ISNIE
Engineering Summer School

Part V

Neutron Guide Systems Engineering

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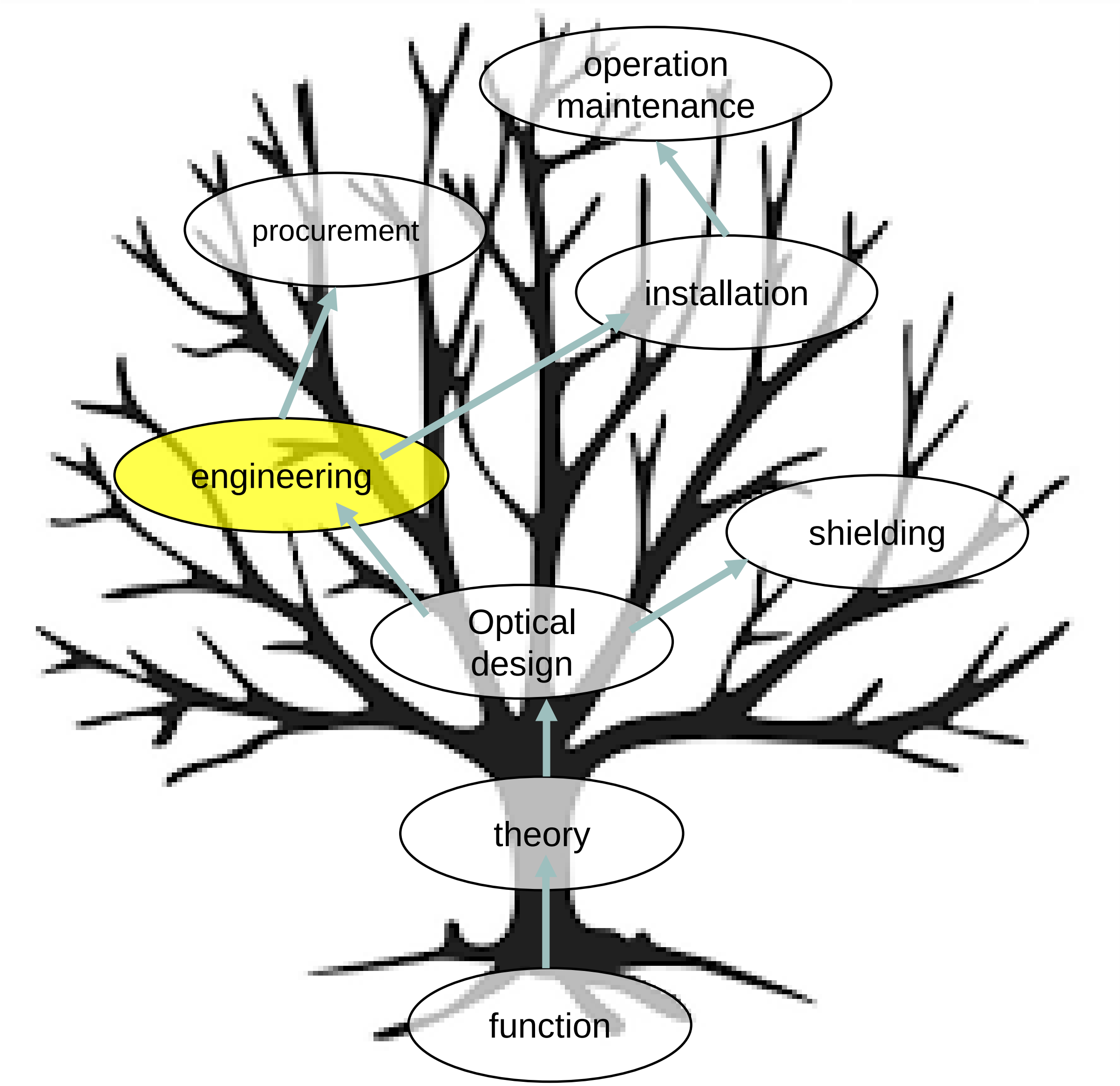
branches


operation
maintenance
procurement
installation
engineering
shielding
Optical
design
theory
function

Engineering unwrapped

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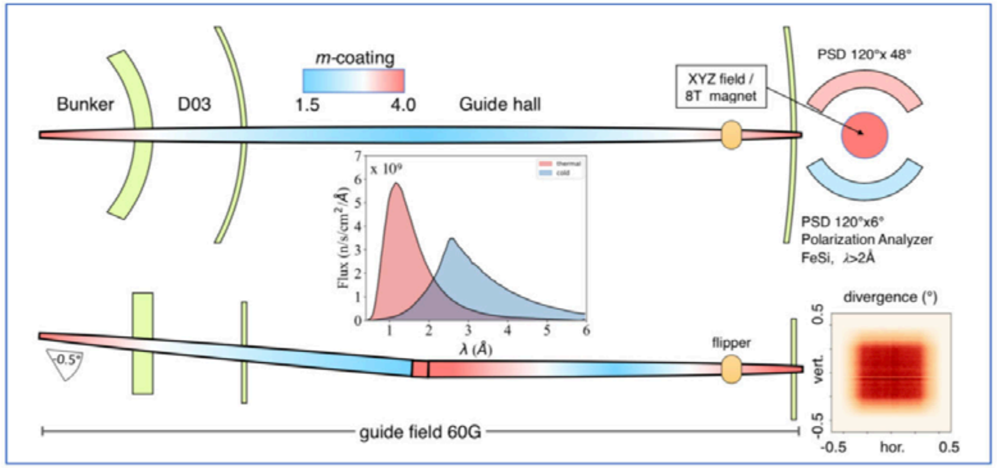
From theory
- Performance requirements

You can't make neutrons so dor loose them !

What we want

- Transport Neutrons
- Filter Neutrons
- Beam section & profile



Instrument MAGiC layout. *Top:* top view of the instrument across the multiple buildings. *Bottom:* side view of the instrument with simulated divergence profile at sample position. *Inset:* neutron flux at sample position as a function of wavelength

- **Real** performance delivered to the sample day in day out
- "Day 1000 performance

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To practice operational requirements and constraints

Constraints

- Interruptions for other systems
- Existing installations

Operational considerations

- Reliability
- Service ability
- Install ability
- Align ability

Life time costing

- Construction
- Installation
- Operation / Maintenance
- Decommissioning

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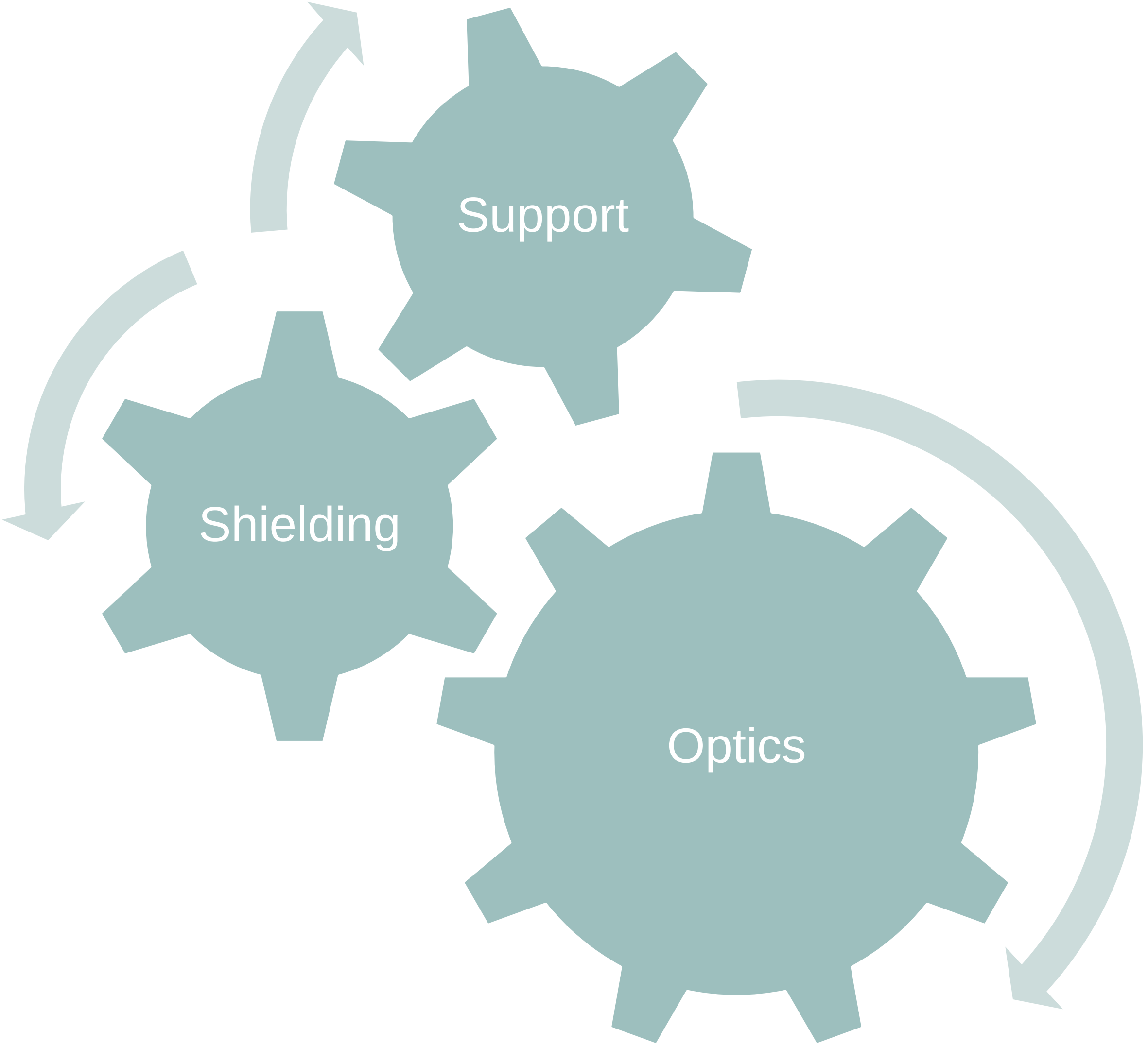
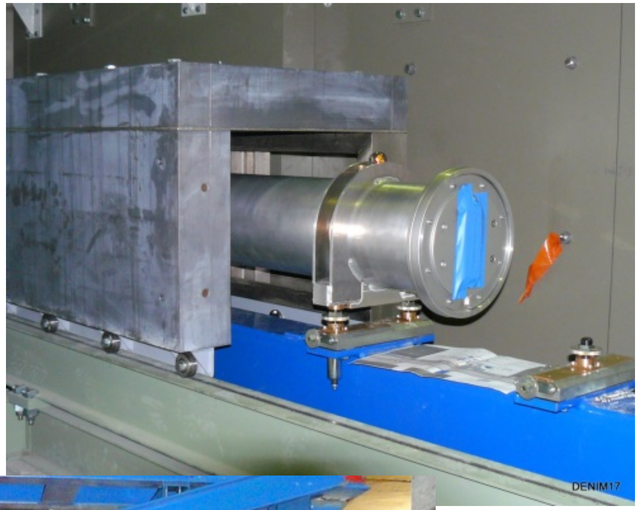
the system level optimum

Interactions

- Physical
- Access
- Radiation
- Cost





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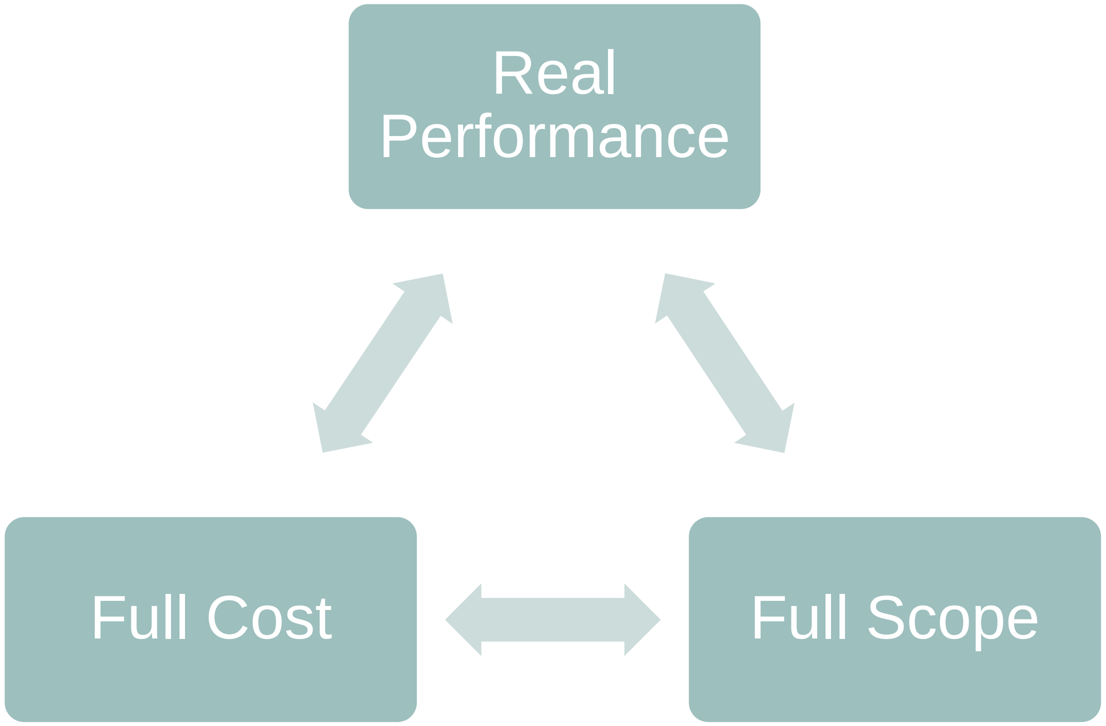
Full scope - Real performance – real cost



Thus the best guide system is

the system which reliably delivers the highest time averaged performance to the sample, within the operational, physical and budgetary constraints.

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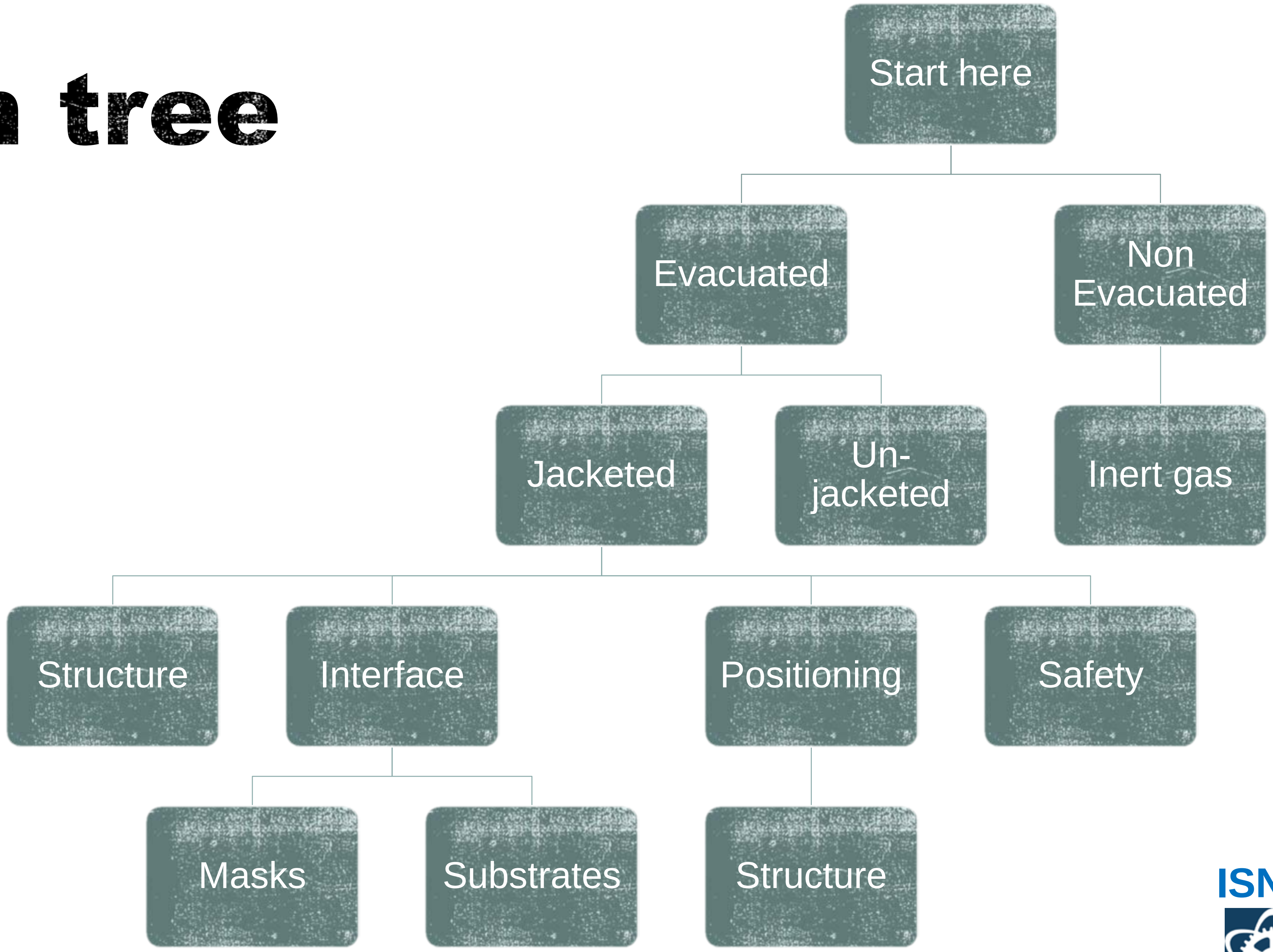
Decision tree

Flight path conditioning

Vacuum load structure

Integration



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To evacuate or not to evacuate that is the question ..

