Neutron Source Manufacturing at SNS

Presented at the

7th High Power Targetry Workshop

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June 6, 2018

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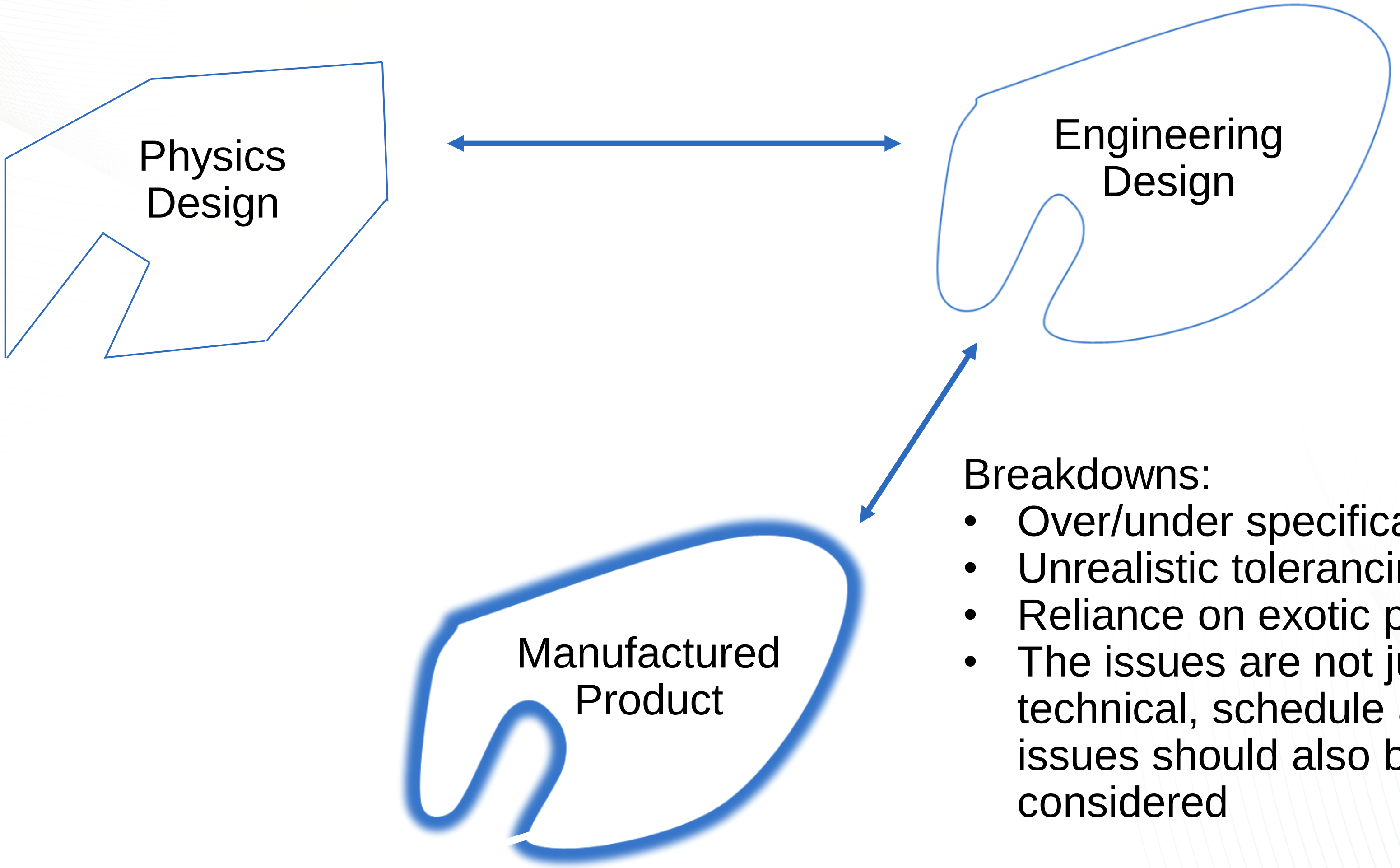
Topics

- Part One – SNS approach to source (target) component manufacturing
- Part Two – What are source components and what processes are employed?
- Part Three – Significant challenges in the history of SNS manufacturing
- Part Four – Current status and future plans for target modules and IRP
- Part Five – Final thoughts and lessons learned

Part One – SNS approach to source (target) component manufacturing

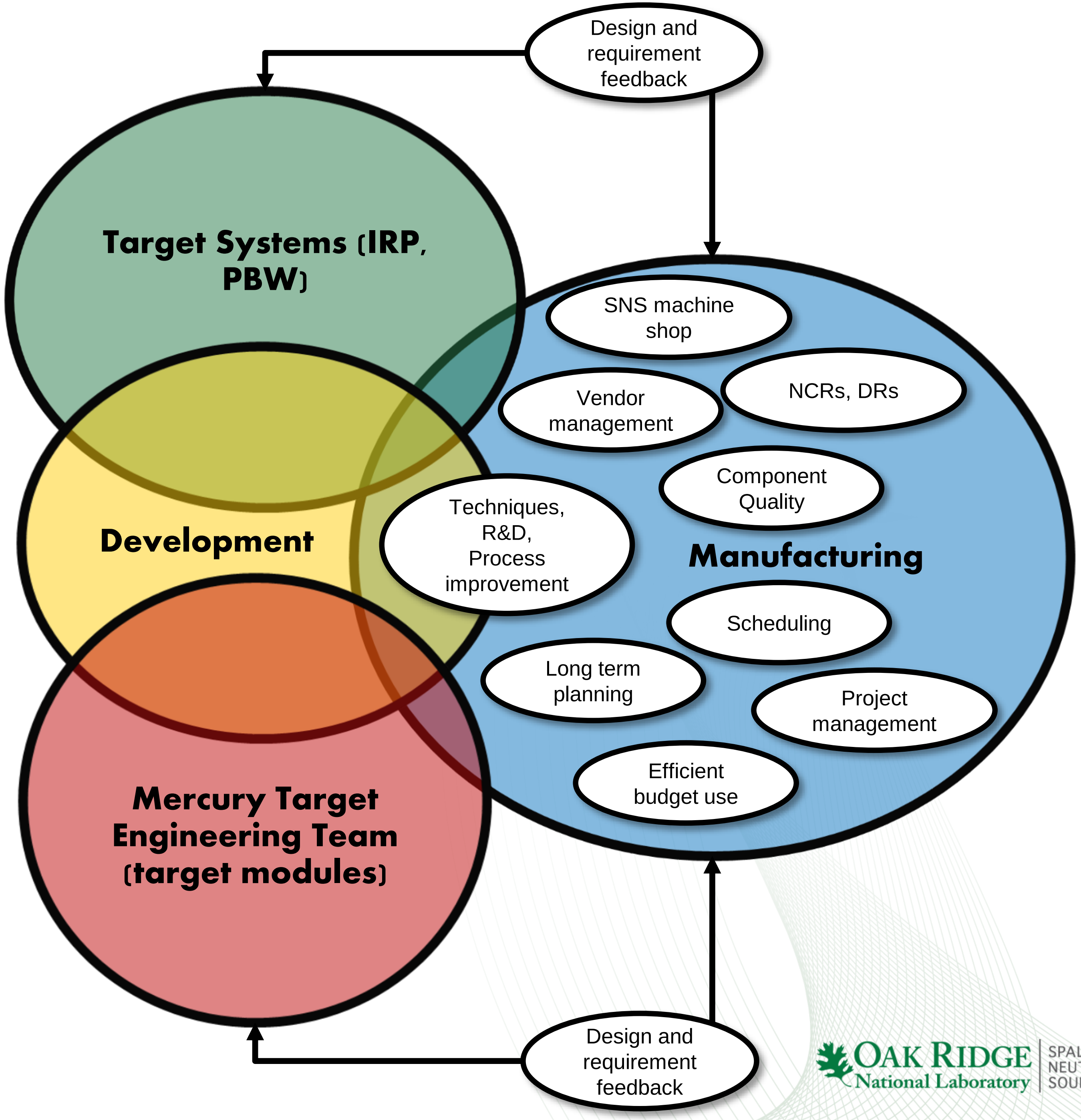
Typical target component engineering paradigm



Breakdowns:

- Over/under specification
- Unrealistic tolerancing
- Reliance on exotic processes
- The issues are not just technical, schedule and budget issues should also be considered

How does the Manufacturing Team fit within the Source Development and Engineering group at SNS



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Mission statement: “to manufacture neutron source components with confidence in quality, schedule, and efficiency”

- We need:
  - Clear and concise design requirement
  - Repeatable, conveyable, traceable processes
  - Non-singular supply chain - cost control, competition,
  - Efficient use of budget – planning appropriate spending spread amongst critical components
  - Eager and successful suppliers

Evolution of SNS approach to critical manufacturing

- 2002 – 2012: manufacturing supported by design engineer
  - Split focus
  - QA representative support was intermittent
- 2013 – 2016: Added a single dedicated manufacturing engineer
- 2016 – present: Dedicated manufacturing team integrated within SDE
  - Current staff includes:
    - 2 manufacturing engineers (adding a 3rd)
    - 1 technician / expeditor / logistical support / internal shop manager / planner
    - 1 team lead
    - Consistent QA support (matrixed)
  - Roles and authorities are defined between manufacturing engineers, design engineers, and QA personnel

