LANL Engineering and Design Support for an Accelerator Facility to Produce Mo99 from Mo100

2018 Mo99 Topical Meeting

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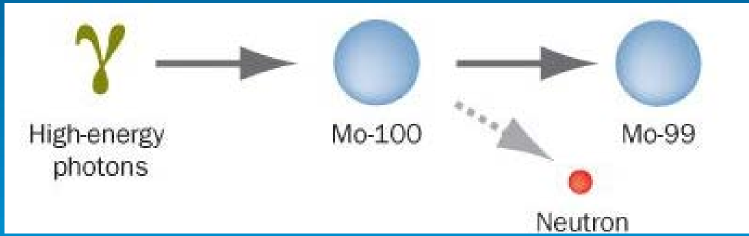
Introduction

Northstar LLC will produce Mo99 using electrons to create a γ-n reaction in Mo100 targets. The baseline target design is comprised of disks, with helium coolant at 300 psi flowing in gaps between the disks. Target solid length is 4.1 cm, made up of 82 disks 0.5 mm thick and 29 mm in diameter. The target is double sided: Beam strikes the target on each end. The total thermal load on the target is 150 kW (42 MeV, 5.71 mA beam, 240 kW beam power).

This presentation is a status update and recommendations for further engineering study and improvements.

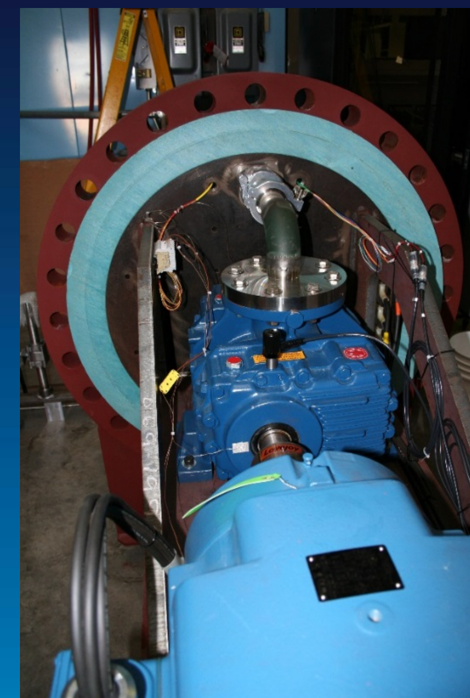


Pressurized Helium System

Target cooling is via a pressurized helium system concept borrowed from Princeton: A roots blower inside a pressure vessel, as is now in operation at ANL and LANL.

300 g/s at 300 psi

Stand alone gas circulators for high pressure are expensive but should be considered for multiple target cooling, as for the Northstar plant design.



Circulating helium loop set up at ANL

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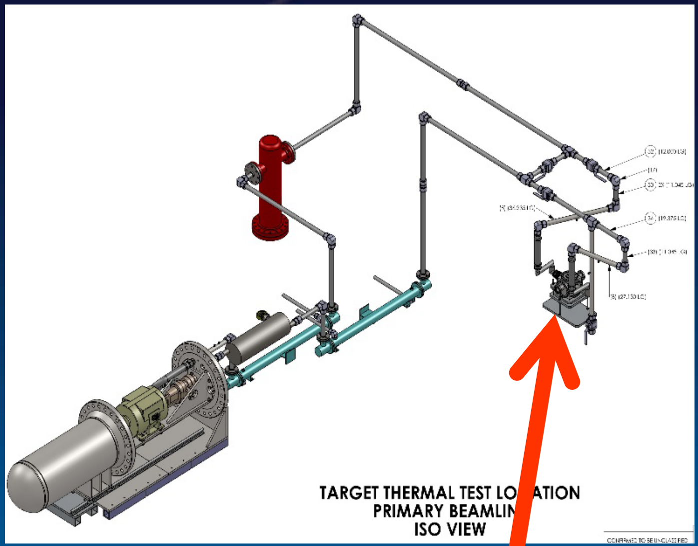
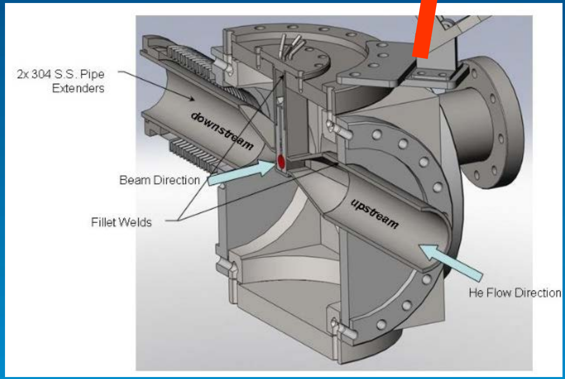
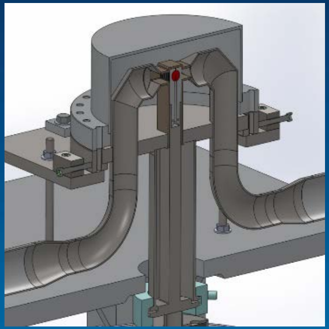
Attempt to perform a double-sided irradiation failed. Could not split and bend the beam. Also problems with cross design

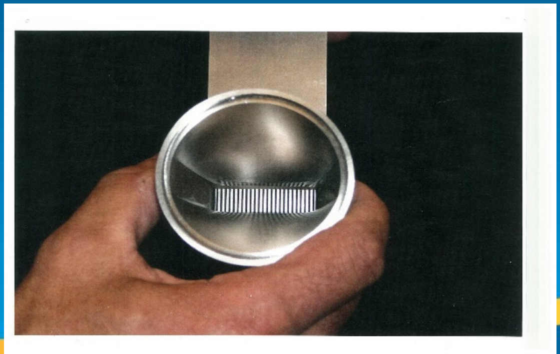
Cross replaced with top hat design.

