Water Cooling System Upgrades, Successes, and Lessons Learned From The Los Alamos Neutron Science Center

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Accelerator Reliability Workshop

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Agenda

- Los Alamos Neutron Science Center (LANSCE) background
- Target 1 water systems upgrades and lessons learned
- LINAC water systems upgrades and lessons learned
- Target 4 water systems upgrades and lessons learned

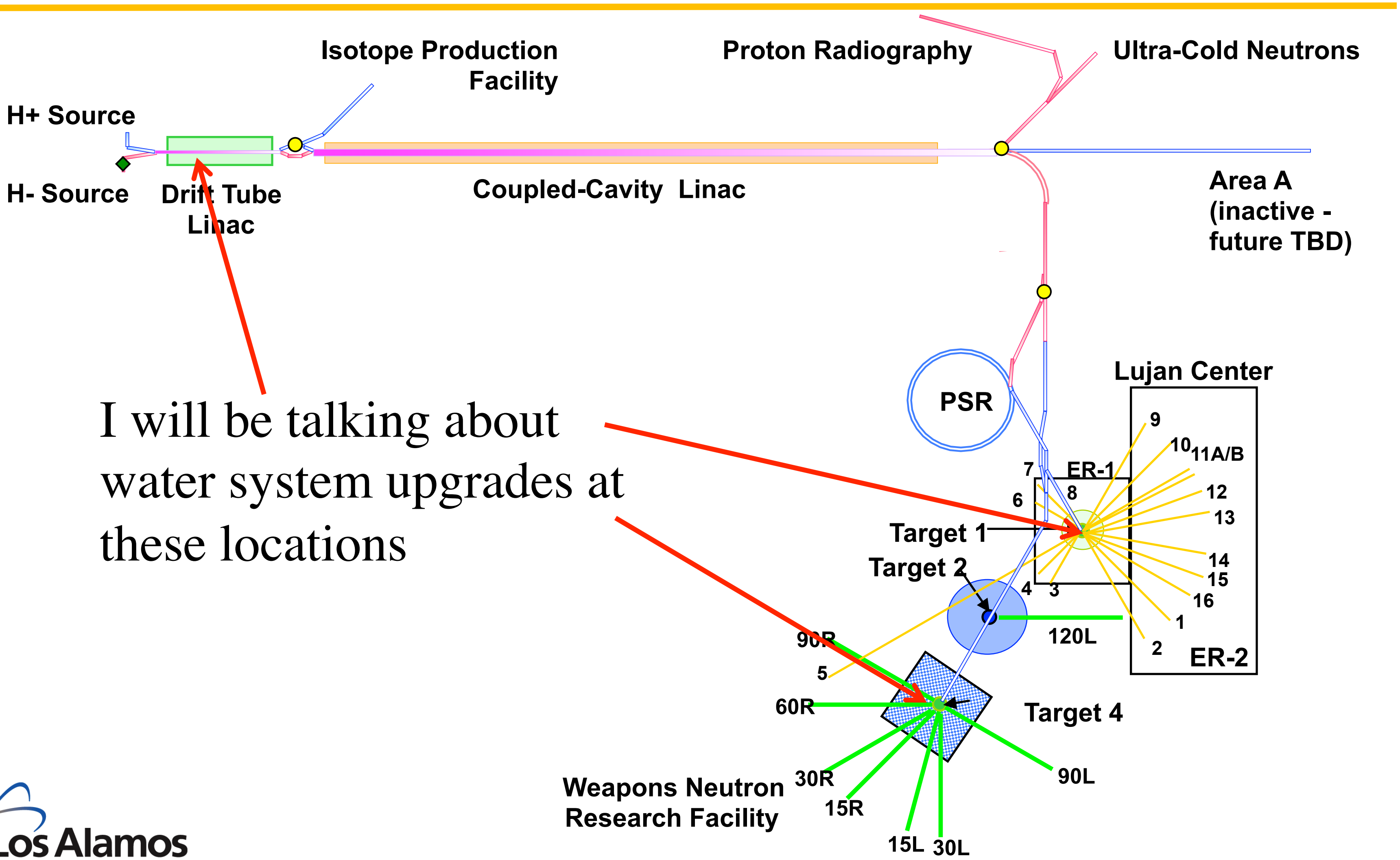
Sometimes upgrades result in lessons learned

Sometimes the lessons learned result in upgrades

What is LANSCE?

