

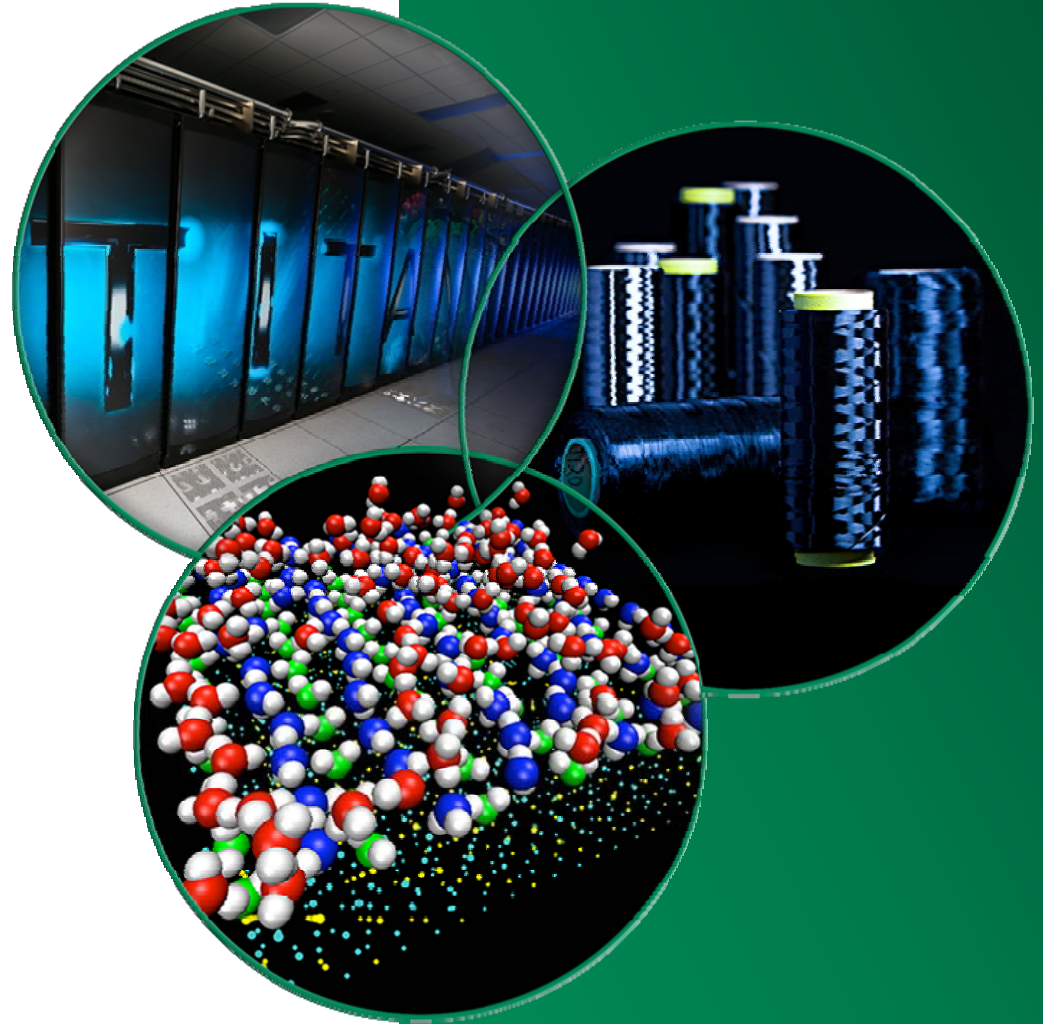
Dose Limit Philosophies Implemented at the Spallation Neutron Source

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5th High Power Targetry
Workshop

May 20-23, 2014

Fermilab, Batavia, Illinois



Question for Group...

Does your facility have fixed administrative lifetime limits for “high dose” components based on concerns with radiation-induced changes in mechanical properties?

Outline

- Overview of the Spallation Neutron Source
 - Dose Limited Components
 - Target PIE
- Dose Limit Philosophies
- Discussion

Four Major Components at the SNS are Dose Limited

- Target Module
 - AISI 316L

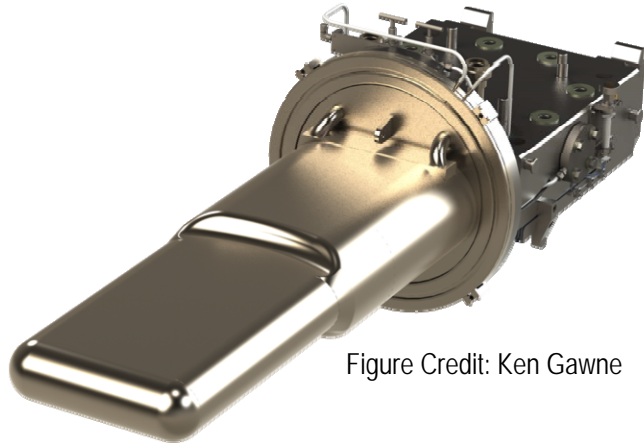


Figure Credit: Ken Gawne

- Proton Beam Window
 - Inconel 718 (solution annealed)
 - Al 6061-T651

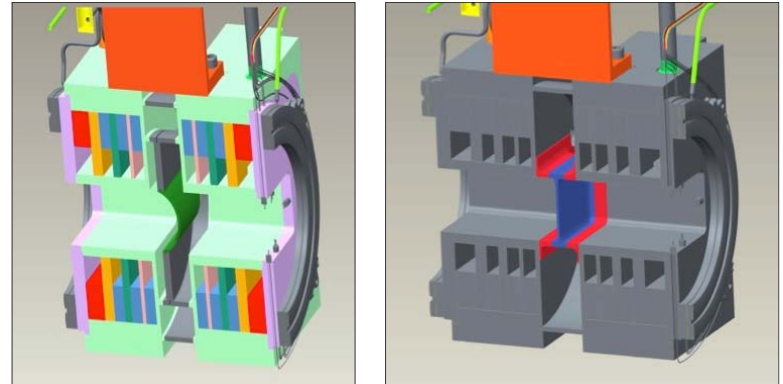
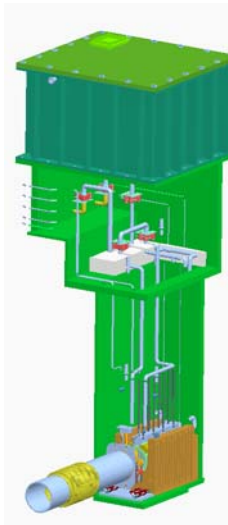
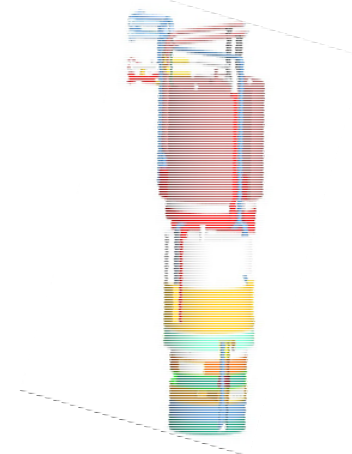