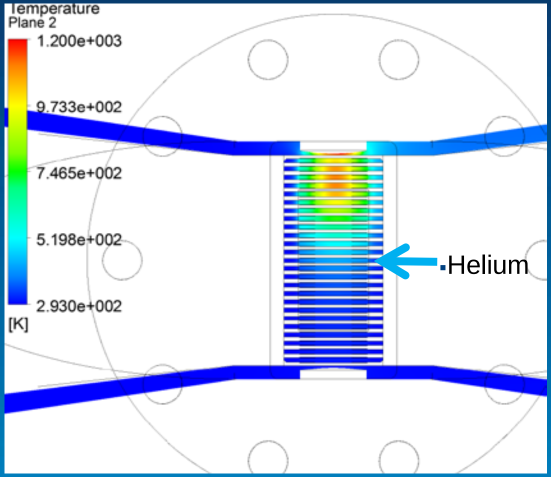
Test done with 25-disk target, 1mm thick, 12 mm dia, 0.5 mm coolant gaps.





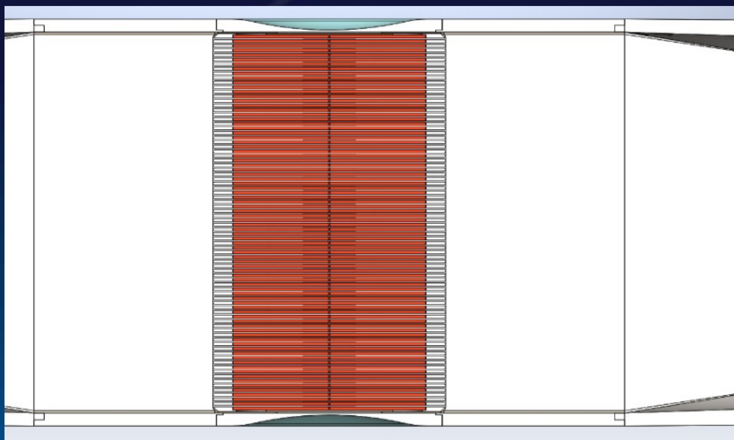




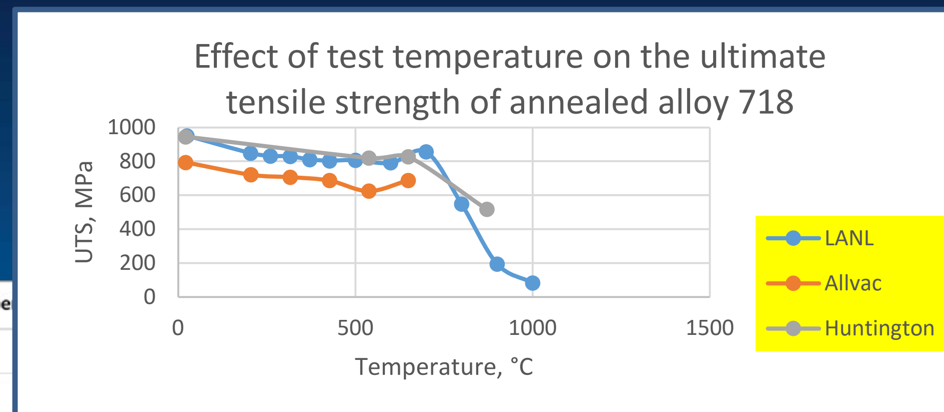


Targets: Plant Design

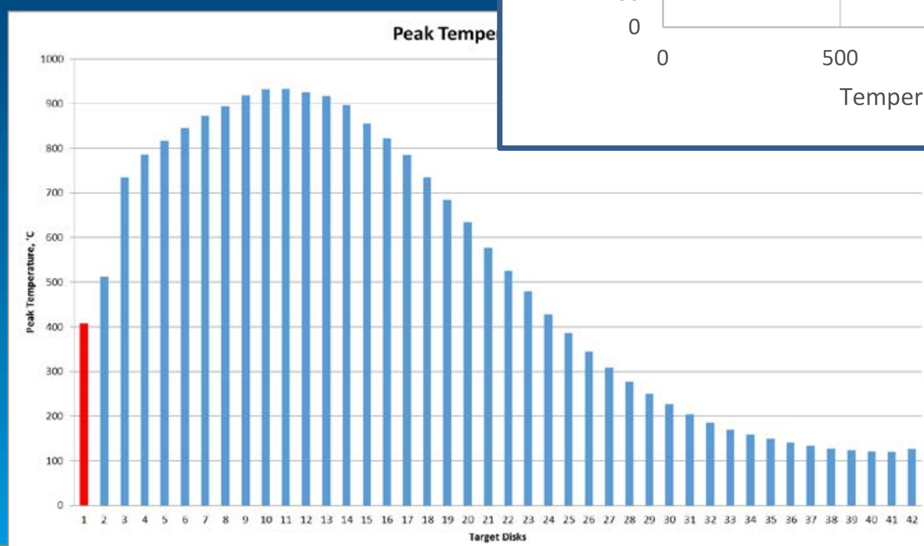
The production goal now has the target at 29 mm diameter, with a 12 mm FWHM beam. Currently, 82 disks are 0.5 mm thick and spaced 0.25 mm apart.



Inconel 718 window: High strength and ductility in annealed state.



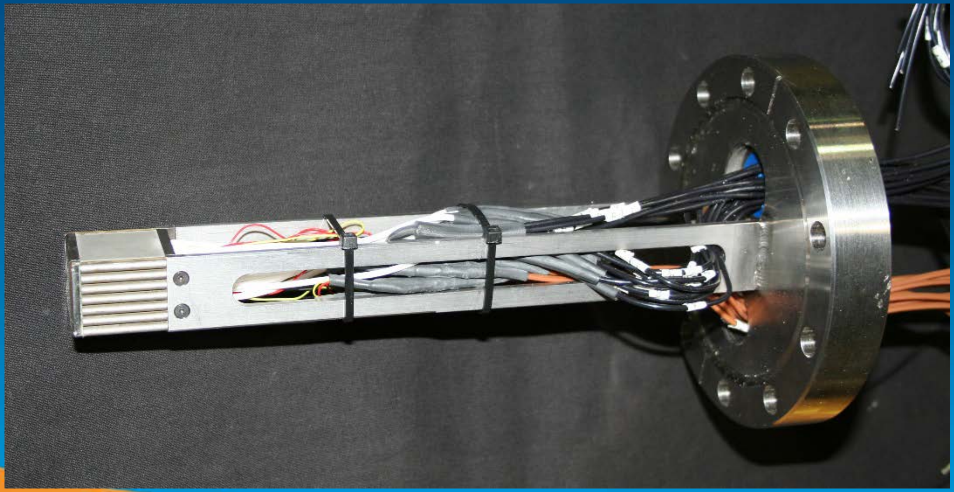
Proprietary window design, not shown, produces helium coolant velocity of 460 m/s, resulting in low window temperature.