- **Why Vacuum?**
  - Neutron Transmission !!

$$\phi/\phi_0 = e^{-kt}$$

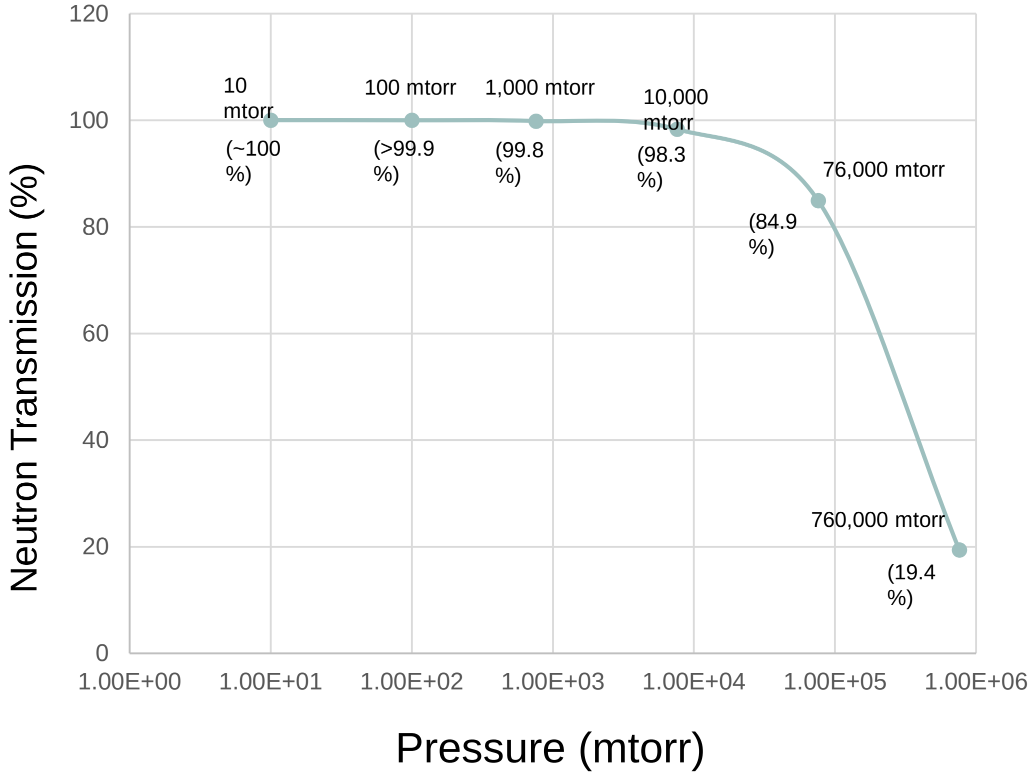
k is dependent on material(s), density, and the neutron wavelength of interest

t is material thickness or neutron path length through the material

- Air - ~ 80% N_2, 20% O_2 (M.W. = 28.8 g/mole)
- At STP, 1 mole occupies 22.4L (22,400 cc)
- Air Density - ρ = 1.29 x 10-3 g/cc
- Standard Pressure – 1 atm = 760 * 10^3 mtorr

<u>Neutron Transmission for 40m Guide</u>

(λ = 8 Angstroms)



https://www.ncnr.nist.gov/resources/activation/

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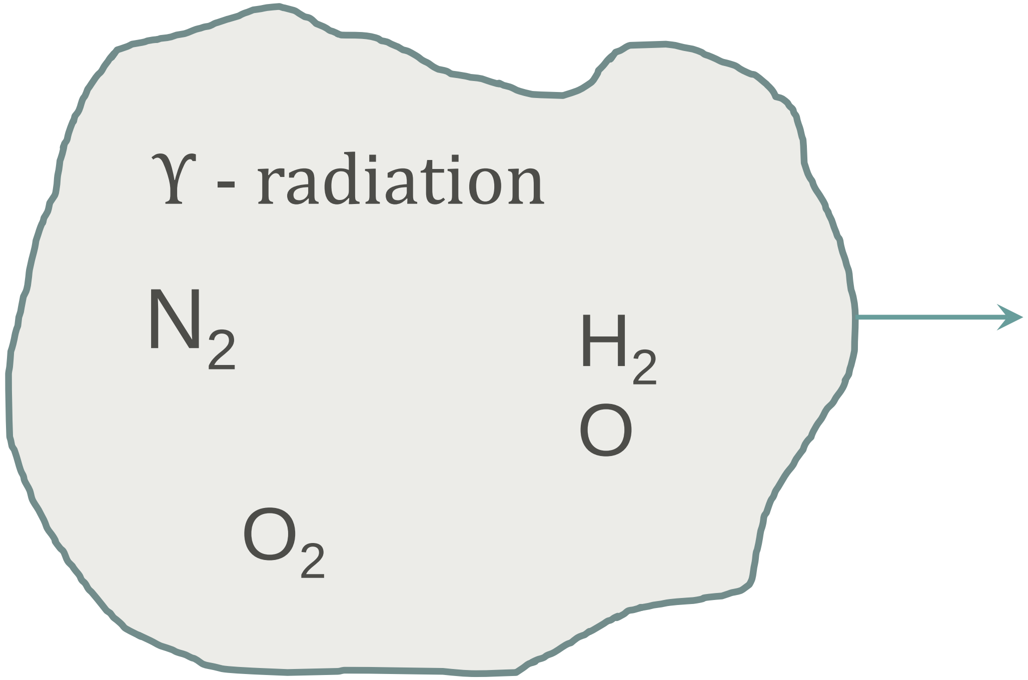
- **Why Vacuum?**
  - Coating Protection



HNO_3 (nitric acid)

Alternatives to Vacuum

- When it is impossible or impractical to evacuate a neutron flight path, replacing the air with another gas is a solution.

- **Possible Blanket Gases :** **Transmission (8Å, @1 atm abs.)**
  - ***Helium –*** ***1m*** – 99.8% ; ***40m*** – 91.8%
  - ***Argon –*** ***1m*** – 99.1% ; ***40m*** – 69.3%
  - ***Carbon Dioxide (CO_2) –*** ***1m*** – 96.7% ; ***40m*** – 26.1%
  - ***Air -*** ***1m*** – 96.0% ; ***40m*** – 19.4%
  - ***Nitrogen (N_2) -*** ***1m*** – 93.7% ; ***40m*** - 7.4%

- For short flight vessels/small gaps or when transmission loss or scattering is not an issue any of the above is satisfactory.

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For the majority of gas blanket applications on neutron instrumentation at the NCNR, helium is used. There are two exceptions:

- Beam ports in the reactor vessel are maintained with CO_2 at a slight positive pressure
- The large detector vessel on the NG-4 Disc Chopper Spectrometer (TOF) contains Argon at a slight positive pressure. Helium is not suitable here as it would diffuse through the large, extremely thin windows.

- Advantages of Helium vs. Other Blanket Gases:
  - Readily available
  - No activation products
  - High neutron transmission (low cross section)

- Disadvantages of Helium vs. Other Blanket Gases:
  - Helium diffuses through most materials (*even aluminum!*)

- Advantages of Helium vs. Vacuum:
  - Low gauge pressures allow thinner windows and lighter structures

- Disadvantages of Helium vs. Vacuum
  - Lower neutron transmission at easily achieved vacuum levels for longer path lengths
  - Require constant supply of helium (access to “house” helium or periodic bottle changes)

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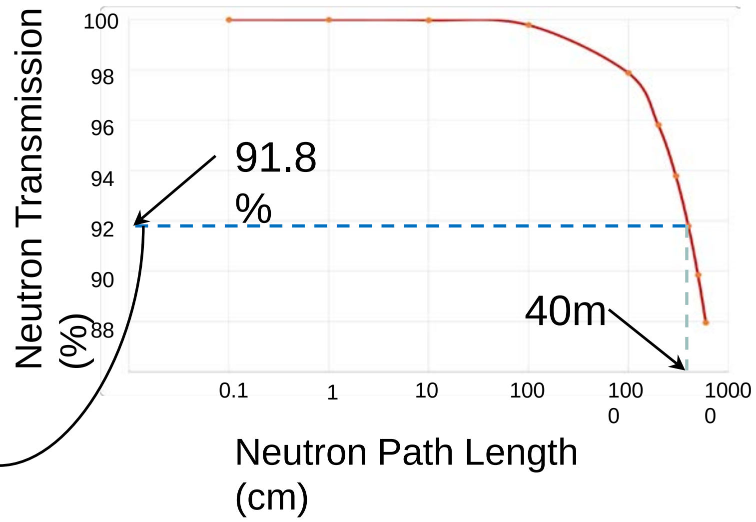
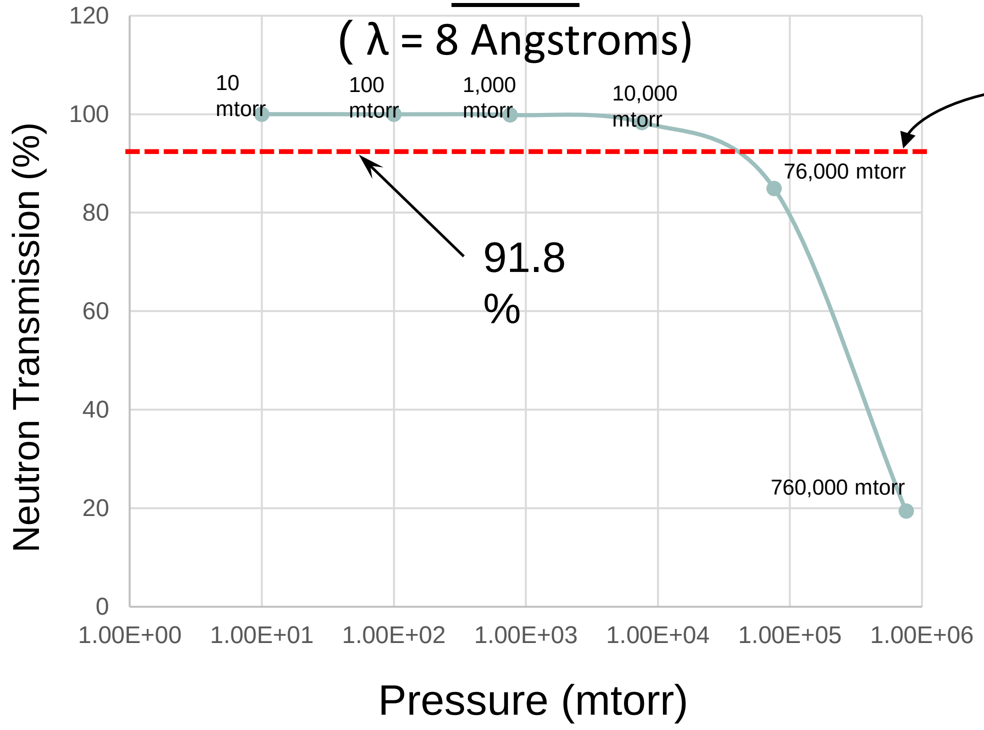
- Helium can provide a “Plan B” for an aging neutron guide line whose vacuum tightness has deteriorated and mitigation is impossible/impractical but should only be considered when it becomes difficult to maintain a rough vacuum

Neutron Transmission vs Path Length for Helium (1 atm) (λ = 8Å)



Neutron Transmission for 40m Guide

(λ = 8 Angstroms)



- Helium blanket systems must be designed to supply helium into the guide system volume and purge air from the lowest point(s) in the system. Maximizing the separation between the supply and return points improves the air purge.

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Example – NG-A thru NG-D Main Shutters

- Helium filled (separated from upstream and downstream by thin windows)
- Loss of transmission (8Å) < 0.7% (windows and He)
- Continuous flow
- Supply – Reactor Helium; Return/Exhaust – Room (Reactor Stack for inpile vessels)

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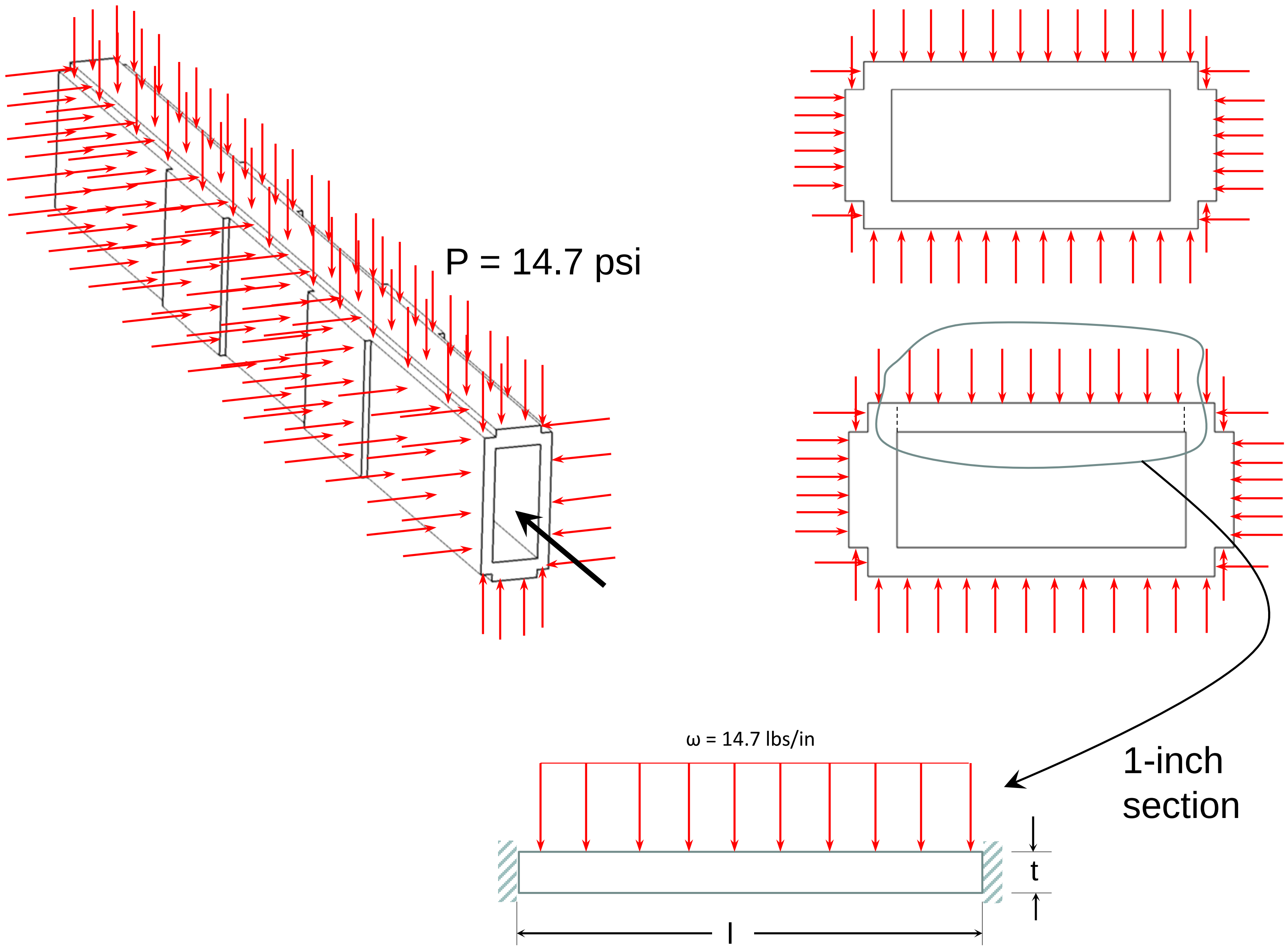
Evacuated Un-jacketed

