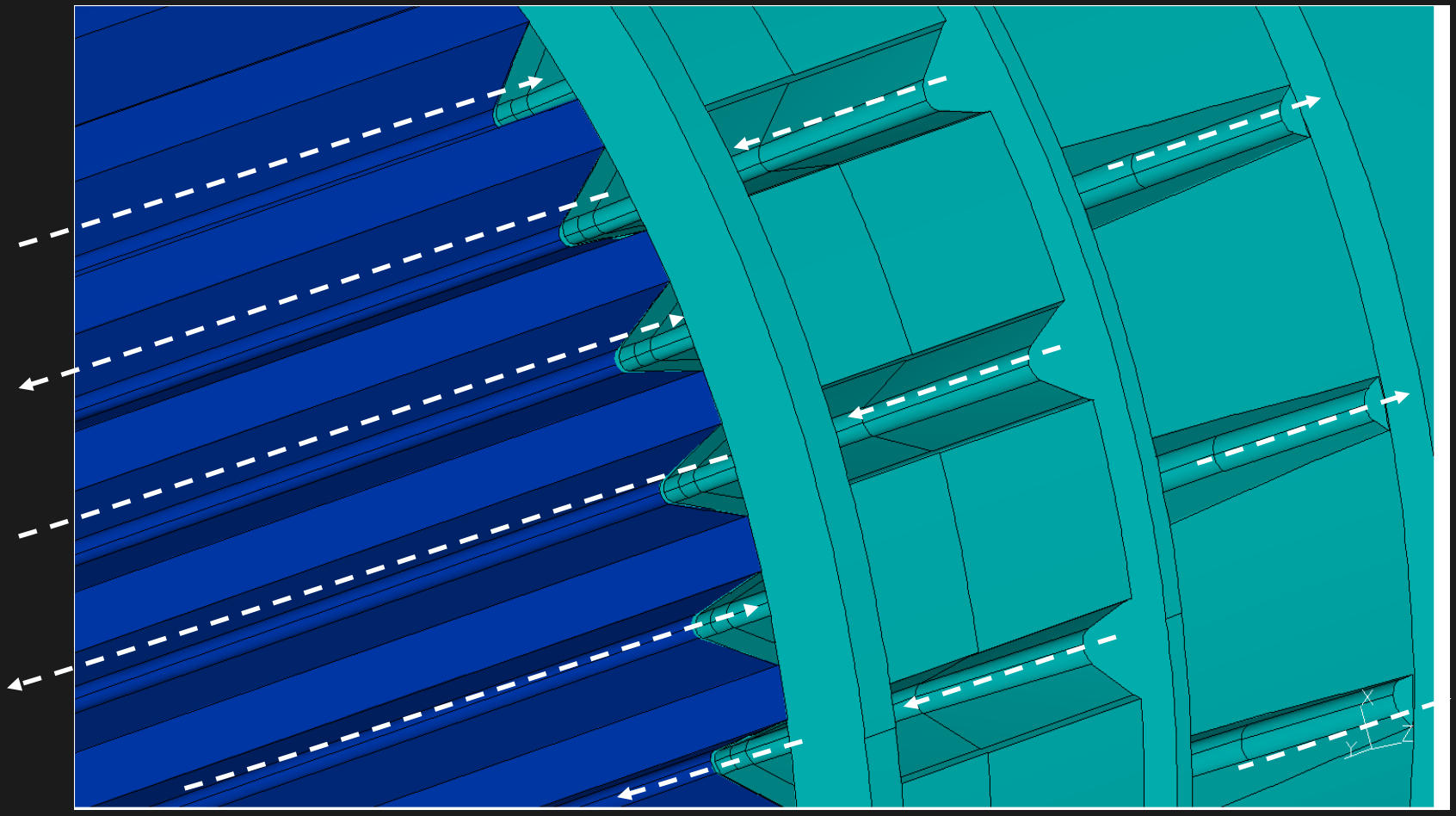


Proposed design of a high-power spallation source for ADS



Inner circulation of cooling fluid in external containment

Proposed design of a high-power spallation source for ADS



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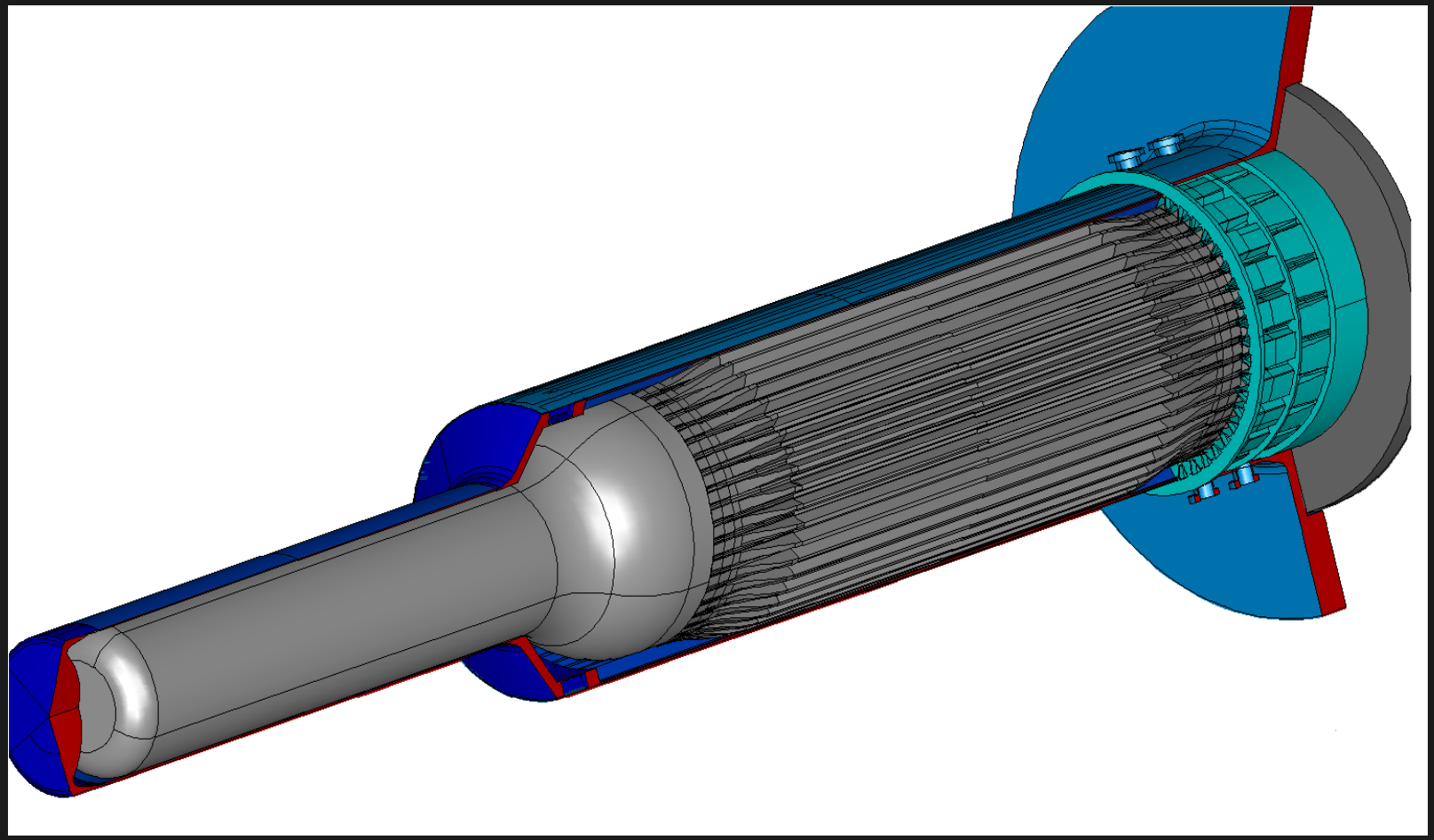

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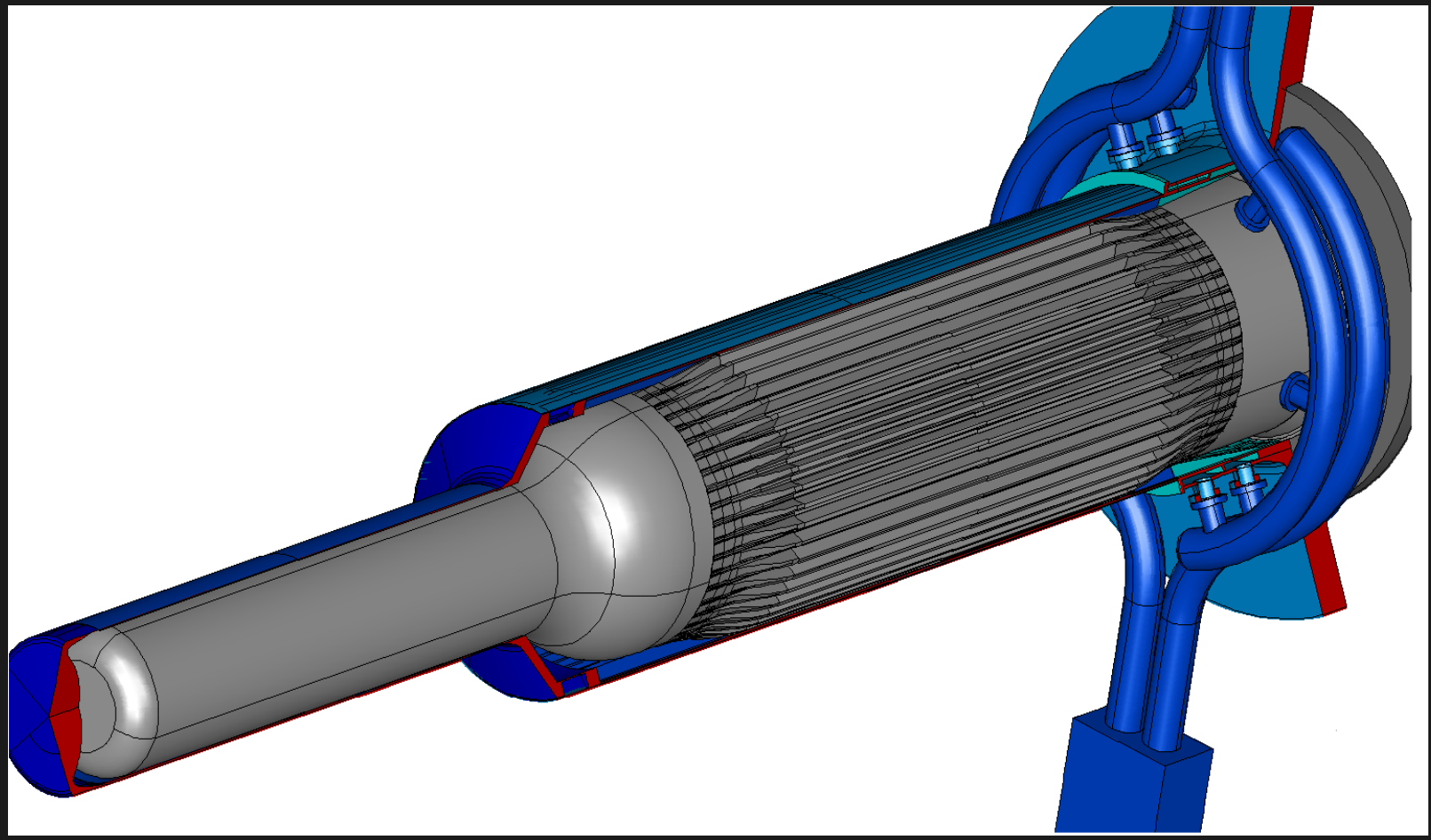
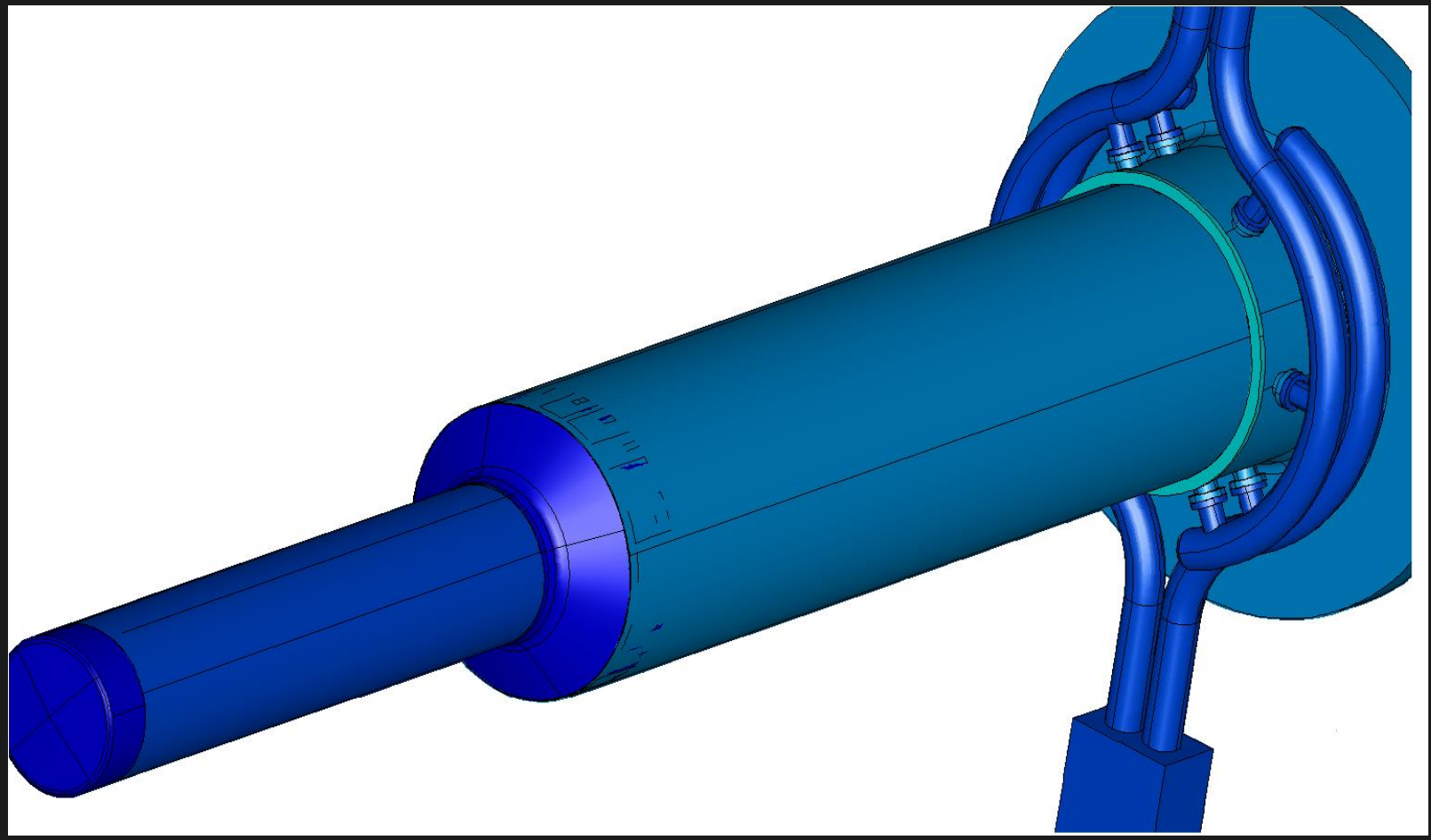