Figure Credit: Jim Janney

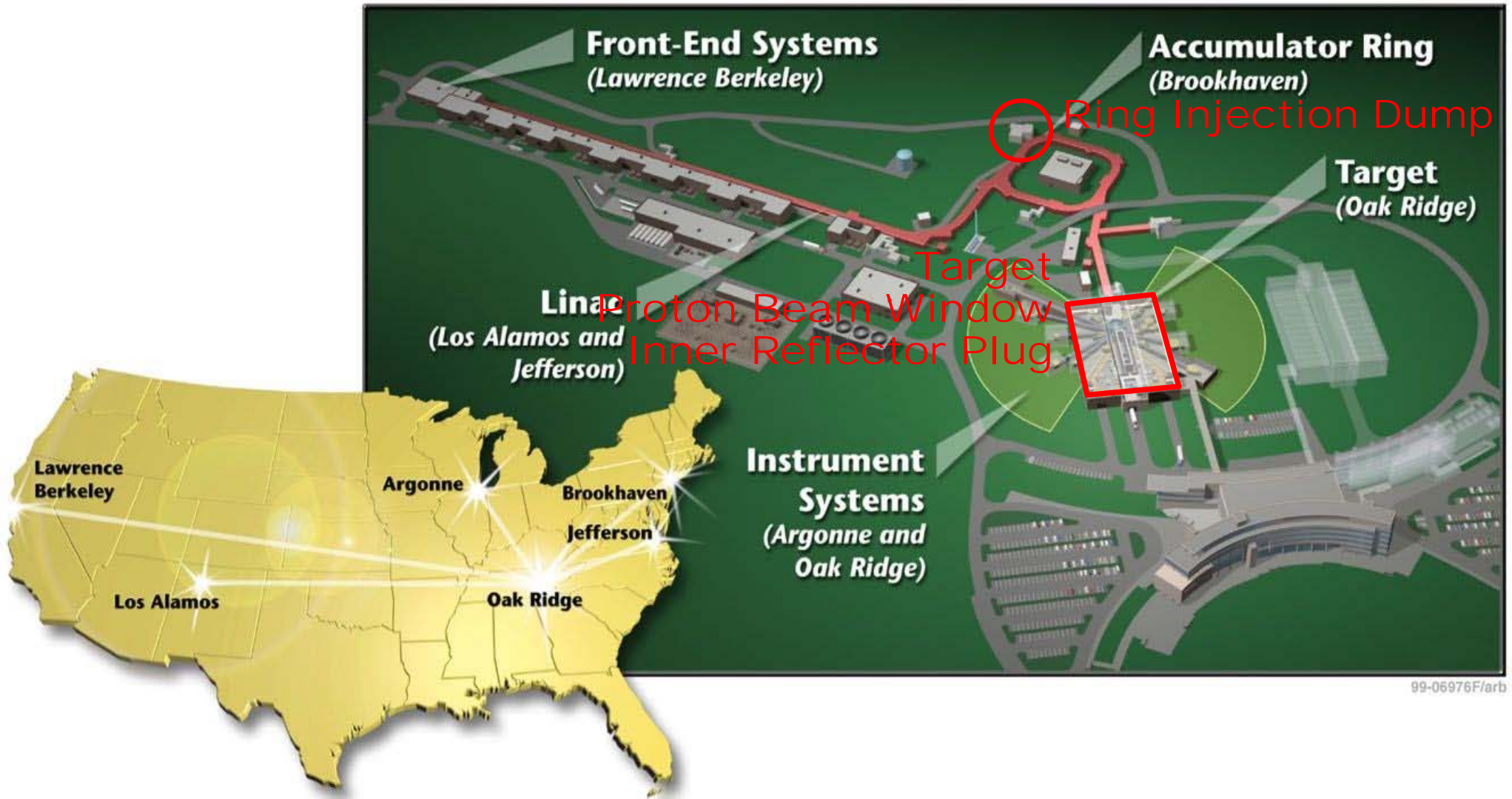
- Ring Injection Dump
 - AISI 316L



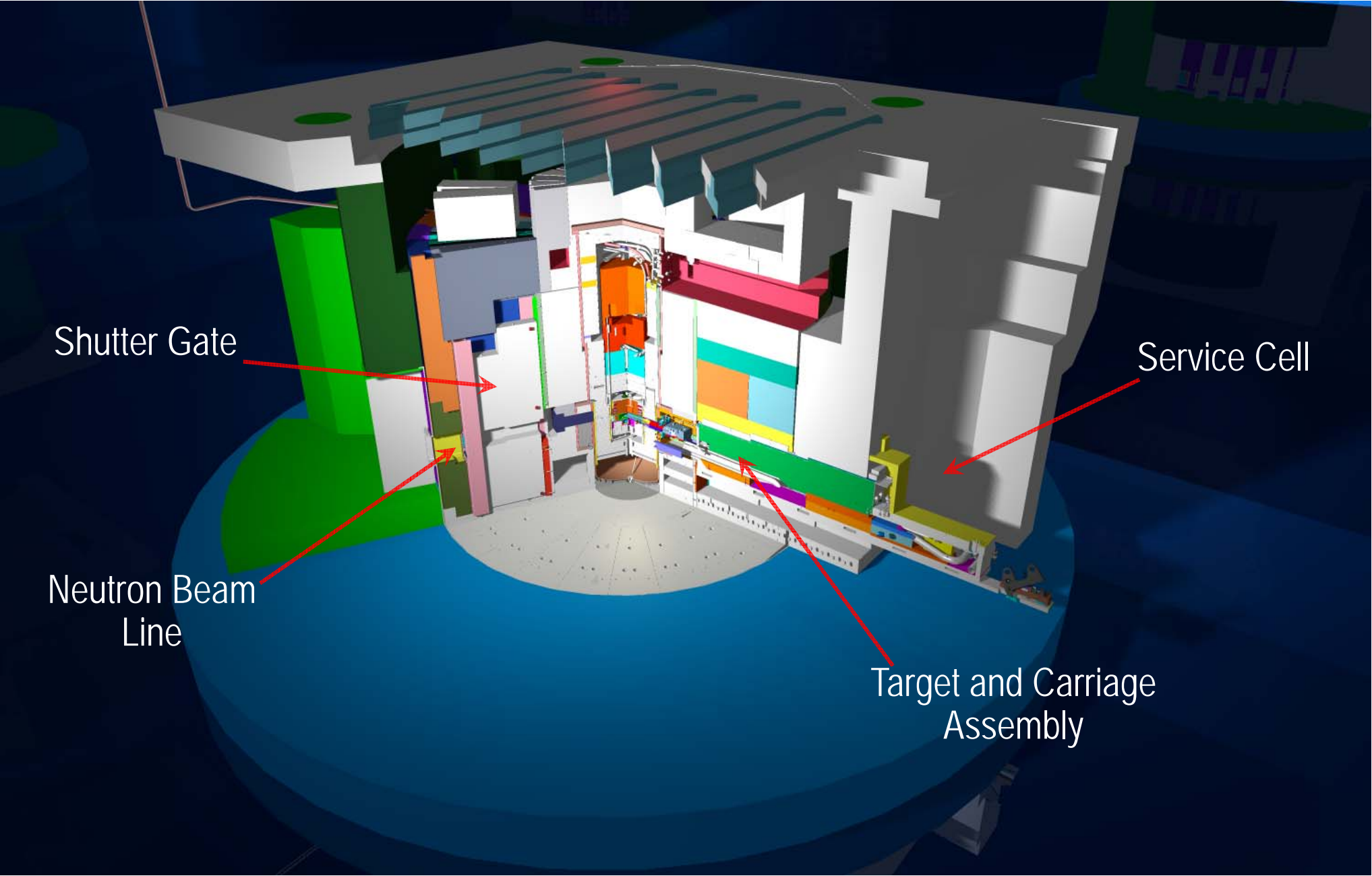
- Inner Reflector Plug
 - Lifetime determined by burnup of Ga in moderator poison sheets



Four Major Components at the SNS are Dose Limited



The target is inserted into a large monolith structure during operation



The target provides neutrons to 24 beam lines

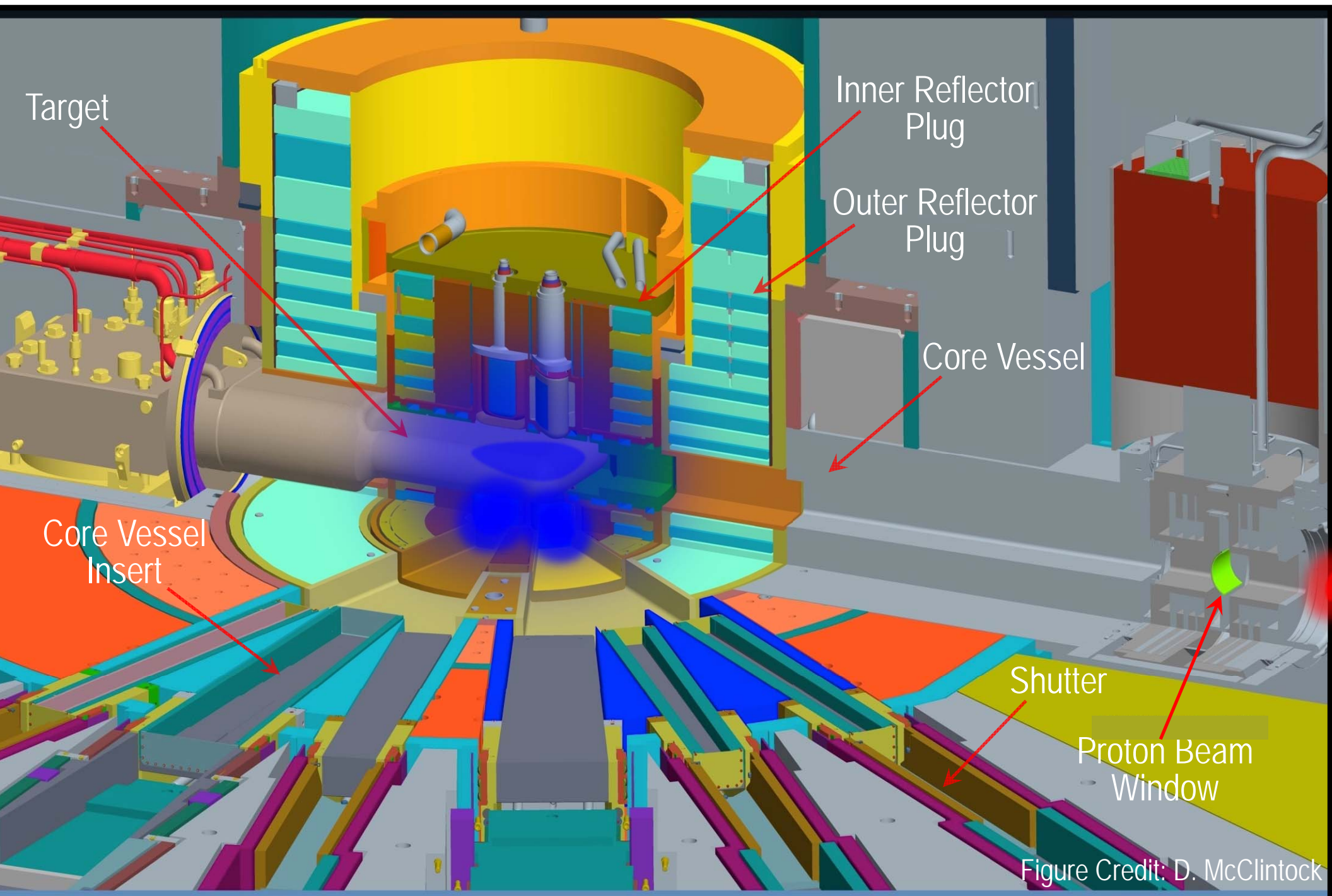


Figure Credit: D. McClintock

Mercury enters through side supply passages and returns through the center return passage