Don Pierce

Mechanical Engineer, NCNR



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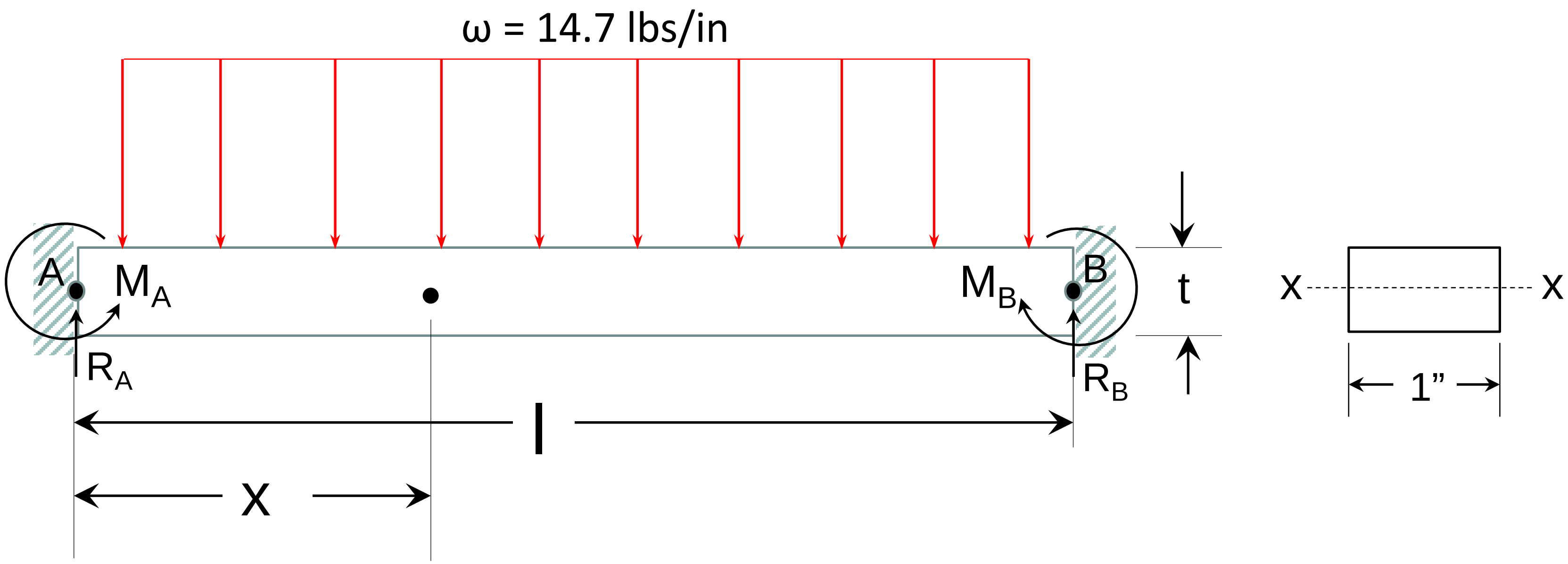

$R_A = R_B = \omega l/2$ $\qquad$ $MA = MB = \omega l^2/12$

$M(x) = (\omega/12)(6lx - 6x^2 - l^2) \longrightarrow M' = 0 \ @ \ x = l/2$

$M_{max} = (\omega/12)(6l(l/2) - 6(l/2)^2 - l^2) \longrightarrow M_{max} = \omega l^2/24$

$I_{xx} = (1/12)bh^3$ $\quad$ b = 1 inch; h = t $\longrightarrow$ $I_{xx} = t^3 (1 \text{ inch})/12 \ \ in^4$

$c = t/2$

$\sigma = Mc/I$ $\qquad$ $\sigma_{max} = M_{max}c/I_{xx}$

$\sigma_{max} = (\omega l^2/24)(t/2)/(t^3 (1 \text{ in})/12)$

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$M(x) = (\omega/12)(-6x^2 + 6lx - l^2)$

$$d^2y/dx^2 = \frac{M(x)}{EI}$$

$$dy/dx = \int \frac{M(x)}{EI} = \left(\frac{1}{EI}\right)\int M(x) = \left(\frac{\omega}{12EI}\right)\int(-6x^2 + 6lx - l^2)$$ ← *SLOPE*

$$= \left(\frac{\omega}{12EI}\right)(-6x^3/3 + 6lx^2/2 - l^2x) + C_1$$

$$= \left(\frac{\omega}{12EI}\right)(-2x^3 + 3lx^2 - l^2x)$$ ← *MAX SLOPE where*

M(x) = 0 ←

$$y(x) = \int dy/dx = \left(\frac{\omega}{12EI}\right)\int(-6x^3/3 + 6lx^2/2 - l^2x)$$

DEFLECTION ←

$$= \left(\frac{\omega}{12EI}\right)(-6x^4/12 + 6lx^3/6 - l^2x^2/2) + C_2$$

$$= \left(\frac{\omega}{12EI}\right)(-x^4/2 + lx^3 - l^2x^2/2)$$ *MAX DEFLECTION where*

SLOPE = 0

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MAX SLOPE where M(x) = 0

$M(x) = (\omega/12)(-6x^2 + 6lx - l^2) = 0$ when $(-6x^2 + 6lx - l^2) = 0$

$M(x) = 0$ when $X = ((-6l) +/- ((6l)^2 - 4(-6)(-l^2))^{1/2})/(2(-6))$; $x = .2113l$ or $.7887l$

$$dy/dx_{\,(.2113l)} = \left(\frac{\omega}{12EI}\right)(-4x^3 + 3lx^2 - l^2x) = \left(\frac{\omega}{12EI}\right)(-2(.2113l)^3 + 3l\,(.2113l)^2 - l^2(.2113l))$$

$$= \left(\frac{\omega}{12EI}\right)(-.0962\ l^3)$$

$$dy/dx_{\,(.7887l)} = \left(\frac{\omega}{12EI}\right)(-4x^3 + 3lx^2 - l^2x) = \left(\frac{\omega}{12EI}\right)(-2(.7887l)^3 + 3l\,(.7887l)^2 - l^2(.7887l))$$

$$= \left(\frac{\omega}{12EI}\right)(.0962\ l^3)$$ for $\omega = 14.7$ lb/in , $E = 11.9 \times 10^6$ lb/in^2, $I_x = t^3 \times 1$

in

$$/dy/dx/_{max} = 9.9 \times 10^{-9}\ (l^3/t^3)$$

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$y = \left(\frac{\omega}{24EI}\right)(-x^4 + 2\,lx^3 - l^2x^2)$

MAX DEFLECTION where SLOPE = 0

SLOPE = $dy/dx = \left(\frac{\omega}{12EI}\right)(-2x^3 + 3lx^2 - l^2x)$

2 solutions: x = 0 and x such that $(-2x^2 + 3lx - l^2) = 0$ → *x = l/2*

and l

At x = 0 and l, y=0

At x = l/2, $y = \left(\frac{\omega}{24EI}\right)(-(l/2)^4 + 2l(l/2)^3 - l^2(l/2)^2) = \left(\frac{\omega}{384EI}\right)l^4$

$= \left(\frac{12\omega}{384E\,t^3\,(1\text{ inch})}\right)l^4$

=

$\left(\frac{12\omega}{384E\ (1\text{ inch})}\right)(l^4/t^3)$

$|y|_{max} = 0$ or $3.86 * 10^{-8}\,(l^4/t^3)$

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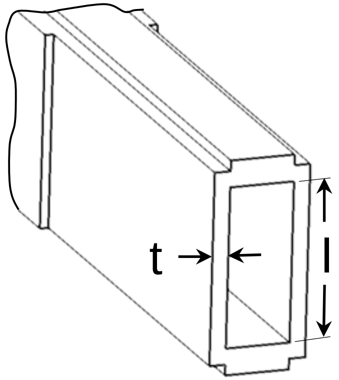
What Do We Care About? (*How can vacuum hurt us?*)

- **Service Life (implosion protection)**
- **Flatness**
- **Dimensional Accuracy**

All Affected by **(l/t)**

- Service Life - σ_{max} – **a function of (l/t)^2**
- Flatness – 2 times $(dy/dx)_{max}$ – **a function of (l/t)^3**
- Dimensional Accuracy – 2 times $(/y /_{max})$/l - **a function of (l/t)^3**



N-BK7 Properties:

E (Young's Modulus) = 11.9 Mpsi

σ_y[1] (yield stress) = 9.2 kpsi

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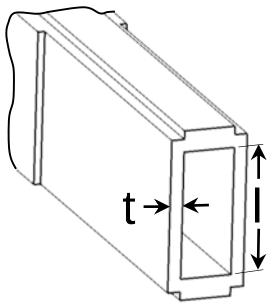
A typical rule of thumb of guide manufacturers for a glass substrate is to make the (l/t) ratio no greater than 10.



For (l/t) ≤ 10:

$$\sigma_{max} = ((14.7\ \text{lb/in})/4\ \text{in}) \times (\leq 10)^2 \leq 3.68 \times 10^2\ \text{psi}$$

Service Life

Neutron Guide BOA specification:

"Neutron Guide reflective coatings and substrates should be designed to withstand a capture (thermal-equivalent) fluence of neutrons of up to 1.5×10^{18} cm^{-2} under the conditions outlined in section 7. (The capture fluence is the fluence of neutrons of energy 25.3meV [velocity=2200ms^{-1}] that would create the same number of reactions per unit volume in a material as would be created by the actual neutron beam)."

- $\sigma_{max} \leq 3.68 \times 10^2$ psi ≪≪≪≪≪ 9.2×10^3 psi
  Virgin Borkron N-BK7

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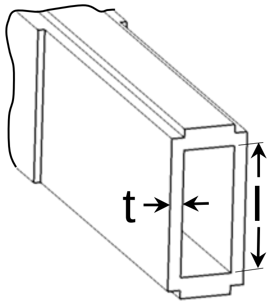
Flatness



For (l/t) ≤ 10:

$$\left| dy/dx \right|_{max} = 9.9 \times 10^{-9} (\leq 10)^3 \leq 9.9 \times 10^{-6} \text{ rad}$$

Neutron Guide BOA specification:

"Flatness – the flatness of any reflecting surface is defined by the angle between any two surface normals and shall be less than 1.5 x 10^{-4} radians."

- Deviation from flatness = 2 x $\left| dy/dx \right|_{max}$

(= 1.98 x 10^{-5} rad)

≈ **1/8 specified flatness**

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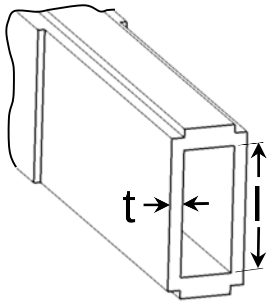
Dimensional Accuracy



For (l/t) ≤ 10:

$(/ y /_{max})/l = 3.86 * 10^{-8} (\leq 10)^{3} \leq 3.86 * 10^{-5}$ mm/mm

Neutron Guide BOA specification:

"Inner Width – the allowable tolerance on the inside width of the guide shall be 3 x 10^{-4} mm per mm of width (or .03%)."

- Deviation from specified width = 2 x $(/ y /_{max})/l$

= 2 x (3.86 * 10^{-5} mm/mm)

= 7.72 x 10^{-5} mm/mm x (60mm/150mm)

= .01 %

> ***1/3 the construction tolerance!***

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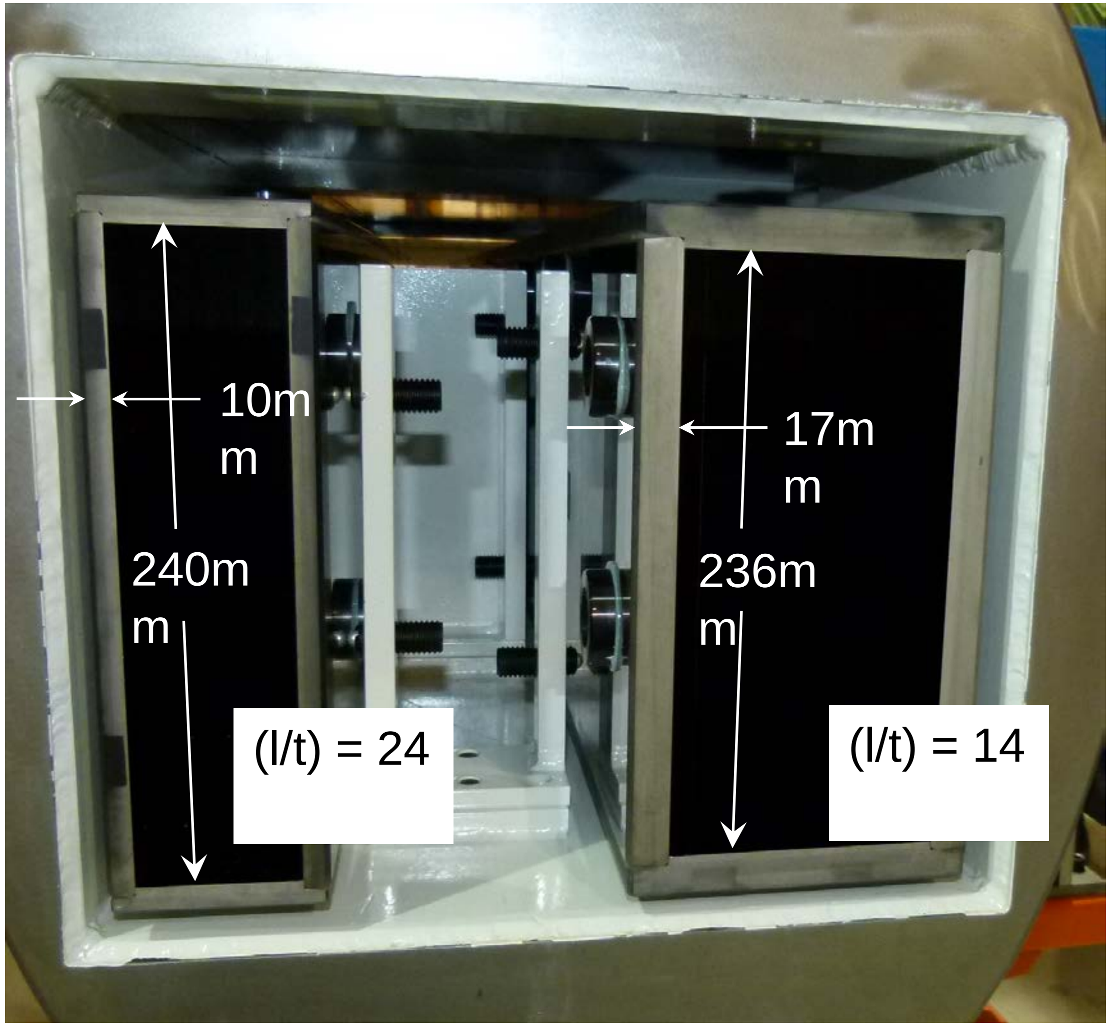
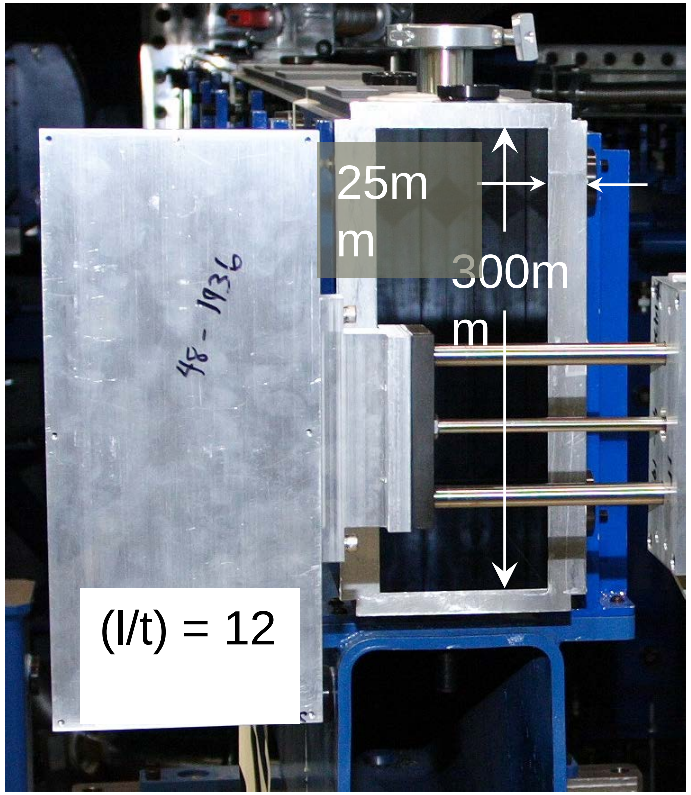
Vacuum Jacketed Guides:



Vacuum-Supporting Guide:



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Interuptions

Guide Cuts – interruptions or gaps in a continuous guide sequence **necessary for the installation of:**

- Monochromators
- Filters
- Velocity selectors
- Shutters
- Mechanical de-coupling of the guide support system at the interface of base structures where independent movement can occur.