Proposed design of a high-power spallation source for ADS



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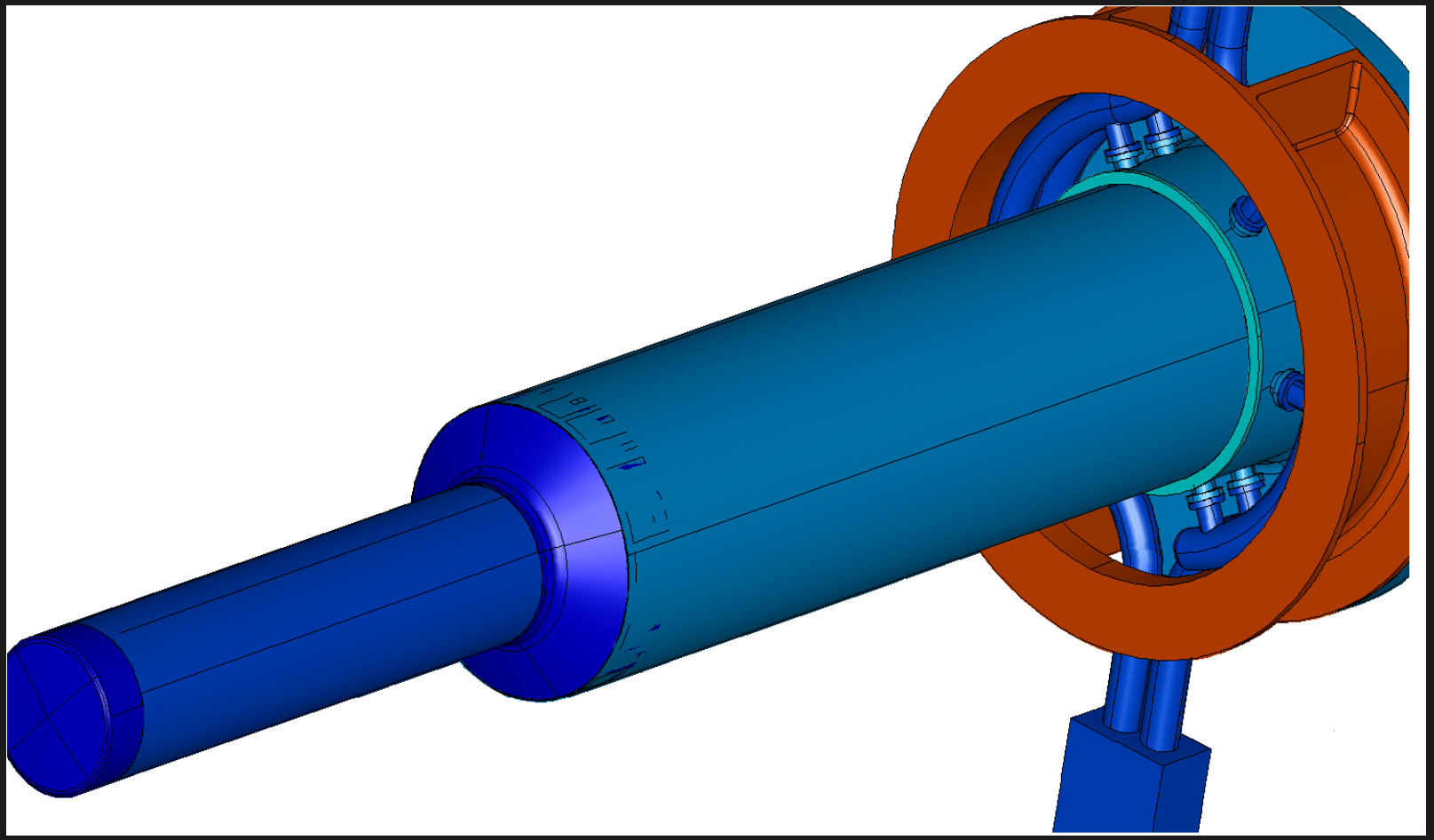

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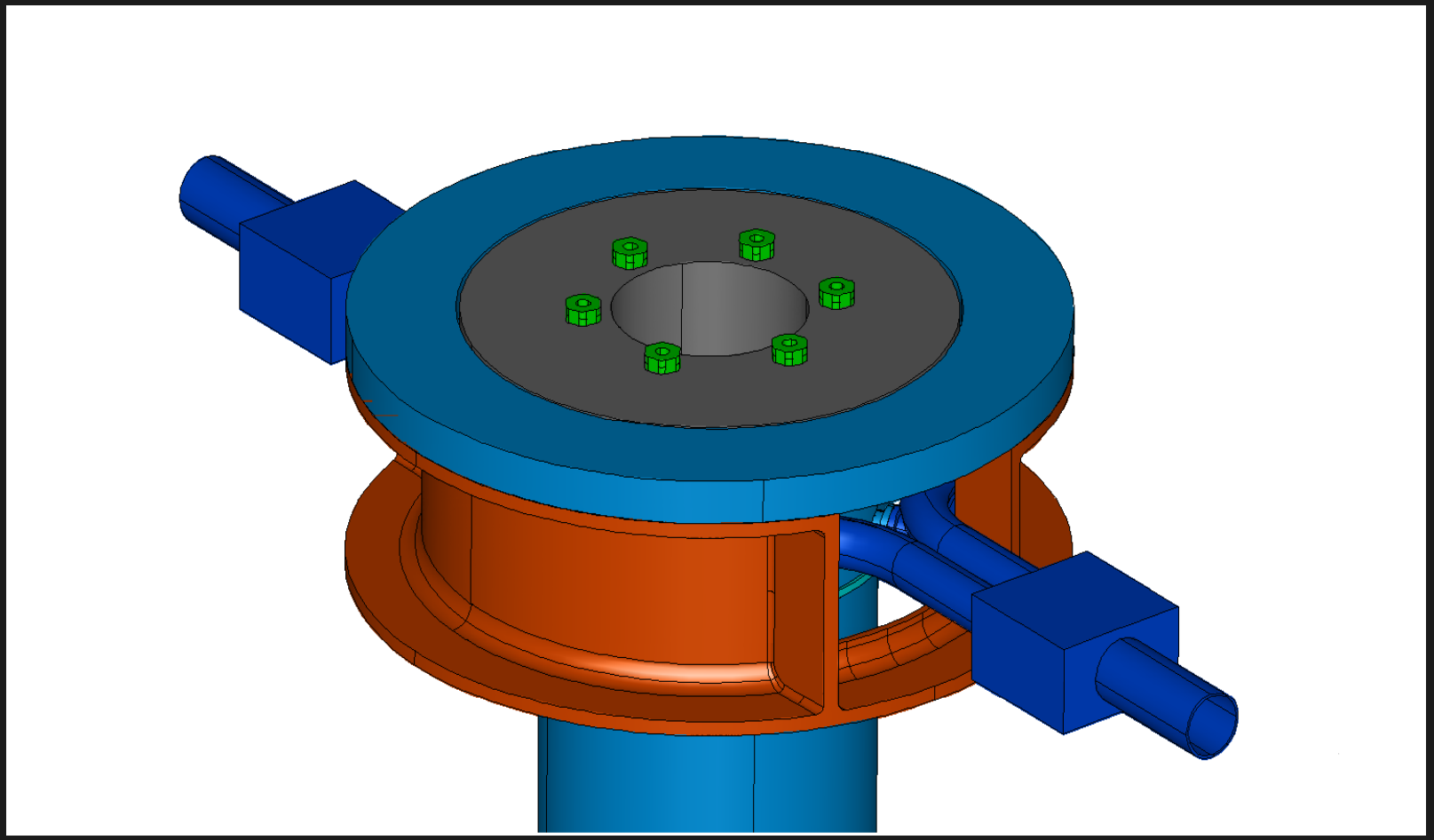