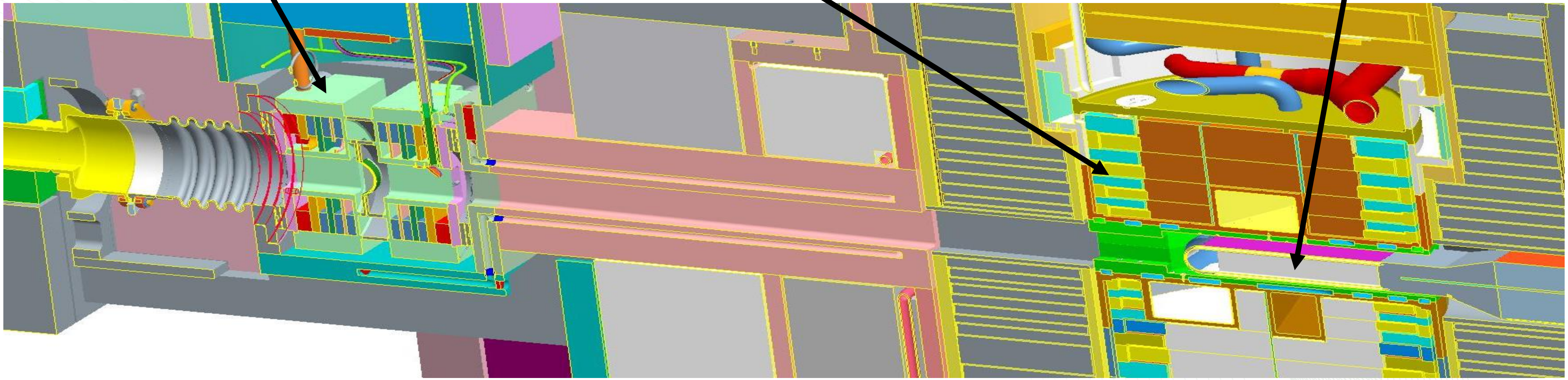
Part Two – What are source components and what processes are employed?

What do we make?

Proton Beam Window (PBW),
lifetime = 2-4 years
Manufacturing time = ~1 year

Inner Reflector Plug (IRP),
lifetime = 4-5 years
Manufacturing time = ~4-9 years

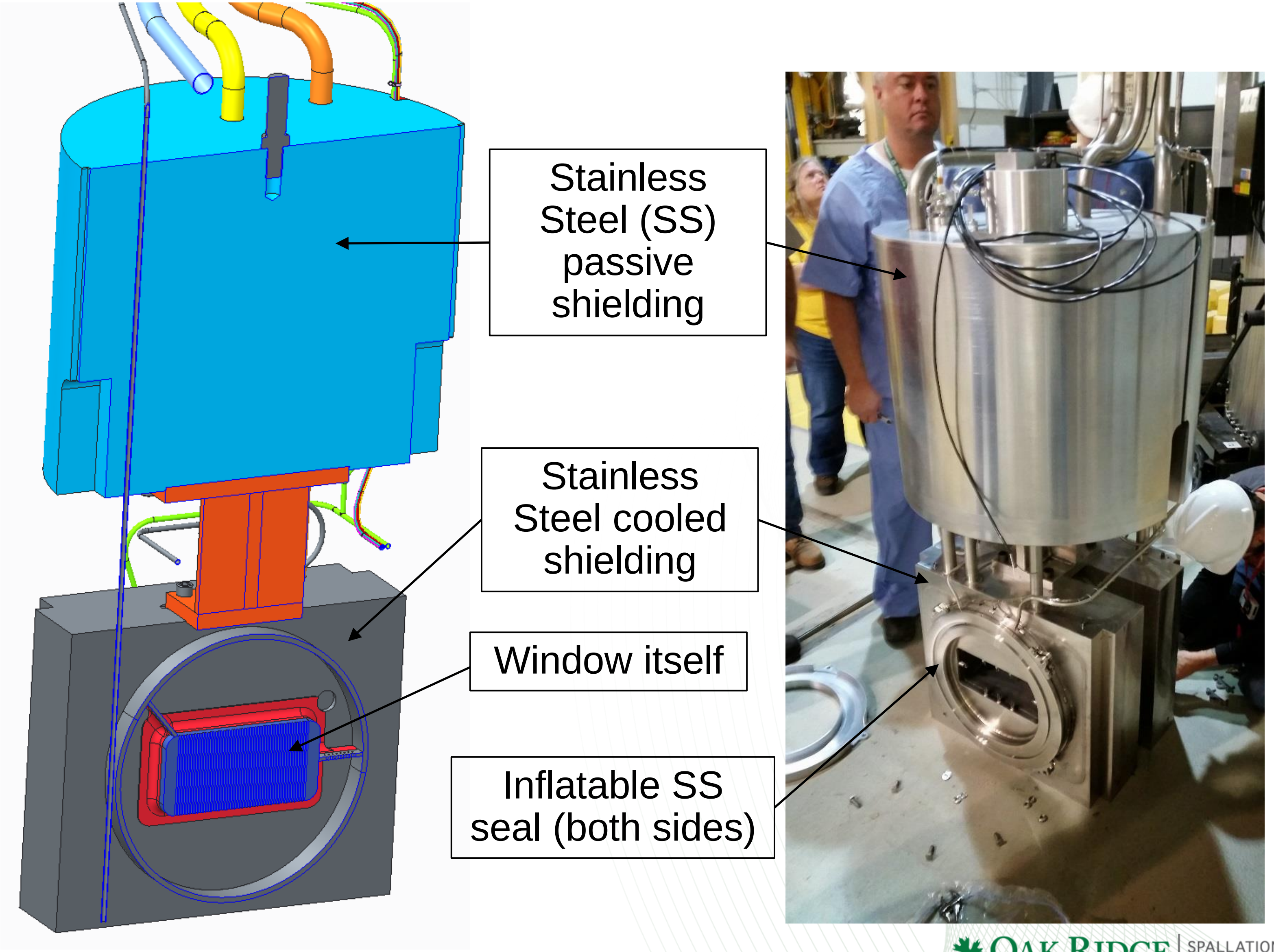
Target Module,
lifetime = 0.33 – 0.5 years
Manufacturing time = ~1.5 years



- At steady state, targets require the largest annual budget, followed by IRP, then PBW

What is a Proton Beam Window?

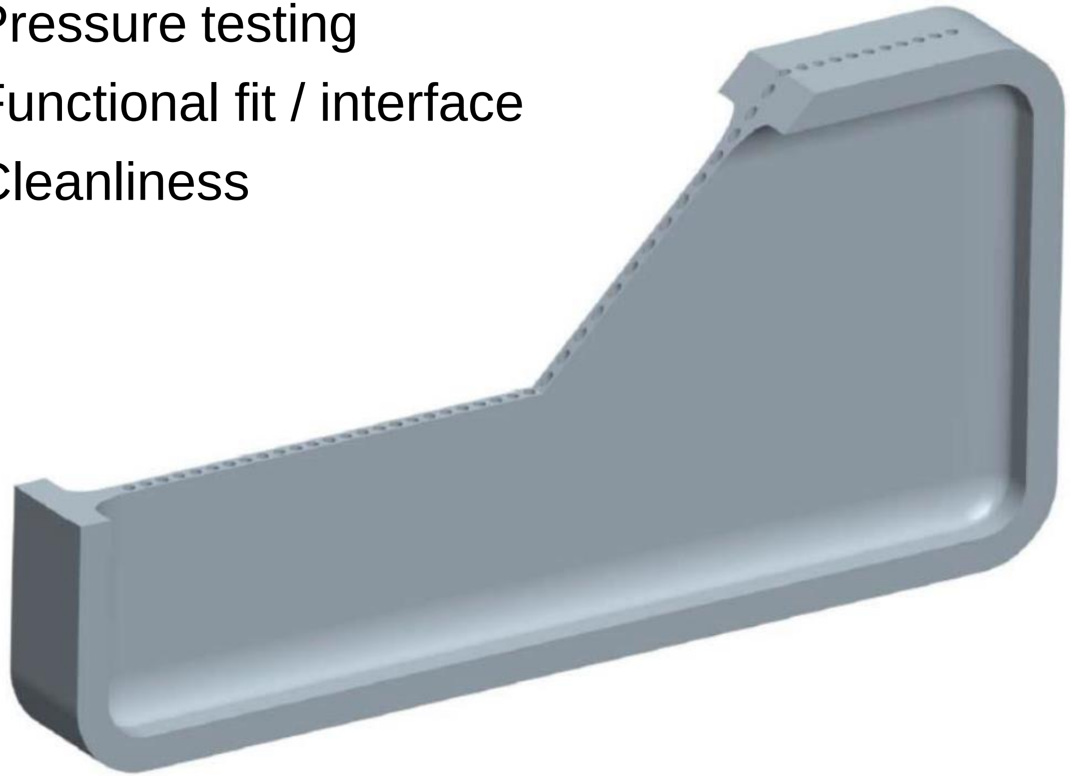
- Provides separation along the proton beam between the high vacuum accelerator and the helium backfilled core vessel
- SNS has used both Inconel and aluminum PBWs