- Located in Los Alamos, NM at Los Alamos National Laboratory
- A linear proton accelerator capable of simultaneously delivering 100-800 MeV protons to 5 target facilities (isotope production, proton radiography, ultra-cold neutron, Lujan neutron scattering, Weapon Neutron Research)

LANSCE Facility Overview



I will be talking about water system upgrades at these locations

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NNSA

Some great improvements at Target 1

- Magnetically driven water pumps for contaminated systems
  - Eliminates local contamination areas from seal leaks
  - Reduces waste from and labor for decontamination efforts.
- Soft start and soft stop pump motor controllers
  - Eliminates water hammer or deadheading pumps during startup
- Dry vacuum pumps
  - Eliminates oil back streaming
  - Eliminate cost to analyze and dispose of oil

Some great improvements at Target 1

- Select the proper components and materials for the application
  - Replaced all Teflon valve seals/seats with PEEK, UHMWPE, or metal
  - Removed all copper from otherwise stainless steel DI system
  - Replaced paddlewheel flow sensor SS shafts with tungsten carbide and standard Vespel SP-3 bearings with Vespel SP-22
- Tungsten clad with tantalum has proven to be very successful at LANSCE
  - Bare tungsten is susceptible to erosion/corrosion when used as a target due to coolant flow and hydrogen peroxide attack

UNCLASSIFIED

Some great improvements at Target 1

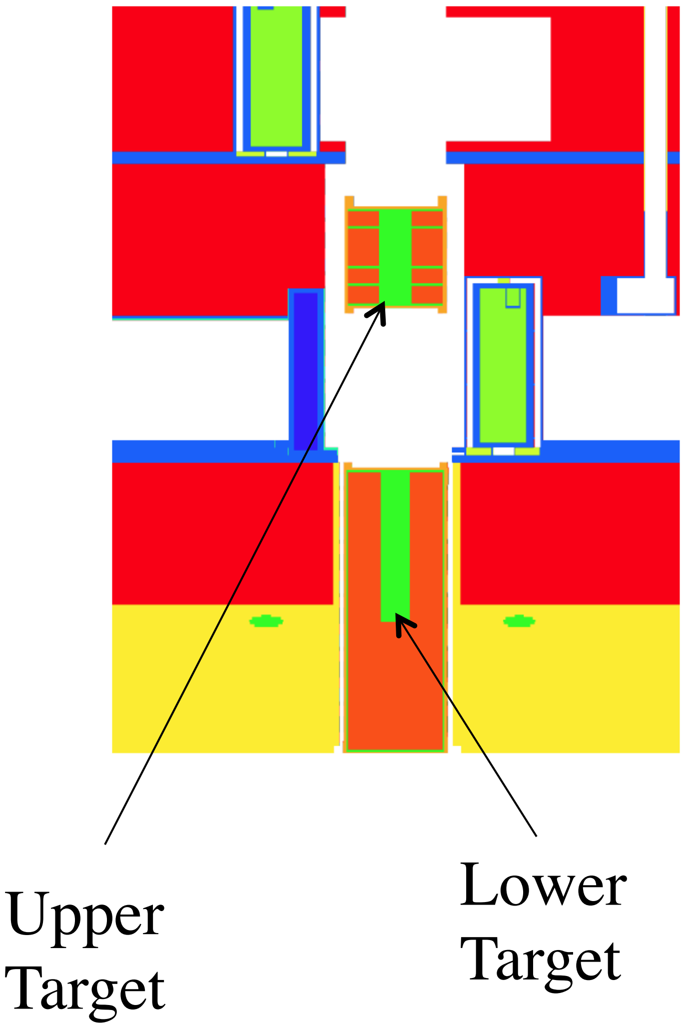
- Installed coriolis flow sensors with remote transmitters
  - No moving parts
  - We have had zero sensor failures after a decade of operation in MRad/yr radiation fields
  - Very steady, they seem less susceptible to noise
  - Expensive
- Installed sufficient diagnostics, sometimes redundant, with adjustable interlocks
  - Gives the ability to display, archive, and track/trend data

and the best improvement at Target 1 is…..