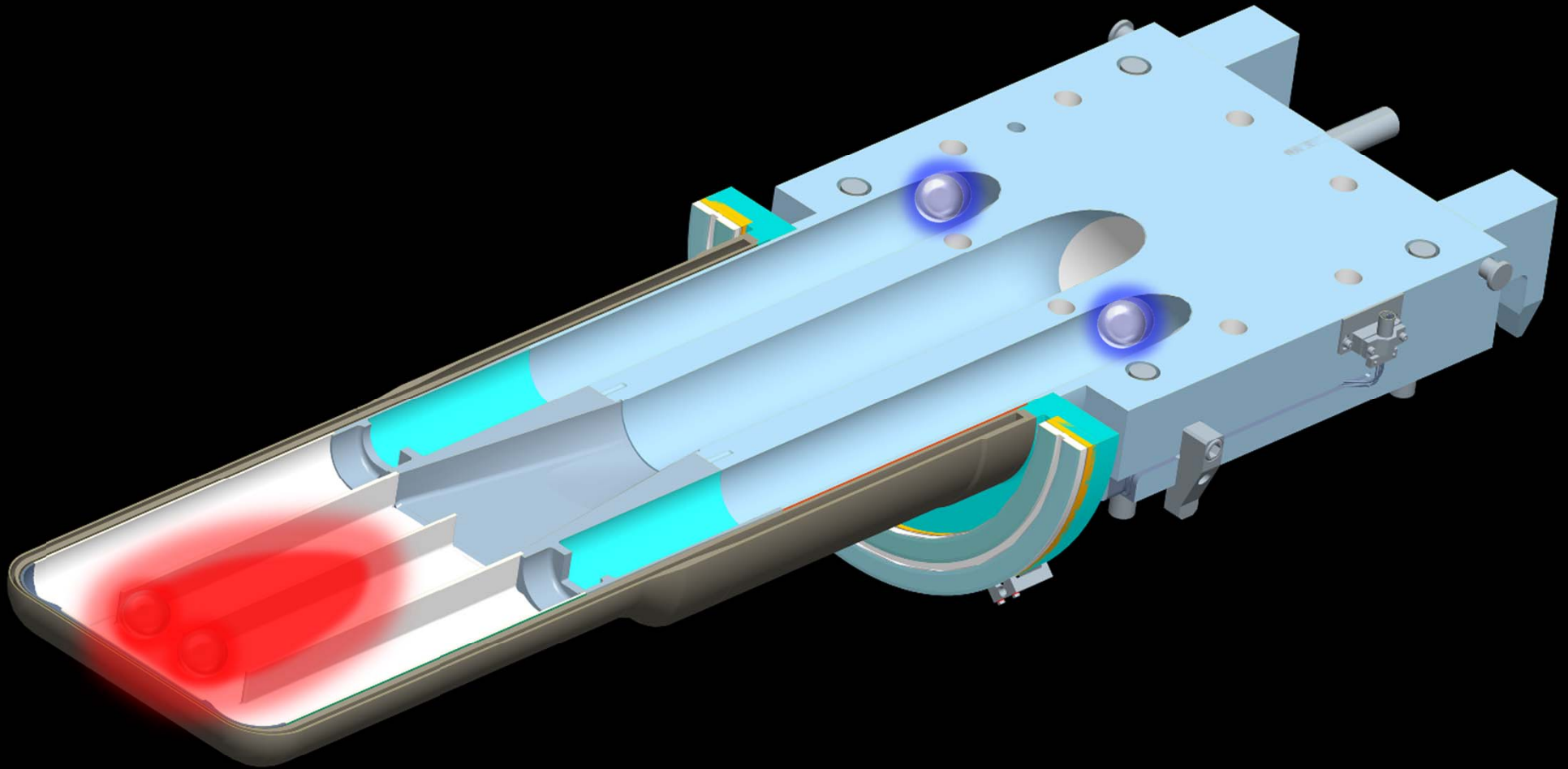
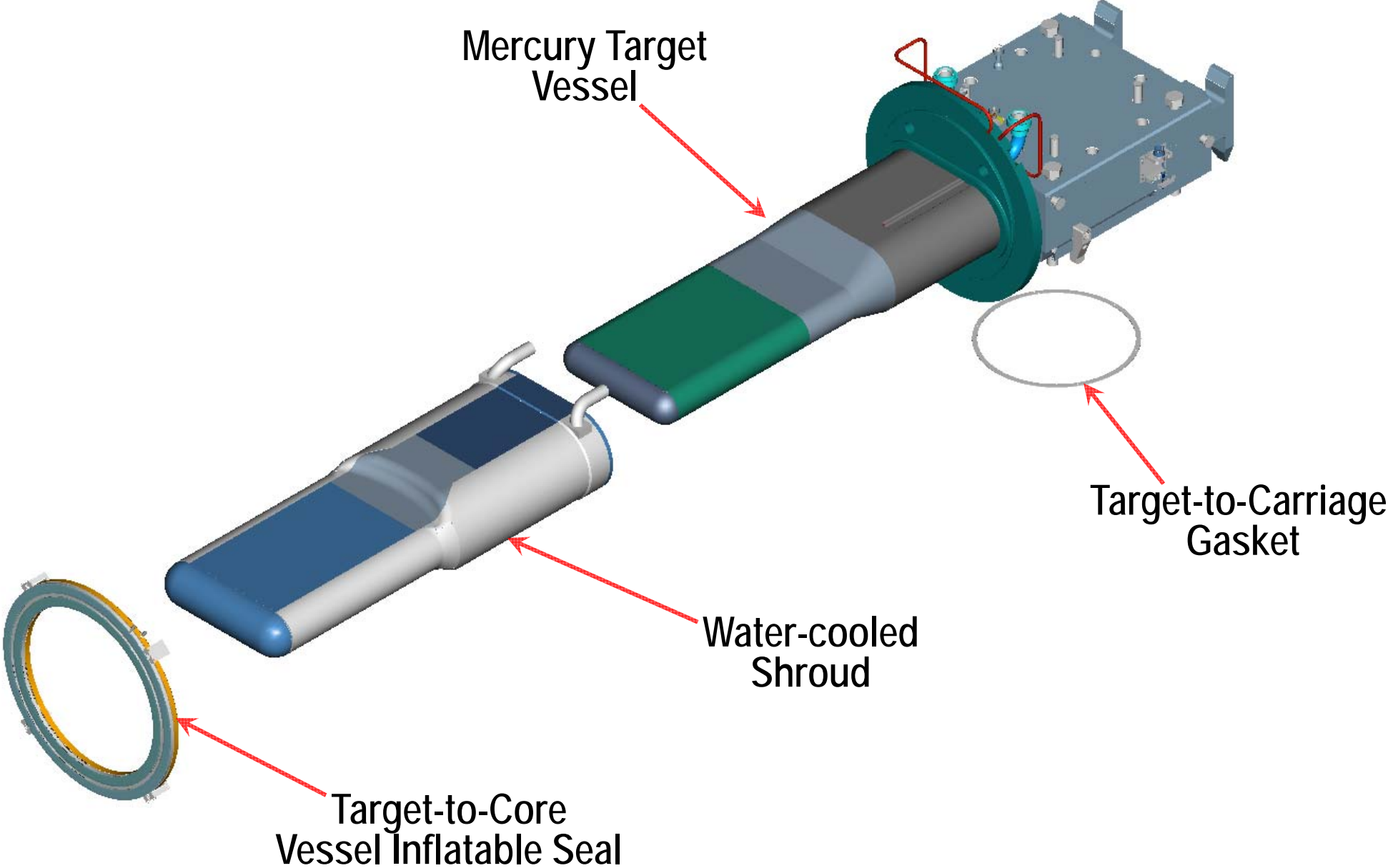


Figure Credit: D. McClintock

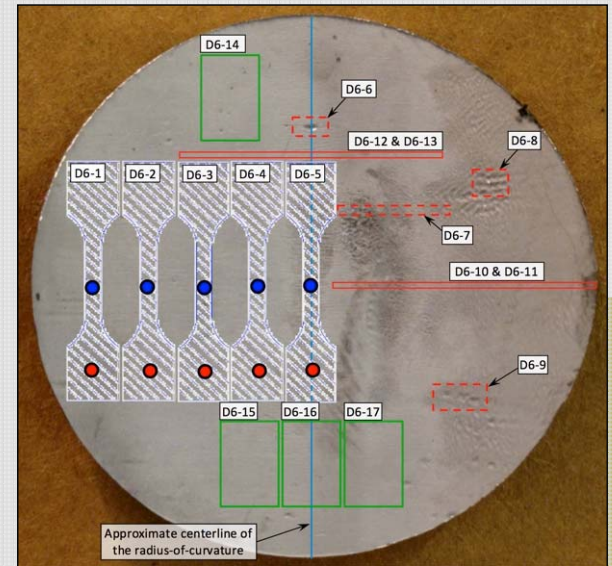
SNS target is composed of two "vessels" welded to a manifold block



Specimens were removed from Targets 1-8 after service and characterized by mechanical testing and microscopy

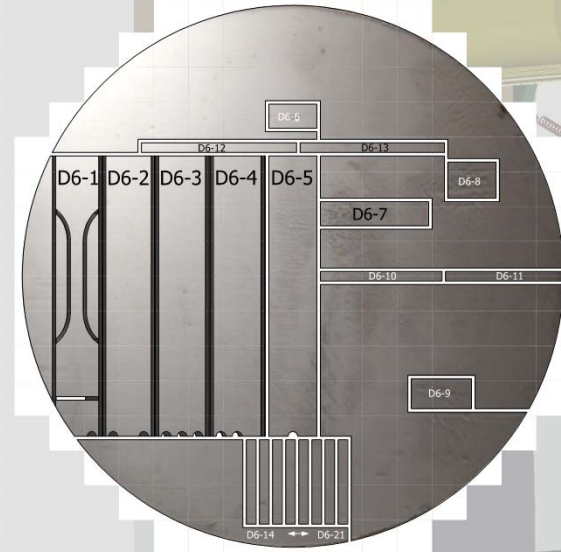


Pneumatic Piston



Specimen Map

CONCAVE



EDM Machining Map

Figure Credit: Adam Carroll

Component lifetime limit philosophies are generally based on *Acceptable Risk*

- What is a lifetime limit?
 - A lifetime limit for a component in a nuclear system is an *administrative tool* used to limit the risk of component failure originating from radiation-induced changes in mechanical properties of the component material.
- How is the lifetime determined for a component?
 - Component lifetime limits are determined by establishing a minimal level of acceptable risk to operation of a facility.
- What criteria are used to set limit?
 - Limits are established after consultation with: (1) experience from facilities with similar operational conditions and (2) data from mechanical properties studies in the available literature.
- How are limits revised?
 - Lifetime limits are revised based on information gathered during post irradiation examination (PIE) of components in question and additional data on radiation-induced changes in mechanical properties.