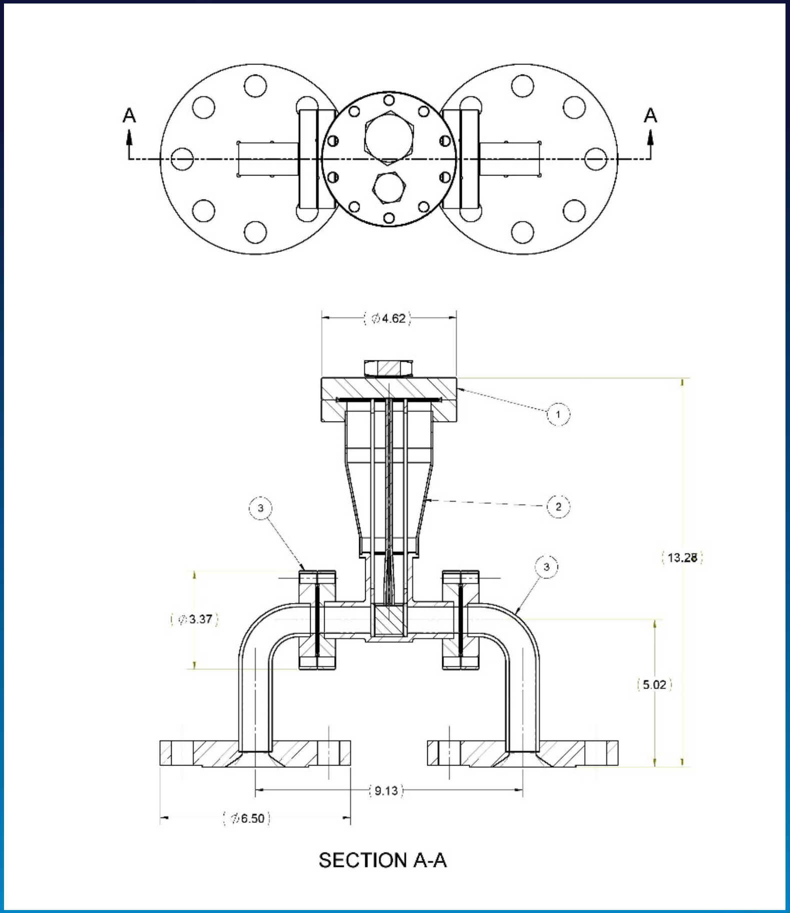


Target: Out of beam tests

Heat transfer tests now being conducted. 7 heaters instrumented with thermocouples. Power density 150 W/cm^2 (10% of beam heating). Test wall effect, helium entry effect, etc., not so easy in beam.

Missing disk and blocked channel tests planned.





Facility layout with linear accelerators

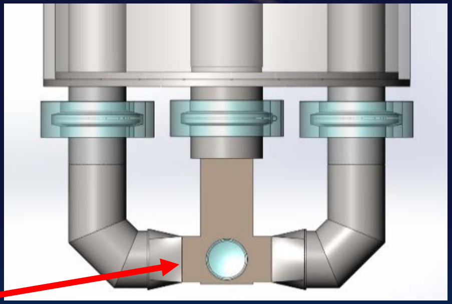
Facility will have 8 target stations, 7 in continuous operation, another cycled in during maintenance.

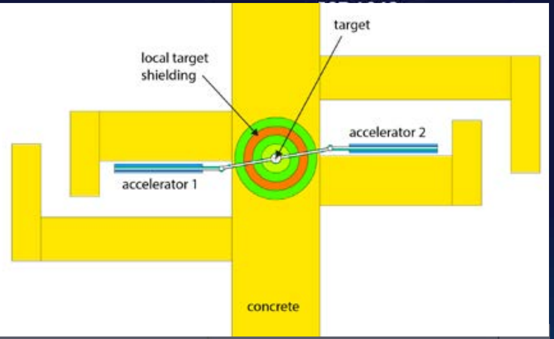
Targets mounted at the end of a long shaft through shielding.

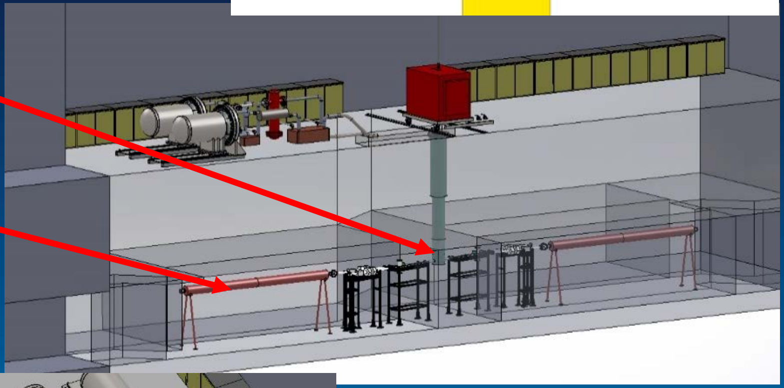
Accelerators on ground level, targets raised through 10 ft thick concrete floor for handing and reload.

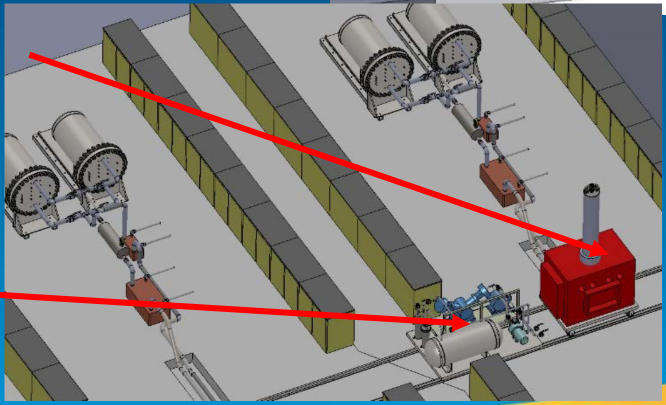
Targets rise directly into a hot cell on rails for removal and load into transport cask.