- **We clad the bare tungsten targets.**
- We suspected erosion/corrosion of the bare tungsten targets throughout the lifetime of the previous targets but never understood how much
  – Coolant velocity of ~7.5 m/s – we knew this was high
  – Building and component radiation levels increased throughout TMRS Mark II lifetime
  – Flow resistance through the target cans decreased over time
  – Tungsten subject to H_2O_2 attack

End of Life Test

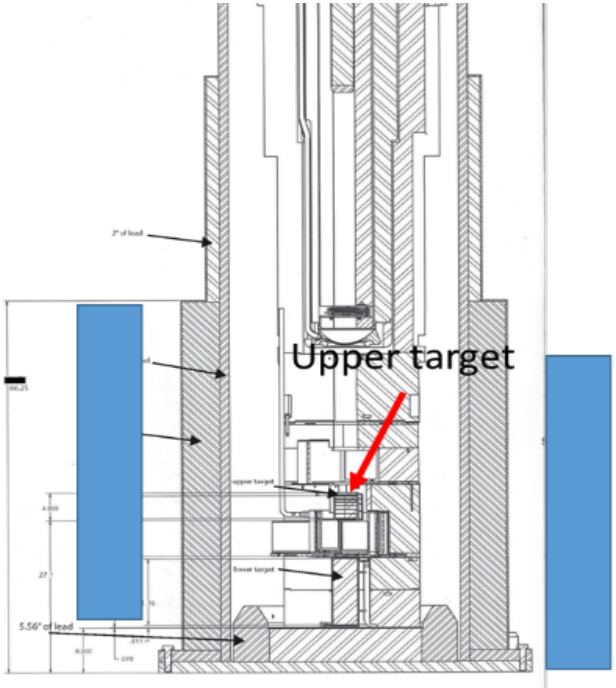
- Performed a TMRS MKII end of life neutron flux test by steering the beam around the target
  - Observed a drastic increase of neutron flux when the beam was steering away from the center of the target
  - Extent of tungsten loss was modeled to be equivalent to a 2" diameter hole bored through the 4" OD upper target and a a 1.25" hole bored 6" into the 4"OD bottom target

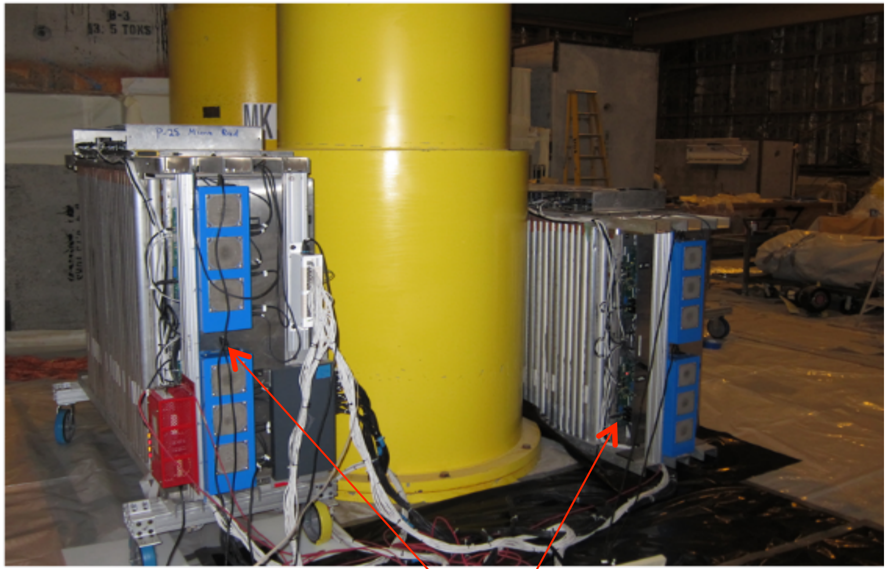


Post Mortem Analysis

- Ultimately we would like to disassemble the target assembly and analyze the targets
  - High dose rates (15,000 R/hr when removed in 2010)
  - No local facilities available to disassemble
  - No DOT cask available to transport
- LANL has recently developed a muon scattering radiography technique that is able to penetrate dense objects and create images.
  - Primary uses include cargo inspection at ports, Fukushima recovery efforts (could reduce cleanup efforts from 30 to 20 years), nuclear fuel rod inspection, and now analysis of neutron targets