Lifetime limits at the SNS are based on different considerations

- AISI 316L and Inconel 718
 - Limit Basis: Maximum dpa
 - Concern: Loss of fracture toughness and ductility

- Aluminum PBW
 - Limit Basis: He concentration
 - Concern: Grain boundary embrittlement by He

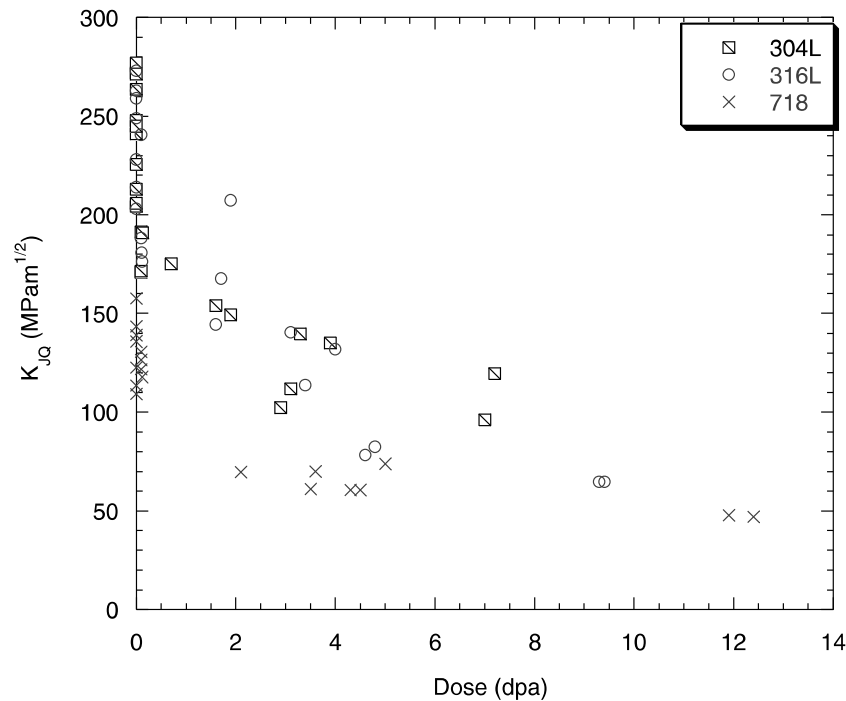
- Inner reflector plug
 - Limit Basis: Burnup of gadolinium coating on the moderator poison plates
 - Concern: Loss of resolution and performance of instruments serviced

	Material	Lifetime Limit	Current Level*
Target	316L	10 dpa	5.9 dpa
PBW	Inconel 718	15 dpa	10.6 dpa
	AL 6061-T651	2,000 appm-He	NA
RID	316L	10 dpa	4.3 dpa
IRP	Gadolinium	32,000 MW-hr	21,840 MW-hr

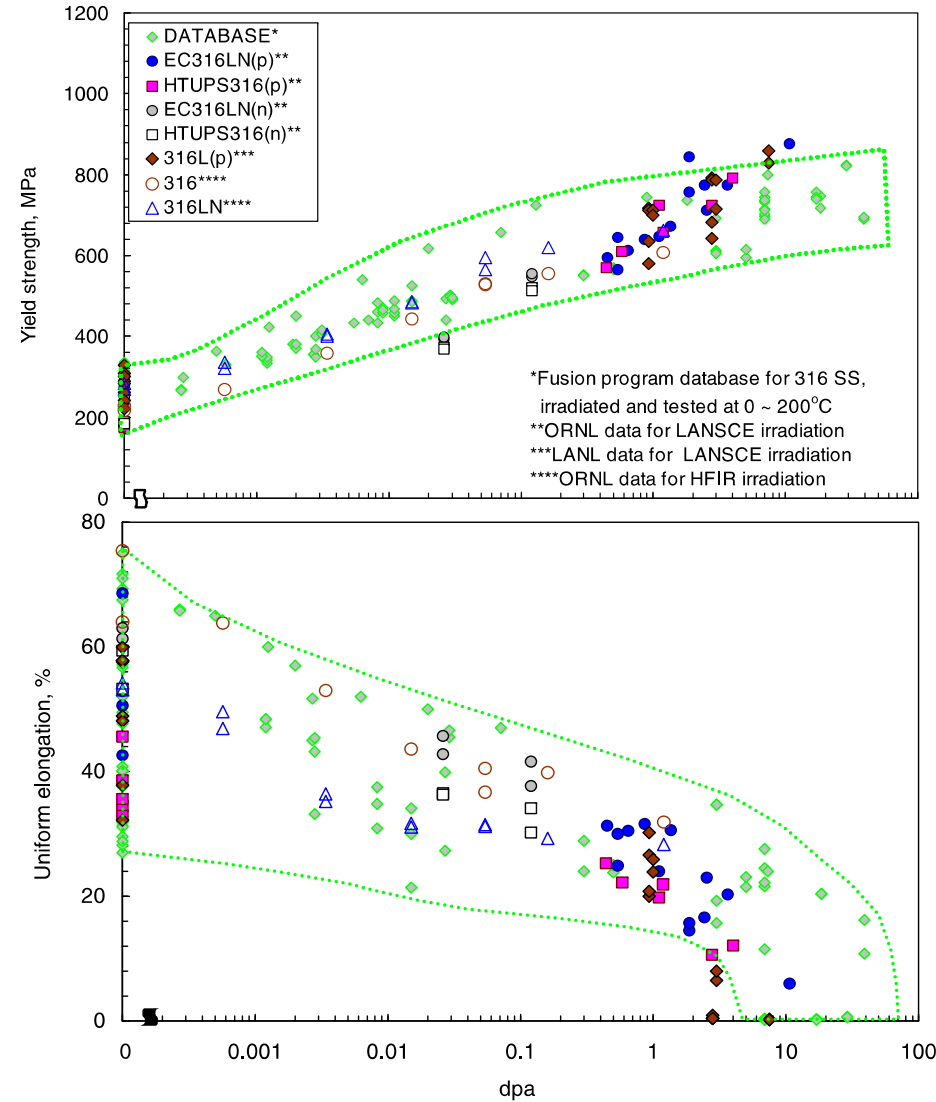
*May 2014

316L – Target and RID Windows

- 316L and similar alloys have a long history in nuclear applications
- Numerous studies have been published on radiation-induced changes in mechanical properties of 316L variants
 - Including irradiations in spallation spectrums



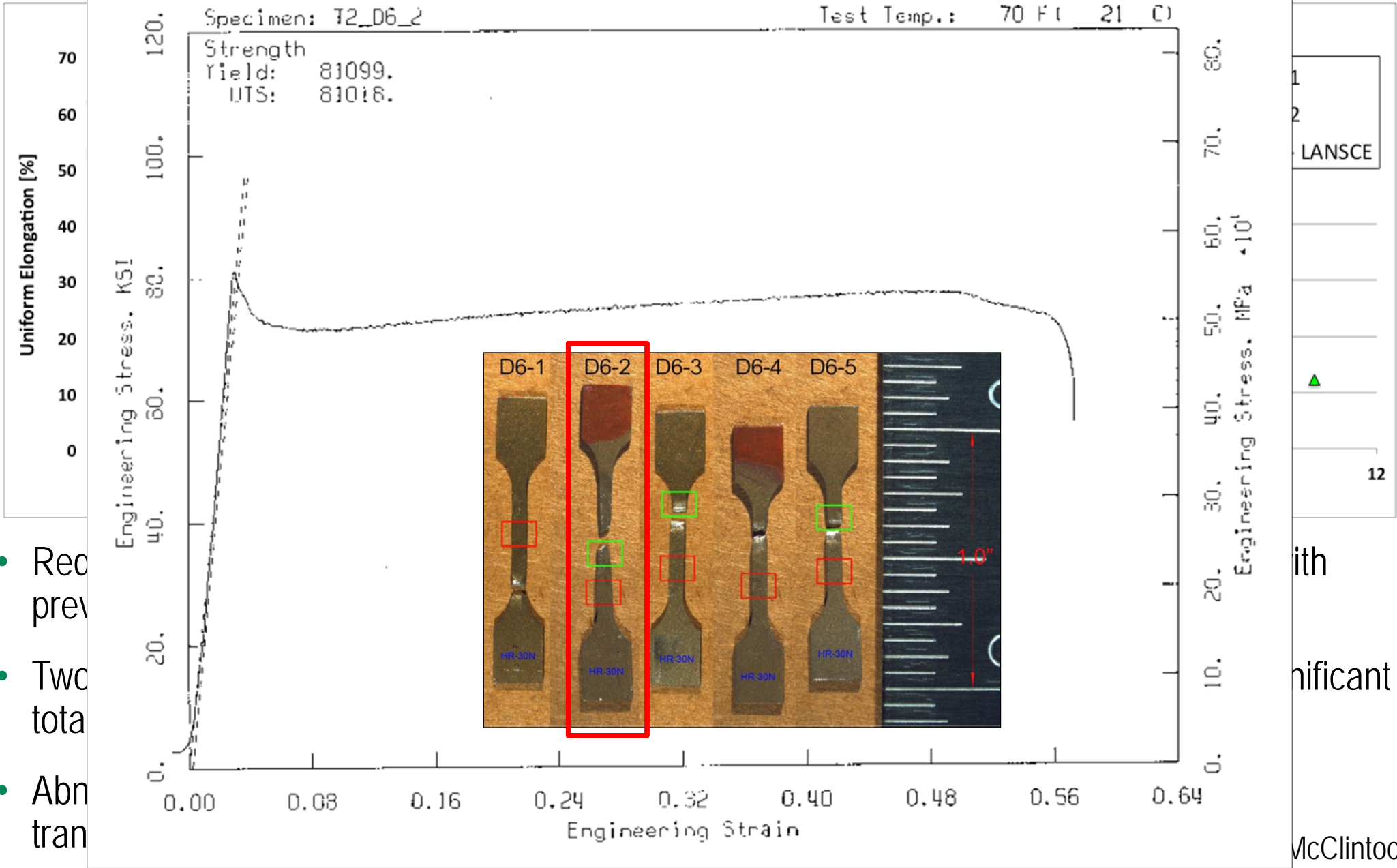
From: S. Maloy et al., *J. Nucl. Mater* 296(2001) 119-128.