Guide cuts create a loss in intensity due to:

- Beam Divergence Below the Critical Angle
- Air Scattering
- Materials in the Gap
- Attenuation Through Neutron Windows
- Protective Mask Overcoverage

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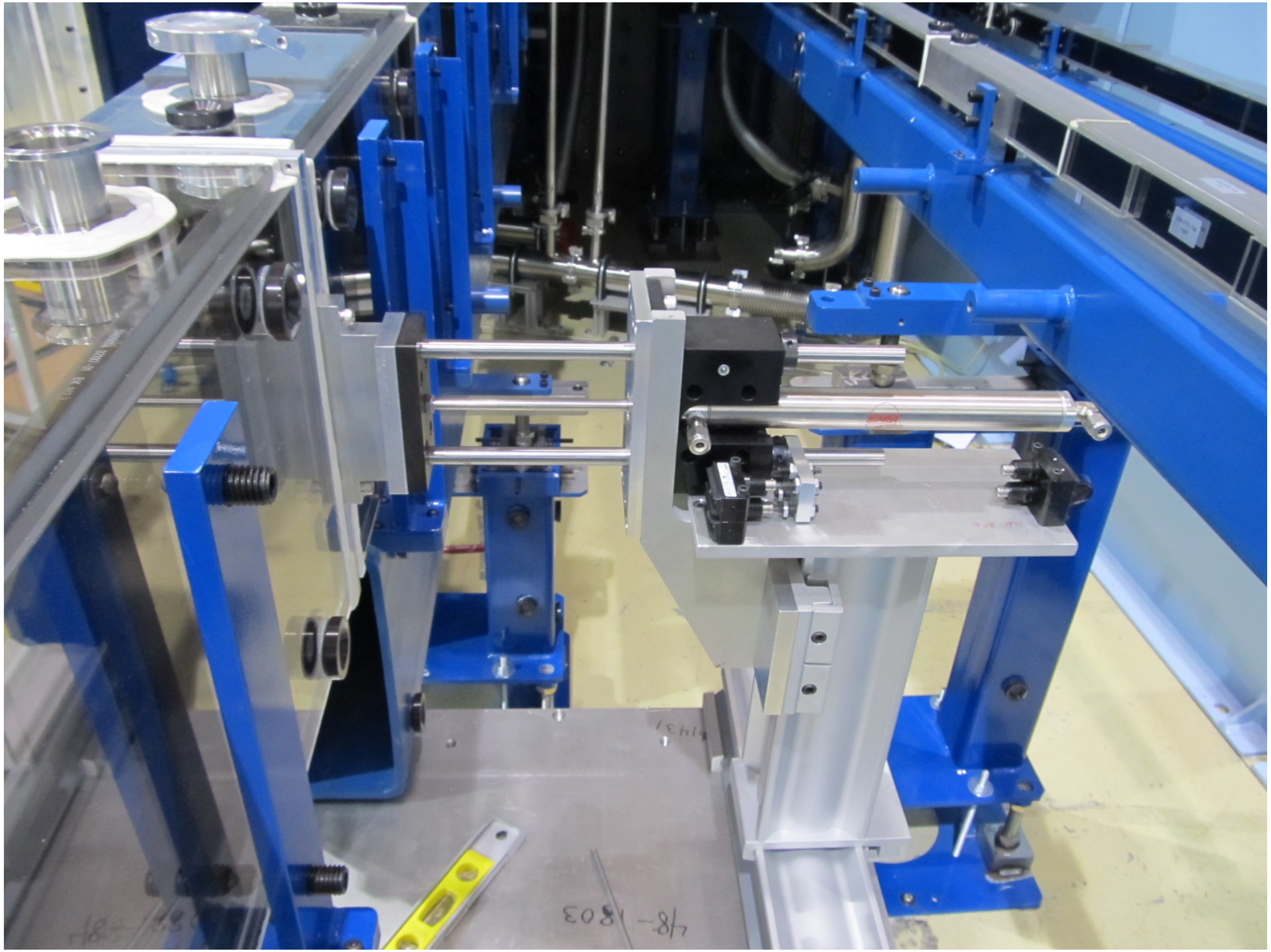
Guide Cut for NG-C Local Shutter:



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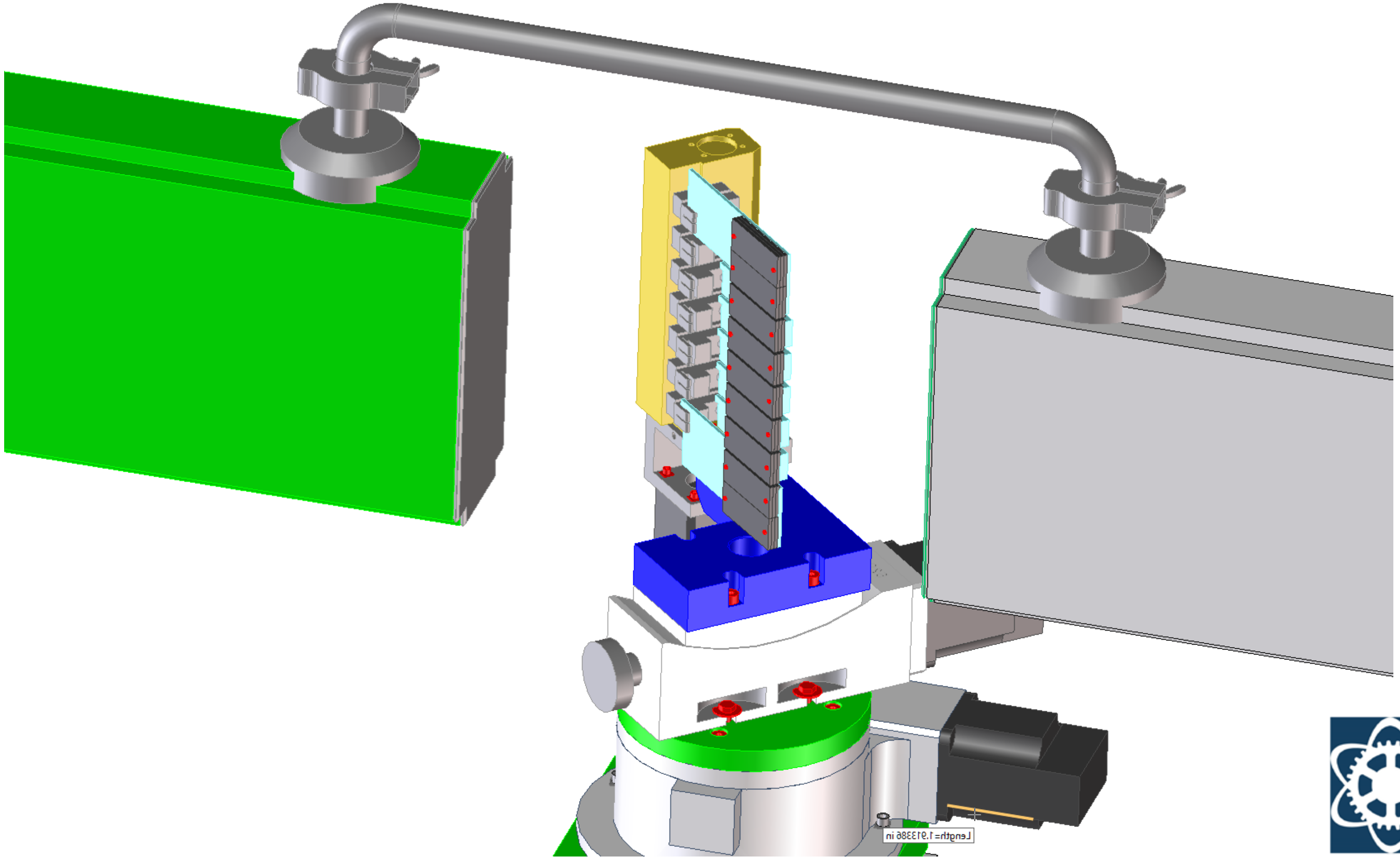
Guide Cut for a Monochromator



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Attenuation Loss Through Neutron Windows

- 60mm x 150mm guide
- .020” thick aluminum window:
  - Transmission for one window (.020”, 8 angstrom neutrons) – 99.68%
  - Transmission for two windows (1 guide cut) – $(99.68\%)^2$ = 99.36%
- On a neutron guide line with n guide cuts:
  - Transmission = $(99.36\%)^n$
  - For n = 3, transmission = 98.09%
  - For n = 5, transmission = 96.84%

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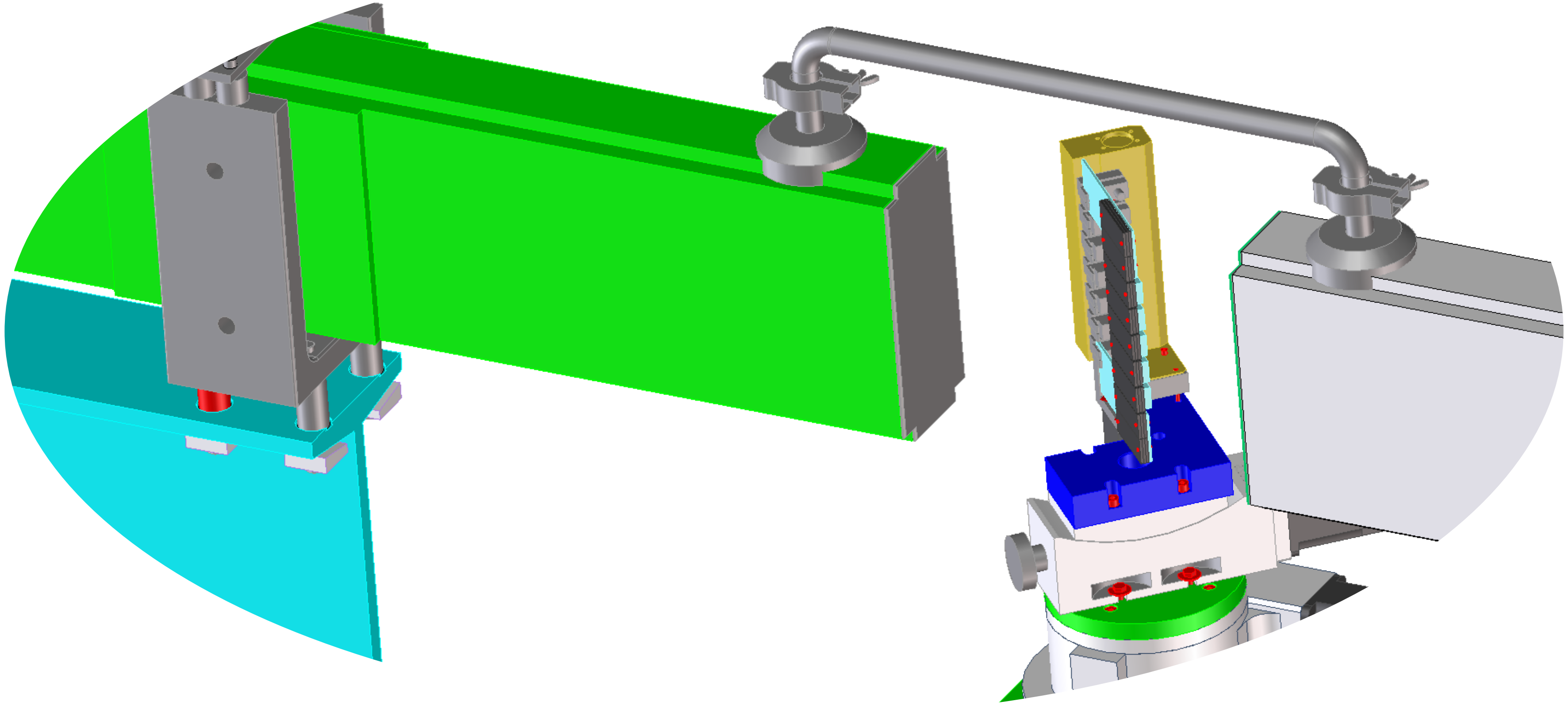

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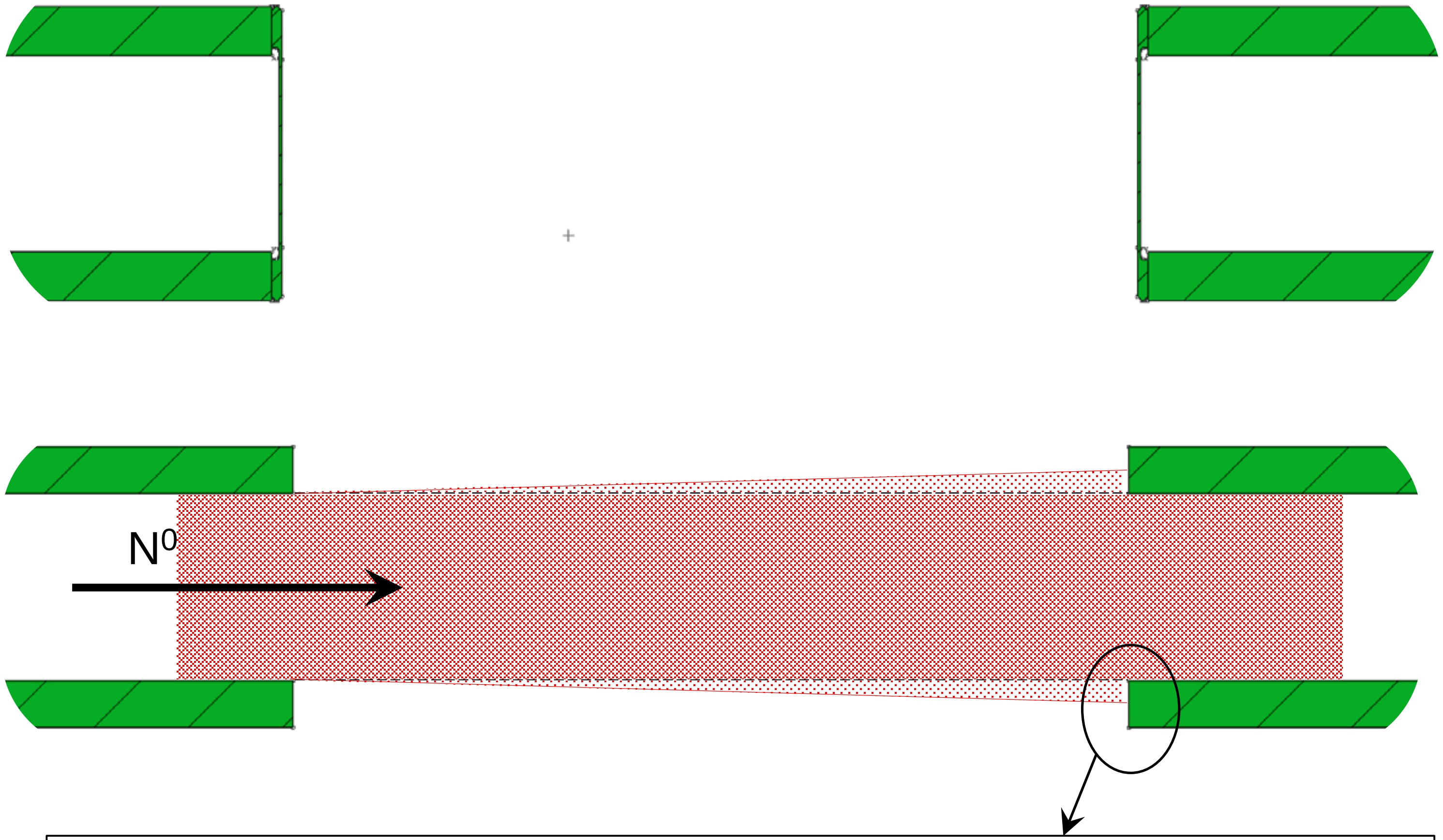

The amount of radiation impingement (fast and thermal neutrons, gamma rays and cold neutrons) depends on several factors:

- Intensity of the source
- Length of the guide cut (gap)
- Distance from the source
- Guide geometry
- Neutron scattering materials in the gap
- Reflective coatings (m-values)

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The neutron impingement on borated glass:

- N-α reaction with boron

- α particles (He nuclei) create "worm holes"

- ……Sufficient time passage….. structural integrity ⇢ 0

- IMPLOSION!