Muon Radiography Setup

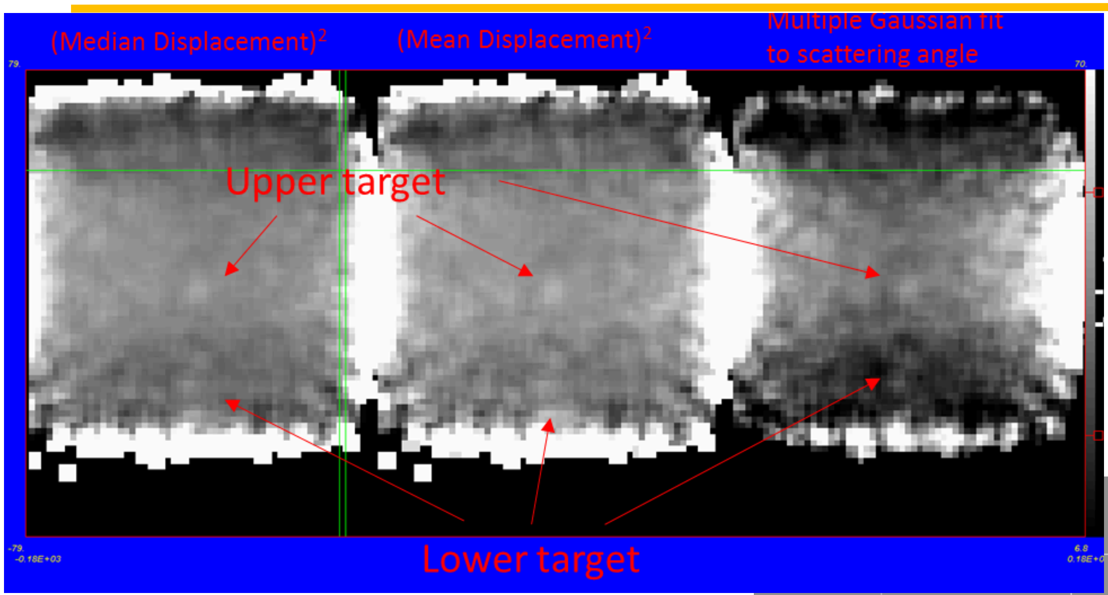


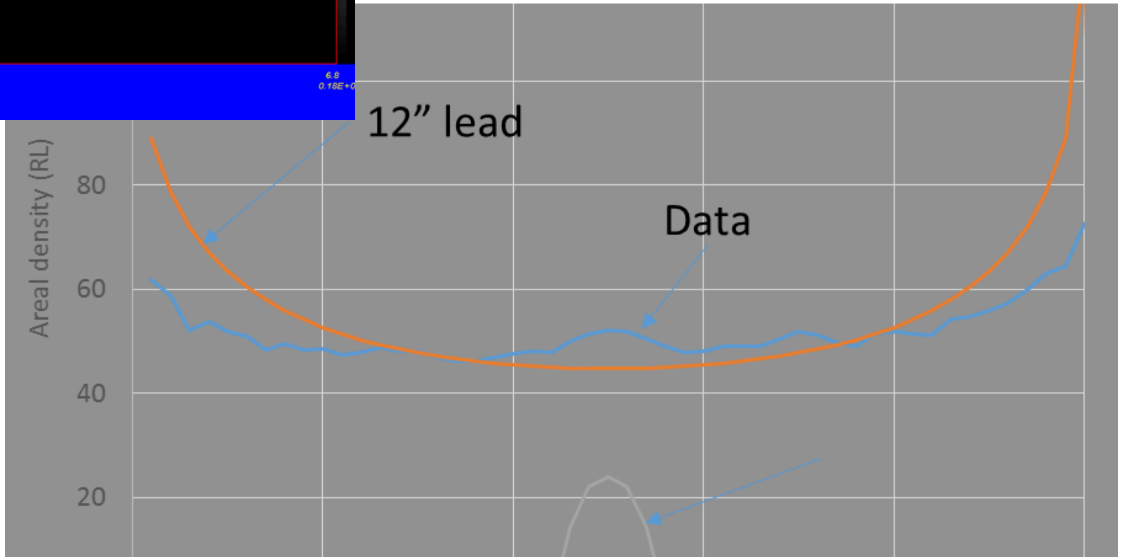


Muon detectors

Detectors looking through 12" lead, 3.5" steel, 16" beryllium, 4" tungsten

Muon Radiography Results



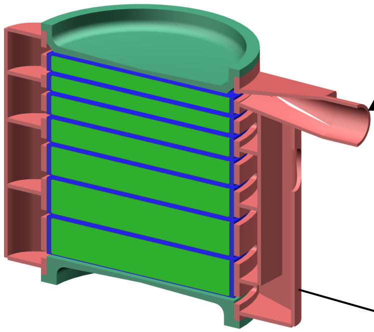


Results indicate only about 1/3 of the upper target tungsten is left!!