Gas handling and clean-up system on same rail.



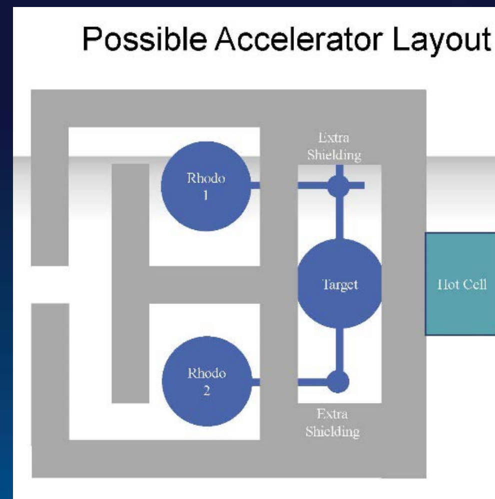


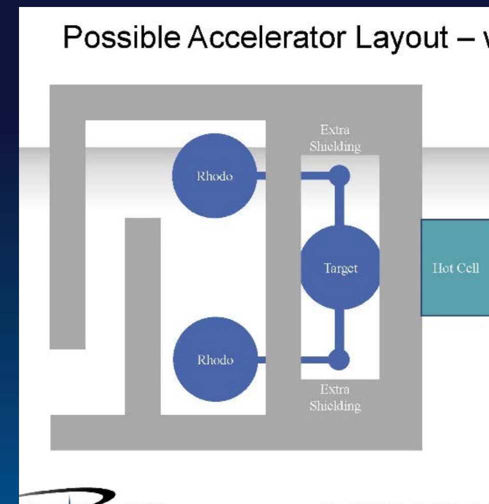


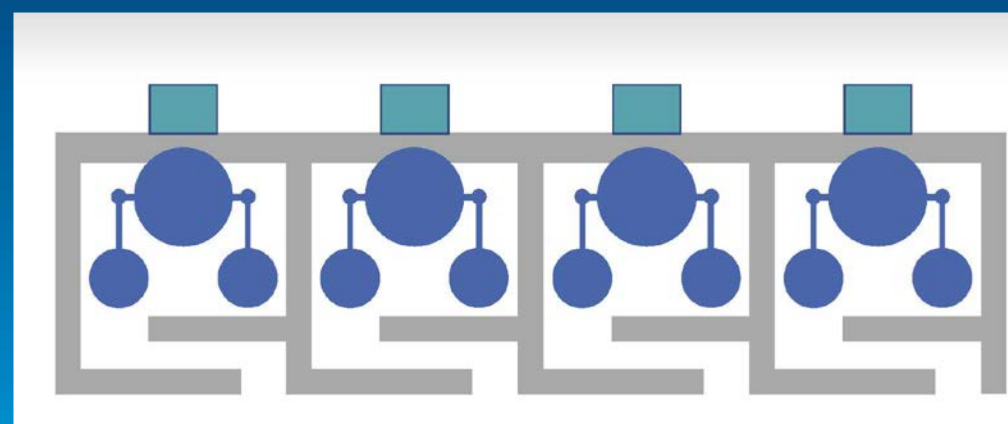


Current Facility Layout with Rhodotrons

- 12 foot diameter rhodotrons are now the electron source for the facility.
- Shielding layout depends on access, maintenance and acceptable continuous occupation dose limits.
- Rhodotron emissions not known.
- Rhodotron maintenance requires lifting the “lid.” 15’ ceiling required.