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Bad things happen

NCNR has suffered 3 such implosions:

- **1991**, < 1 year service, the guide closest to the reactor imploded
  - Lengthy clean-up operation
  - Vacuum jackets for first 22 meters of guide (entrance to Guide Hall)
- **1995**, < 3 years of service, downstream of guide cut, 54 meters from the reactor
  - Vacuum jumper limited debris travel upstream
  - Introduced BoAl masks to downstream guide face
    - Inner dimensions of mask slightly less than inner guide dimensions to prevent any intensity loss
- **2011**, < 7 years of service, downstream of guide cut, 30m from reactor
  - Vacuum jumper limited debris travel upstream
  - Analysis pointed to undercoverage on BoAl mask
  - Cataloged facility guide cuts, created plan to replace BoAl masks with ones having slight overlap with guide inner dimensions

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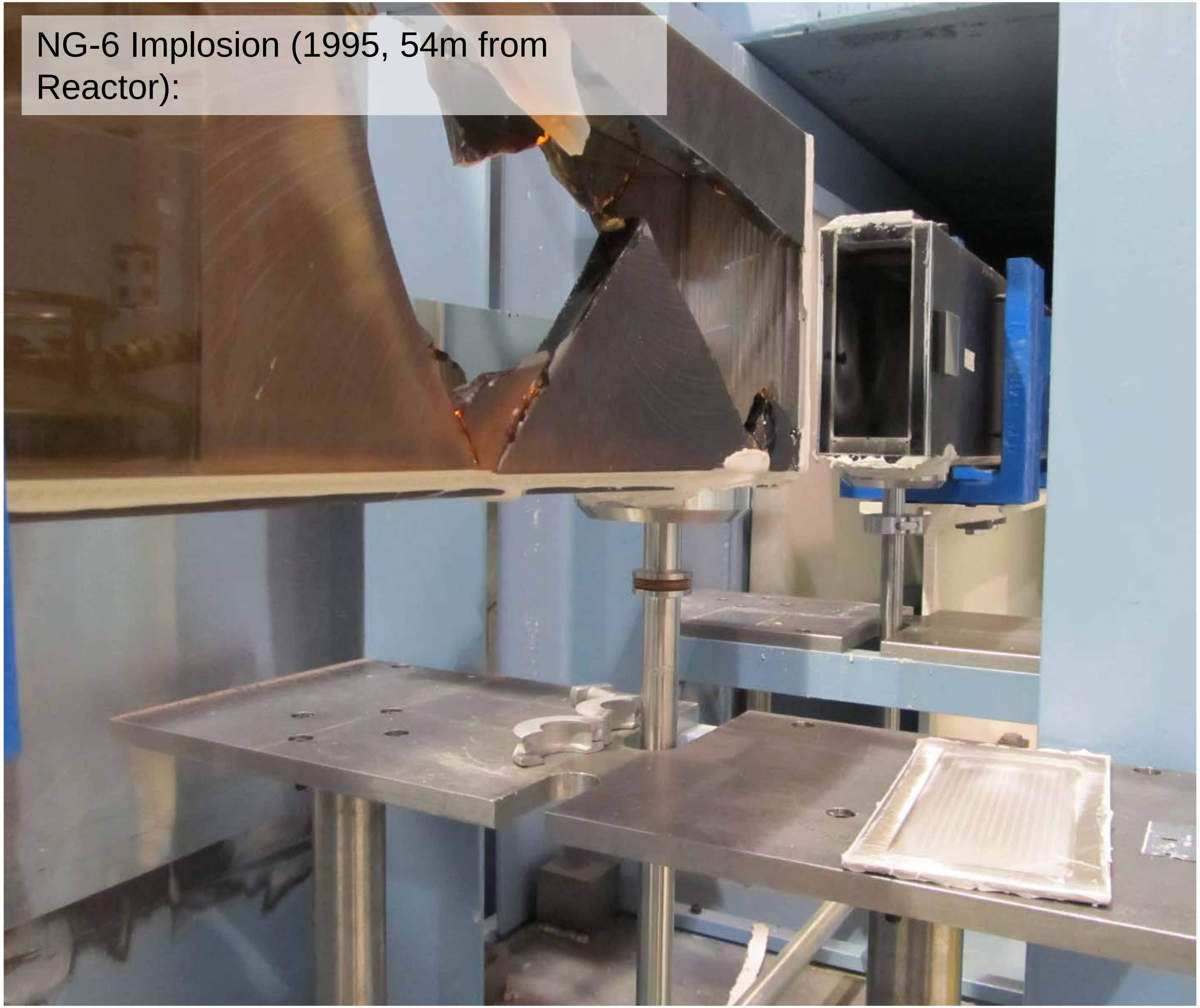
NG-6 Implosion (1995, 54m from Reactor):



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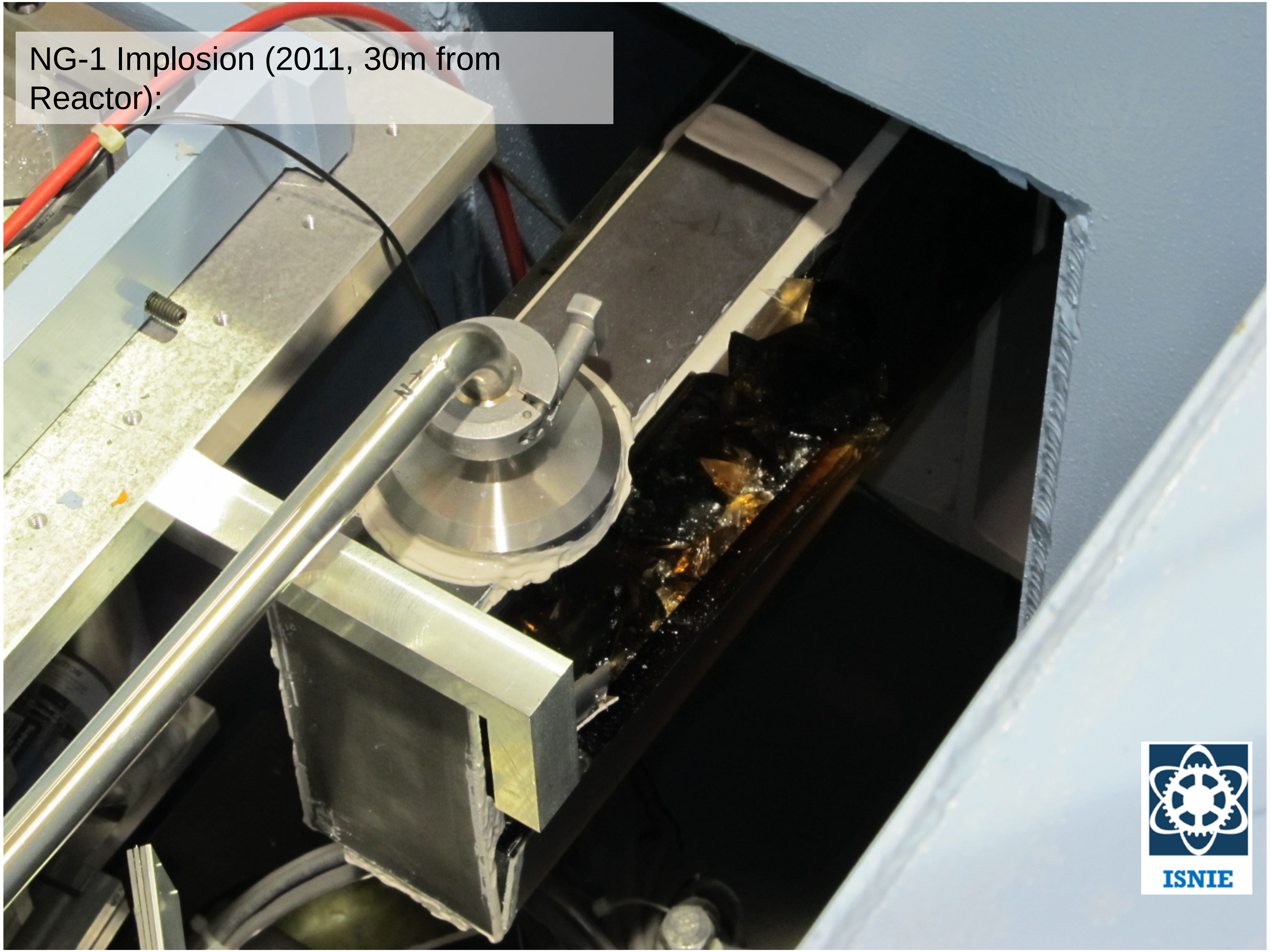
NG-1 Implosion (2011, 30m from Reactor):



Jerome Beaucour of the ILL has cataloged guide failure events that include those at NIST. Here is a snapshot of a portion of his spreadsheet:

Institut	Guide	Environnement	Part	Evac guide?	L: Height mm	Width mm	Thick mm	Capture Fluence E17n/cm2	d: dist. to source (m)	Merit Factor LxLxF/d	Capture Flux 1E10n/cm2/s	Age (year)	Commis.	Incident date	Comments
LLB	G6	downstream guide cut (d=5cm; vanne vat)	G6-1-1	YES	150	25	15	21.75	5.4	906	0.8	16	déc.-80	janv.-97	implosion
LLB	G3	casse au milieu du carter ou il n'y a rien	G3-5-1	YES	150	25	15	9.72	3.5	625	0.3	19	déc.-80	janv.-00	implosion
LLB	G3	pas de fenetre: casse au milieu d'un guide	G3-2-1	YES	150	25	15	6.85	3.5	441	0.4	11	déc.-80	oct.-91	implosion,
LLB	G2	pas de fenetre: casse au milieu d'un guide	G2-3-2	YES	150	25	15	5.98	3.5	384	0.4	9	févr.-95	juil.-04	fissure
NIST	NG6	Just outside reactor shield		YES	150	60	15	6.00	5.5	245	3.0	3	1991	dec-91	implosion
LLB	G3	pas de fenetre: casse au milieu d'un guide	G3-5-1	YES	150	25	15	3.72	3.5	239	0.2	11	déc.-80	sept.-91	implosion
LLB	G5	downstream guide cut (d=5cm; vanne vat)	G5-1-1	YES	150	25	15	5.67	5.4	236	0.5	6	sept.-97	févr.-04	fissure
LLB	G4	downstream guide cut (fenetre mono)	G4-44-1	YES	150	25	15	3.55	3.5	228	0.1	19	déc.-80	déc.-99	implosion attri
LLB	G4	downstream guide cut (fenetre mono)	G4-48-1	YES	150	25	15	3.43	3.5	220	0.1	19	déc.-80	nov.-99	implosion attri
LLB	G2	casse au milieu du carter ou il n'y a rien	G2-5-2	YES	150	25	15	2.97	3.5	191	0.3	5	févr.-95	mai-00	implosion
LLB	G3	casse au milieu du carter ou il n'y a rien	G3-10-1	NO	150	25	15	2.38	3.5	153	0.2	9	févr.-95	sept.-03	Broken inside
LLB	G6	pas de fenetre: casse au milieu d'un guide	GG6-4-2	YES	150	25	15	2.32	5.4	97	0.6	3	janv.-02	janv.-05	fissure
ILL	H17	OT1 H17	2	YES	150	30	15	12.70	31.3	91	1.20	7	1998	mars-05	implosion
NIST	NG6	Downstream Guide cut		YES	150	60	15	3.90	54	16	0.2	12	1993	mars-05	implosion
ILL	H25	OT1 H25, Mono S18	2	YES	120	30	15	3.78	58.6	9	0.25	10	1995	févr.-05	specific desig
NIST	NG1	Downstream Guide cut		YES	150	60	15	3.90	54	16	0.2	12	1993	oct.-11	implosion

Some common factors in the majority of these entries:

- Occur downstream of a guide cut
- Guide height of 150mm
- Occur at lifetime capture fluence < 1 * 10^{18} n/cm^2

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Substrates

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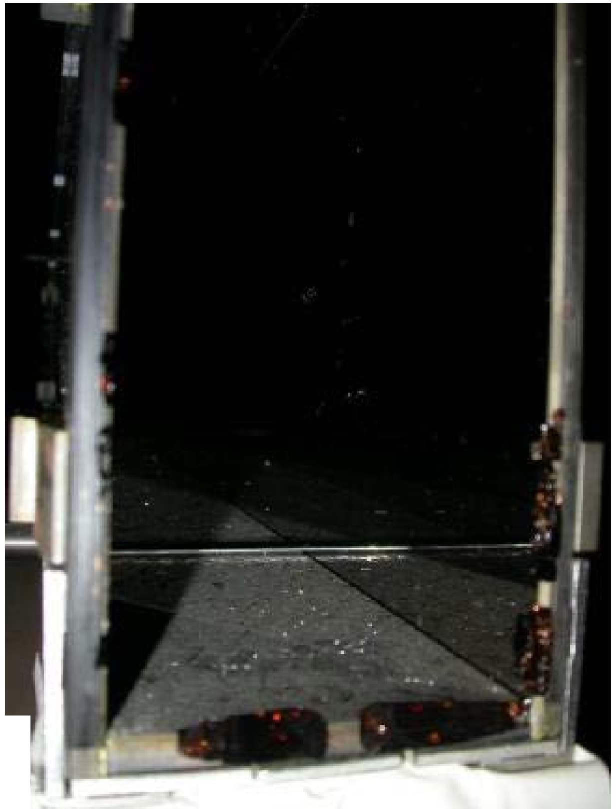
Need more life

FLUENCE LIMIT FOR DIFFERENT GLASS TYPES

- BORKRON (N-ZK7) : ~ **$5 \cdot 10^{17}$** n/cm^2
- BOROFLOAT : ~ **$2\text{-}3 \cdot 10^{16}$** n/cm^2
- N-BK7 : > **$1.5 \cdot 10^{18}$** n/cm^2
- "Russian borkron" : > **$1.5 \cdot 10^{18}$** n/cm^2



Irradiation damage of the substrate material

- Fluence limit for Borofloat33 substrate in external vacuum housing $F < 10^{16}$ n/cm² (degradation of the neutron reflectivity)
- Fluence limit for Borkron substrates $F \sim 2 \cdot 10^{18}$ n/cm²
- Fluence limit for vacuum tight guide elements reduced to $F < 5 \cdot 10^{14}$ n/cm² (appearance of first scratches!)
- No Fluence limit known for Boron free floatglass – but higher level of secondary γ production leads to shielding issues