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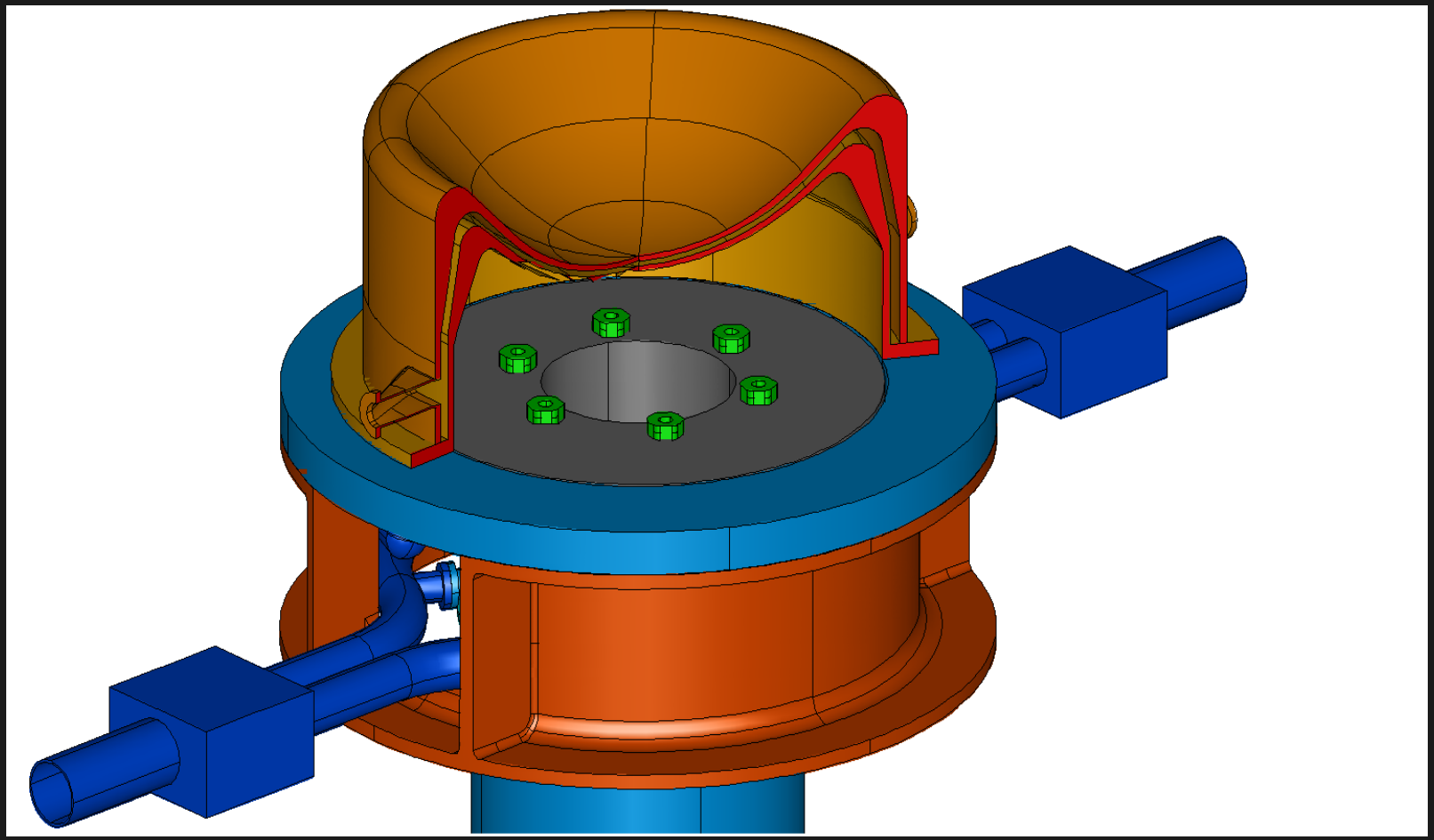

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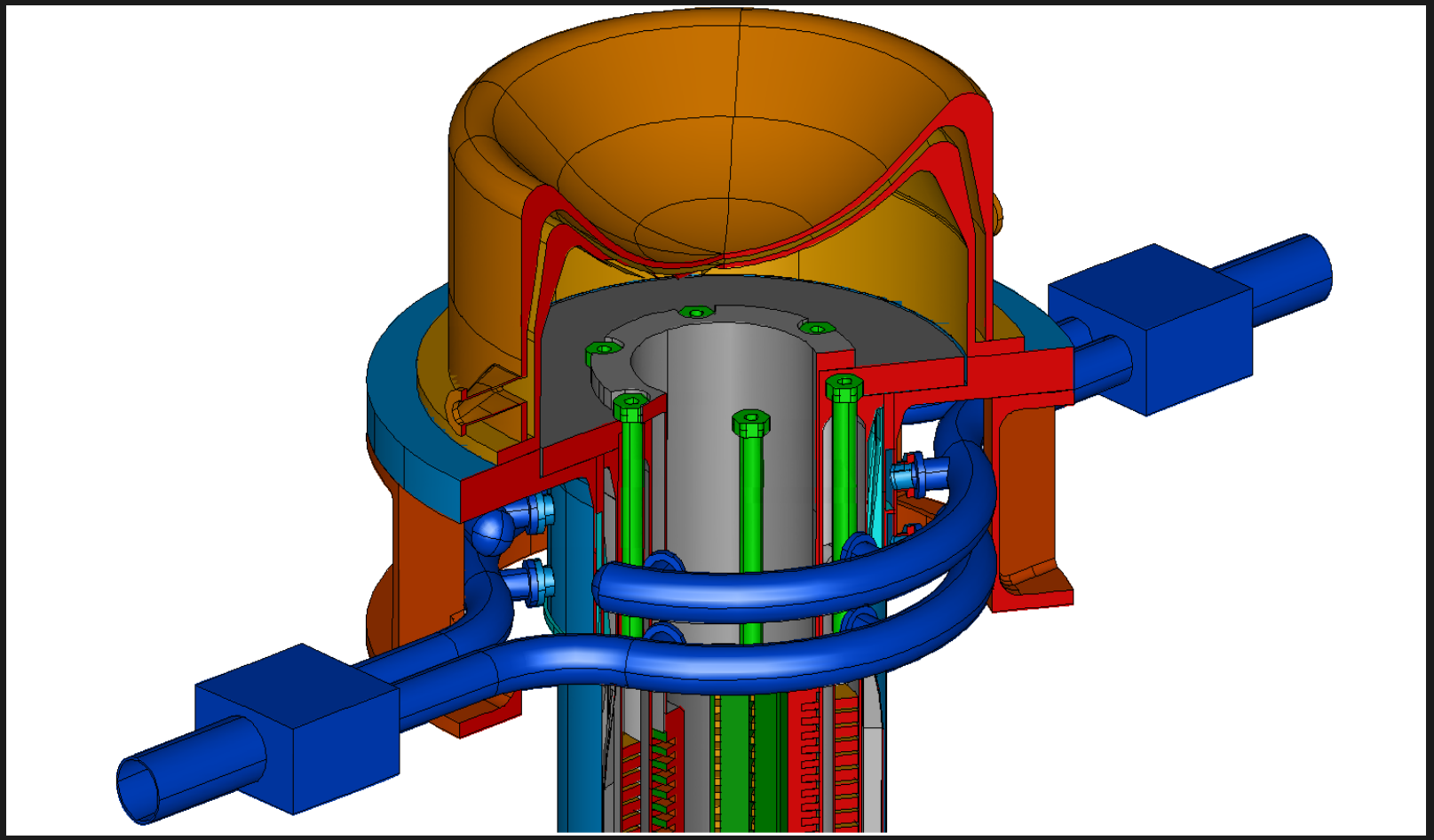

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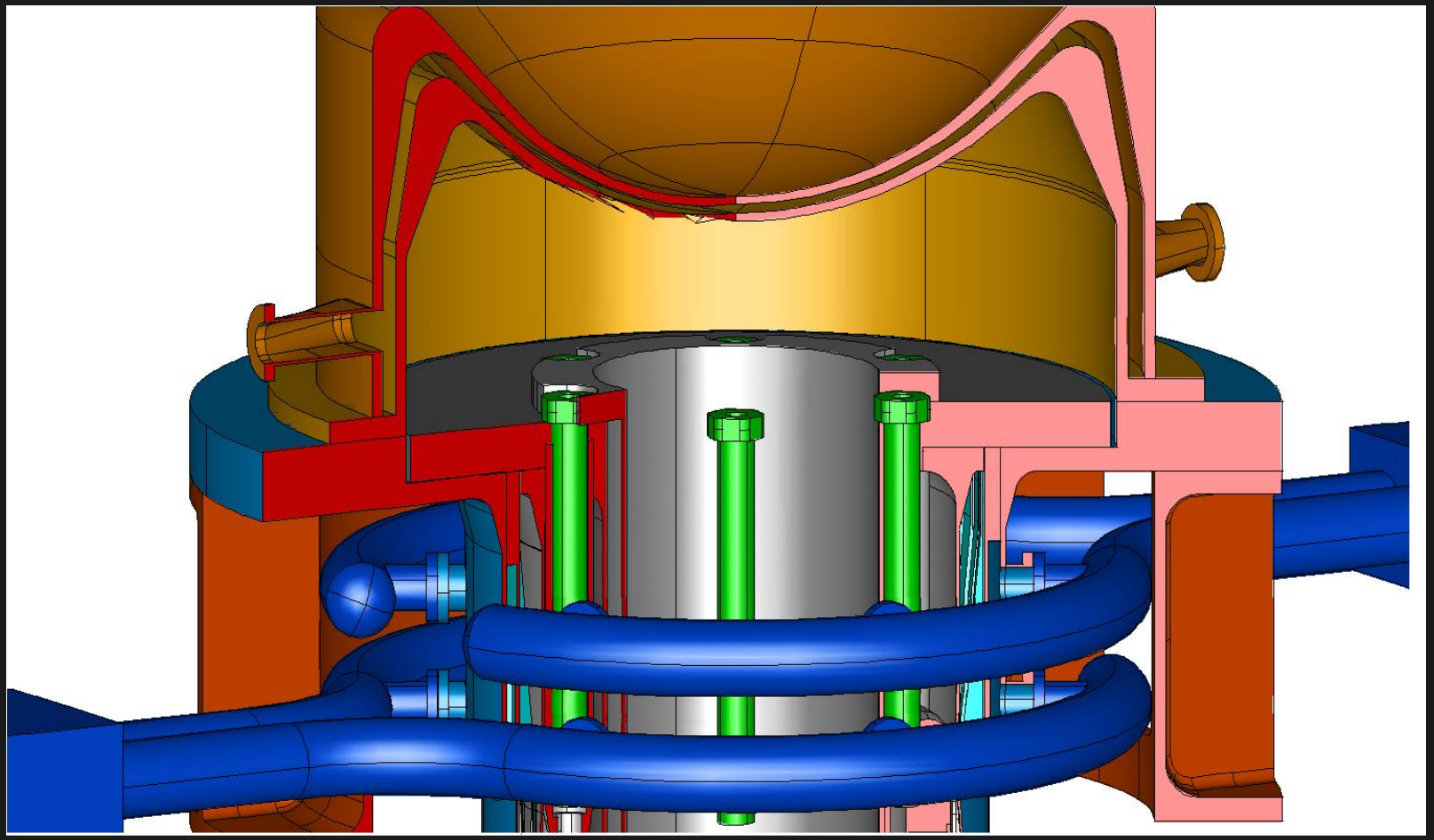