From: L.K. Mansur and J.R. Haines, *J. Nucl. Mater.* 356 (2006) 1-15.

Unanticipated behavior can complicate the assessment

30 Sep., 2012
File: T2_D6_2



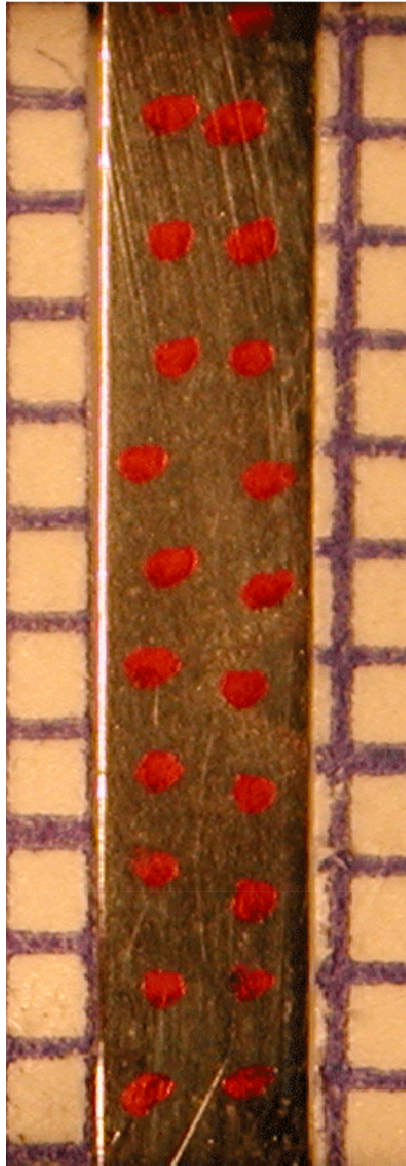
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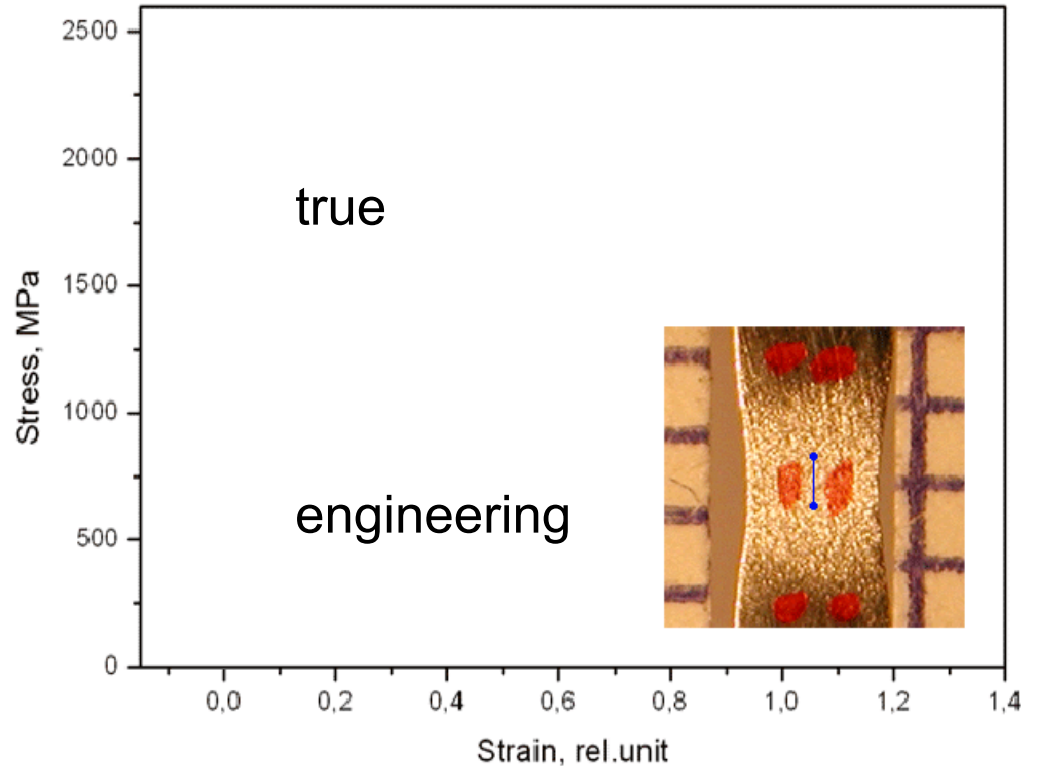
Localized deformation is typical post-yielding behavior in irradiated austenitic steels*

*Slide Courtesy of: Frank Garner and Maxim Gusev

Austenitic steel
Cr16Ni11Mo3
Analog of 316 SS
12 dpa at 300°C
BN-350 reactor
Strain rate of
0.5 mm/min



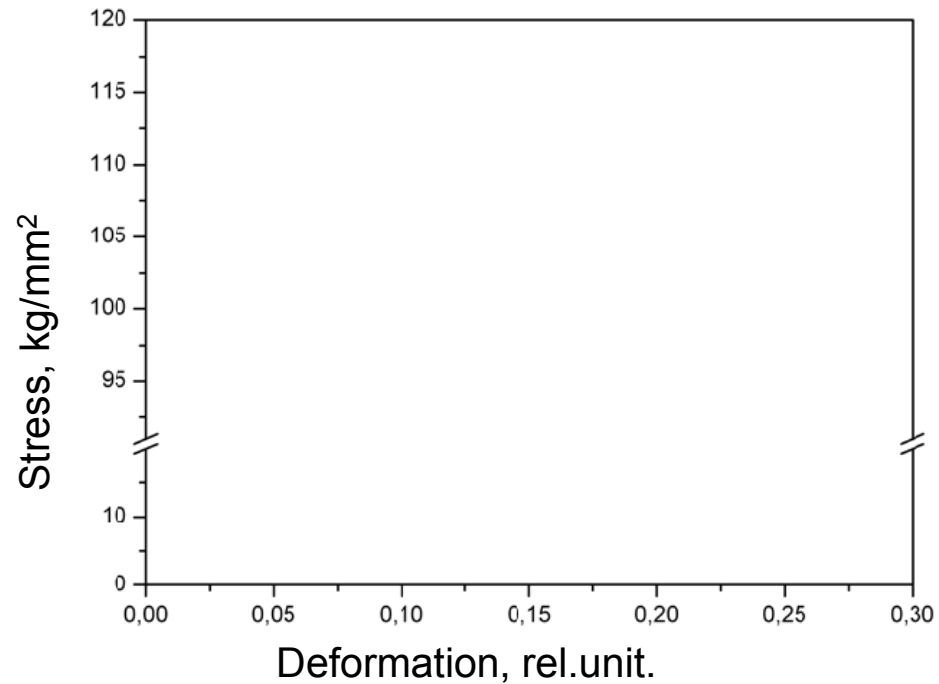
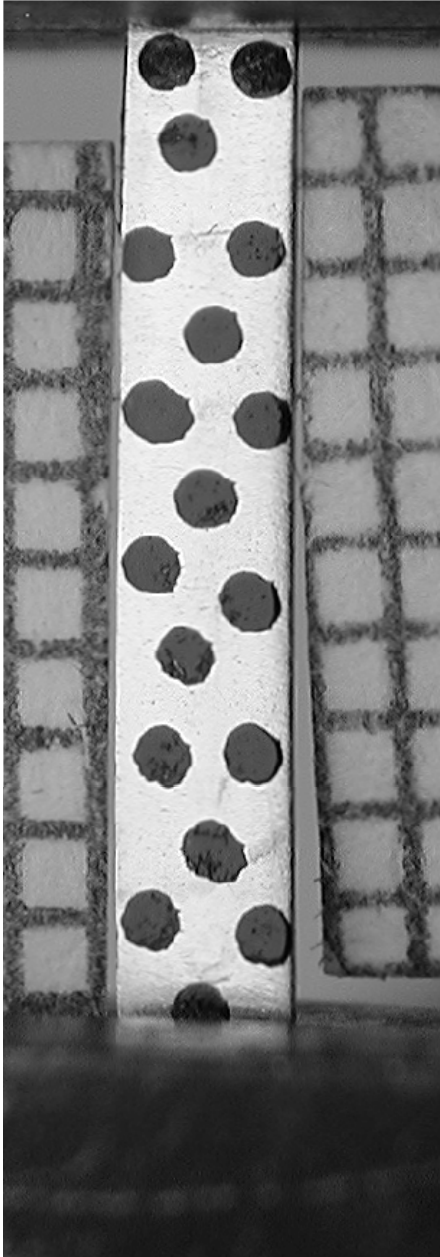
Engineering and true stress-strain curves



**~9-11% total elongation of specimen
but >100% local deformation**

Inability to neck may produce a “deformation wave” in highly irradiated stainless steel* - Is this occurring in the SNS Target?