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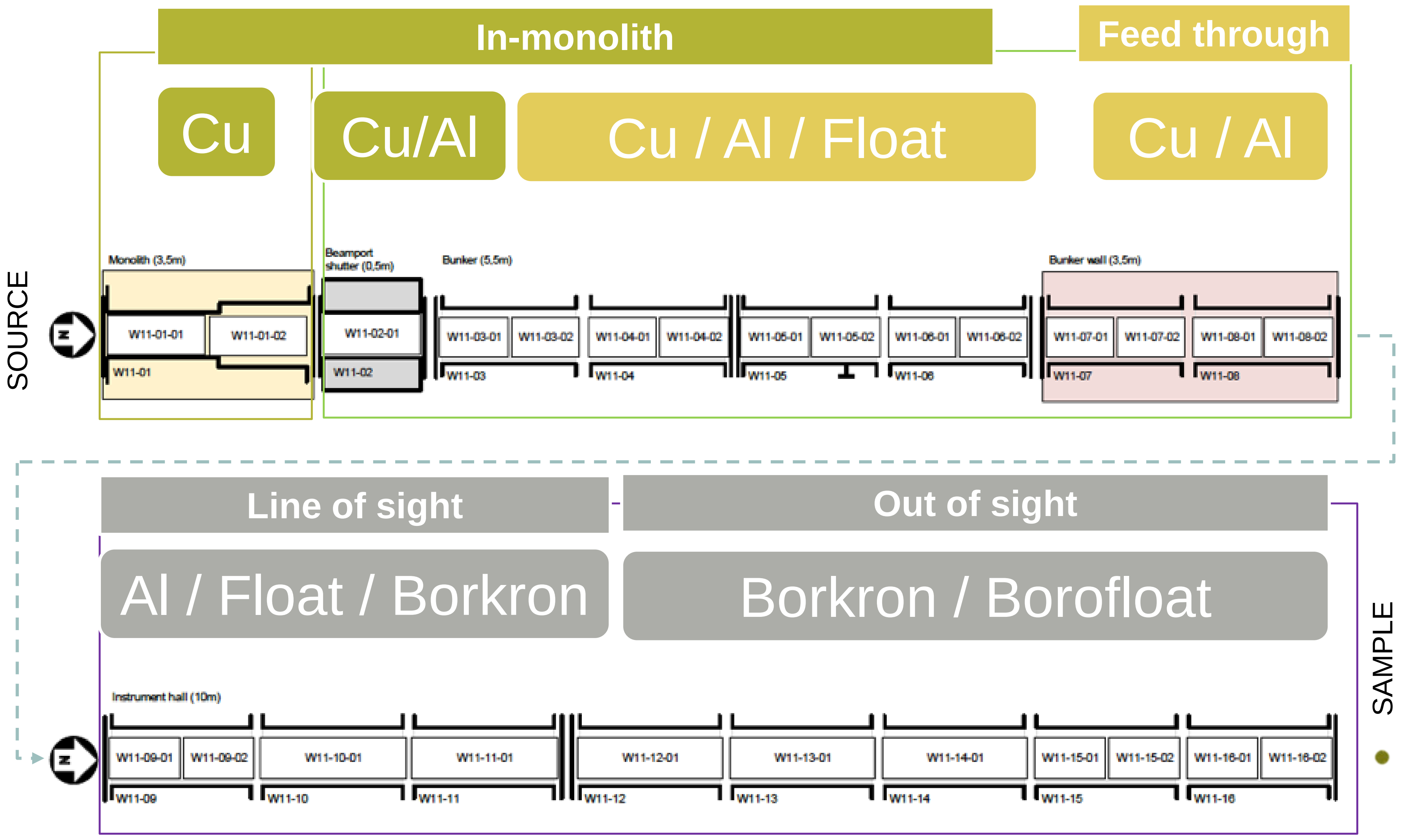
Guide Substrates



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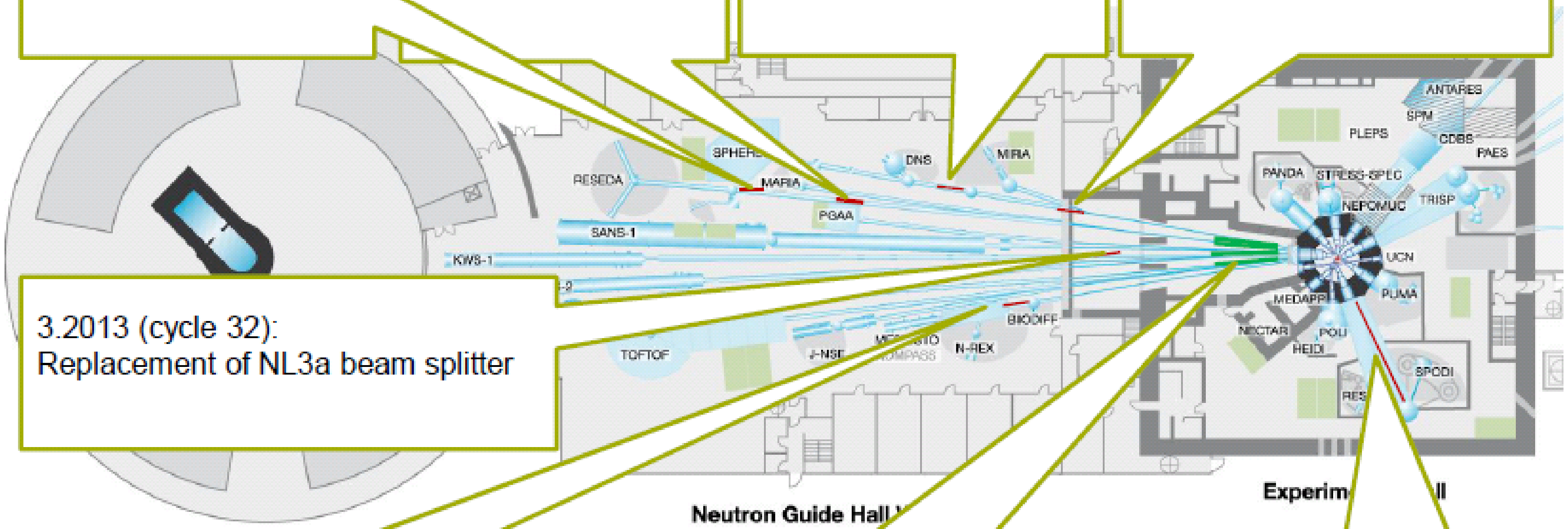
Neutron Guides: Incidents and Refurbishments

22.9.2012 (cycle 29):
Implosion NL5-31

22.2.2012 (cycle 27):
Implosion NL5-26

3.9.2013 (cycle 33):
Implosion NL6-19

16.4.2012 (cycle 28):
Implosion NL6-14



3.2013 (cycle 32):
Replacement of NL3a beam splitter

28.6.2012 (cycle 29):
Implosion NL1-16

6/2011:
Refurbishment of NL 1,3,5,6
in tunnel (section 1)

8/2012:
SR8a Spodi operating the guide with 1atm. He because of vacuum leakage

Covering up Masks

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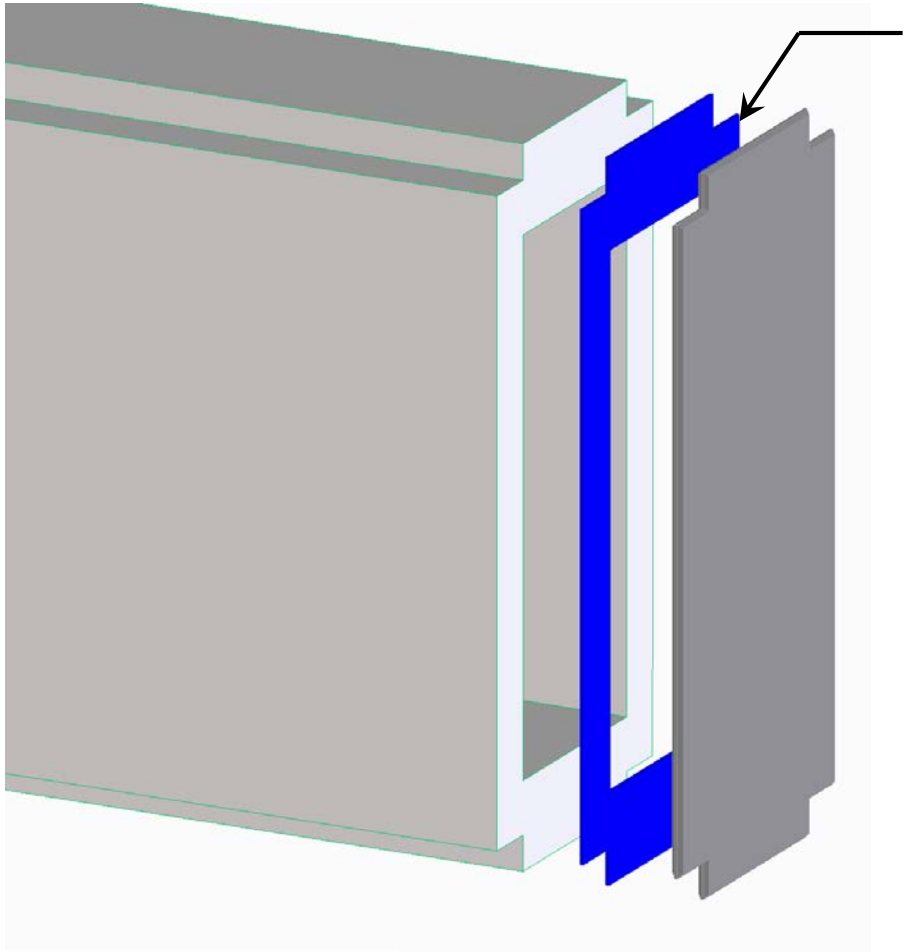
To prevent future implosions, the NCNR has placed a mask made from 1-mm thick boron aluminum on the downstream face of the guide following a guide cut:



Boron Aluminum Mask

Material[1] – boron aluminum containing 4.5 % by weight of ^{10}B

Thickness – 1mm (nominal)

Dimensions[2] –

outer – match guide outer dimensions

inner – 1mm shorter and narrower than guide inner dimensions

Notes:

1. No known current source – previously made and sold by Eagle-Picher (now 3M Ceradyne).
2. Neutron flux loss ≈ reduction in cross-sectional area (2-3 % loss for a 60mm x 150mm guide)

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Boron Aluminum Masks

Neutron transmission is reduced by the area reduction for the boron aluminum mask. For a 60mm x 150mm guide, the transmission is calculated as the area fraction for the boron aluminum mask:

For a .020” (.5mm) inside offset for the BoAl mask:

Transmission = (149mm x 59mm)/(150mm x 60mm) = .9768 or 97.68%

Transmission (for n gaps) = $(.9768)^n$ (for 3 gaps, trans. = 93.2%; for 5 gaps, trans. = only 88.9%)

Reducing the overlap of the boron aluminum mask to a .010” contour offset can increase the transmission of the mask to 98.84% making the transmission loss more palatable

Transmission (for n gaps) = $(.9884)^n$ (for 3 gaps, trans. = 96.6%; for 5 gaps, trans. = 94.3%)

Consider Vacuum Jackets

- Where space and budget allow, placing guides in vacuum jackets eliminates the stress and strain that vacuum places on a self-evacuated guide.
- Aluminum guide substrates are attractive for their durability but deflection under vacuum is roughly equal to that of glass for equal (l/t) ratios (actually worse!)
- Advantages
  - Eliminates vacuum-induced stress and strain on guides
  - Reduce guide costs
  - Provide support structure and alignment features
- Design considerations
  - Structural rigidity
    - Analysis of deformation under vacuum (FEA) and alignment effects
  - Good vacuum practices
    - Continuous interior welds
    - Minimize virtual leak sources
    - Interior coating (epoxy paint)
  - Guide installation sequence
  - Access/visibility of alignment features
- Disadvantages
  - Space/cost
  - Disposal (irradiation)???

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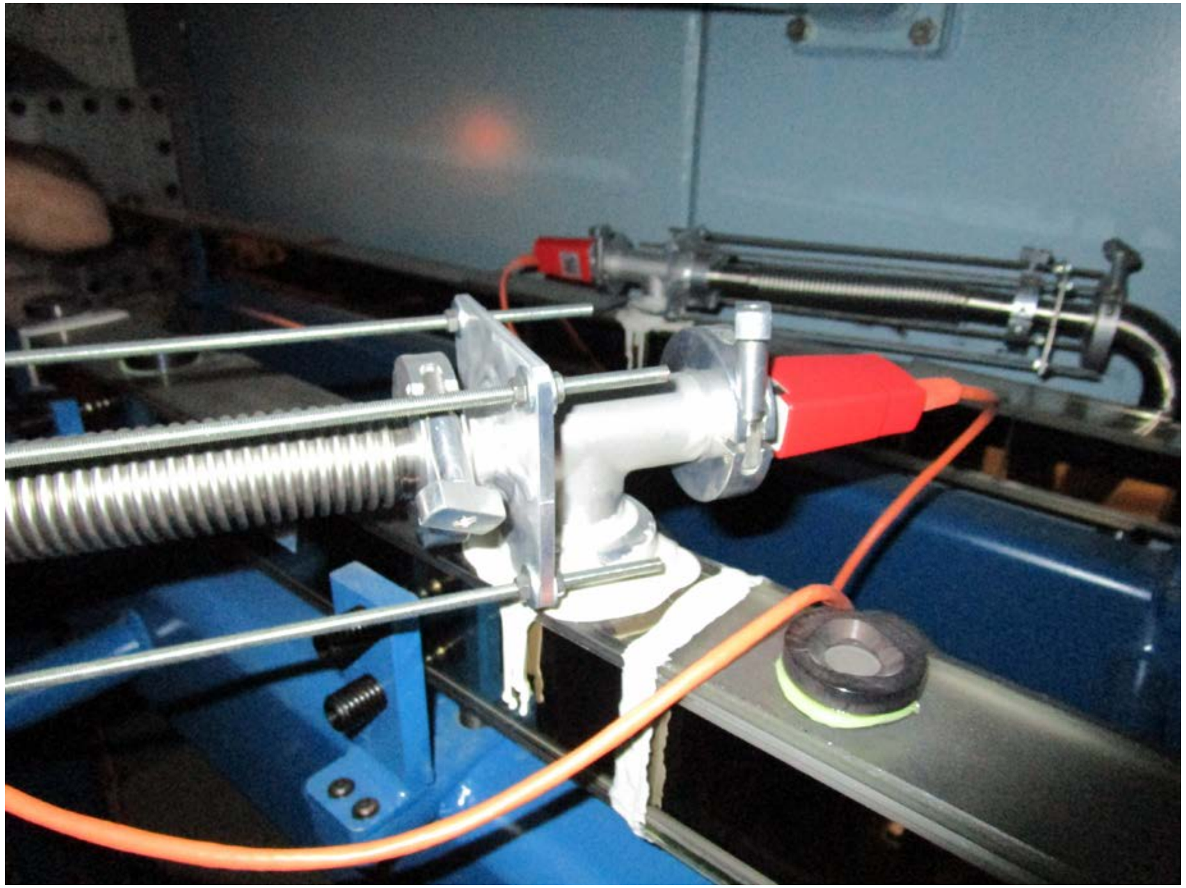
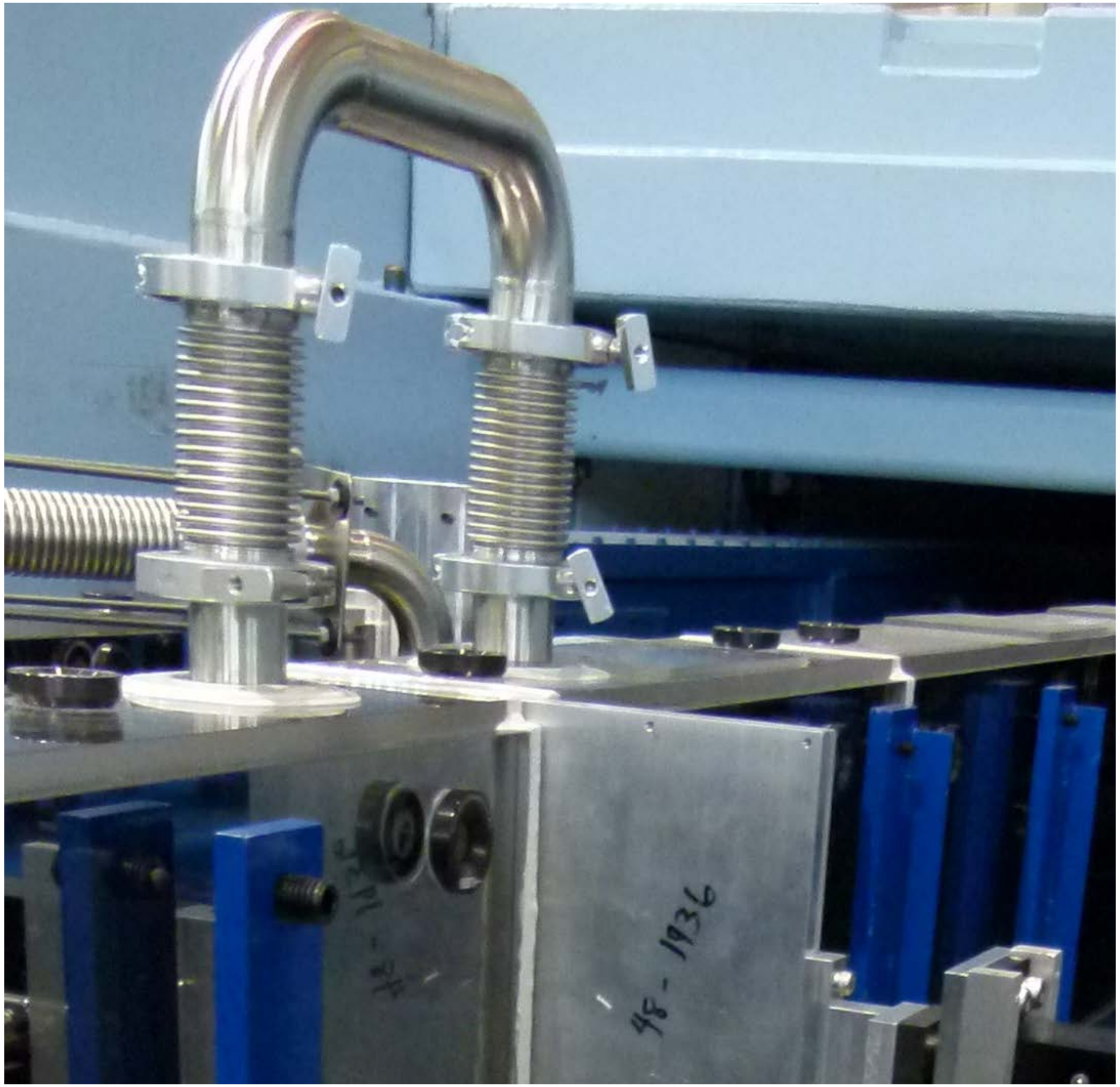
VACUUM TAPS & JUMPERS