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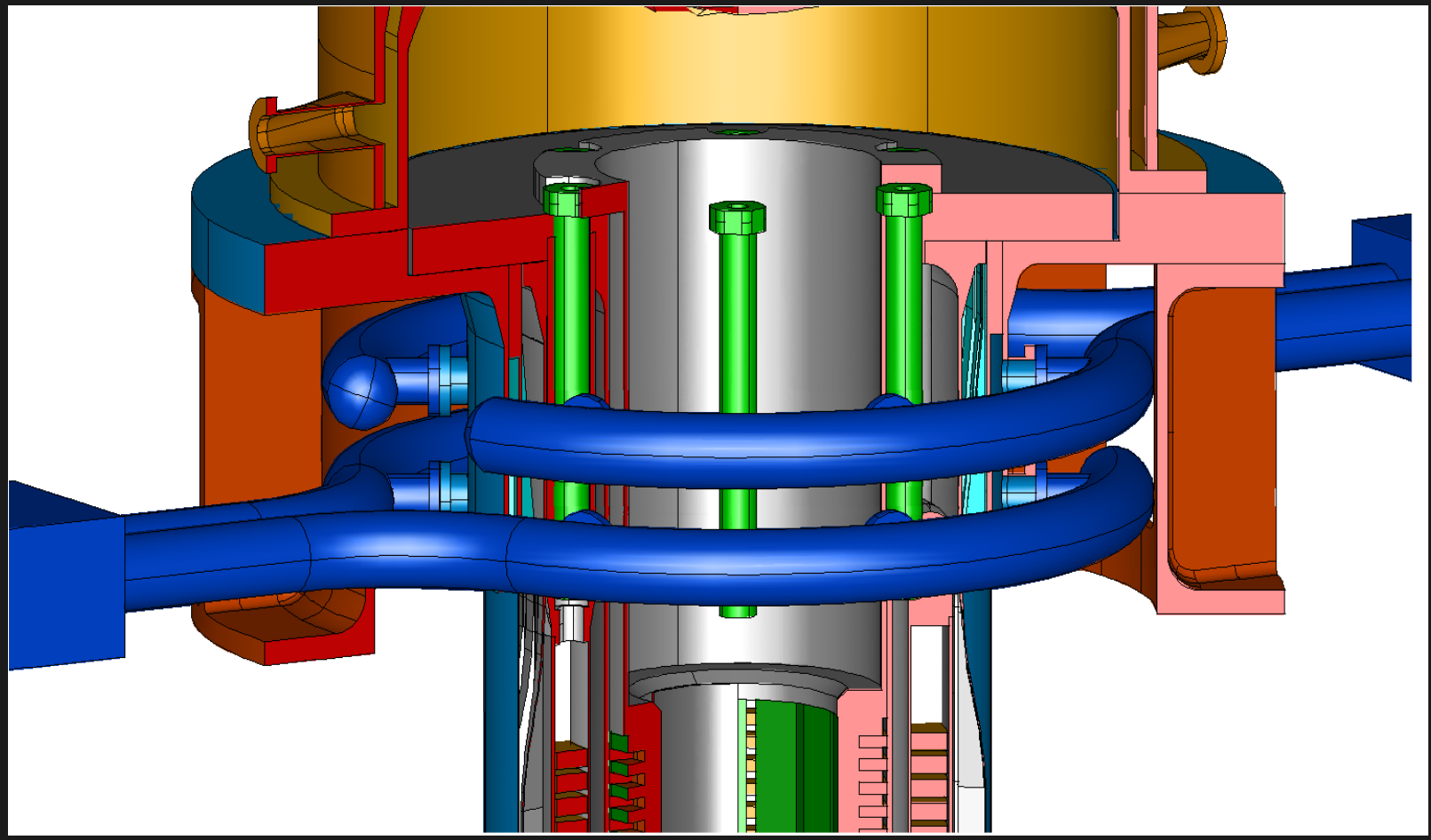

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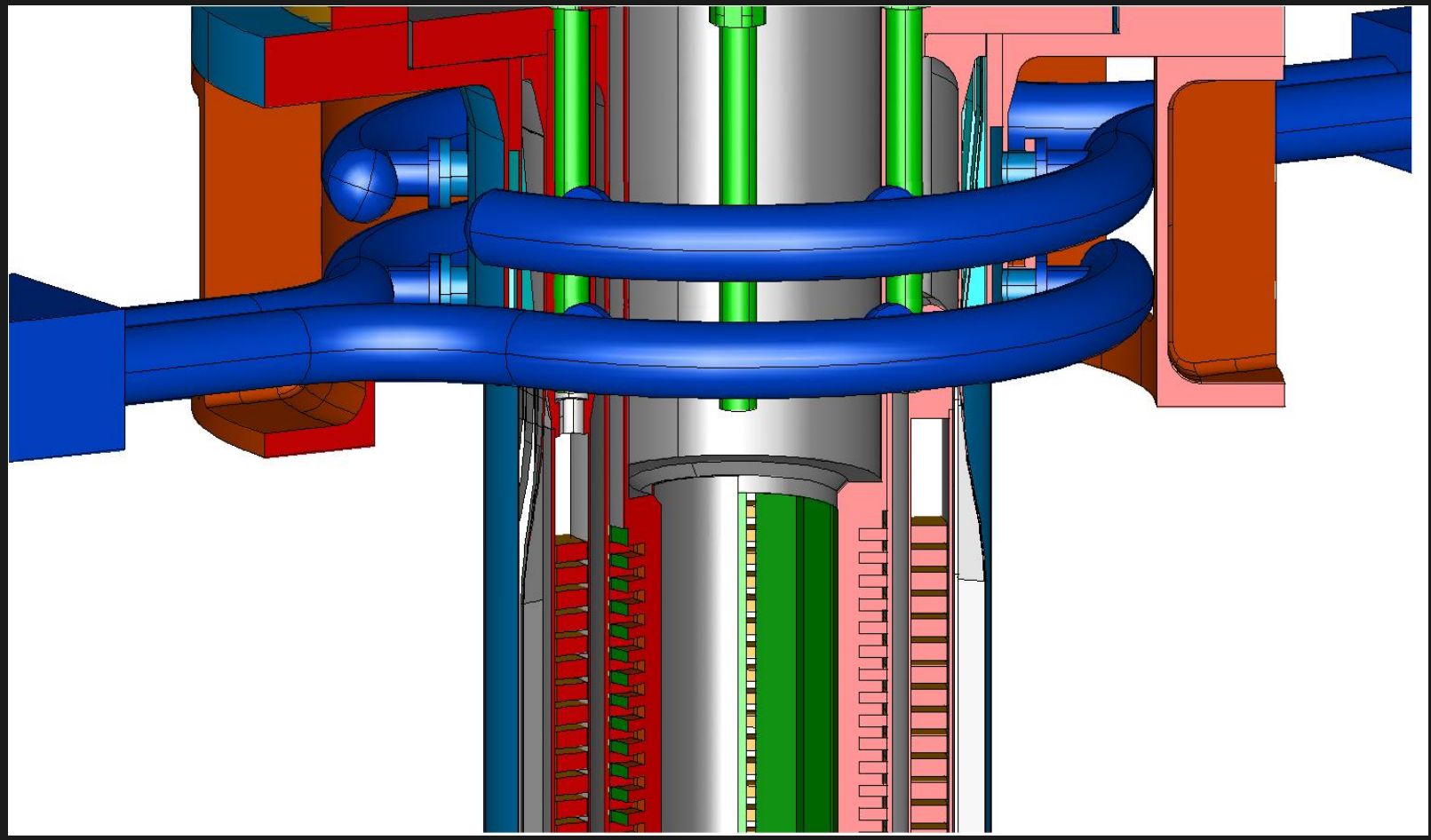

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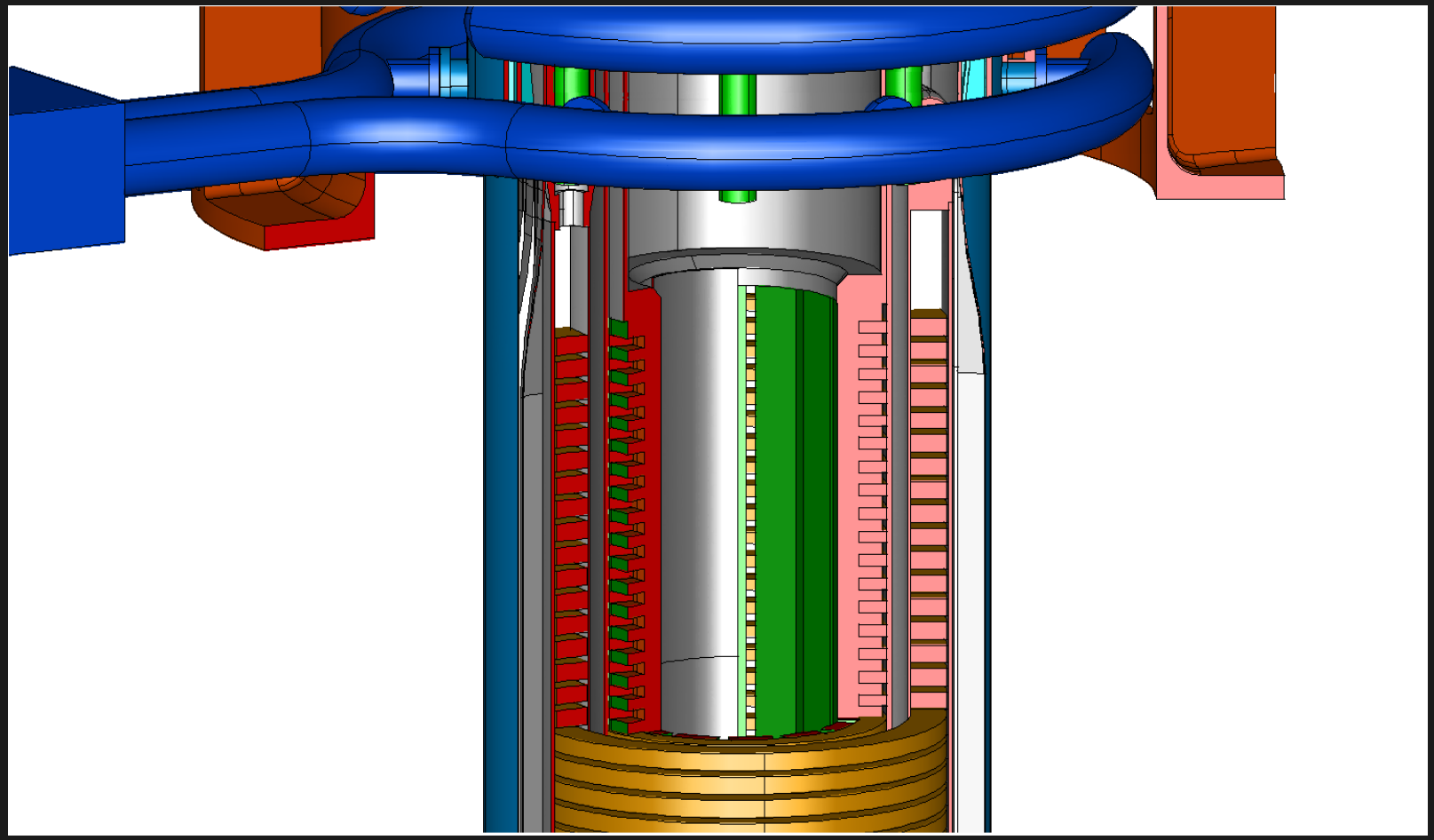

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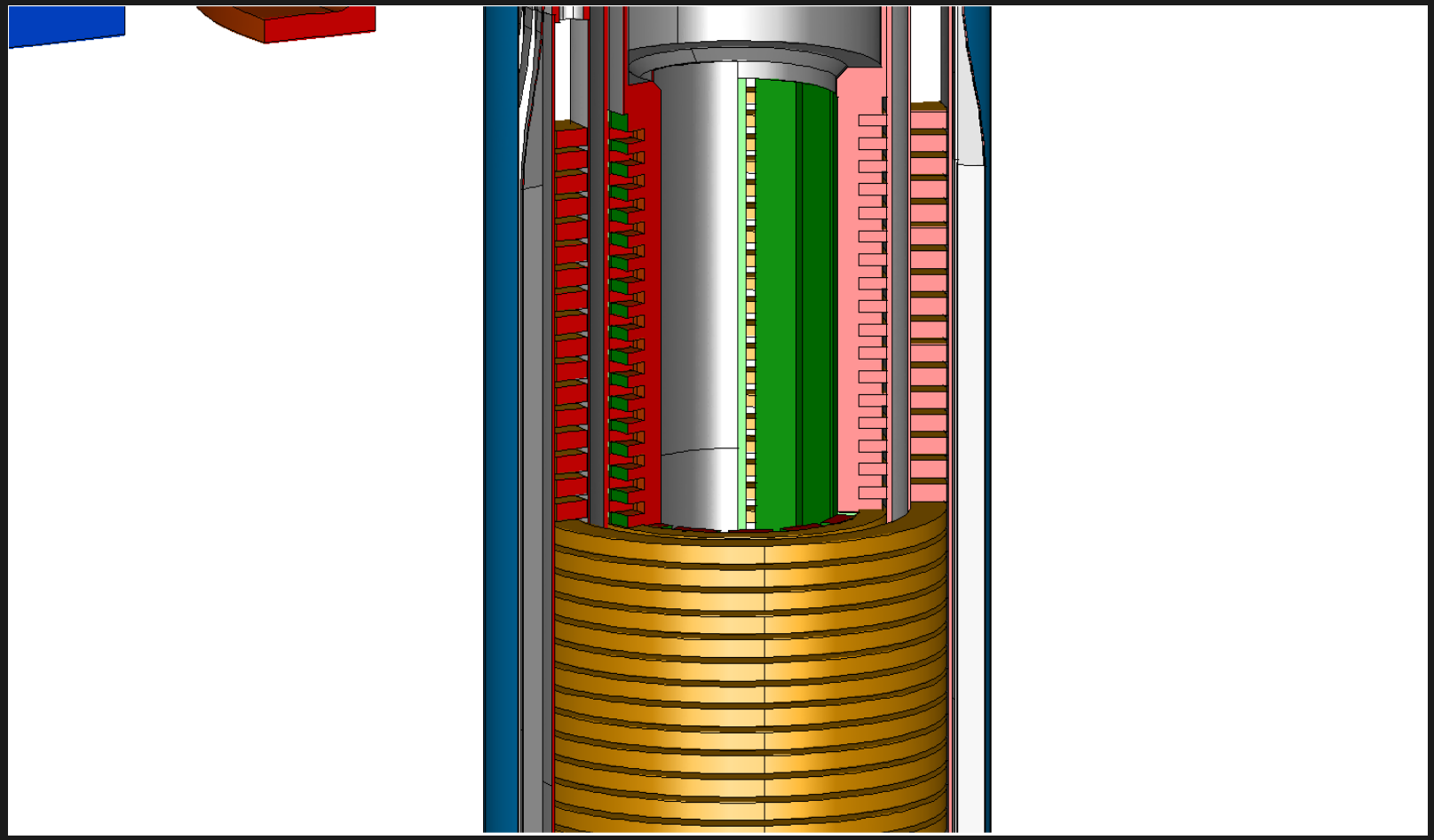