Proton Beam Window Processes

- Manufacturing Processes
  - Material production
    - Forging, plate, pipe, bar, etc.
  - Conventional machining
  - Explosion bonding
  - GTAW welding
  - EB welding
  - Bellows edge welding
  - Gun drilling
  - Electroplating

- Inspection processes
  - Dimensional inspection
  - Weld inspection
    - Visual, penetrant, ultrasonic, radiograph
  - Leak testing
  - Pressure testing
  - Functional fit / interface
  - Cleanliness



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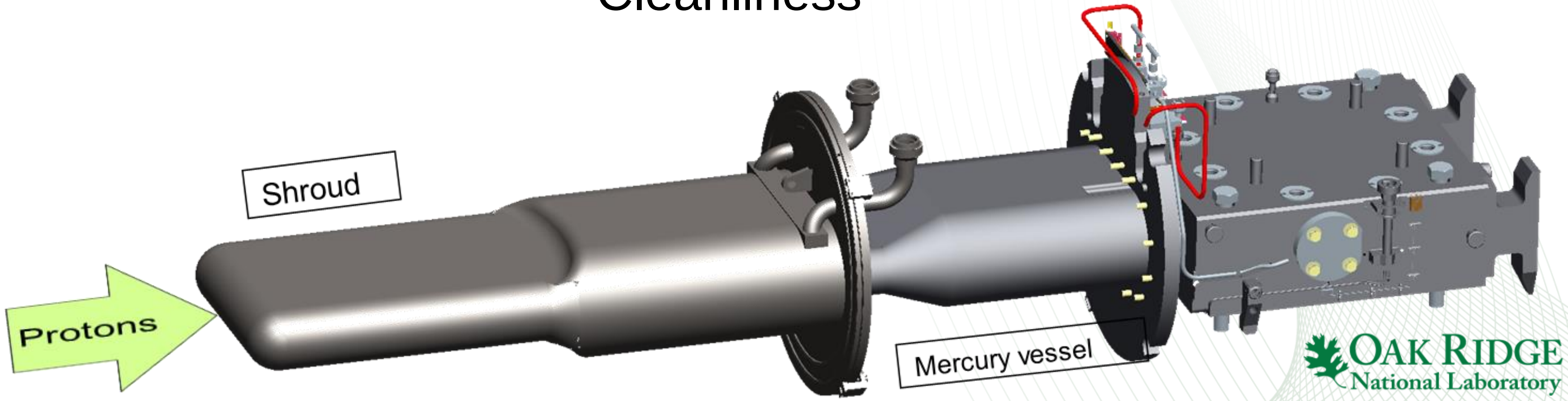
Target Module Processes

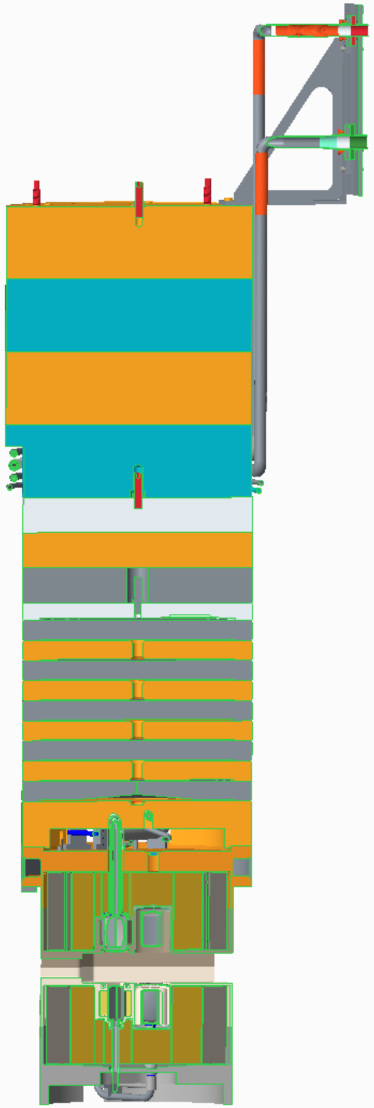
- Manufacturing Processes
  - Material production
    - Forging, plate (ESR), pipe, bar, etc.
  - Conventional machining
  - Wire and Plunge EDM
  - GTAW welding
  - EB welding
  - Bellows edge welding
  - Gun drilling
  - Electroplating
  - Kolsterizing
  - Electropolishing
  - Removal of EDM HAZ
  - Hot isostatic pressing

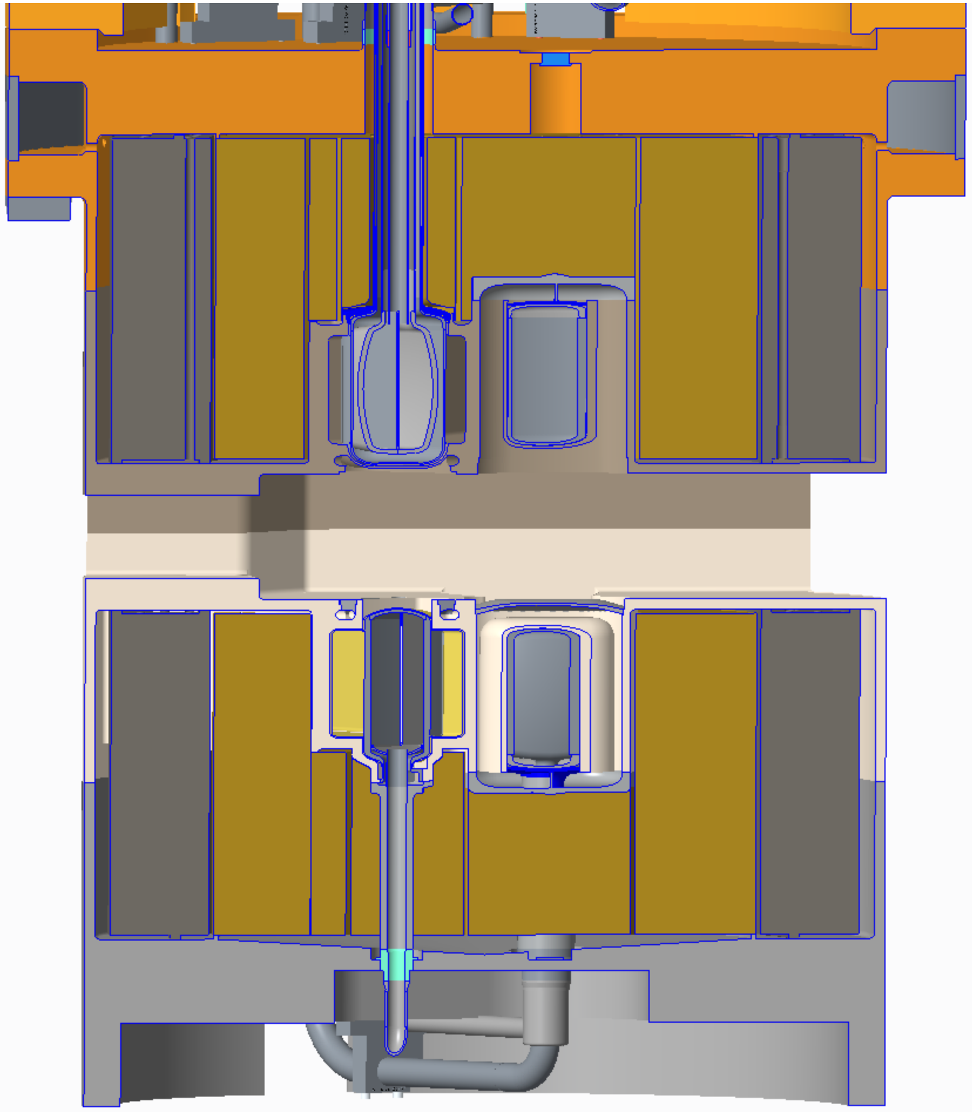
- Inspection processes
  - Dimensional inspection
  - Parent material radiograph
  - Weld inspection
    - Visual, penetrant, ultrasonic, radiograph
  - Leak testing
  - Pressure testing
  - Hole continuity
  - Instrumentation testing
  - Functional weight / center of gravity
  - Cleanliness