*Slide Courtesy of: Frank Garner and Maxim Gusev



55 dpa, 310° C
in BN-350

Russian analog to 321
stainless steel

room temperature test

A “deformation wave” appears on the surface and moves along the specimen gauge section

Gusev et al., J. Nucl. Mater. 386–388 (2009) 273–276

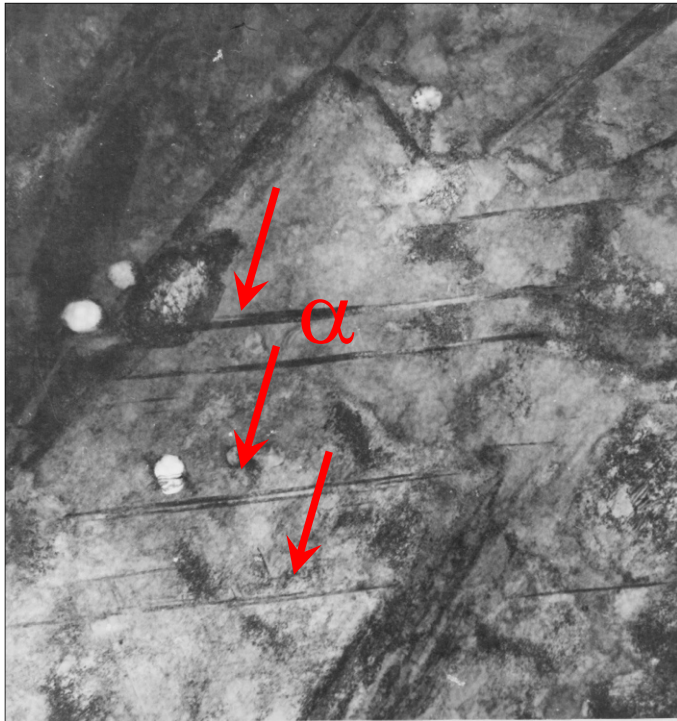
Gusev et al., J. Nucl. Mater. 403 (2010) 121–125

Deformation waves are caused by a martensitic transformation in the gauge section during plastic deformation*

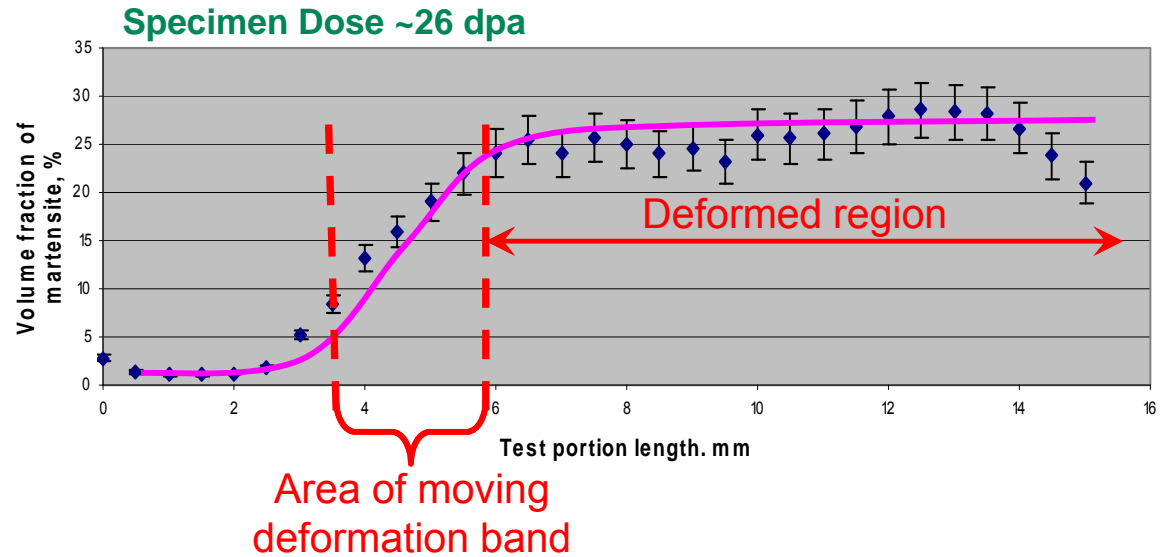
*Slide Courtesy of: Frank Garner and Maxim Gusev

Typical amount of martensite in deformed non-irradiated sample:

$$V_{\alpha} \sim 5-10 \%$$



Distribution of martensite along gage section of Cr18Ni10Ti specimen



Specimen Dose ~55 dpa

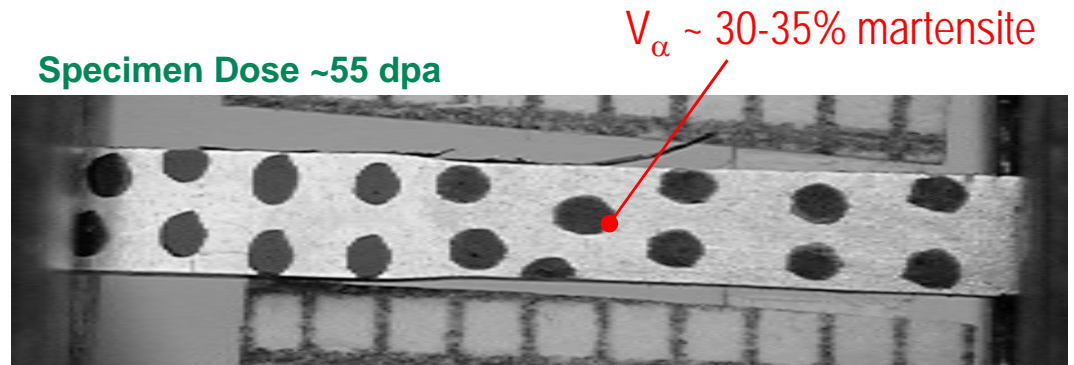


Photo Credit: Maksimkin O.P. et al., Institute of Nuclear Physics, Almaty, Kazakhstan.

Solution Annealed Alloy 718 – PBW

- Very little data on the radiation-induced changes in mechanical properties exist for alloy 718 in the solution annealed condition
- The Alloy 718 (SA?) PBW at the ISIS First Target Station experienced an estimated 30-90 dpa maximum dose without failure...
- The radiation-induced changes in mechanical properties of Alloy 718 is expected to be similar to other austenitic stainless steels (304L, 316L, 321...)

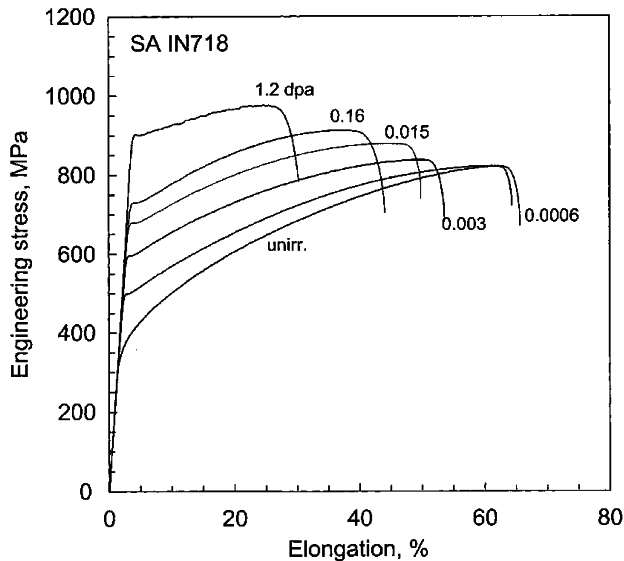


Fig. 3. Engineering stress-strain curves of solution-annealed IN718 at various doses.

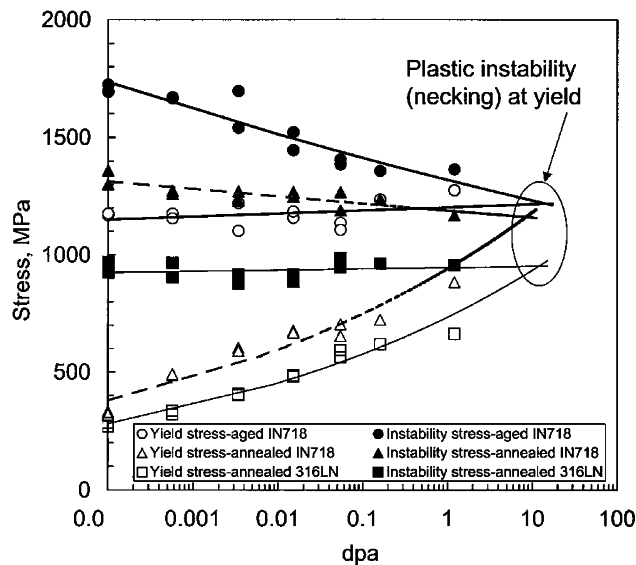


Fig. 9. Dose dependences of yield stress and instability stress and prediction of the dose to plastic instability at yield.