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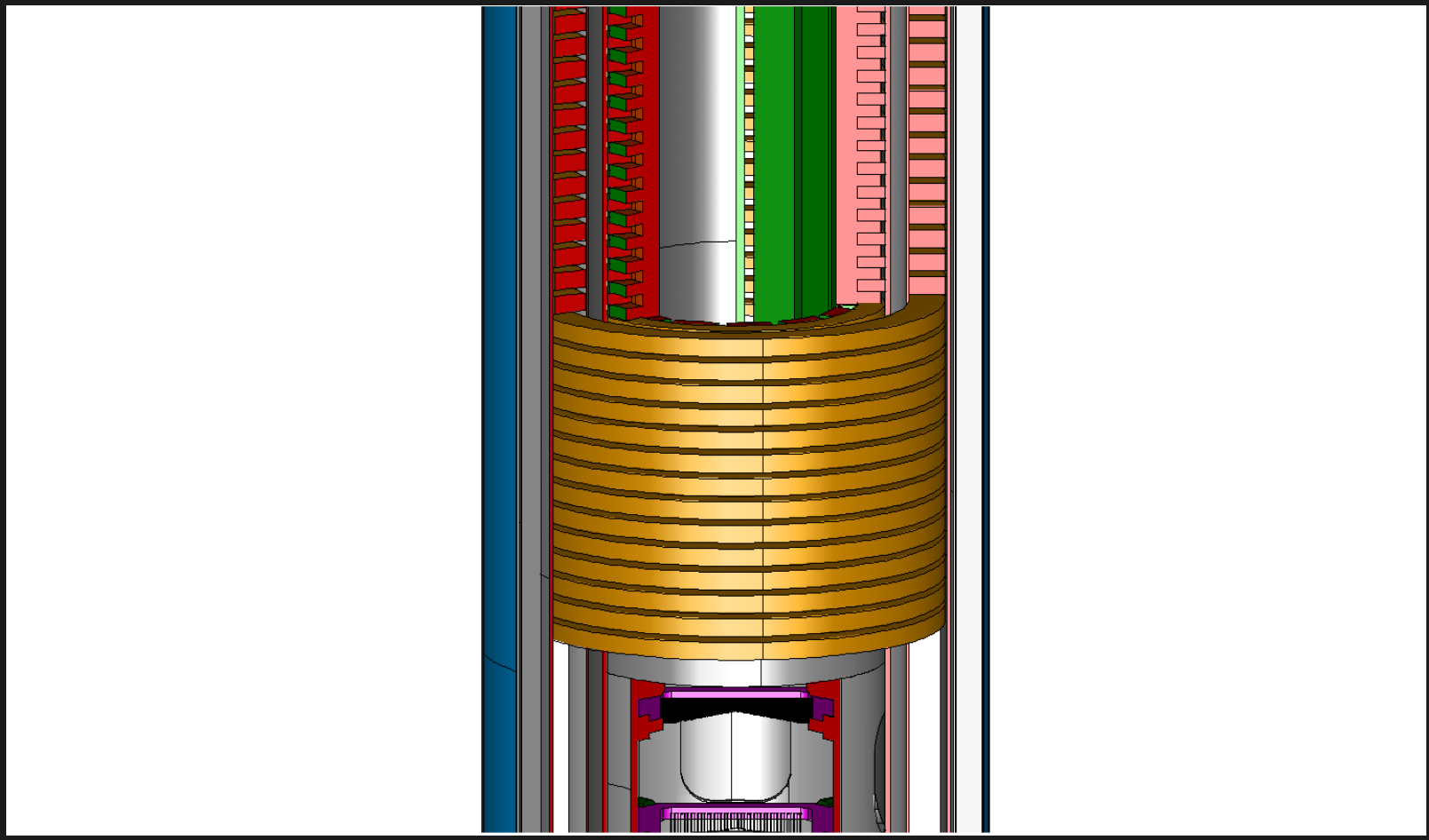

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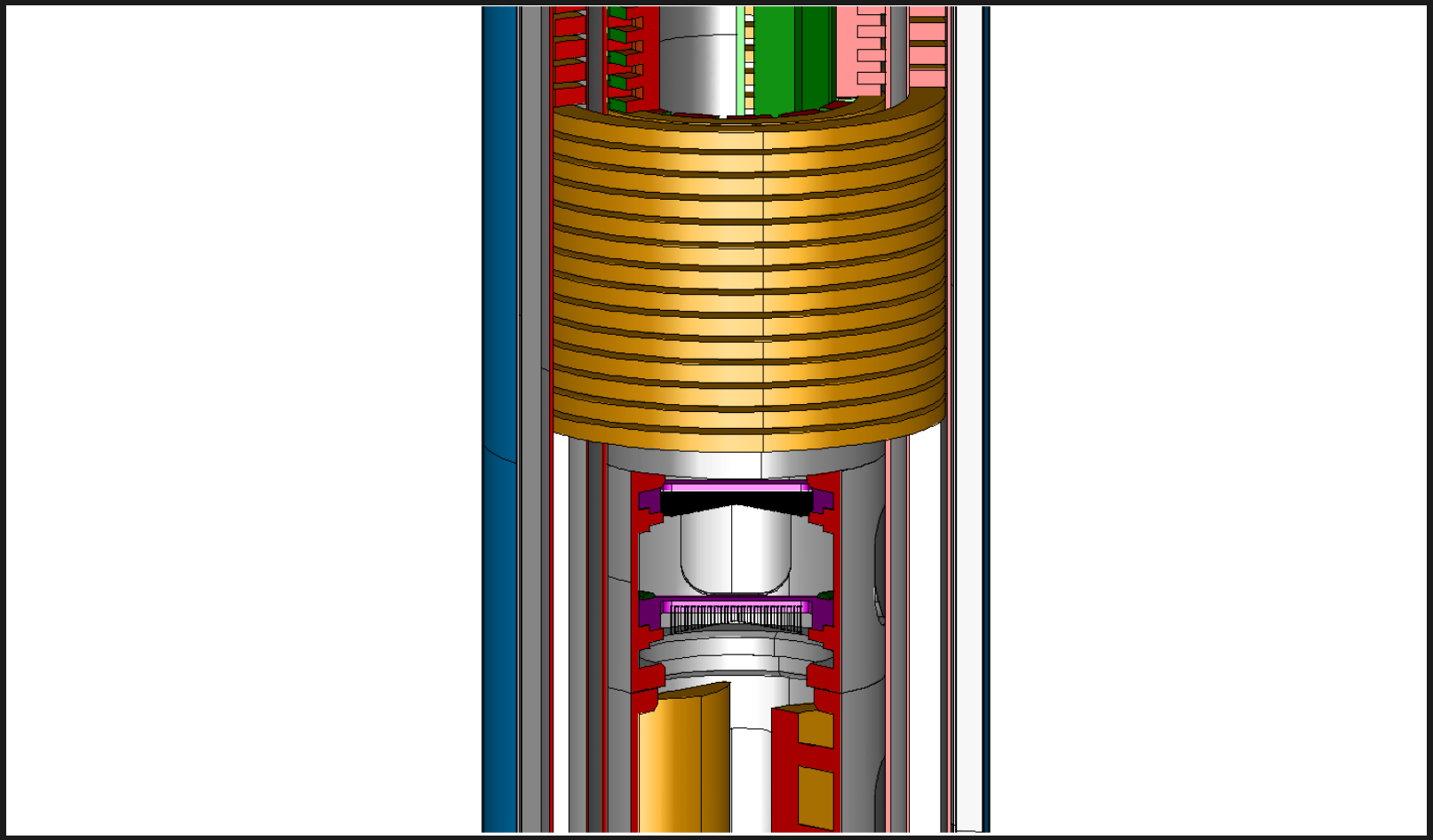

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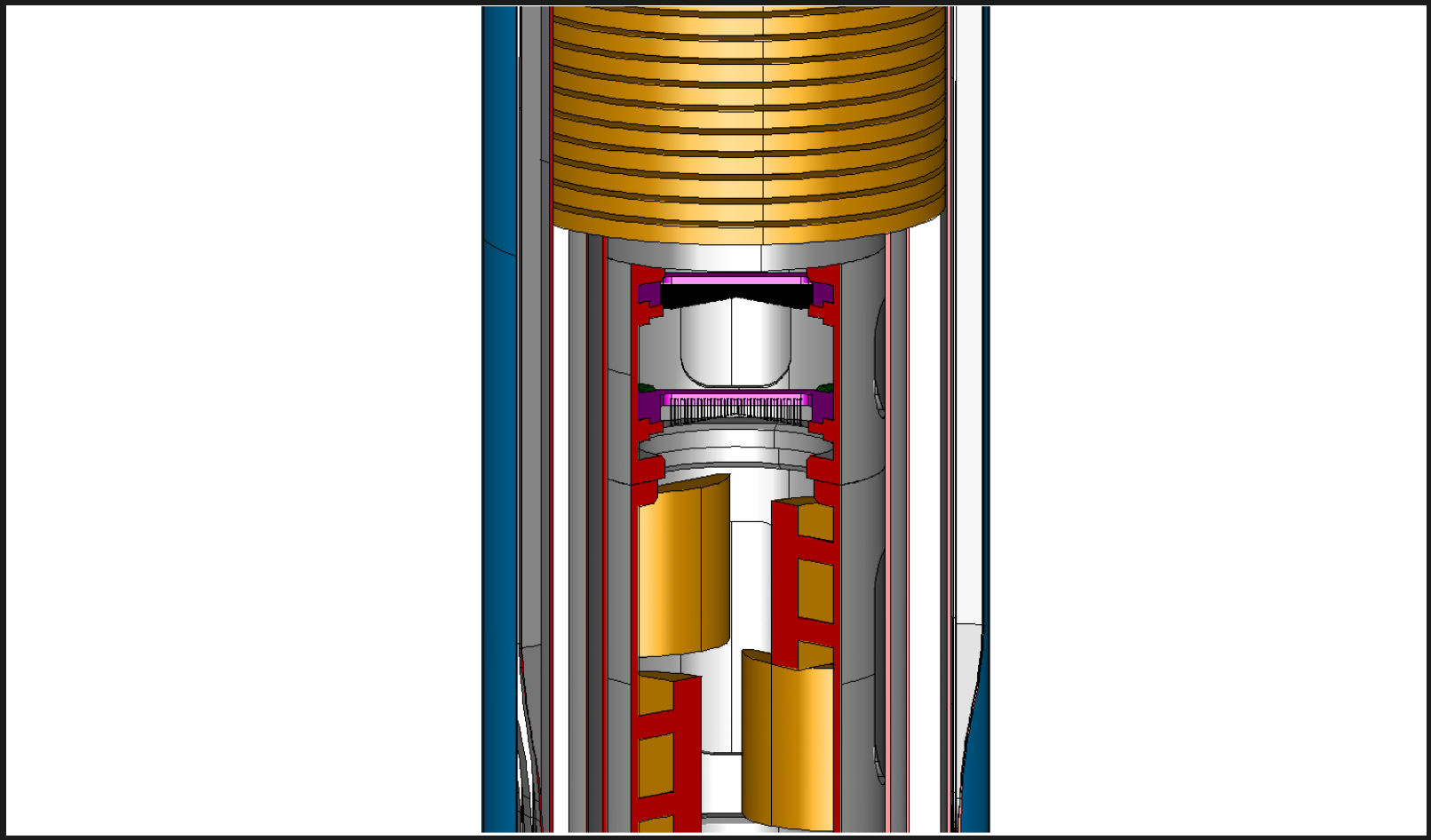