For evacuating a non-jacketed guide that does not communicate with a vacuum jacket or to evacuate a guide train across a guide cut or gap, a vacuum tap must be added with a penetration to the guide interior. These must be designed and installed in a fashion that does not place strain on the guides:



Example of Pumping Line with Strain Relief



Vacuum jumper across a guide cut:

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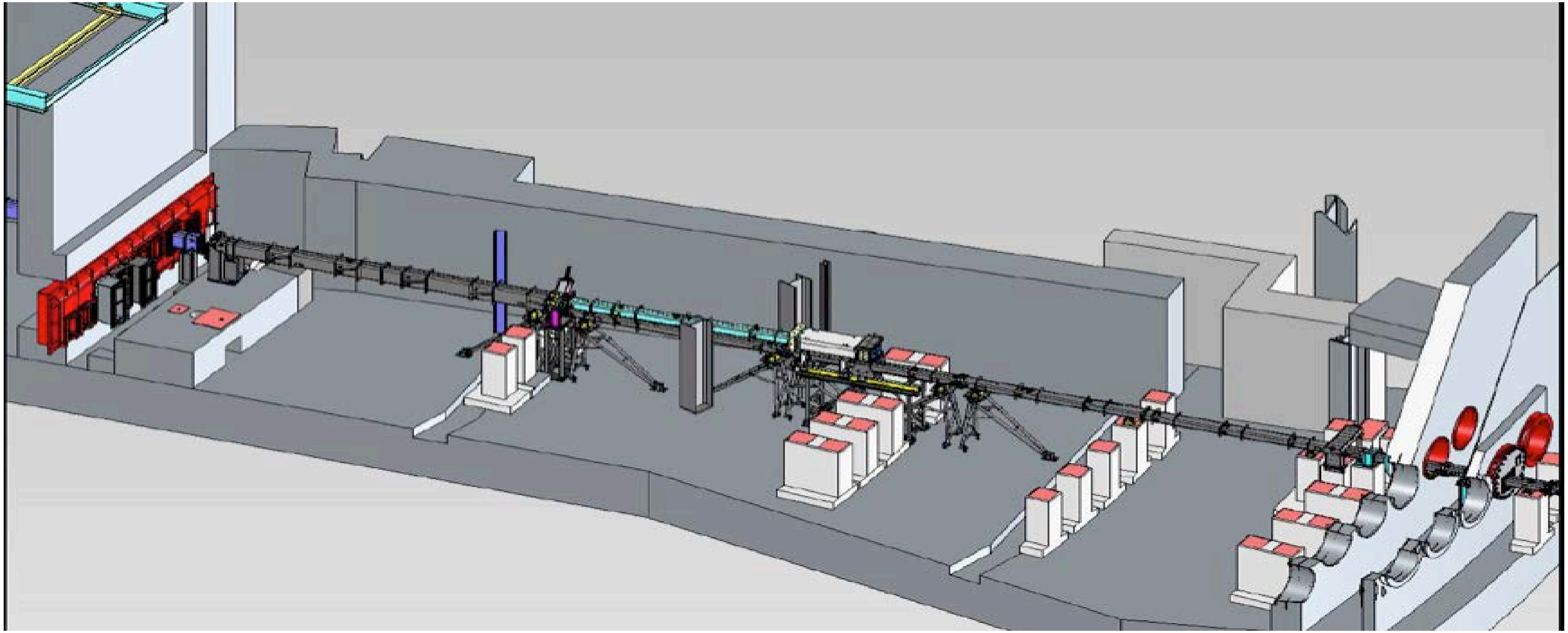
Full metal Jacketed

General layout



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Architecture
a Historical Context

Generation I ‘1960-90’

- Evacuated glass & strong-back

Generation II ‘1990 -’

- Evacuated housing

Generation III ‘2000 –’

- Reinforced housing

Generation IV 2010

- Uni-jacket

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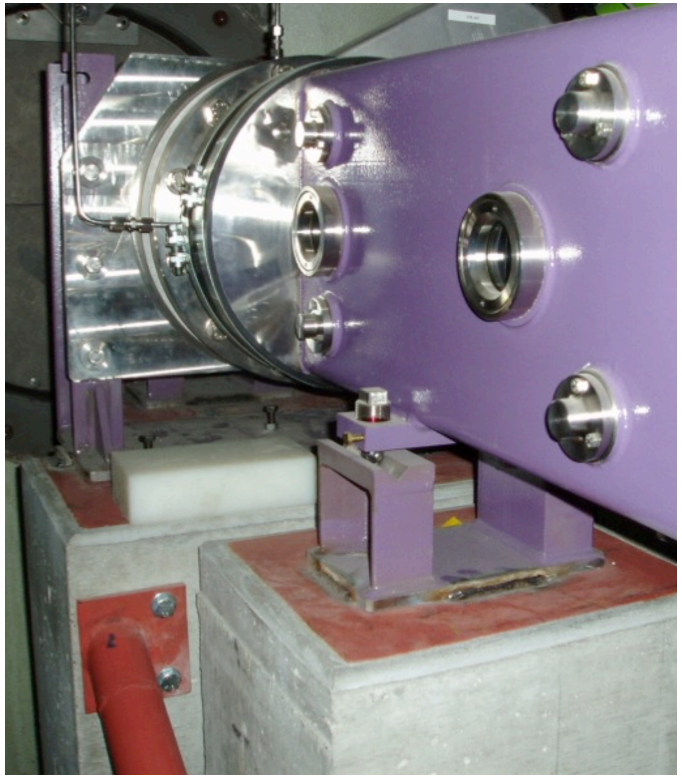
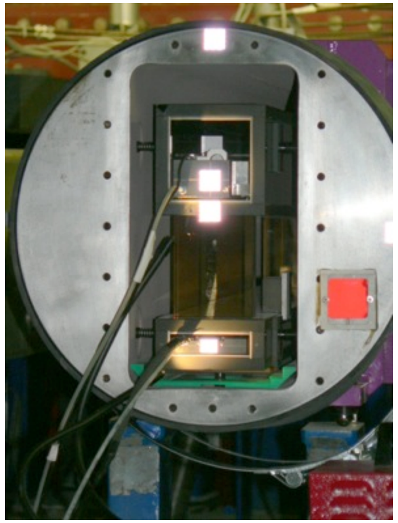


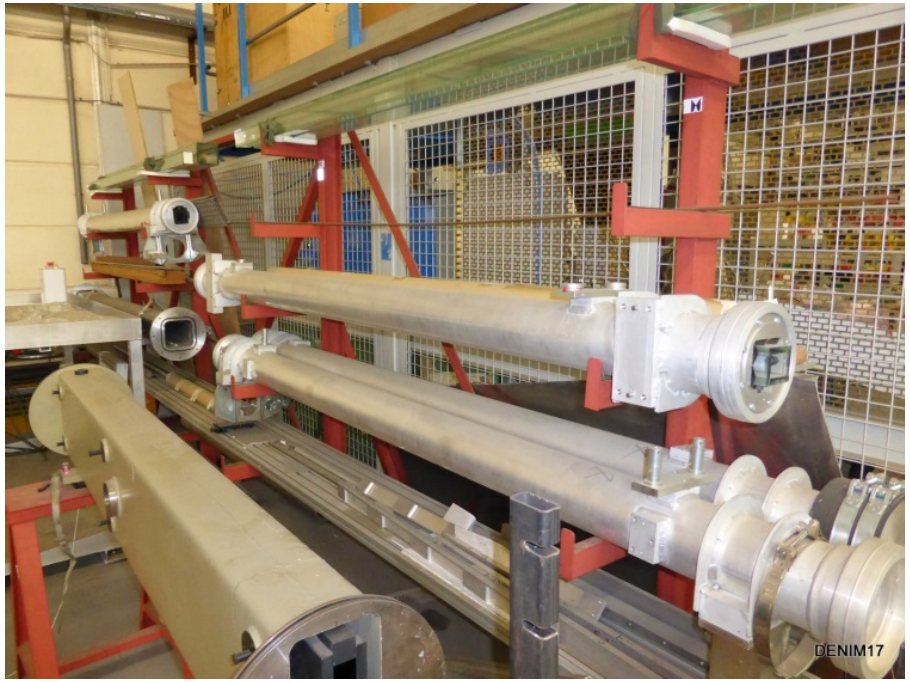
Gen 2 Jacket

Key features

- Evacuated guide volume
- Steel housing takes air pressure.
- Optic supported by screws within steel beam (housing)
- Sealing : ‘O’ rings and rubber bellows
- Distance between alignment supports
  - 10m
  - mid ‘support’ at 5m

Gen 3 Jacket + Key features

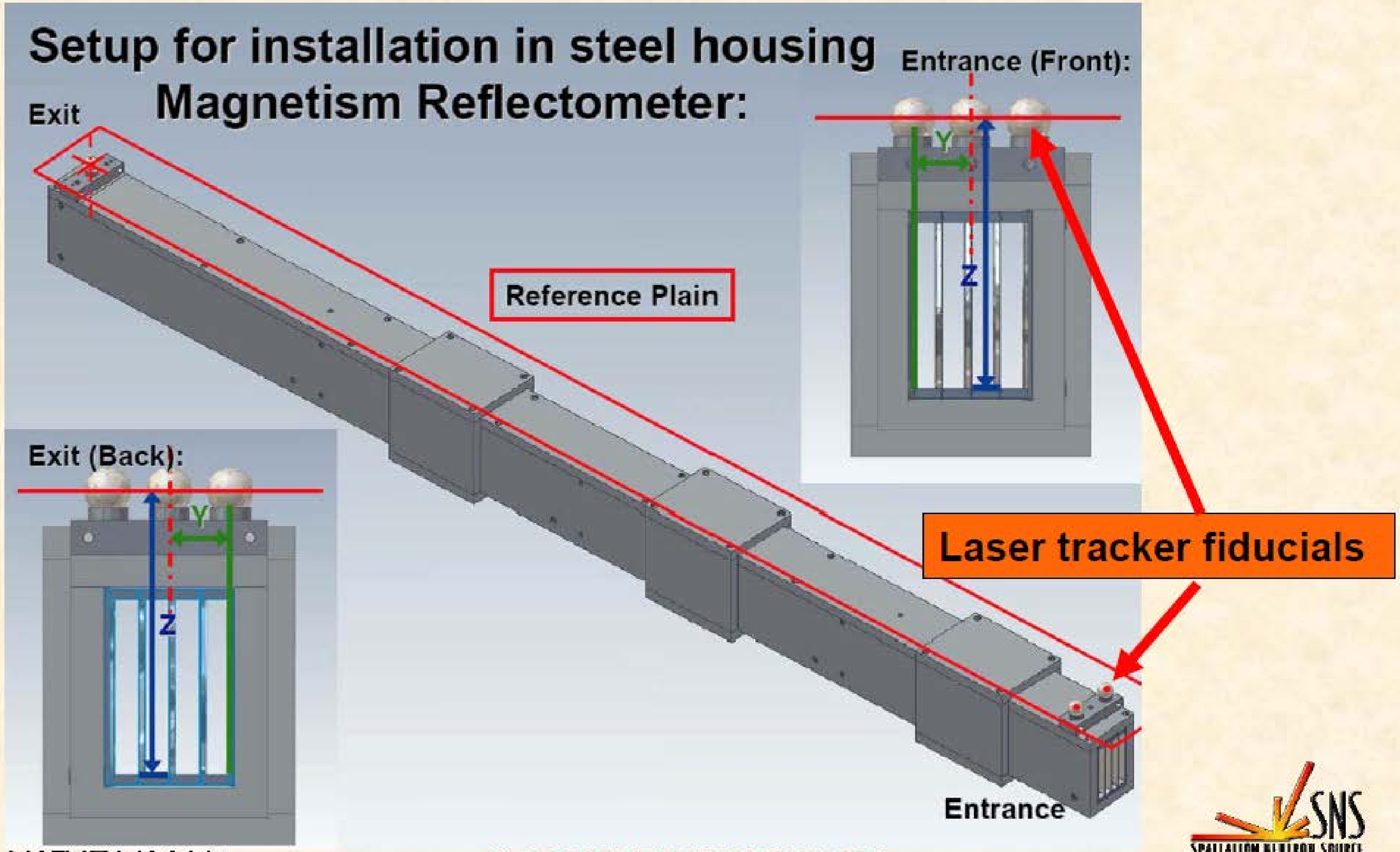




Gen 4 uni-jacket Key features

- Short (2.5m) standard type pressure housings .
- Single optical unit per housing
- Optics – housing pre aligned
- Housing aligned with Lazer tracker.
- Housings supported on 10 or 5m beams
- Or suspended
- Integrated optics and shielding concept
- Separate load paths

Laser Tracker Based Guide Alignment



Increase performance
Reduce misalignment (unit)

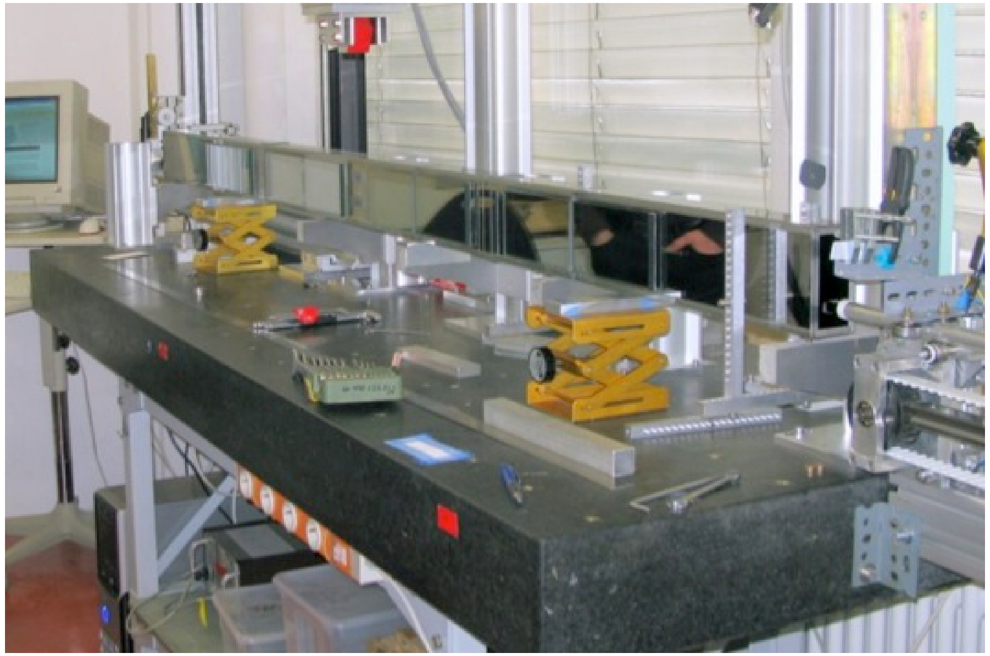
Solution

Use the longest feasible guide section.