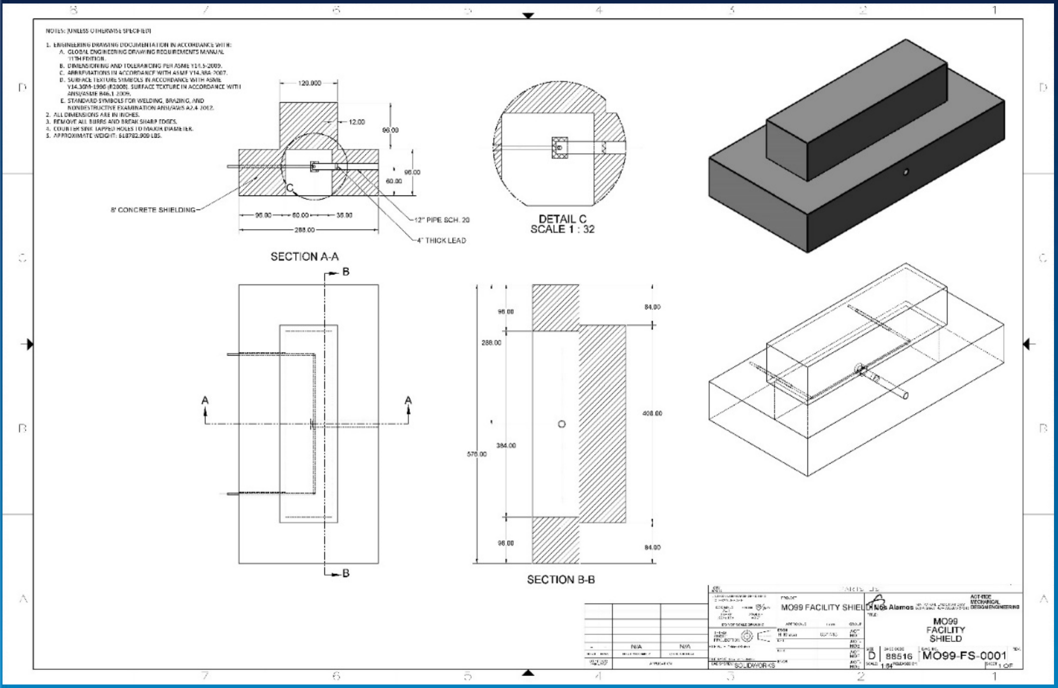


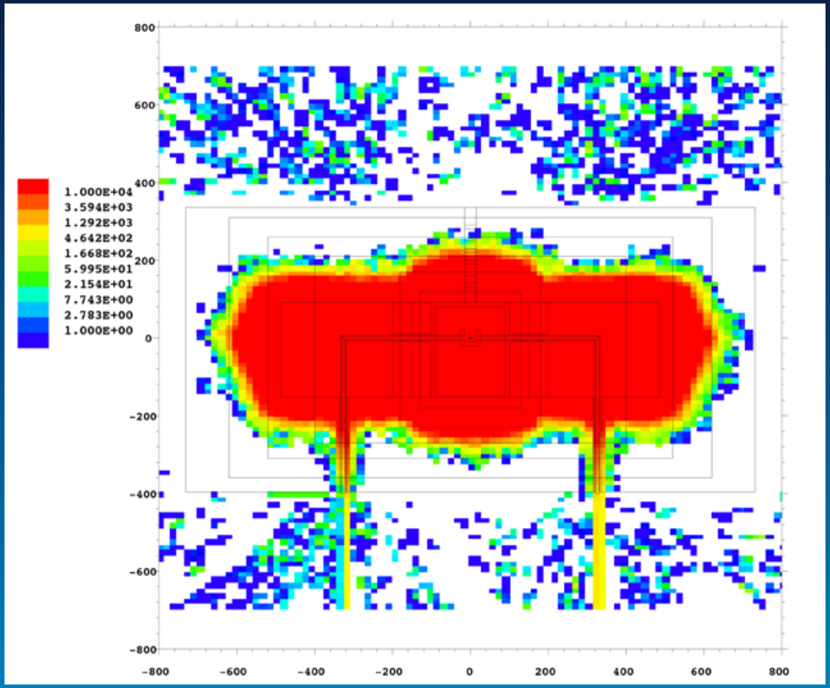




Target cell block shielding preliminary layout

8’ thick high density concrete all around. Too many neutrons escaping.





Target cell block shielding 2nd iteration

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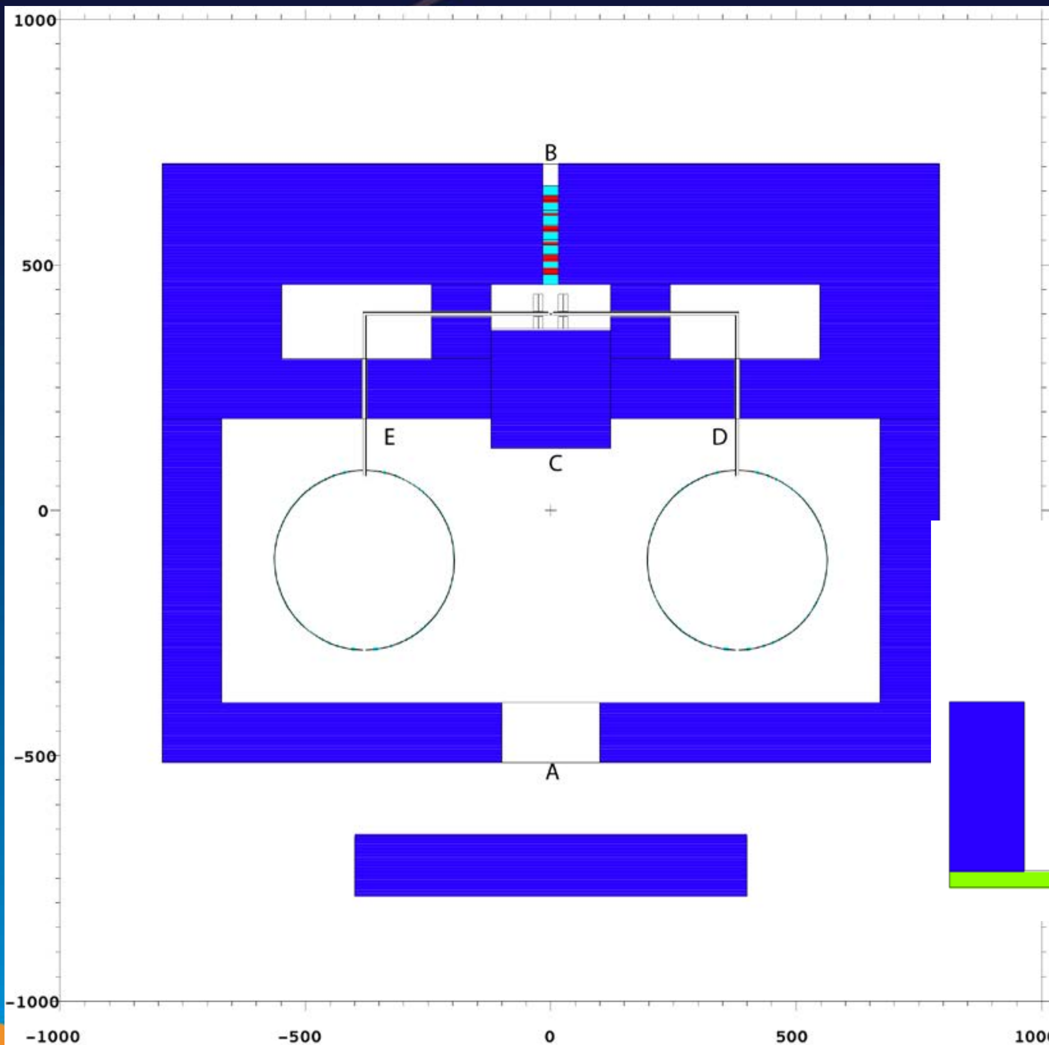
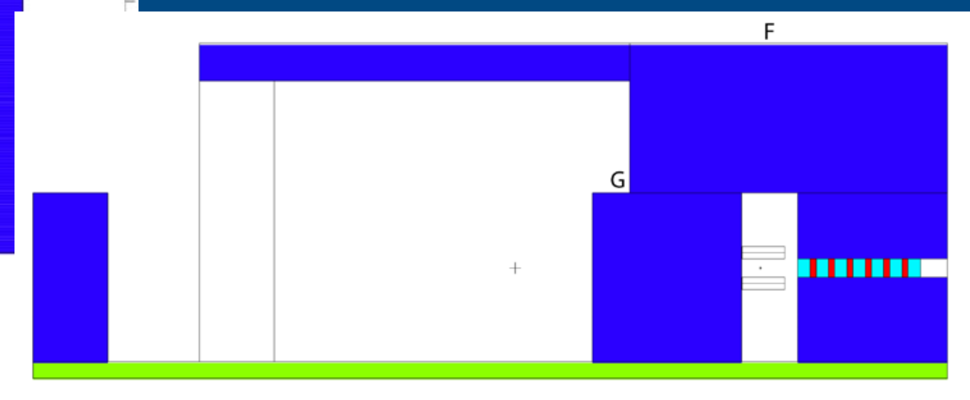