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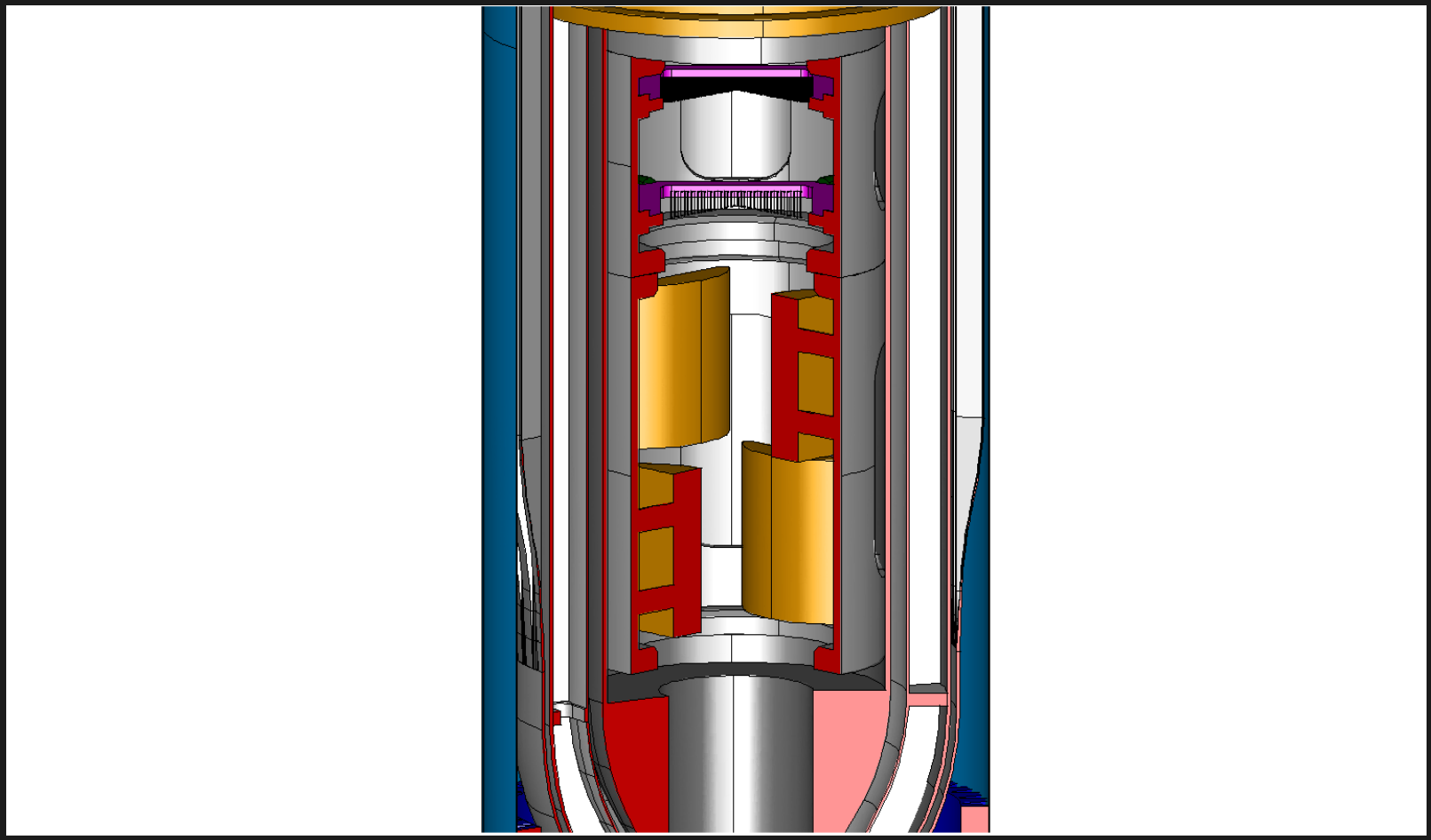

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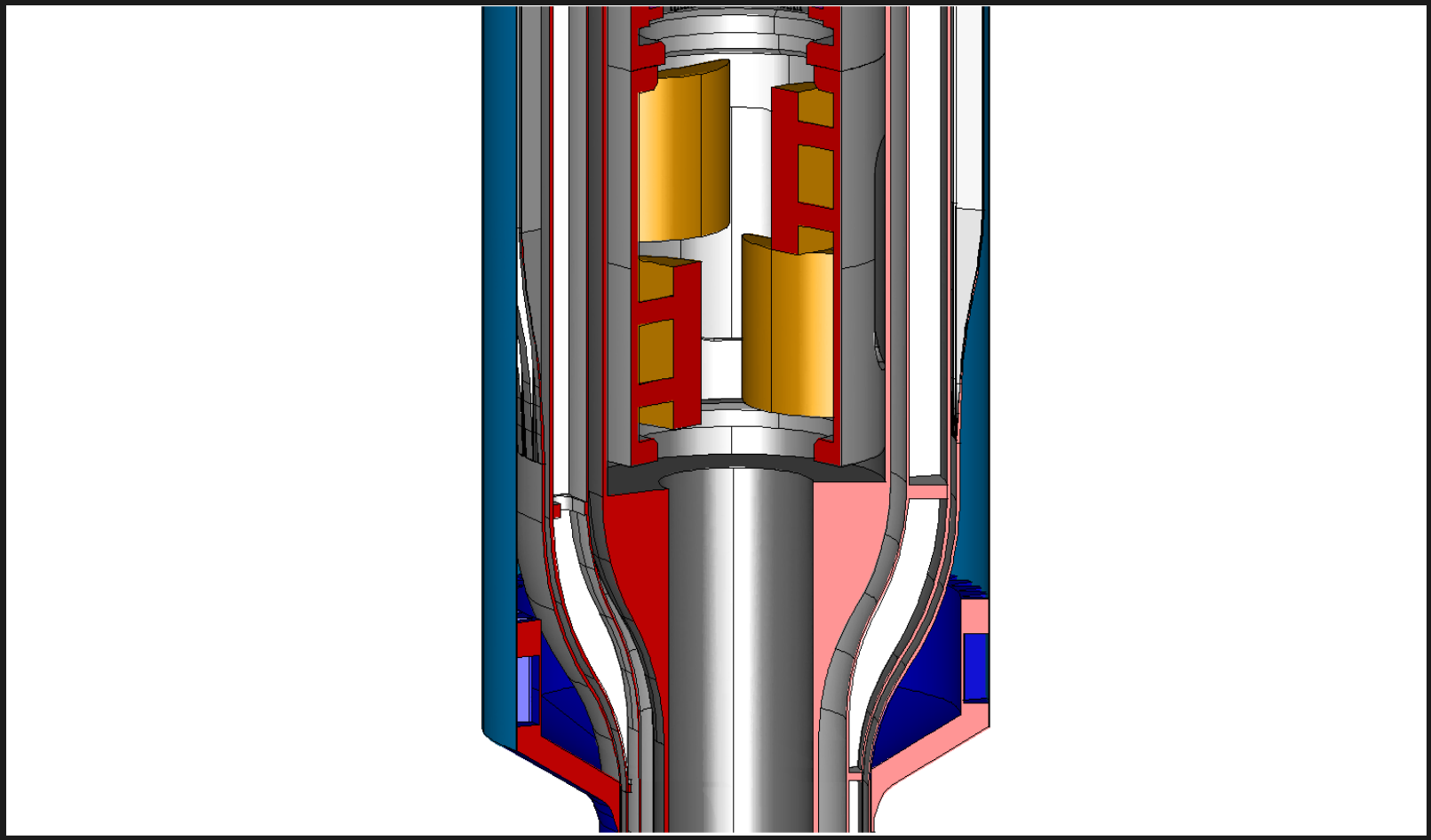

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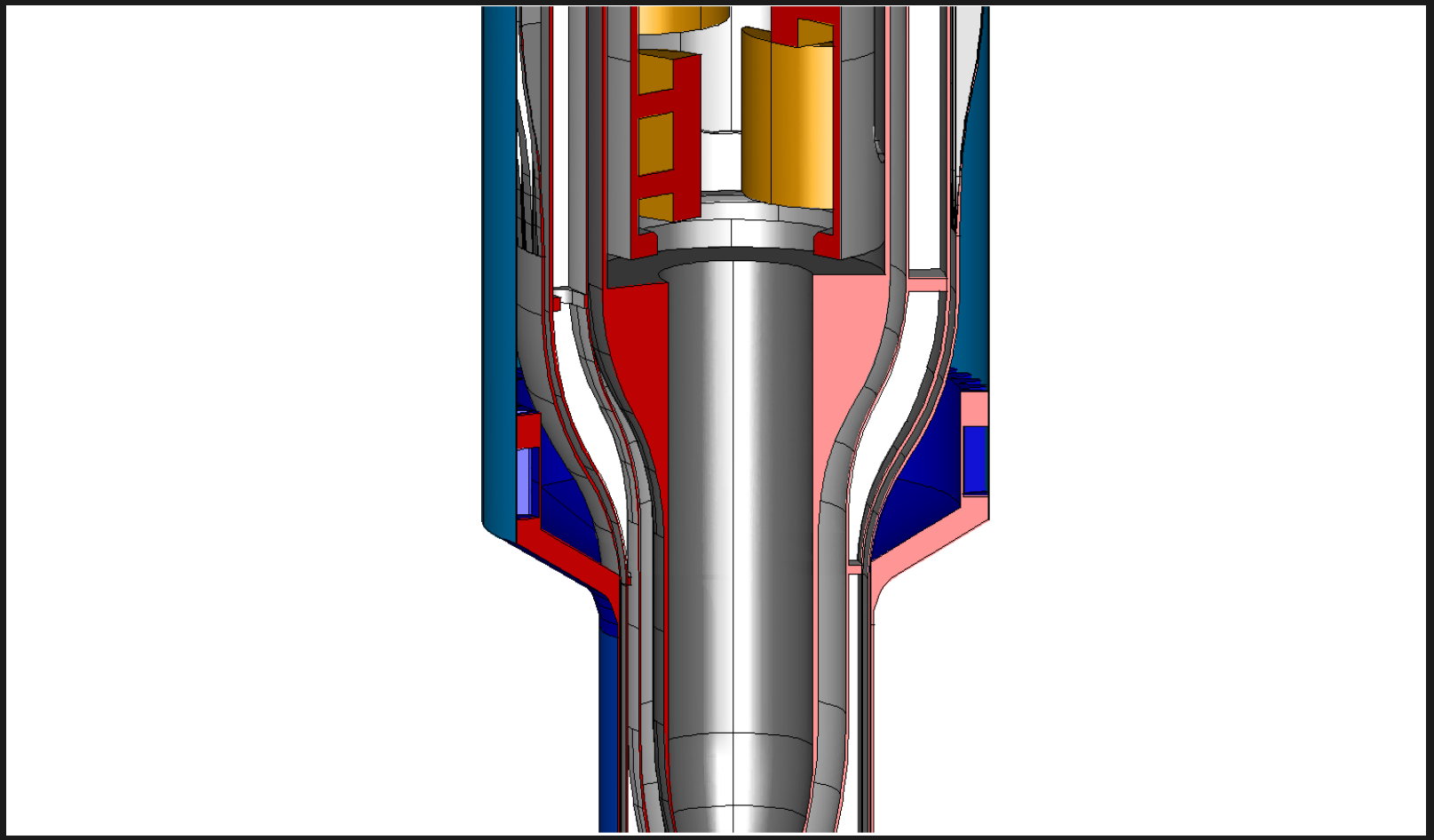