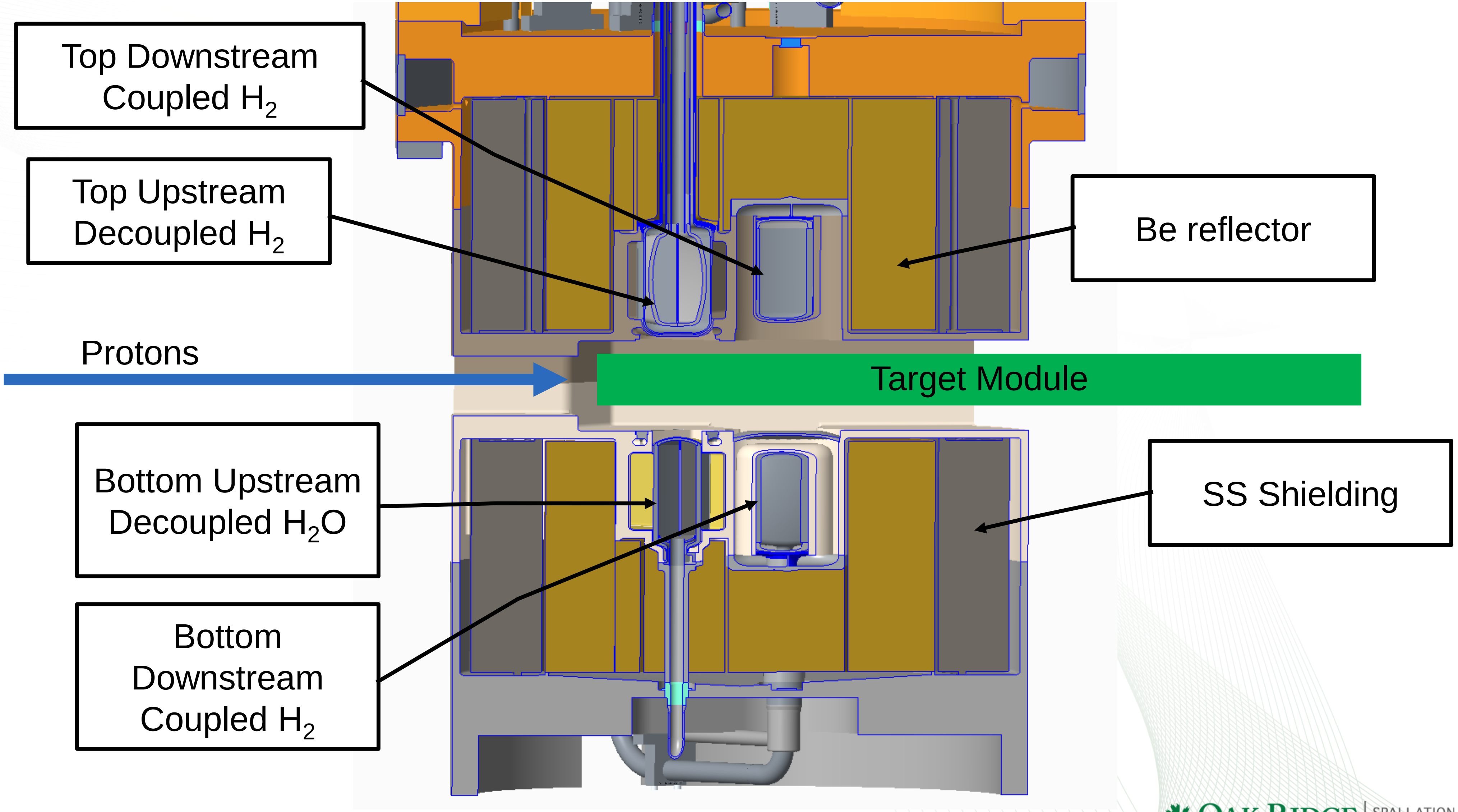
Inner Reflector Plug Overview

- The IRP is a 63,000lb plug divided into 3 main segments
  - Upper IRP – Plated carbon steel shielding
  - Middle IRP – Water cooled stainless steel shielding
  - Lower IRP – Water cooled aluminum vessel filled with steel and beryllium surrounding aluminum ambient and cryogenic moderator vessels
  - Water piping and cryogenic transfer lines transverse all three assemblies





Overview of Lower IRP, critical region



Inner Reflector Plug Processes

- Manufacturing Processes
  - Material production
    - Forging, plate, pipe, bar, etc.
  - Conventional machining (match machining for heat transfer)
  - Wire and Plunge EDM
  - GTAW welding
  - EB welding (*6061-T6 aluminum*)
  - Gun drilling
  - Electroplating
  - Electropolishing
  - Hot isostatic pressing
  - Cadmium flame spray
  - Cadmium machining
  - Multilayer and multi-material piping (4-6 layers)
  - Friction welding
  - Explosion bonding

- Inspection processes
  - Dimensional inspection
  - Parent material radiograph
  - Weld inspection
    - Visual, penetrant, ultrasonic, radiograph
  - Leak testing (layered piping, complex geometry)
  - Pressure testing
  - Instrumentation testing
  - Functional interface
  - Cleanliness
  - Cadmium adhesion testing

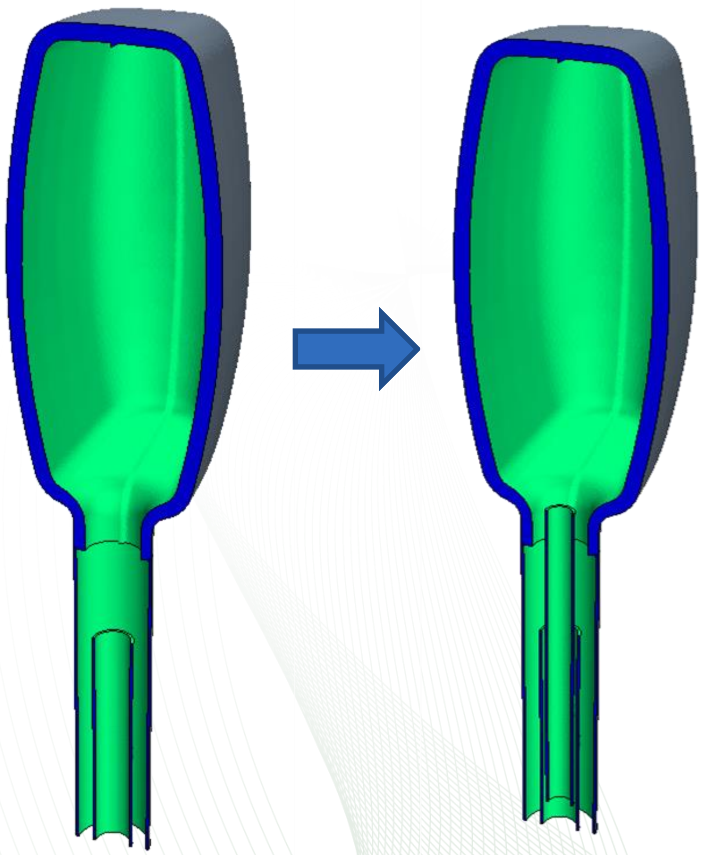
Part Three – Significant challenges in the history of SNS manufacturing

4 of the defining moments in history of SNS source component manufacturing

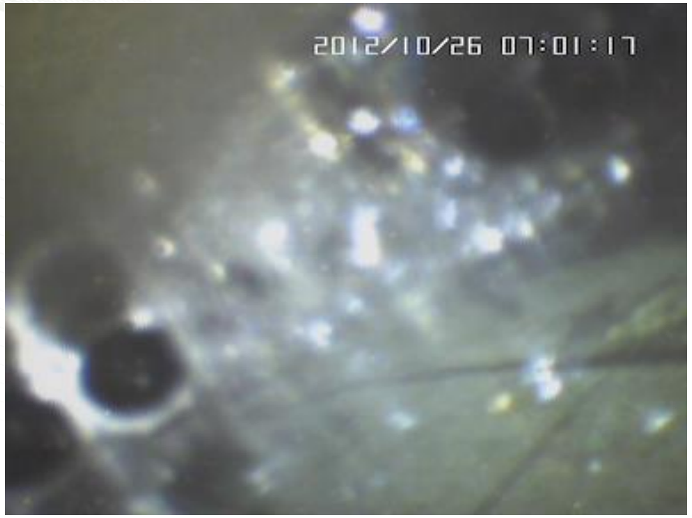
- 2004 – Interface problem between IRP and moderator piping leads to short moderator hydrogen supply pipe and loss of cooling (no neutrons)
  - Nearly disabled ¼ of SNS instrument capacity for many years
- 2012 – Poor weld fit-up and leads to premature failure of 2 target modules within 2 months
  - Lead to significant changes in weld inspection and vendor oversight (cost increase)
- 2013 – Discovery of internal cracks within moderator vacuum vessel requires major rework of IRP-2 during fabrication leads to ~2 year delay of IRP-2
  - Lead to significant schedule and cost over-runs, fundamentally changed relationship with most prolific supplier
- 2017 – Detection of leak in the water-helium boundary atop the top upstream moderator leads to ~1 year delay of IRP-2
  - Caused IRP-1 to run at least 6 months longer than lifetime, which impacted pulse shapes at instruments

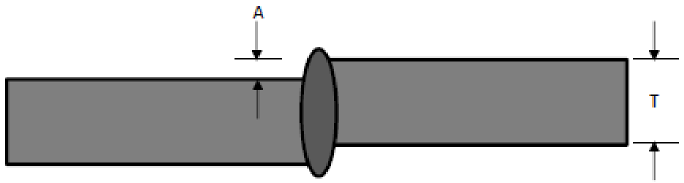
2004 – Interface problem between IRP and moderator piping leads to short moderator hydrogen supply pipe and loss of cooling (no neutrons)