Spot	Two sided mrem/h	One sided mrem/h
A	0.7	0.4
B	0.3	0.1
C	0.6	0.3
D	25	20
E	25	1
F	<0.1	<0.1
G	3-4	3



Target cell block shielding 2nd iteration

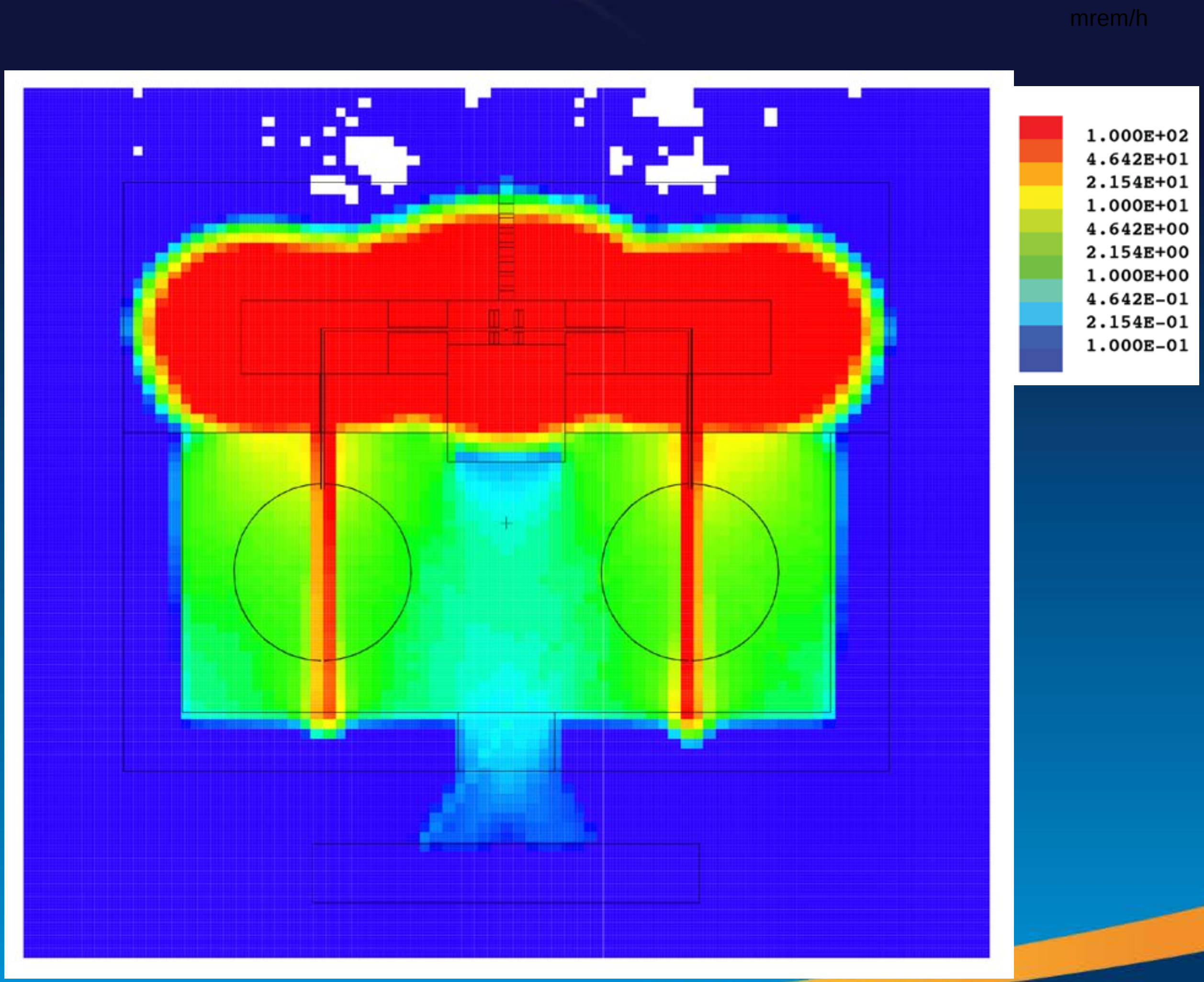
Things not yet known:

Rhodotron emissions

Rhodotron maintenance requirements

Shield wall between rhodotrons?