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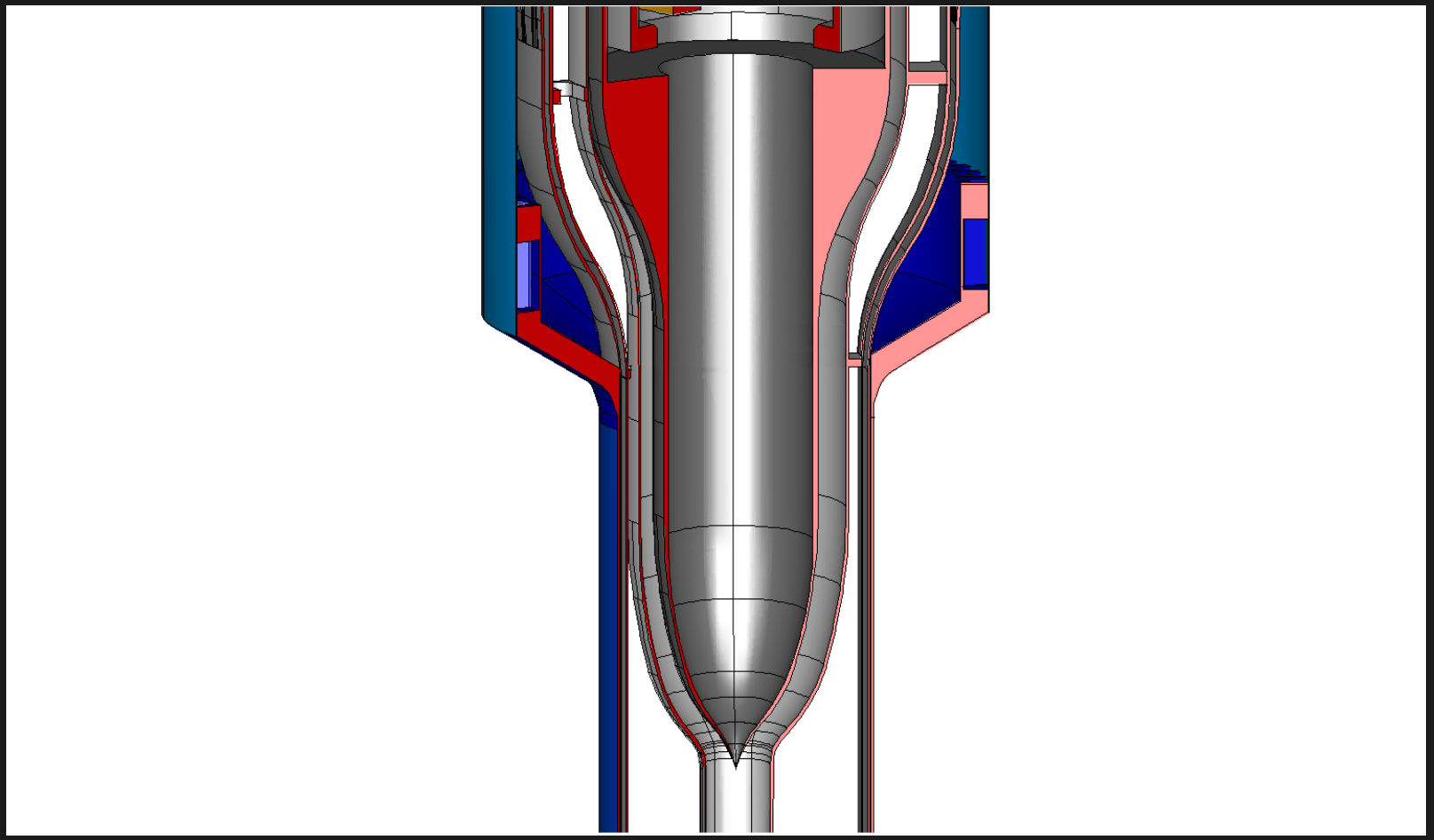

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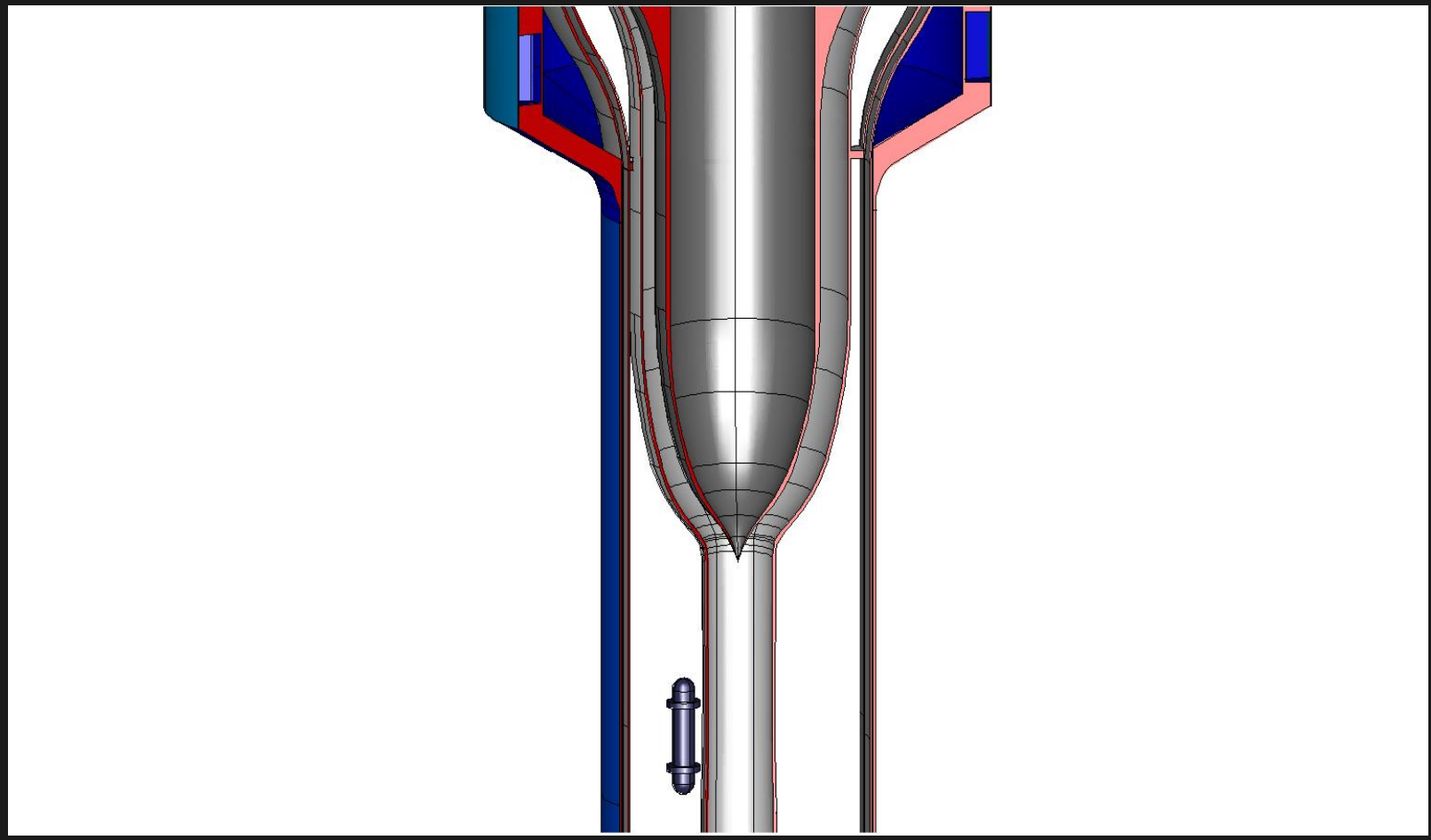

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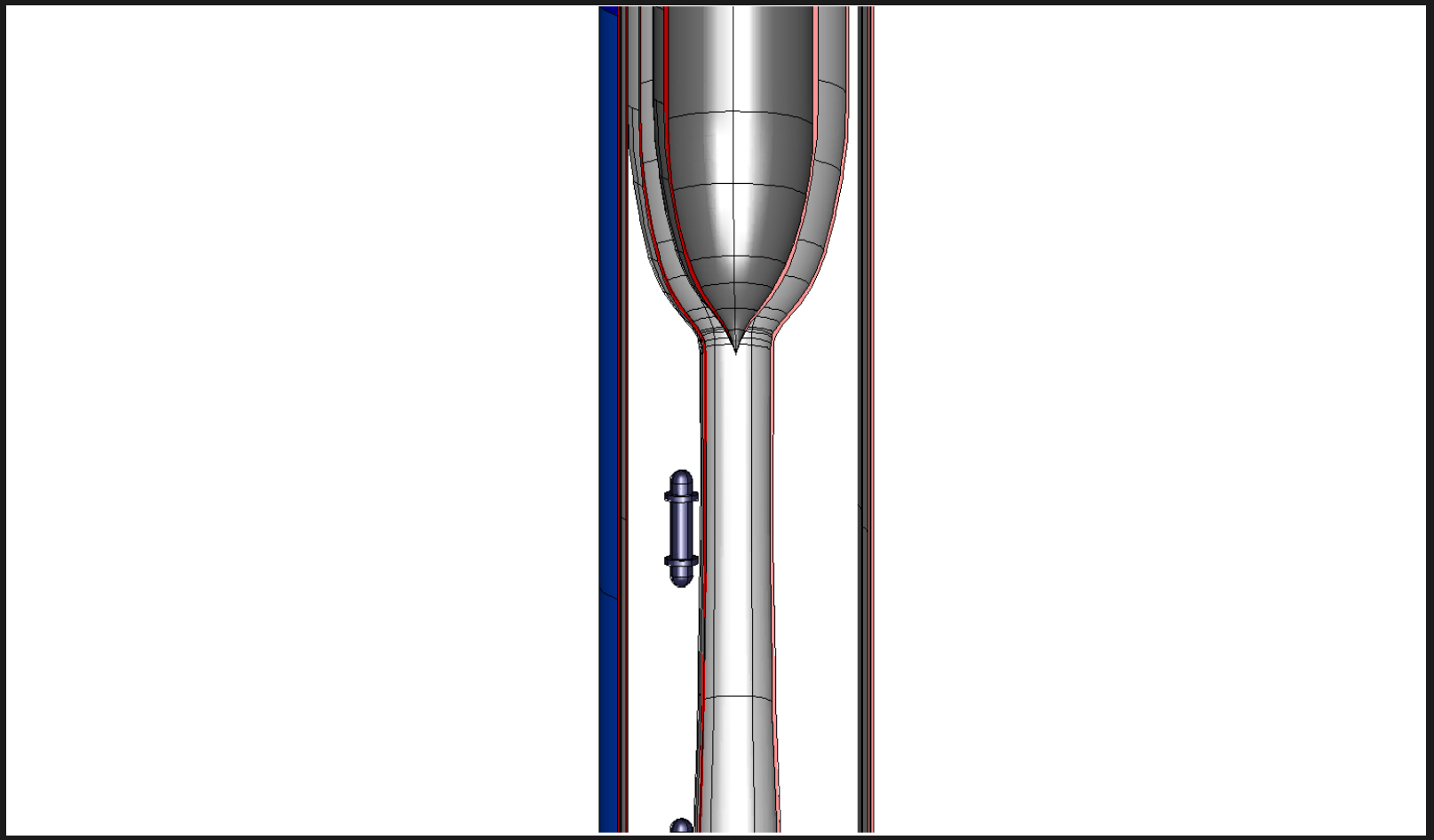