- Moderator piping vendor was different than IRP vendor
- A design change was approved with the IRP vendor, but not communicated to the moderator piping vendor
- Issue was remedied by inserting a stint (tight spring) through 15 meters of piping that essentially extended the length of the supply pipe

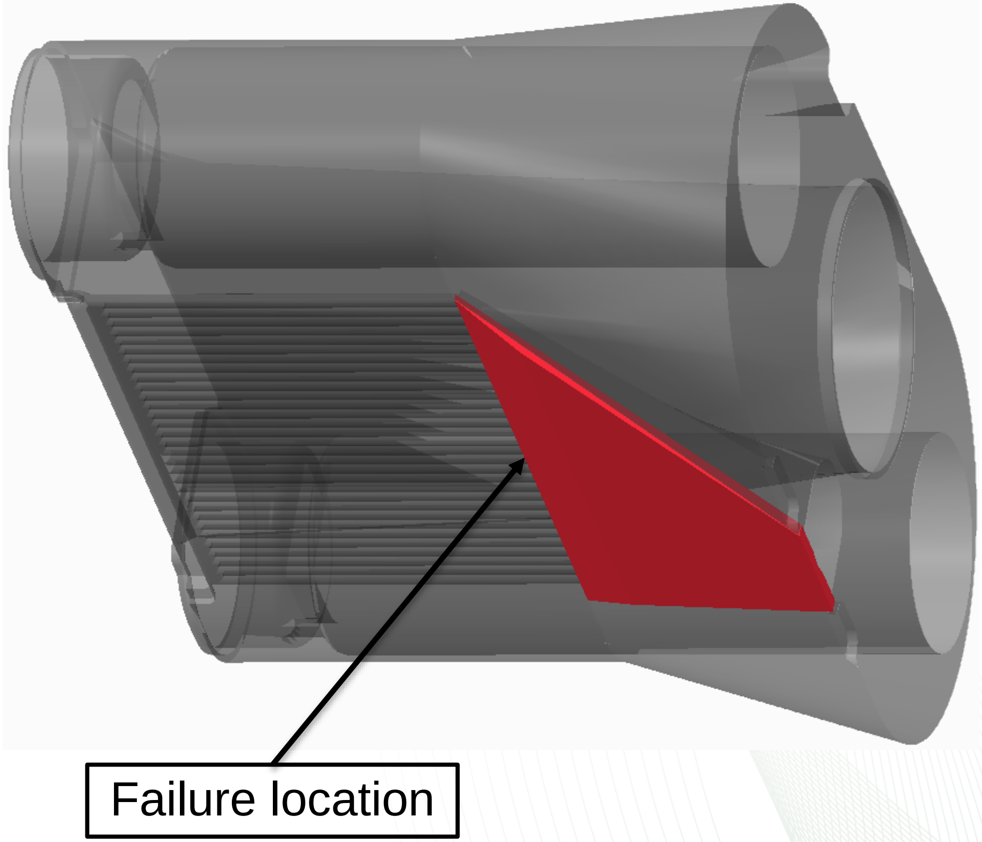


2012 – Poor weld fit-up and leads to premature failure of 2 target modules within 2 months

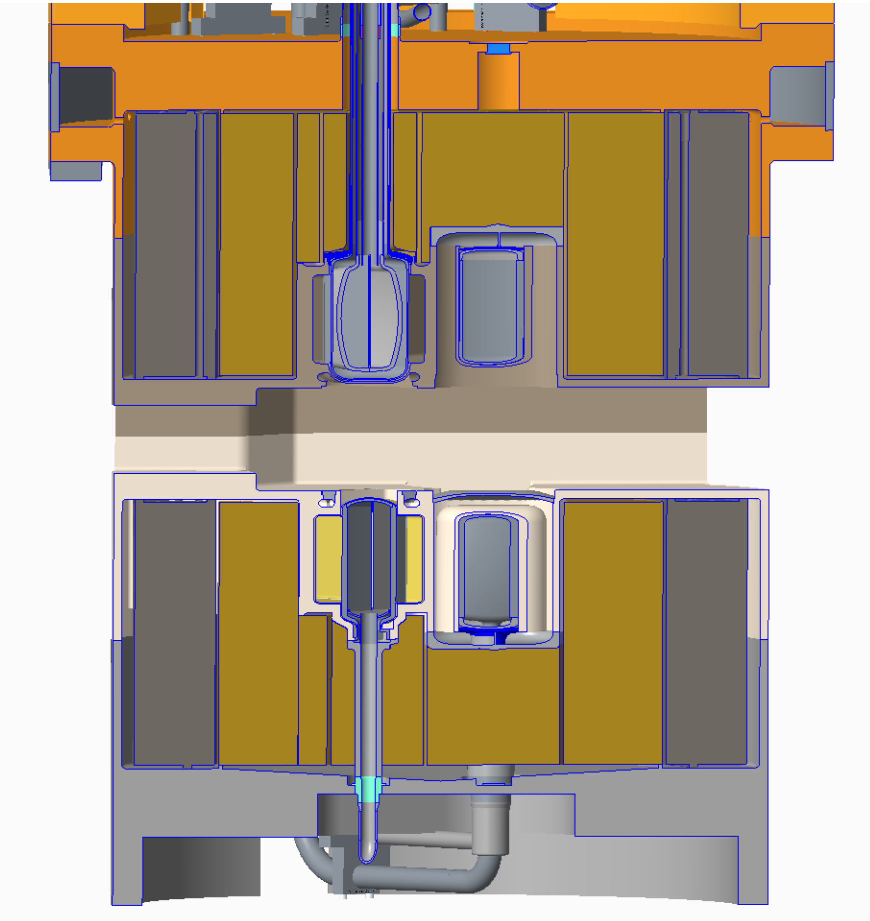




Poor weld fit-up / incomplete penetration lead to 4 premature mercury vessel leaks

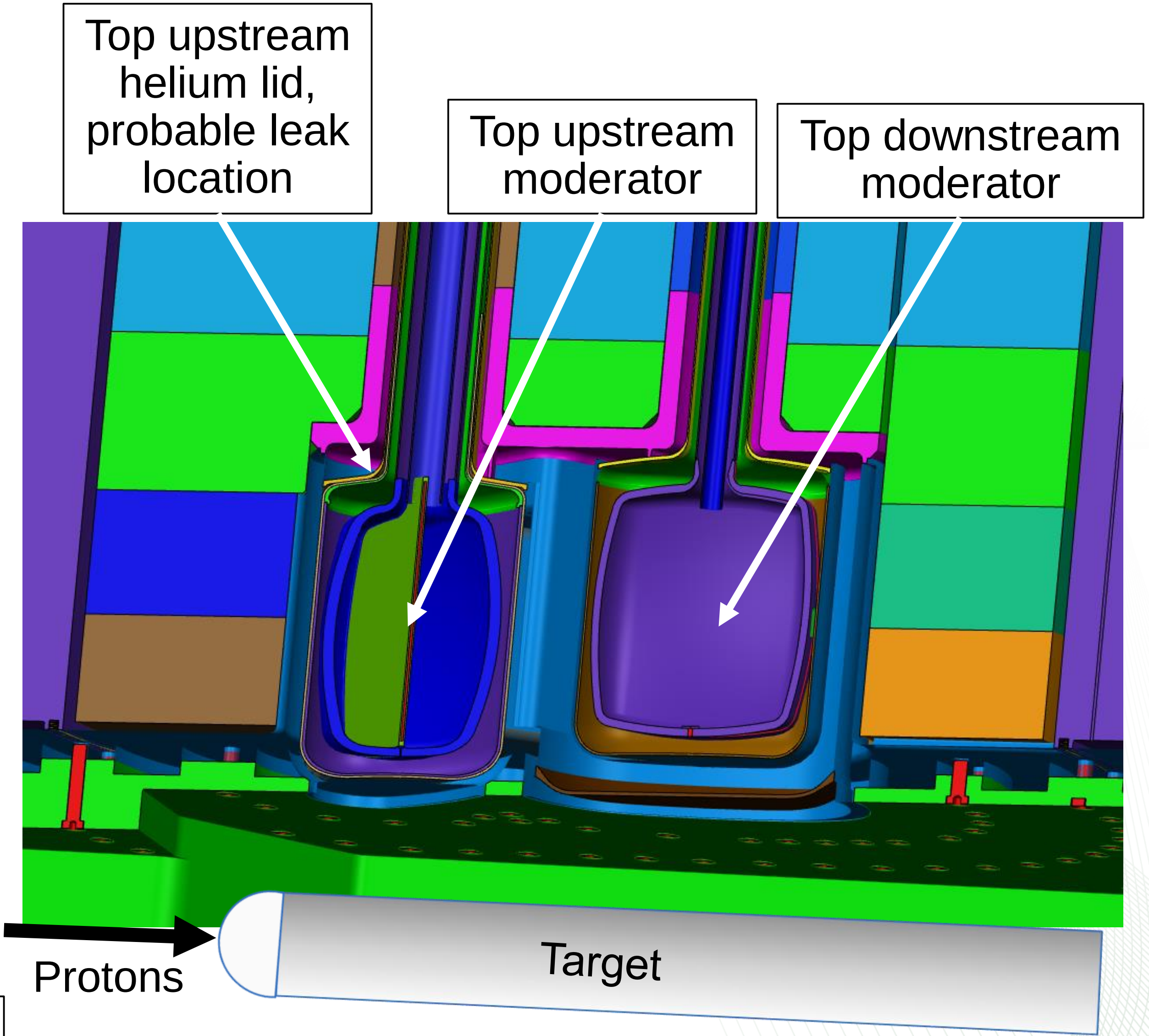


2013 – Discovery of internal cracks within moderator vacuum vessel requires major rework of IRP-2 during fabrication leads to ~2 year delay of IRP-2