Cladding Performance of New Target Assembly

Unclad Upper Target

New

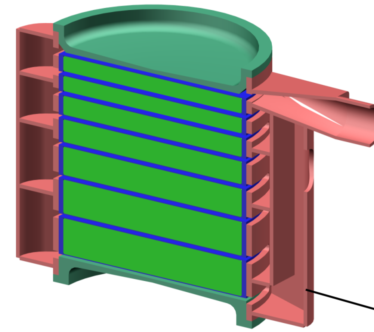


P in=188 psig

dP = 86 psi

P out=102 psig

1200 mA-hrs →



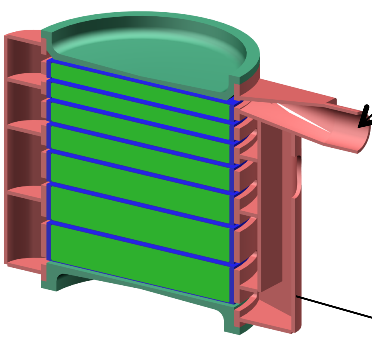
P in=188 psig

dP = 32 psi

P in=156 psig

Clad Target

New

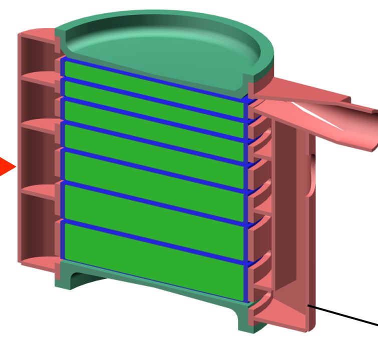


P in=198 psig

dP = 45 psi

P out=153 psig

1200 mA-hrs →



P in=204 psig

dP = 48 psi

P in=156 psig

TMRS Mark III Clad Target Results

- Very low area radiation levels compared to unclad target
  - Jobs that used to result in 500 mR of radiation exposure are less than 50 mR
  - General area radiation measurements are down by about a factor of 10
  - With unclad target we waited at least 30 minutes before entering equipment service area to perform emergent repairs – with clad target we wait about 5 minutes
- Clad target water is much cleaner
  - Unclad target was 10^6 disintegrations/min, clad is 10^3 disintegrations/min
  - Cladding the target has almost eliminated failures of moving components such as paddlewheel flow sensors

Pay attention to and understand your instrumentation – Lessons Learned

- We willingly operated deionization and oxygen beds beyond their useful lifetimes
  - Resulted in a lowering of pH and a steady increase in the concentration of metal cations (mostly Cu^{2+}) and anions such as chlorides and sulfates which resulted in decomposition of the oxygen scavenging resin
  - Major damage to system welds and probably tungsten target material
- Copper brazes on the heat exchanger (HX) dissolved and plated out on other components

Corrective Actions

- Replaced copper brazed heat exchanger with nickel brazed heat exchanger
  - Prior to eliminating the copper brazes, failures of moving components such as paddlewheel flow sensors and spring flow switches were common and resulted in one 4-8 hr downtimes per every 2 months of operating. Copper oxide was the culprit
  - Without copper brazes the failure of moving components was virtually eliminated
  - Hot deposits on the target water cooling system piping and components were reduced.
  - From a reliability standpoint this has been the **second** best improvement made at the target facility
- Replaced predominantly welded system with Swagelok fittings.
  - Leak free, easy to install, and easy to modify

Eliminated an Environmental Vulnerability

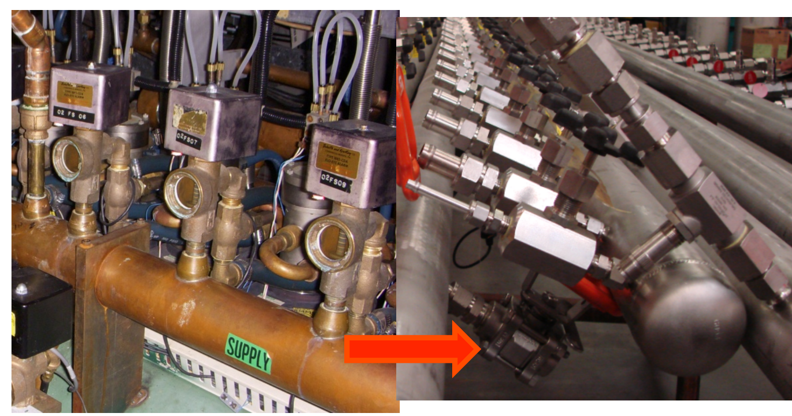
- Installation of a double wall nickel brazed heat exchanger (replaced single wall heat exchanger between contaminated system and clean cooling water) resulted in many hours of downtime
  - Performed hydrostatic pressure test and then installed
  - The target's safety rated flow switches failed their test – they stuck open
  - Grit was removed and analyzed to be iron and silicon carbide, **believed to be from a newly installed heat exchanger**
  - Two years later a filter is still installed upstream of the flow switch
- **All new equipment is now also flushed prior installation**