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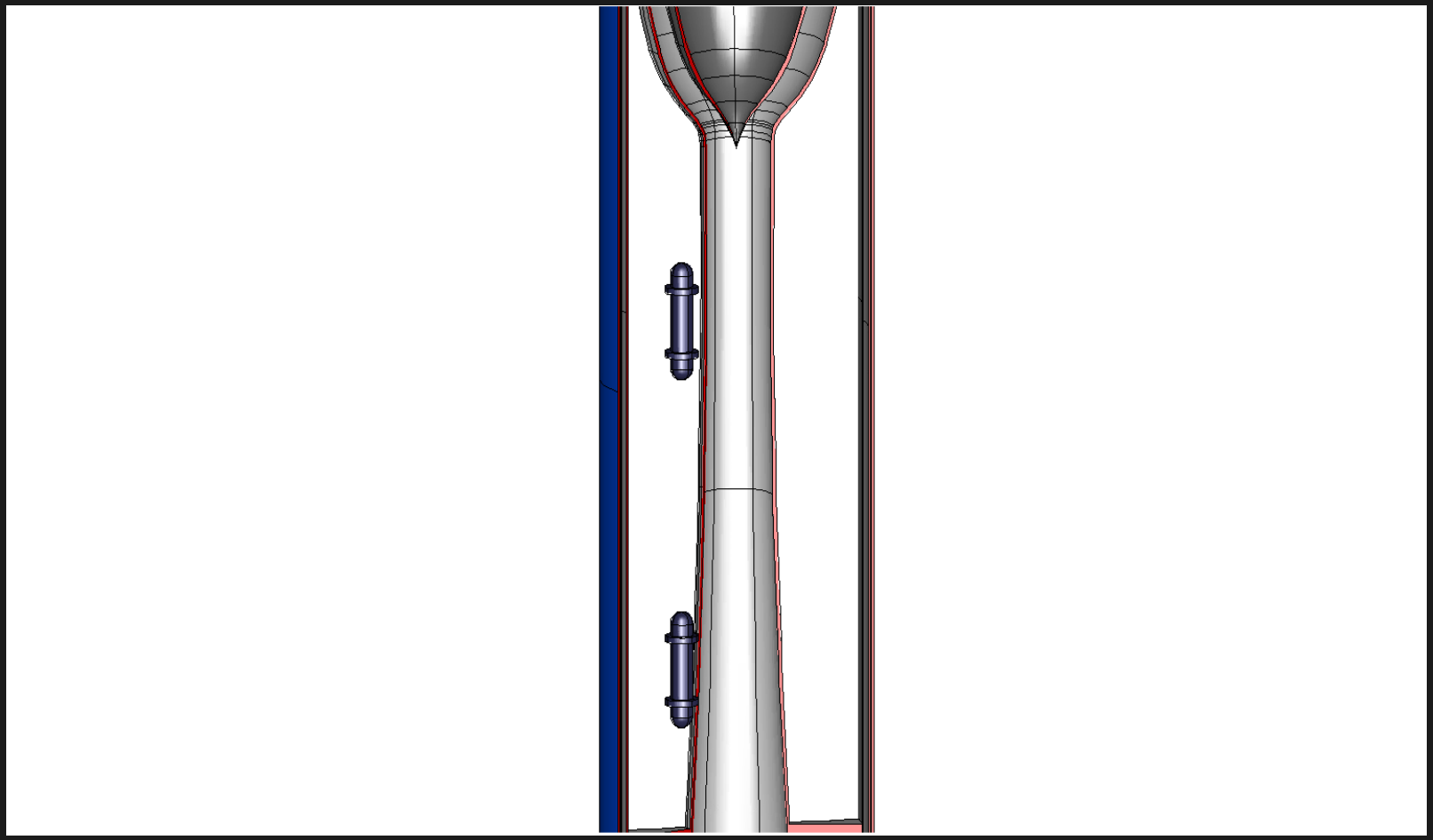

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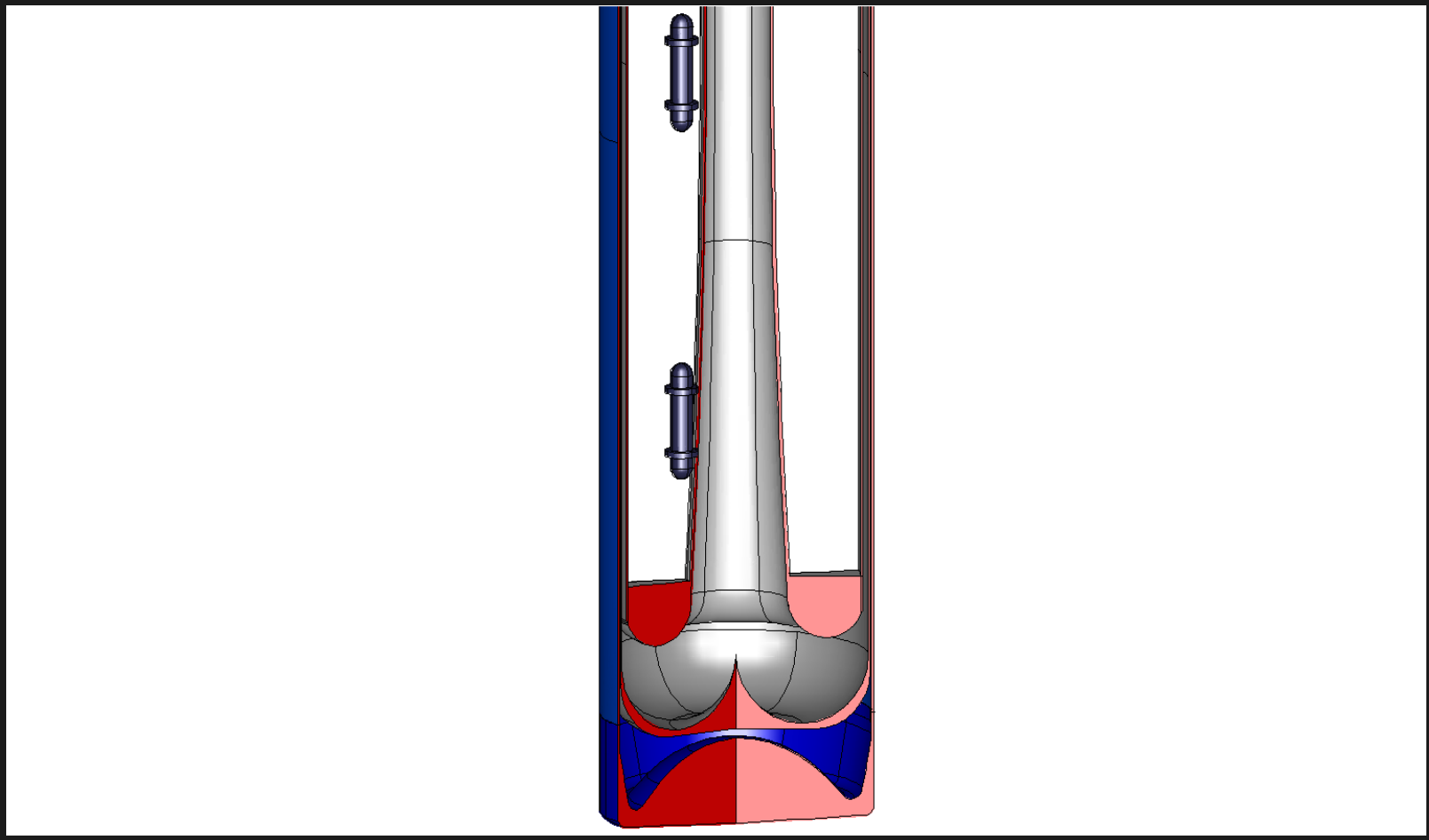

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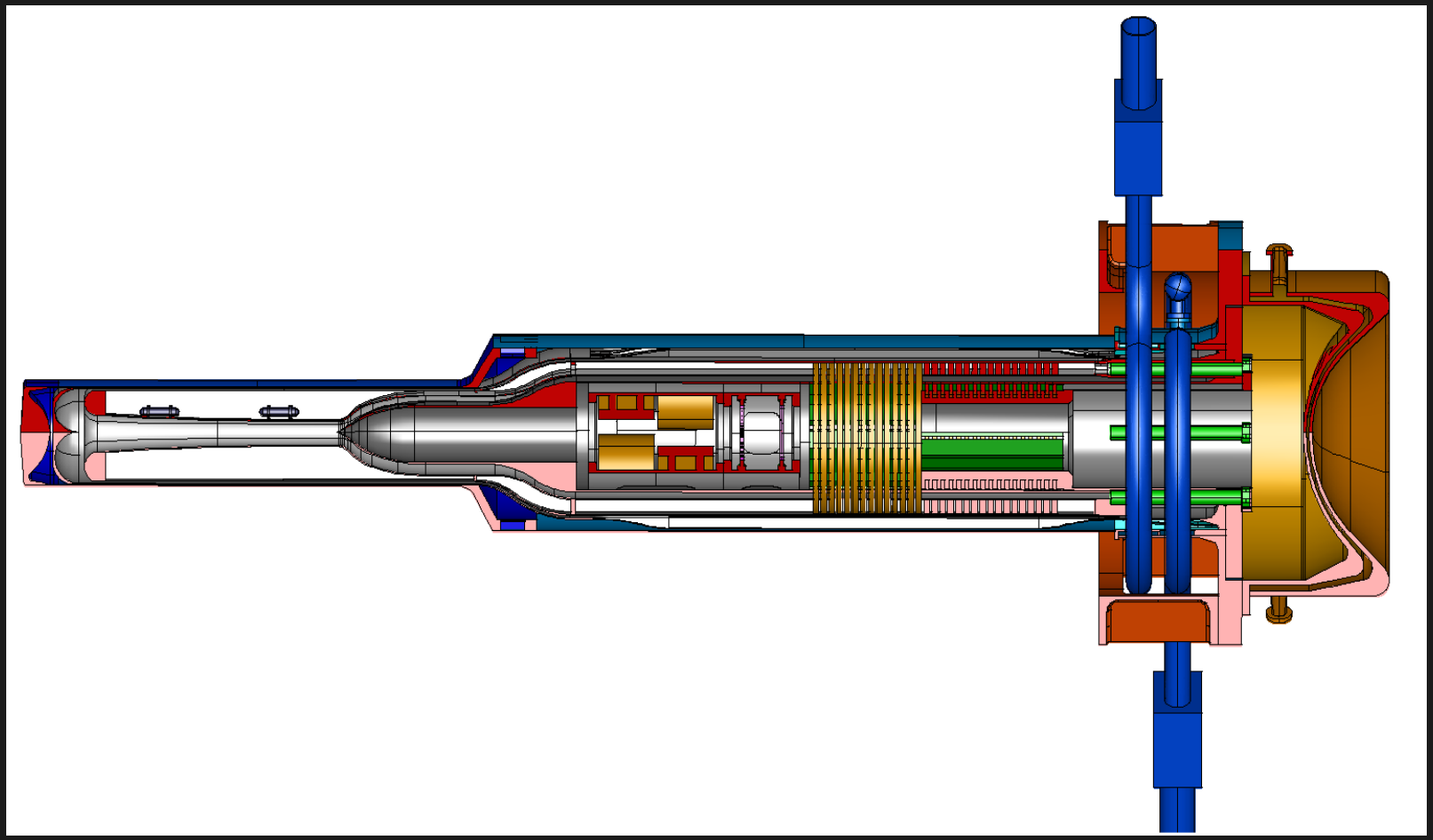

Concluding remarks

- Today, ADS projects are progressing -if at all- slowly. Yet a growing number of specialist are aware of the potential of this reactor for burning waste
- At a time of decreasing public spending, a new project on par with ITER is not a realistic expectation.
- There are however sufficient resources available in the form of existing projects or infrastructure, which could, if well coordinated, mark the beginning of a new era, in which the ADS can demonstrate its capabilities. This is where the scope for international cooperation exists.