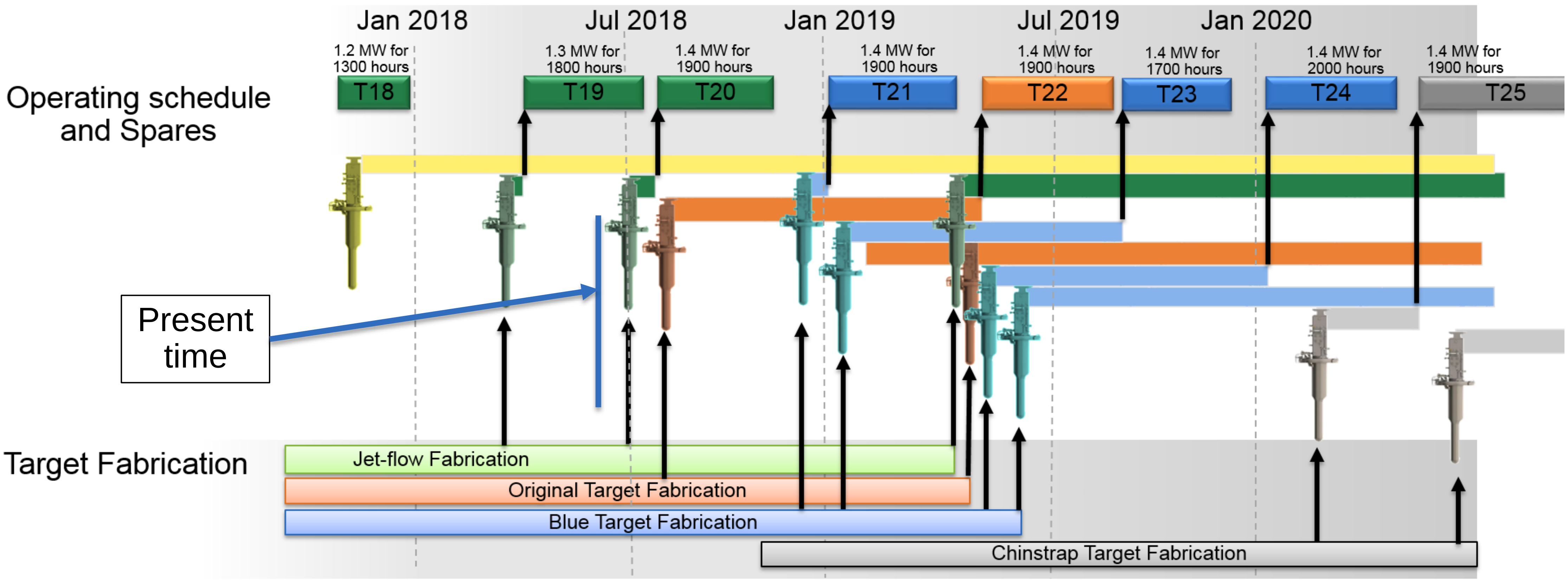
2017 – Detection of leak in the water-helium boundary atop the top upstream moderator leads to ~1 year delay of IRP-2

Cross section through top moderator centers



Part Four – Current status and future plans for target modules and IRP

Current status of target module use (1), inventory (1), and production (8)

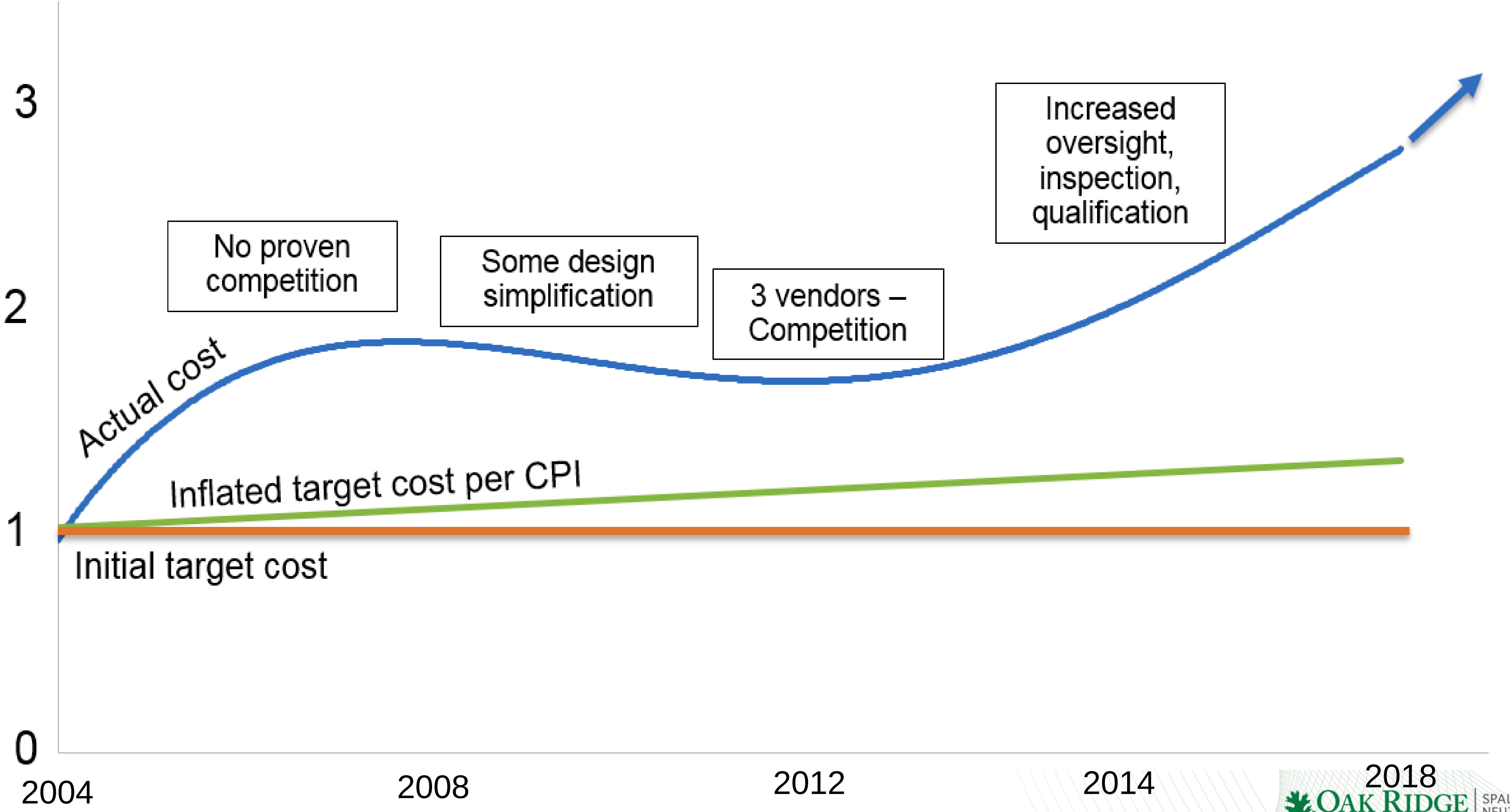


Target Type Key
Original – Yellow
Original, CDE reinforced, gas injection – Orange
Jet-flow, CDE reinforced, gas injection – Green
Blue – Blue
Chinstrap – Grey

Pondering target module procurement history

- In early days, there was an assumption that target module price would go down over time through
  - Value engineering and design for manufacturing
  - Experience gained by suppliers
  - Competition
- In practice, costs have risen significantly
  - Some value engineering and design for manufacturing has been achieved, but it has been trumped by increased complexity elsewhere
  - Auxiliary requirements (inspection, qualification, reporting, QA, etc.) have increased significantly
  - SNS oversight has increased significantly
    - double whammy - driving internal and external costs