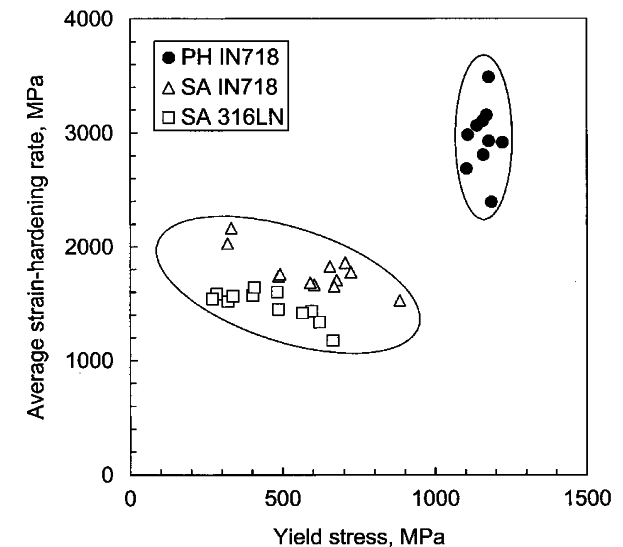


Fig. 8. Comparison of the yield stress dependences of average strain-hardening rate.

From: T.S. Byun and K. Farrell, *J. Nucl. Mater.* 318 (2003) 292-299.

PIE of Proton Beam Windows at the SNS

- Lifetime limit for the upcoming Al 6061-T651 PBW was established based on the experience with the AlMg₃ safety hull of the SINQ target
- Admittedly, the SINQ safety hull is not a direct comparison with spectrum or alloy type (solid-solution hardened verses precipitation hardened)
- Lack of mechanical properties data from Inconel 718 and Al 6061-T6 irradiated in a spallation spectrum reinforces the need for PIE of PBWs at the SNS

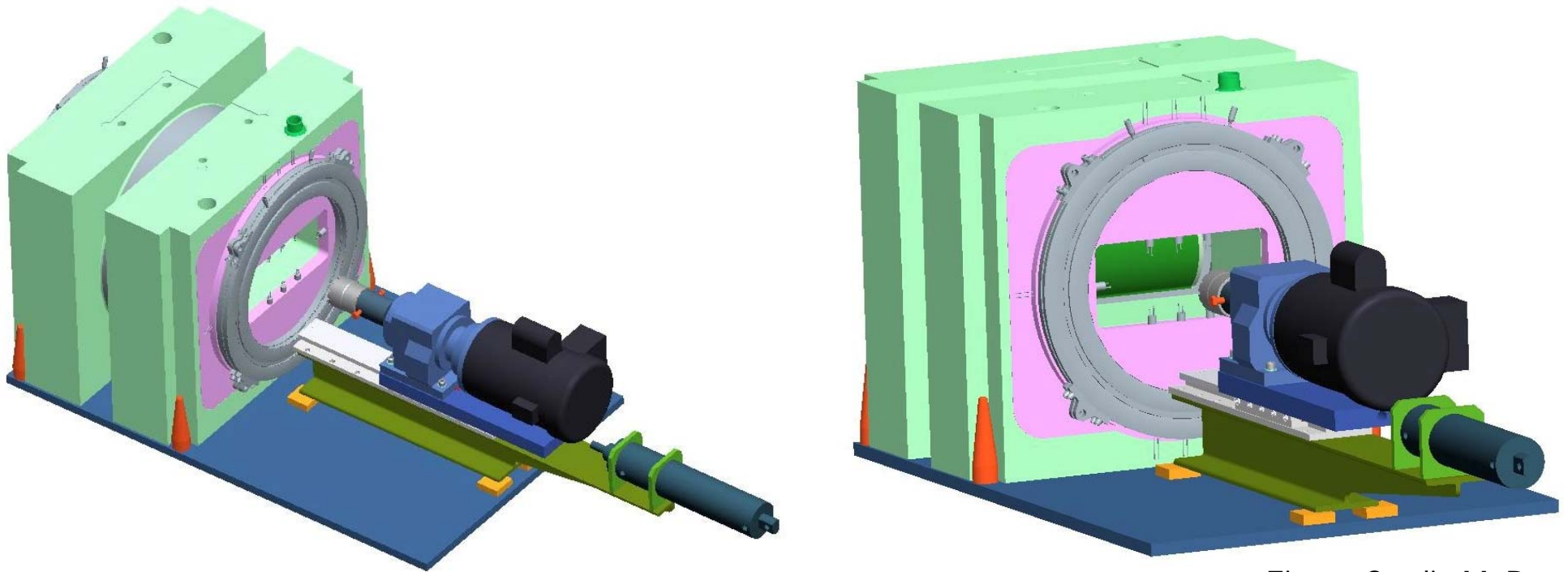


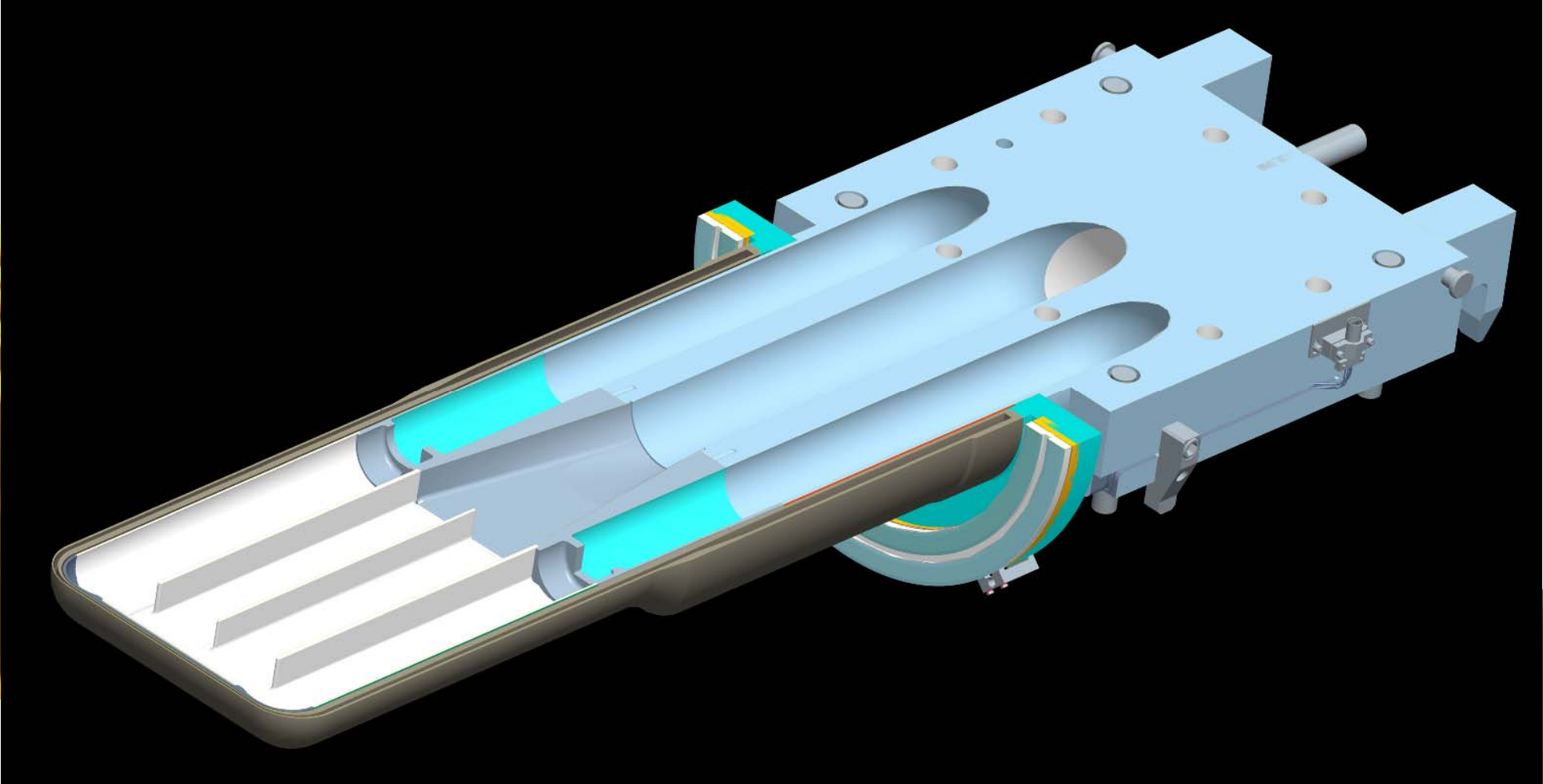
Figure Credit: M. Dayton

What are your lifetime limit philosophies?

- What is a lifetime limit?
- How is the lifetime determined for a component?
- What criteria are used to set limit?
- How are limits revised?