Effect of local neutron shielding



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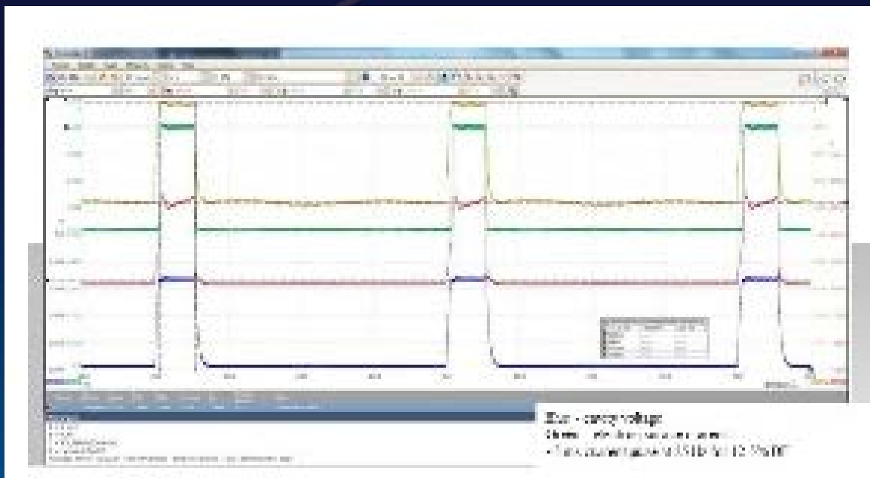
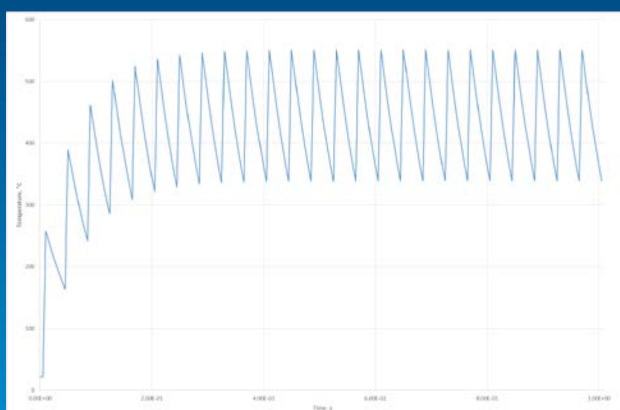
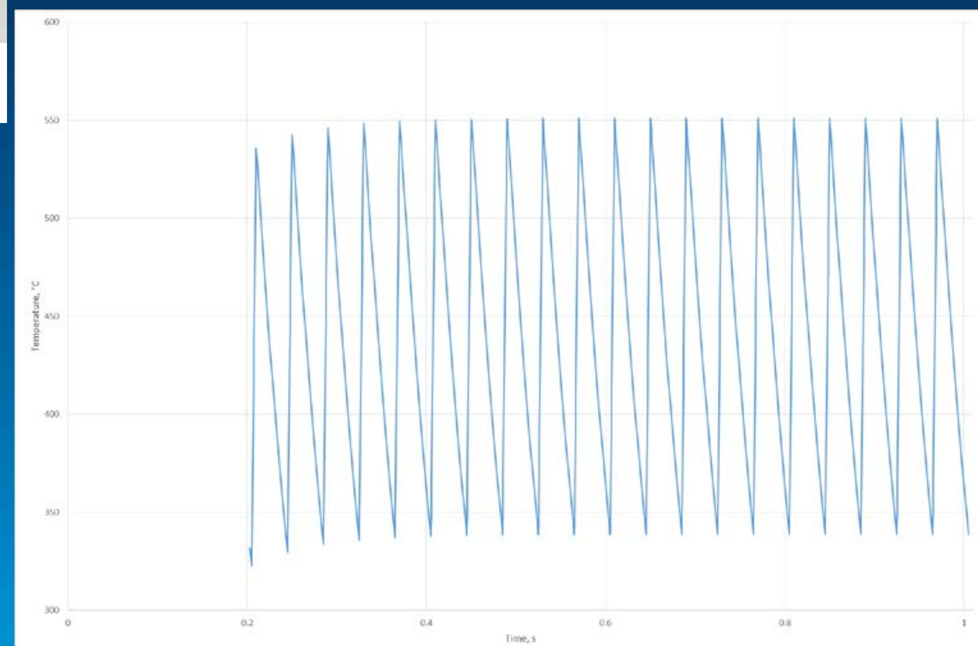
Rhodotron has pulsed beam at 12.5% duty cycle

- Pulse is 5 microsec wide at 25 Hz.
- There is a steady stress/strain state caused by pressure, with a superimposed 200 C thermal cycle.
- Strain range is high but stress is reasonable.







Fatigue

- 10^9 cycles per year at 25 Hz.
- Peak combined primary and secondary equivalent stress is 452 MPa.
- Roughly ½ of the stress is secondary thermal.

Specialty Metals:

Annealed material is used for the window.

FATIGUE STRENGTH

Room-temperature fatigue properties of annealed and annealed and aged (1750°F, plus 1325°F/8 hr, F.C. to 1150°F, hold at 1150°F for total aging time of 18 hours) forging specimens are shown in Table 31. Table 32 presents fatigue strength of hot-rolled plate annealed and aged in accordance with AMS 5596.

Fatigue strength of cold-rolled sheet is shown in Figure 3.

If fatigue strength is of prime importance, INCONEL alloy 718 forgings can be used in the annealed rather than the annealed and aged condition; aging raises fatigue strength only slightly (less than 4 ksi in Table 31).

Grain size is a major factor in achievement of high fatigue strength. Its effect can be seen in Figure 4. The low-temperature heat-treatment schedule (such as that in AMS 5596) will promote the requisite fine grain. See also Tables 31 and 32. High-temperature fatigue strength of annealed and aged bar is shown in Table 33.

Low-cycle fatigue life of INCONEL alloy 718 is the same whether tested in fully reversed bending or in zero-to-maximum bending. Test results are shown in Figure 5.

Table 31 - Room-Temperature Fatigue Strength of 6- by 9-in. Forging[a]

Condition[b]	Tensile Properties				Grain Size, in.	Fatigue Strength, ksi		
	Tensile Strength, ksi	Yield Strength (0.2% Offset), ksi	Elongation, %	Reduction of Area, %		10^6 Cycles	10^7 Cycles	10^8 Cycles
Annealed	143.0[c]	99.5[c]	32[c]	32[c]	0.0023[c]	74.0	67.5	66.5
Annealed and Aged	191.25	169.5	10.5	20	0.0021	77.5	71.0	69.5

458 MPa

[a]Rotating-beam fatigue tests. Values are average of 2 samples (polished specimens)--center short transverse and mid short transverse.
[b]Annealing at 1750°F/1 hr Aging at 1325°F/8 hr, F.C. to 1150°F, hold at 1150°F for total aging time of 18 hr.
[c]Values for center short transverse only.