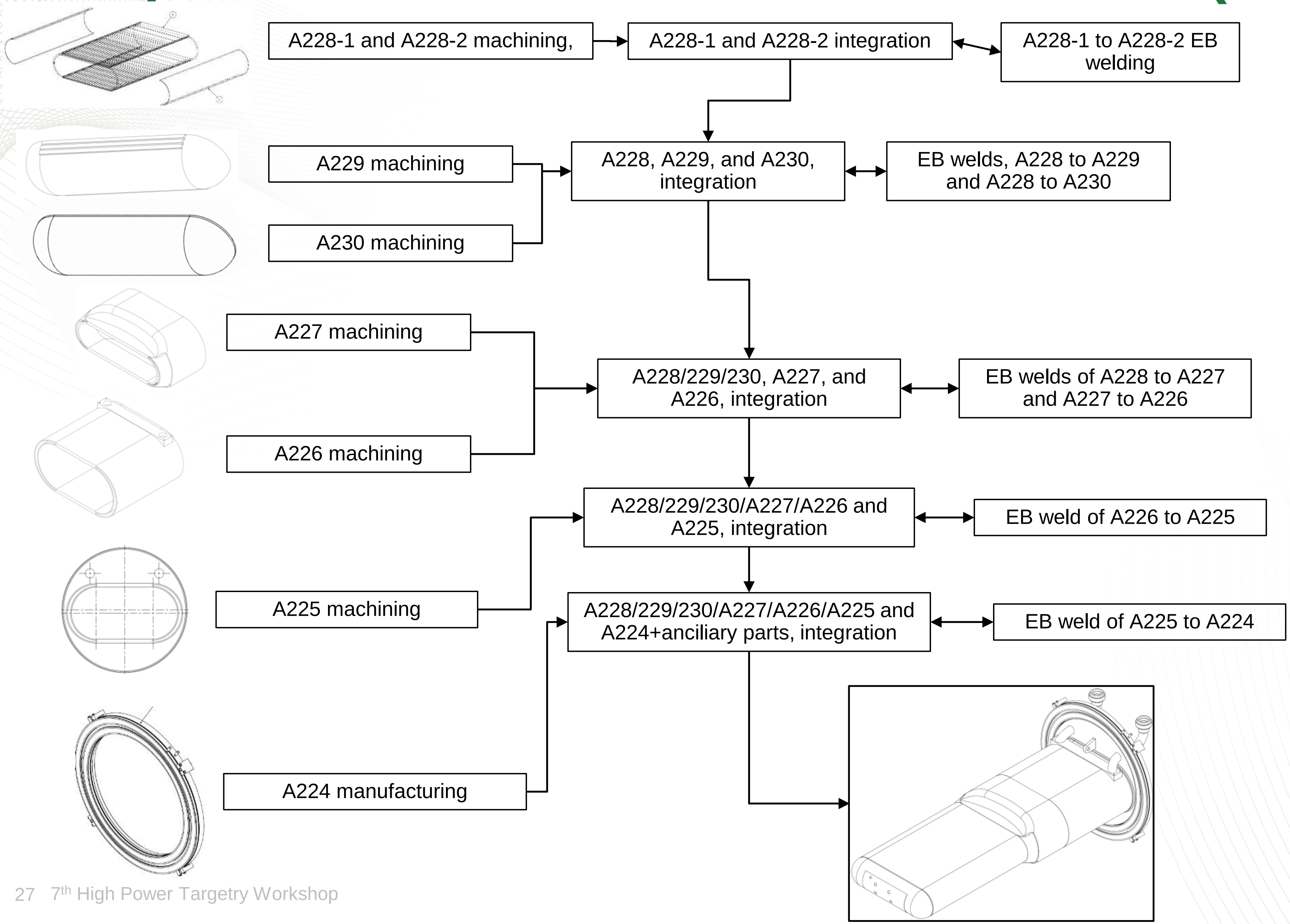
Historical Target Module Cost



A new pilot program has begun – SNS built target module components

- SNS has started the process of self managing manufacture of a water cooled shroud
- Manufacturing is broken down into smaller tasks such as:
  - Material procurement and treatment
  - machined parts
  - EB welds
  - Tungsten Inert Gas Welding (TIG) welding / integration
  - Assembly
  - Non-destructive Examination (NDE)
- These tasks will be completed via smaller purchase orders or with internal ORNL staff

Sample flowchart of water cooled shroud (WCS) manufacture



- Current process involves 2 purchase orders to procure a WCS
- New process will take ~25 purchase orders

If you thought targets were tricky…let's talk IRP

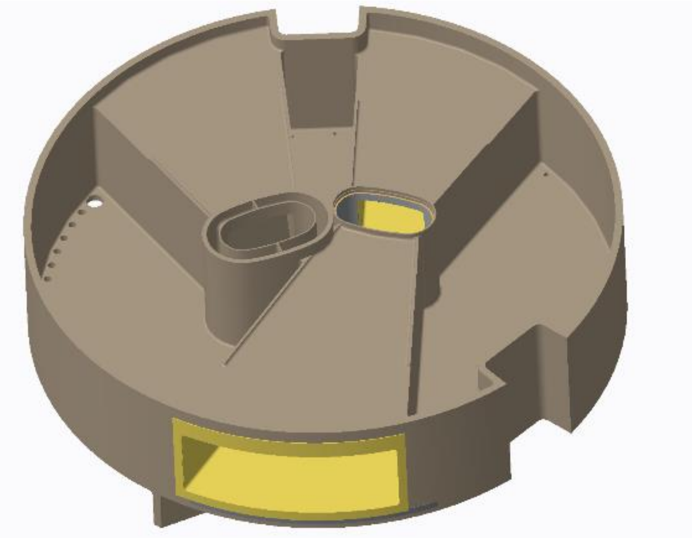
- IRP-1
  - Arrived at SNS incomplete as a set of parts due to vendor budget and schedule issues
  - SNS self completed assembly via heroic efforts just in time for first neutrons
- IRP-2
  - Design/build contract
  - Thought to be a simplified approach
  - Continuous design and manufacturing challenges
  - Work stoppages
  - Cost overruns
  - Total manufacturing time: ~9 years

IRP must be managed more effectively

- IRP-3 design incorporates significant lessons learned from IRP-1 and IRP-2
- IRP-3 will be "build to print"
- SNS staff are much better positioned to execute work:
  - IRP-2 oversight consisted of:
    - a single TPO (which changed at least 5 times)
    - intermittent QA support
  - IRP-3 will benefit from:
    - Dedicated design engineer
    - Dedicated project manager
    - Dedicated manufacturing engineer(s)
    - Dedicated QA staff

IRP procurement strategy and annual plans, *Late FY18 into FY19*

Moderators (weld development included)

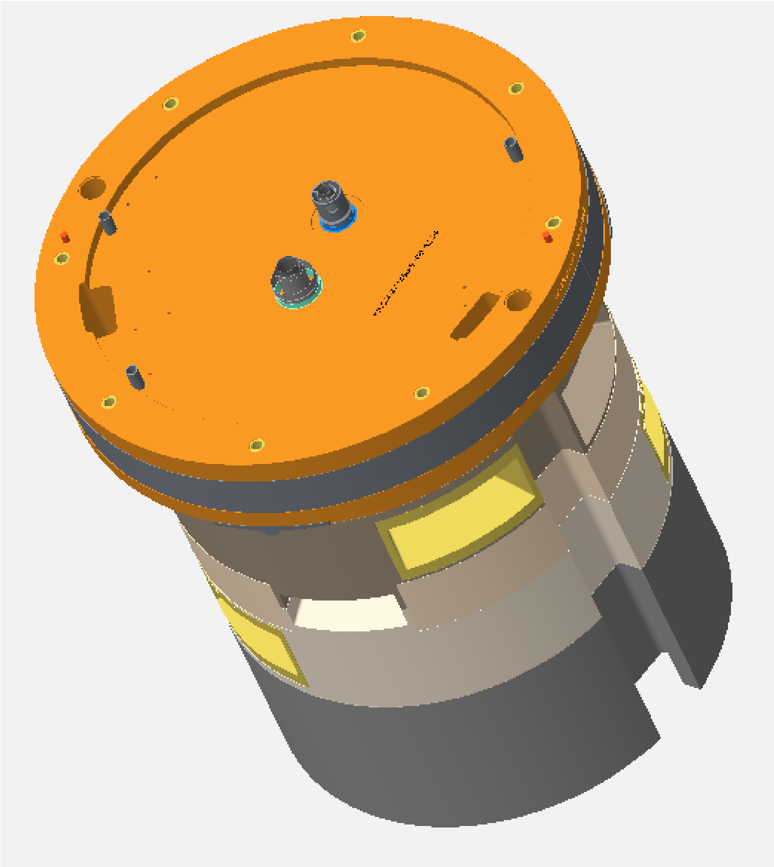


Cadmium and lower IRP weld development

Piping fabrication development

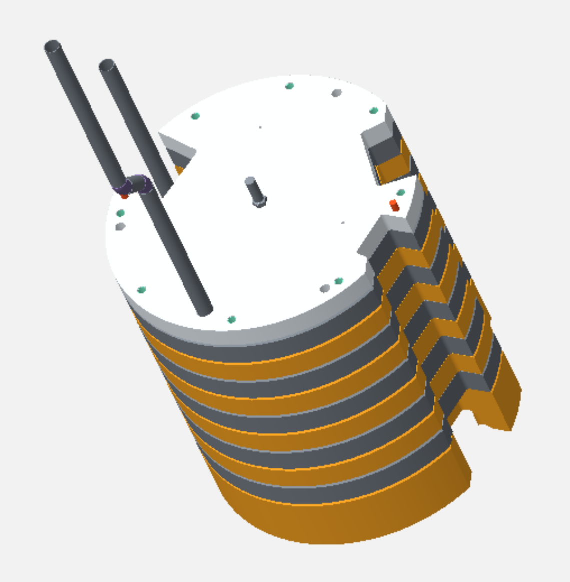
IRP procurement strategy and annual plans, *FY19*