LINAC Water System Upgrade

- In 2014 a module of the 201 MHz linac water cooling system was replaced
  - Cooling for quad magnets, tank walls, drift tube circuits
  - System design based on SNS water cooling system

1970s

2014



1970s

2014

LINAC Water System Upgrade

- Old System:
  - 6 temperature sensors
  - 6 pressure transducers
  - 68 flow switches
  - Copper
- New System:
  - Nearly 100 temperature sensors for full energy balance estimates
  - 25 pressure transducers
  - 78 flow meters
  - Variable frequency drive pumps
  - 150 micron filtering
  - Pressure relief protected, surge tanks, drains, gas vents installed.
  - ASME B31.3 Process Piping compliant.
  - Stainless steel
  - Fully documented

LINAC Water System Upgrade Successes

- Thermal hydraulic models match experimental results
- Used laser scanner to model room geometry during design phase resulted in great component fit-up during installation
- Additional diagnostics allow for increase in system monitoring and trending

Despite the superior design, we are still having some growing pains

- Vendor specified a turbine flow sensor with different bearings than specified for SNS. New bearings were a grade of Graphitar
  - Graphitar has great wear resistance, cheaper than SNS bearings, and has an available grade that is compatible with deionized water
- Within days the bearings started falling apart and tripping machine safety interlocks. Interlocked flow sensors were bypassed as they failed during last run cycle
- In 2014/2015 all Graphitar bearings are being replaced with carbide bearings at a cost of ~$200,000

Growing Pains

- Schedule constraints didn't allow for complete system testing under load
  - During beam production the linac cavity tank wall temperature could not be maintained well resulting in frequency tuner slugs cycling more than normal. We experienced two tuner slug bellows failure resulting in several hours of downtime
- Designated too many new inputs as machine protection interlocks
- Lots of instrumentation can be a great thing for tracking and trending but also creates additional failure mechanisms, especially if designated as an interlock – there is a balance

Target 4 Loss of Cooling

- Target 4 station has a primary and a secondary port that allows different targets to be inserted, but only one at a time. Primary port is a tungsten target used for neutron production
  - Water cooling to each port is controlled with valves
- Experiment was inserted into the secondary port and operated for a short period of time and then the primary target was placed into service again
  - Not long after changing back to the primary target, a water leak developed in the crypt vacuum space
  - Staff thought that the leak was coming from cooling lines from the secondary port so the cooling water lineup was reversed.
  - Operated like this for about a week without cooling water to target. Target was damaged and operations were halted for the remainder of the run cycle

Problems and Corrective Actions/Upgrades

- Lacking conduct of operations experience/culture
  - Created operating procedure
  - Created piping and instrumentation diagrams
  - Labeled components
  - Reorganized – operations group took ownership
- Lack of maintenance
  - Installed over-pressure protection
  - Created equipment maintenance and testing procedures
- Lack of system diagnostics
  - Added circuit and sum flow diagnostics (coriolis flow sensors and flow switches), temperature sensors, chemistry diagnostics, and pressure sensors. Now use pressure, flow, and temperature inputs as target protection interlocks
- Easy to make a mistake
  - Modified plumbing so that it would take more than valve manipulation to change cooling configuration from one target port to another

Summary

- Many simple and inexpensive upgrades and practices can really improve system reliability and save money in the long run
  - Eliminating copper
  - Cladding targets
  - Picking the correct diagnostics (maybe not the cheapest)
  - Installing magnetically driven pumps/variable speed pumps
  - Developing operating and testing procedures
  - Flushing components prior to installation
  - Allowing adequate time to test new systems

Summary

- System upgrades should improve a system in the long run but sometimes there are lessons learned and growing pains encountered along the way
  - Adequate planning, reviewing, and testing (preinstall and post install) can go a long way to ease these pains

Thank You

- Questions?