Backup Slides

A crack-like feature was observed on the center flow baffles of Targets 2-6



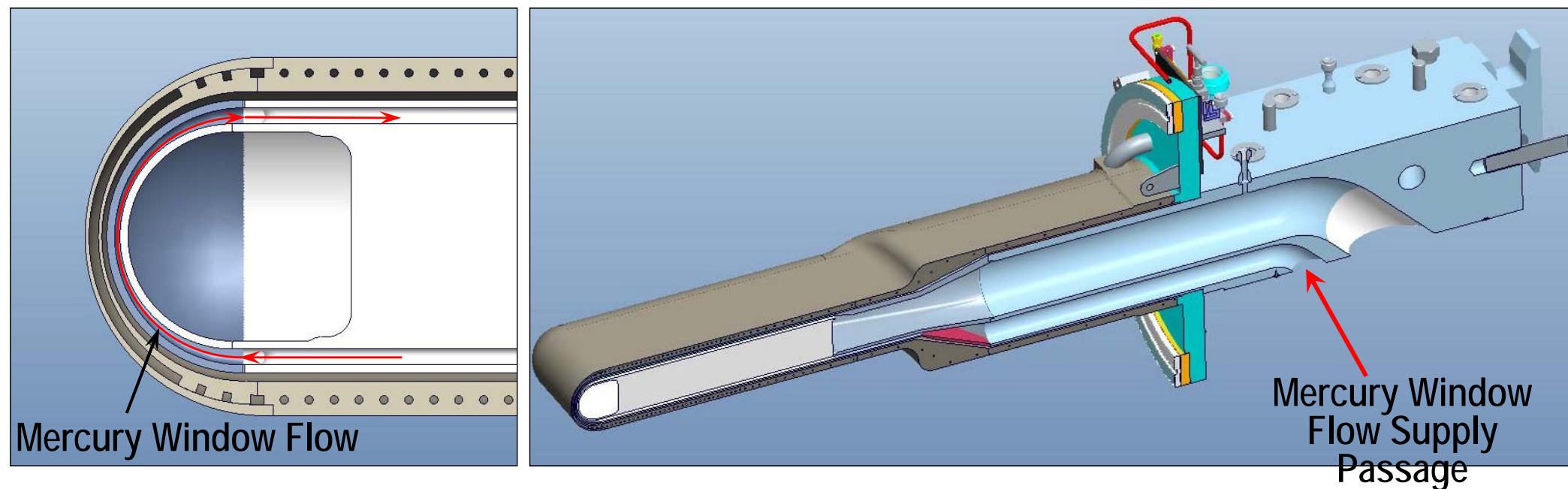
Crack-like feature observed on center baffles of Targets 2-5



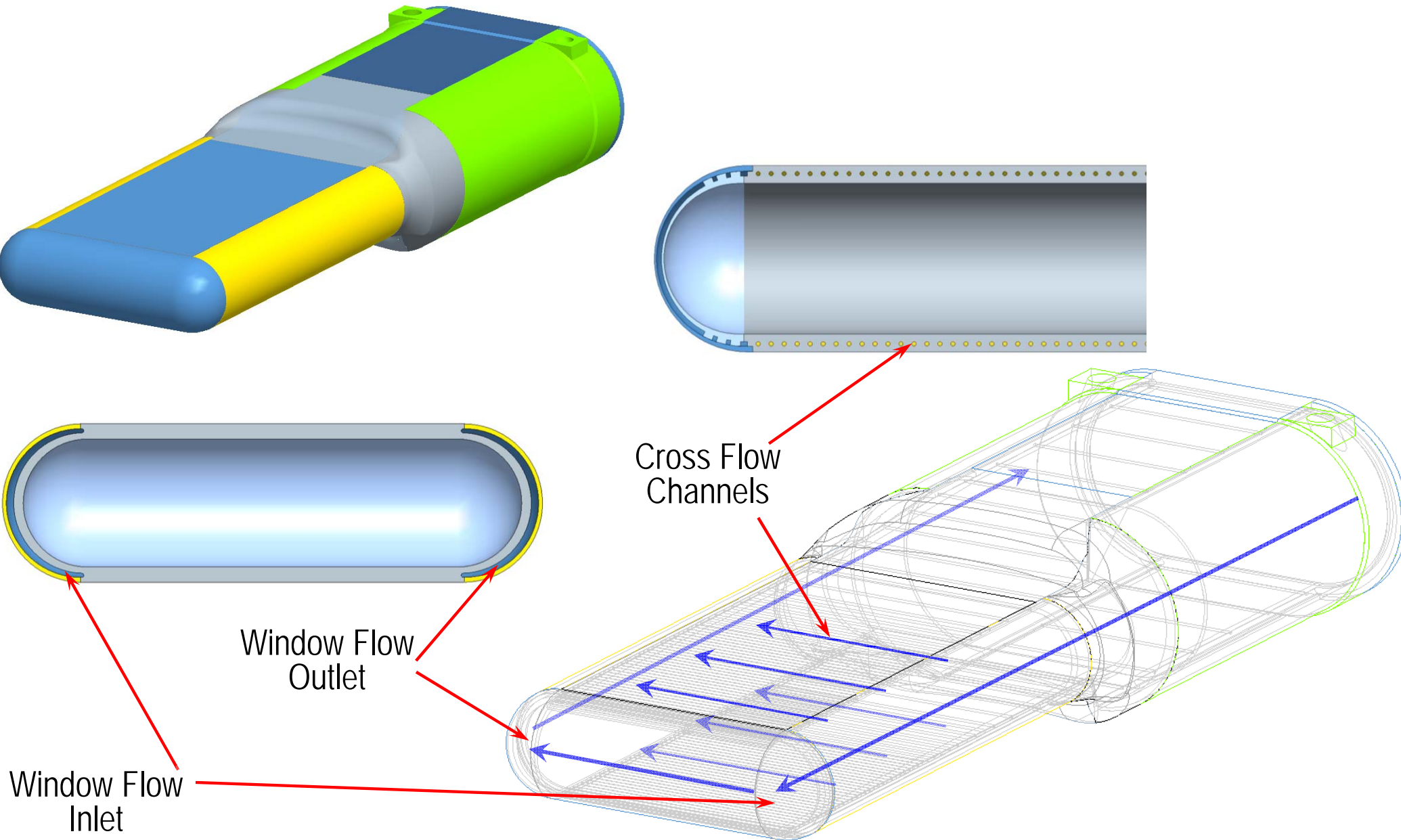
Figure Credit: D. McClintock

Mercury flows between layers two walls of the target vessel beam entrance region

- Beam entrance region of the mercury target vessel is cooled by a uniform high-velocity (2.5 – 3.0 m/s) “window-flow” of mercury
- The high velocity mercury and narrow channel *appear* to play a role in mitigation of cavitation-induced erosion



Shroud vessel is cooled by flowing water



Target Power Histories

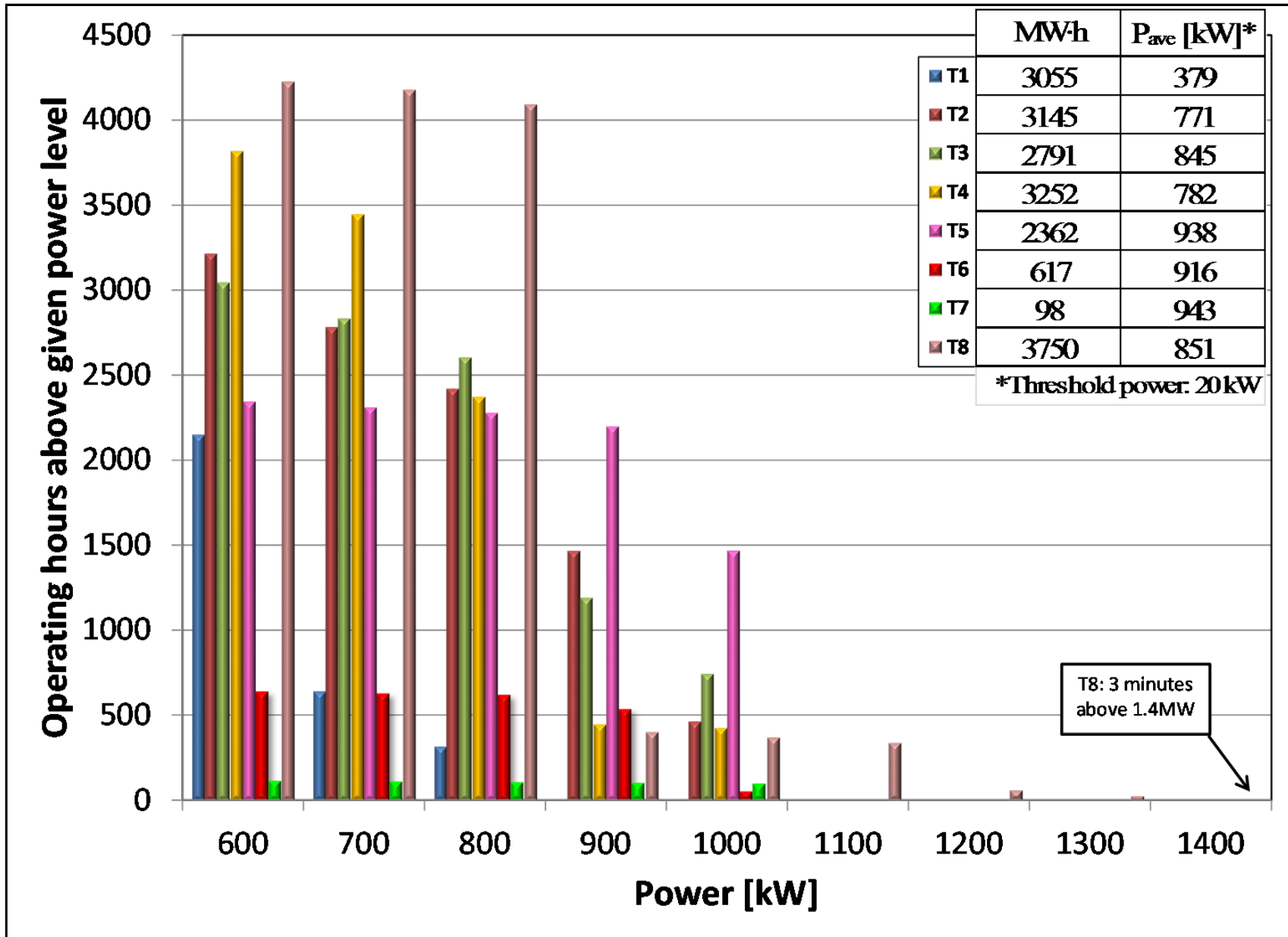


Figure Credit: Bernie Riemer