Neutron Source Manufacturing at SNS

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Peter Rosenblad
Manufacturing Team Lead
Source Development and Engineering

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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
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

[Diagram showing the components of a proton beam window, including Stainless Steel (SS) passive shielding, Stainless Steel cooled shielding, Window itself, and Inflatable SS seal (both sides).]
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
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

- **Top Downstream**: Coupled H$_2$
- **Top Upstream**: Decoupled H$_2$
- **Bottom Upstream**: Decoupled H$_2$O
- **Bottom Downstream**: Coupled H$_2$
- **Be reflector**
- **SS Shielding**

TARGET MODULE

PROTONS
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)

Operating schedule and Spares

Target Fabrication

Jet-flow Fabrication
Original Target Fabrication
Blue Target Fabrication
Chinstrap Target Fabrication

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

- No proven competition
- Some design simplification
- 3 vendors – Competition
- Increased oversight, inspection, qualification

Actual cost

Inflated target cost per CPI

Initial target cost

2004 2008 2012 2014 2018
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
Part Five – Final thoughts and lessons learned
Threshold for procurement strategies

Requires significant oversight and process control

High risk zone, allow significant cost and schedule contingency

Ideal zone for individual procurements

If achieved be dividing scope, mind your interfaces carefully

Significant vendor financial risk

Cost

Technical complexity
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?