Moderators (weld development included)

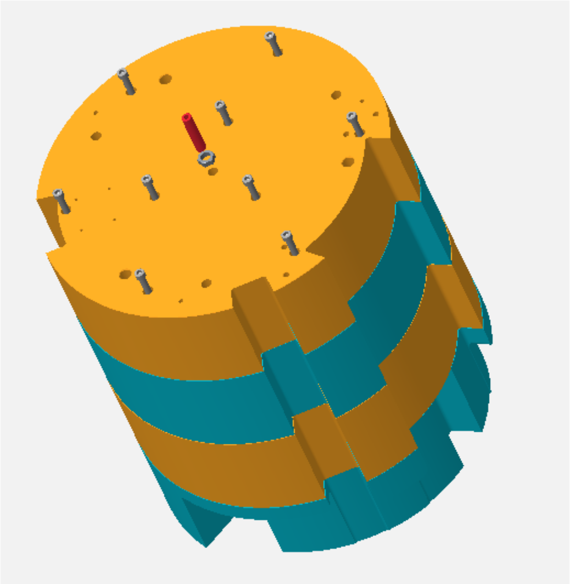


Lower IRP

IRP procurement strategy and annual plans, *FY20*



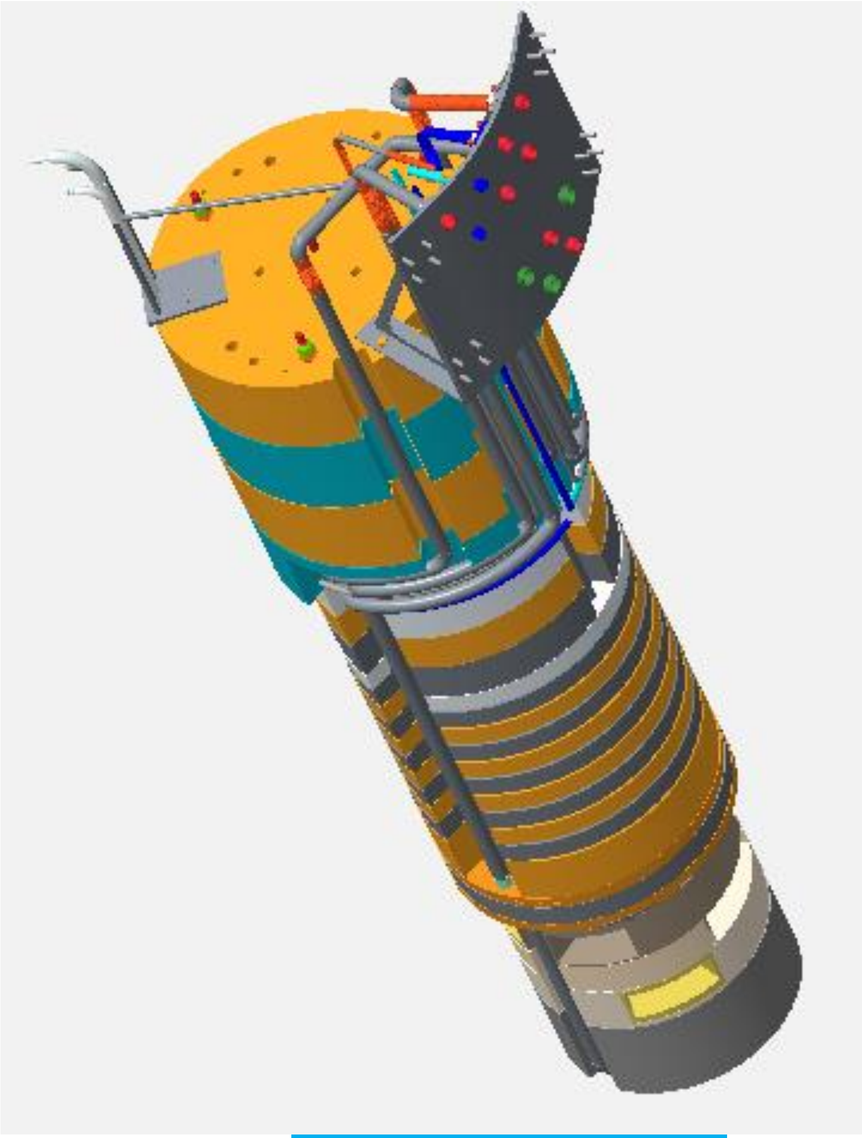
Middle IRP



Upper IRP

IRP piping

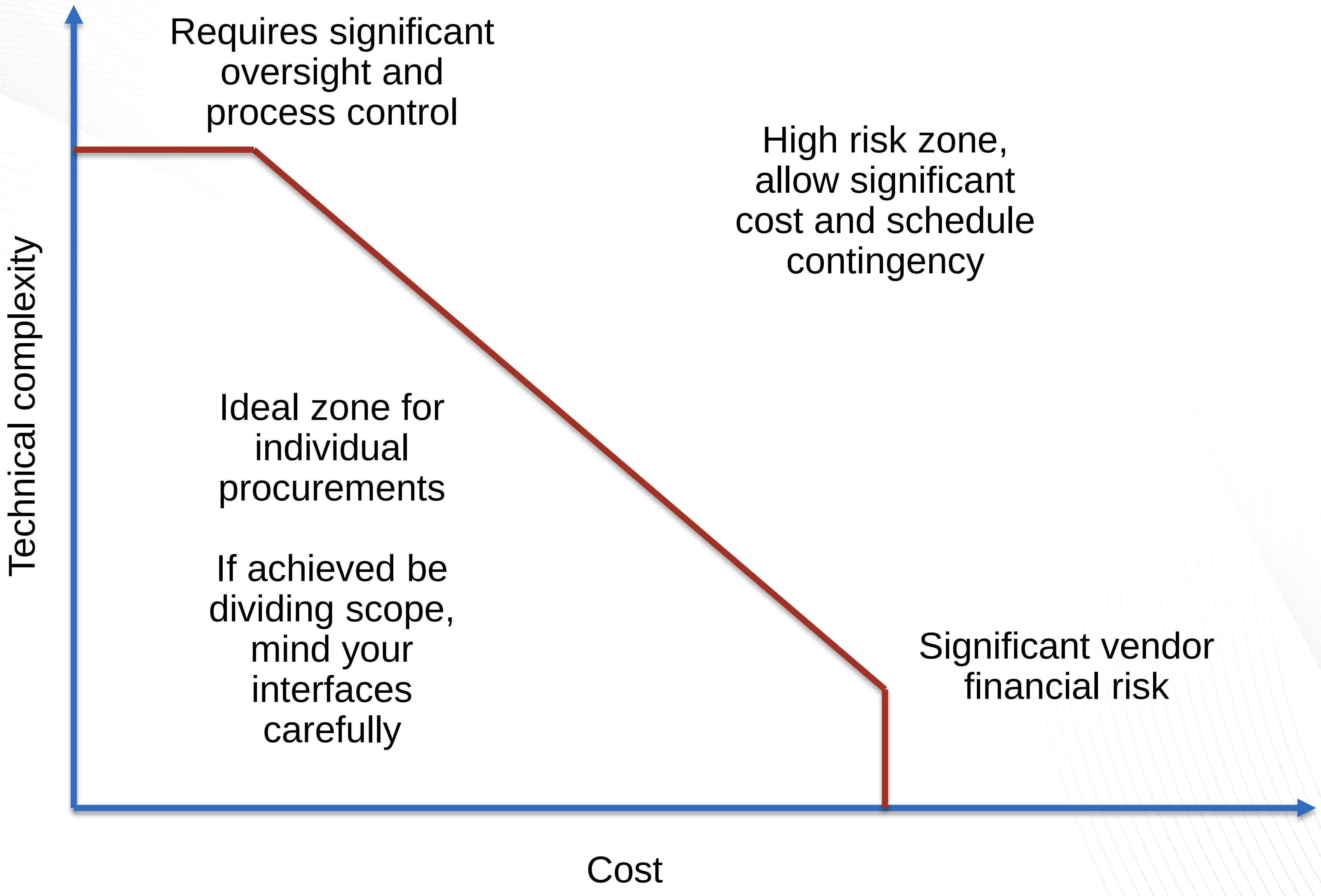
IRP procurement strategy and annual plans, *FY21*



Final Assembly and integration

Part Five – Final thoughts and lessons learned

Threshold for procurement strategies



Lessons learned

- All things matter – complex requirements can lead to complacency regarding simpler requirements for supplier and customer - **if it matters (at all), it needs to be explicitly verified**
- If you can machine it, machine it
- Avoid dependence on single source specialists
- Stuff happens - leaks, weld rejections, machine breakdown, machine crashes, design errors, part movement, shipping errors, misunderstandings, programming errors, cracked parts, dropped parts…
- Allow at least 50% schedule contingency for manufacturing
- Directly control the development and the process to the extent possible – this depends on how often you will repeat the process
- Intentionally strive for multiple profitable suppliers

Questions?