Table 33 - High-Temperature Fatigue Strength of Hot-Rolled Bar (Annealed 1750°F/1 hr, A.C. and Aged)[a]

Test Temperature, °F	Fatigue Strength, ksi			
	10^5 Cycles	10^6 Cycles	10^7 Cycles	10^8 Cycles
Room	132.0	101.0	92.0	90.0
600	115.0	110.0	110.0	110.0
1000	111.0	102.0	95.0	90.0
1200	100.0	94.0	88.0	72.0

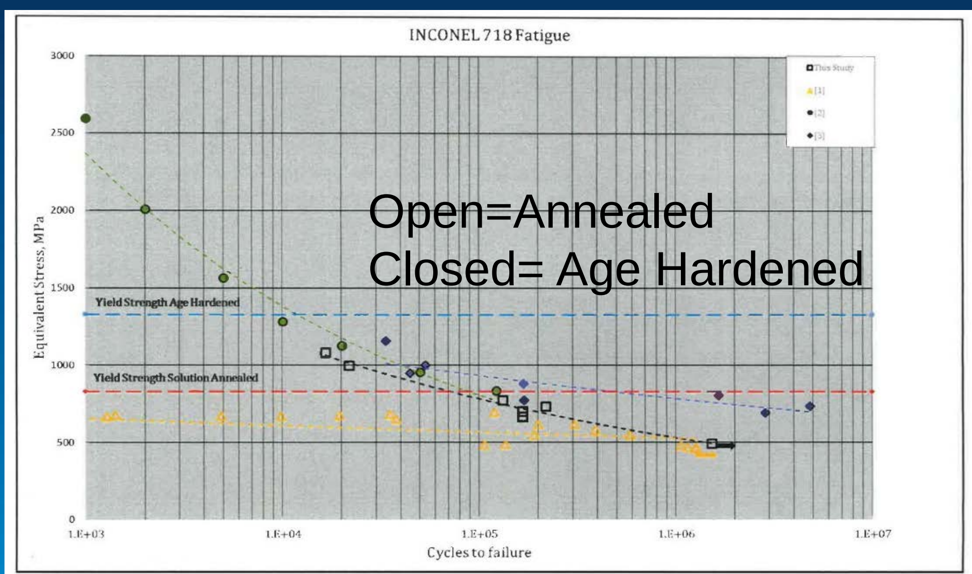
620 MPa

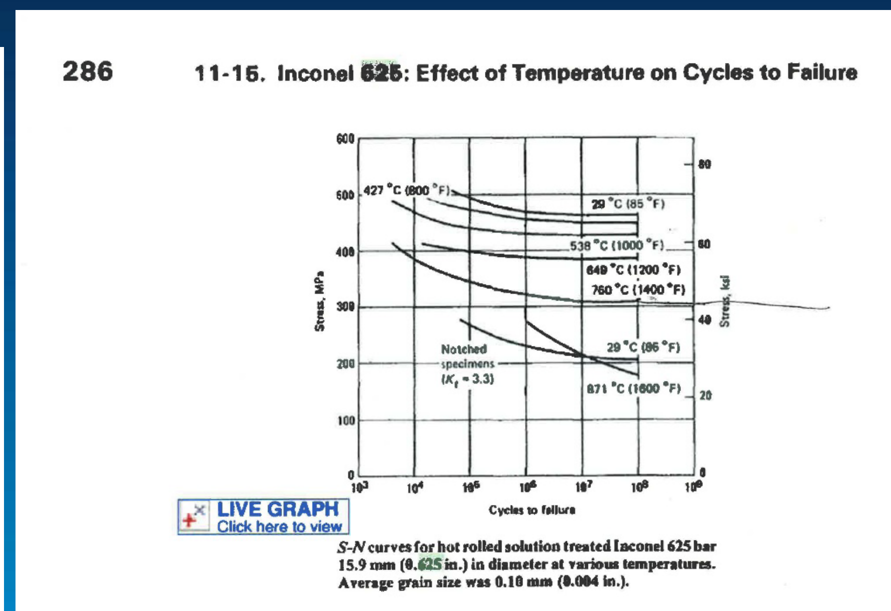
[a]Rotating-beam tests. Average grain size, 0.0008-in. Aging--1325°F/8 hr, F.C. to 1150°F, hold at 1150°F for total aging time of 18 hr.

Fatigue

- Kyle Buchholz, U. of Florida, “High-Cycles Fatigue of Inconel 718” (https://nationalmaglab.org/images/education/searchable_docs/college_early_career/reu/2017/buchholz.pdf).

”Atlas of Fatigue Curves,” American Society for Materials, H. E. Boyer, 1986

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11-15. Inconel 625: Effect of Temperature on Cycles to Failure

S-N curves for hot rolled solution treated Inconel 625 bar 15.9 mm (0.625 in.) in diameter at various temperatures. Average grain size was 0.10 mm (0.004 in.).

Fatigue

- Strain range is 1.7%. Fail on first day! But "The investigators observed no apparent strain rate effects in the elastic regime."
- 50 Hz beam is expected, reducing temperature swing to about 100 C, reducing strain range but not equivalent stress.

AFCI Material Handbook, Rev. 5, LA-CP-06-0904

Materials Data for Particle Accelerator Applica
Chapter 2. Design Properties of Alloy 718

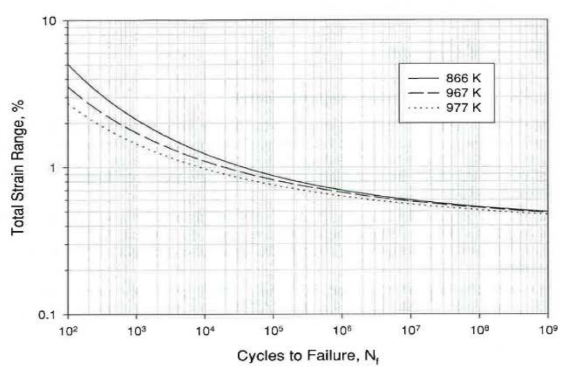

Figure 2-40. S-N curves for fatigue of Alloy 718 for temperatures of 866 K, 922 K, and 977 K.

Fatigue

The target has been designed over a period of years with no consideration for pulsed beam. The switch from a linear accelerator to rhodotron introduces a fatigue failure mode and consequently risk of failure not previously evaluated.

In any case, the rhodotron must be protected from a target window failure. In the event of failure, helium will propagate up the beam pipe at Mach 1, 1000 m/s.

Currently funded LANL activities

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- Continue blower operation.
- Ceramic heater tests, including missing disk and blocked channel.
- Facility design and engineering support. Catchall work package includes:
  - Shielding
  - Target handing
  - Equipment staging, including IR and OTR cameras
  - Critical path du jour

Critical not funded activities:

Plant target not yet built nor tested.

Off normal beam analysis and testing: Off center or noncircular or focused beam.

THANK YOU!