2m

Why ?

Because alignment require skill, equipment & controlled conditions – i.e. suppliers lab!



Benefits

- Lower cumulative alignment error
- unit – unit & section - section
- Cheaper housing
- Cheaper installation

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Sealing

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Vacuum Sealing Methods/Materials

- **RTV Silicone Caulk** – referred to as “Tecsil” at the NCNR for the commercial product originally recommended by CILAS-ALCATEL for sealing and joining guides and still in use today
  - Advantages – low viscosity, excellent adhesion, toughness, fairly good radiation resistance, can be applied post installation/alignment, repairable
  - Disadvantages – difficult to apply to bottom joints, several applications needed, disassembly/reassembly time consuming

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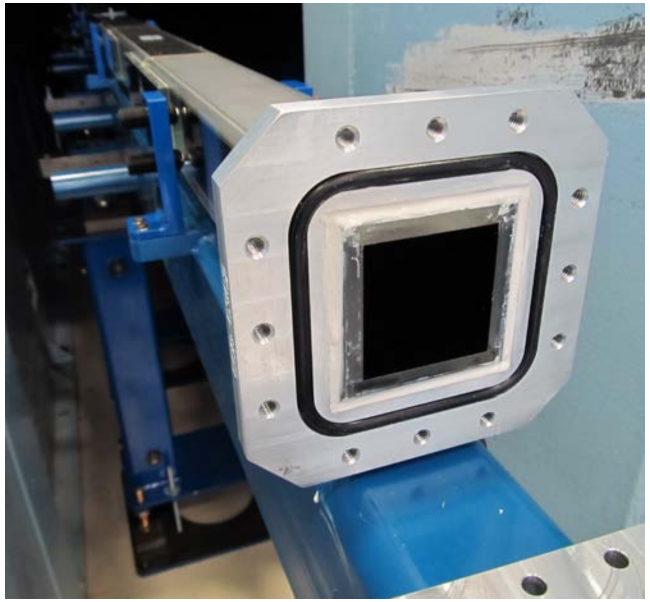
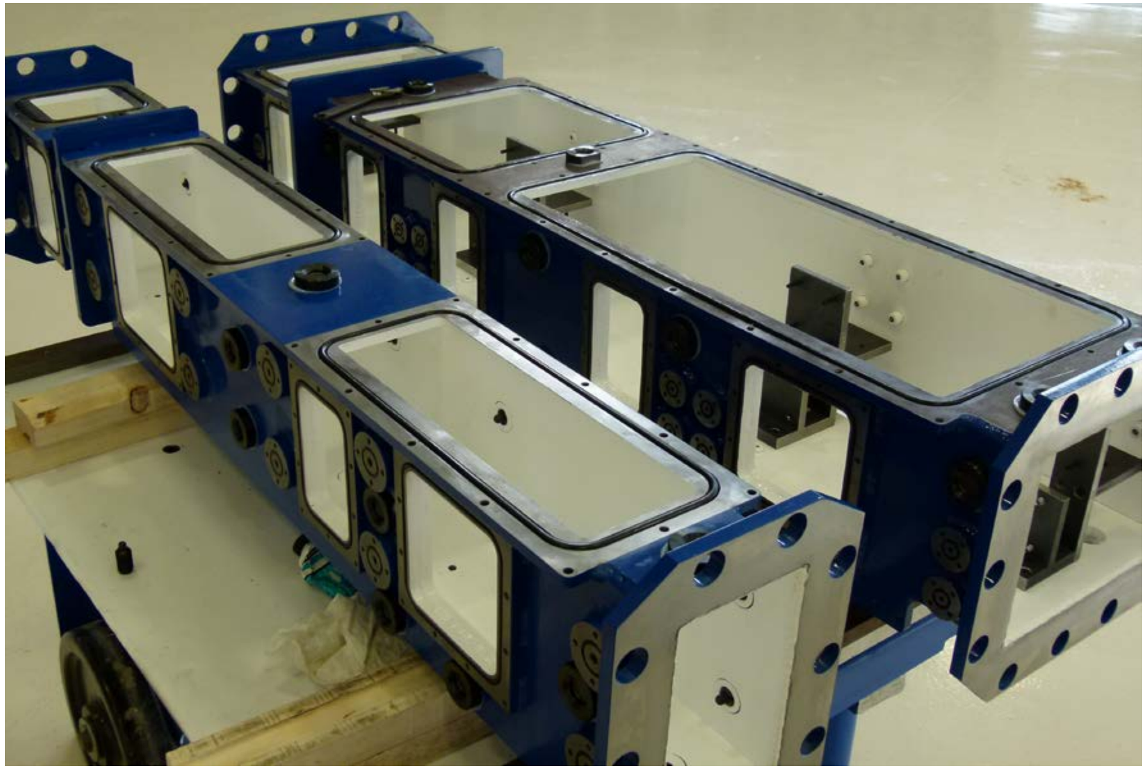
- **Elastomer O-Rings** – widely used throughout the NCNR to seal lids and ports on metal vacuum jackets, pressure and vacuum vessels. Widely available in a variety of sizes and materials, including cord stock.
  - Advantages – unrestricted gland size and shape (using spliced cord stock), fairly good radiation resistance (Viton), easy assembly/disassembly/replacement
  - Disadvantages -





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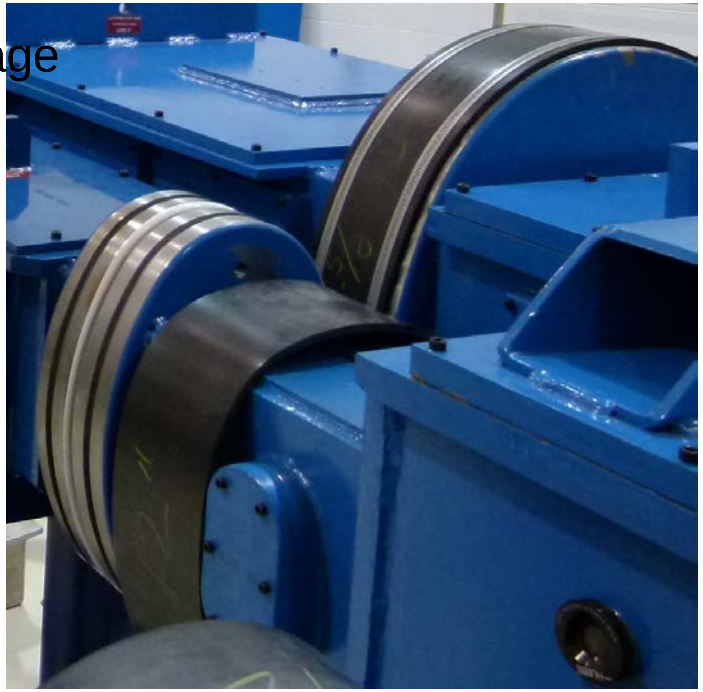
- **Metal O-Rings** – actually, C-rings, coated with a soft metal. In our case, we use Inconel C-rings coated with Indium. Our first use of these was to replace Buna-N O-rings that had vulcanized near the reactor creating leaks within a year of installation. We found a supplier to make and coat custom ring shapes to match the gland shape and cross section for the various ports and windows near the reactor (1.5 meter proximity). This supplier no longer exists. We now use a supplier for the custom C-rings and a separate supplier for Indium coating.
  - Advantages – Radiation resistant, high longevity, low leak rate
  - Disadvantages – high cost and long lead time, high squashing force, no interchangeability, new ring needed for each disassembly/reassembly

Suppliers:

Custom Inconel C-rings : ww.techneticsgroup.com

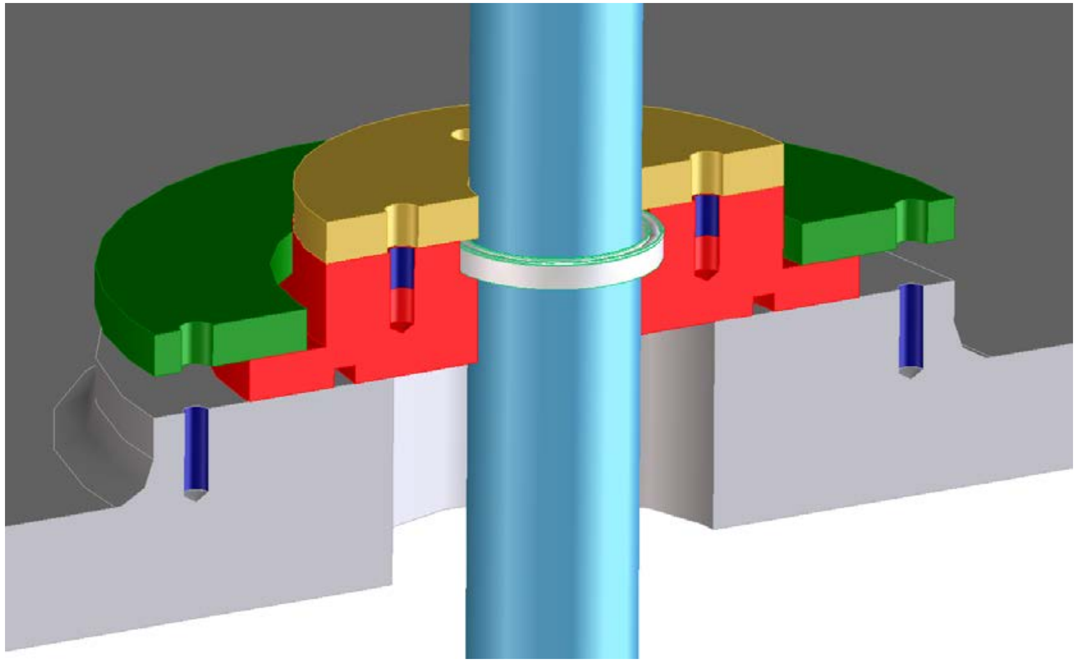
Indium Plating : www.nbplating.com

- **Rubber Hoop Seals** – used to seal vacuum jackets in serial fashion while allowing a gap for installation/removal of these jackets. There is no gap created in the guide train nor is it necessary for a guide joint to be near the gap.
  - Advantages – allows VJ removal without disturbance of upstream/downstream VJ’s, allows slight linear/angular misalignment at the VJ to VJ interface
  - Disadvantages – sourcing, deterioration with age

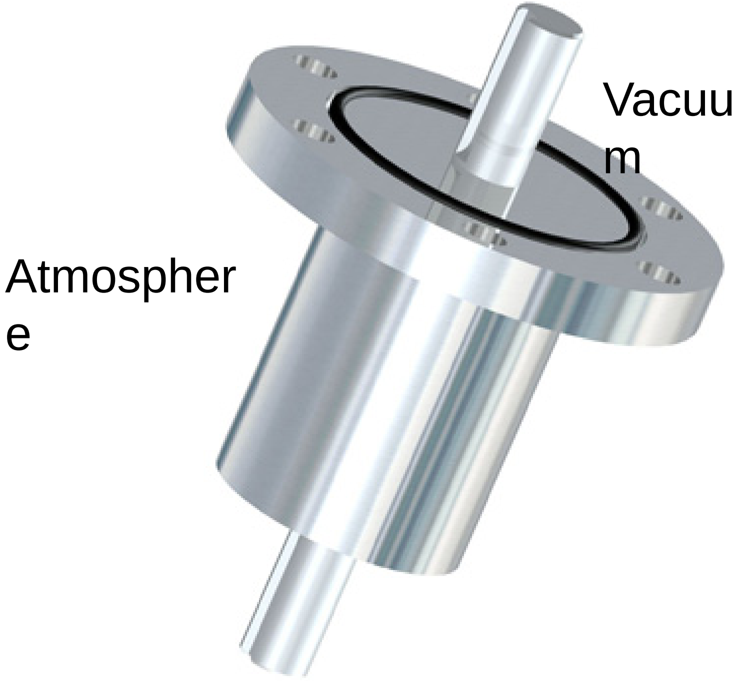


- **Rubber Hoop Seals (cont'd)**
  - Material – Neoprene, 50-60 Durometer, .375" thick, cast to customer specified length and diameter (circumference)
  - Design Considerations:
    - Where space allows, hoop seal flanges should be circular to maintain a constant (clamping belt tension : normal force) ratio around the seal. Elsewhere, a 2-arc elliptic approximation works – keep the radius of the larger arc as small as possible.
    - An o-ring gland should be cut on the circumference of the hoop seal flange where the clamping belt centerline will be.
    - Design a gap between mating hoop seal flanges just larger than the thickness of the hoop (>.375" in our case). This will allow removal and replacement of the hoop without moving either VJ. If a larger gap is necessary, consider half rings to fill the gap and reduce the stress on the rubber hoop under vacuum.
    - When considering the guide loading scheme for the VJ's during design, ensure that removal of one guide (upstream or downstream) will allow the guide traversing the hoop seal gap to be slid clear of the gap for seal replacement or removal of the VJ.

- **Dynamic Seals** – there is a variety of products for transmitting linear or rotary motion across a vacuum boundary.
  - **Linear** – the main beam shutters on our original guides act like gate valves when closed creating three separate vacuum spaces (upstream guides, shutter vessel, downstream guides). When open, there is a continuous vacuum space with the upstream and downstream guides and a short guide segment bridging the gap with a small amount of clearance. The shutter moves vertically by actuation of an air cylinder. A centerless ground shaft (Thompson shaft) penetrates the vacuum vessel top passing through a PTFE spring energized cup seal (Bal Seal).



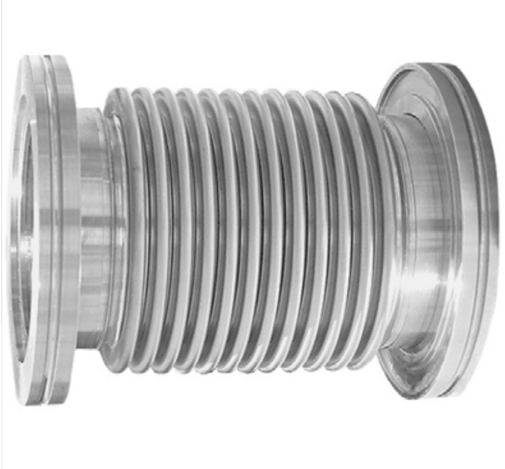
- **Dynamic Seals** – (cont'd.)
  - **Rotary** – PTFE cup seals are also available to transmit rotary motion across the vacuum boundary. Another option and one used previously at the NCNR is a ferrofluidic coupling or passthrough. Such a device was deployed on an early cold neutron instrument to rotate a monochromator crystal placed directly in the guide interior without the need for a guide cut. (The reflected beam passed through an opening covered by a window in the side of the guide). This device worked well for roughly 15 years until the loss of ferrofluid created a leak and required replacement.



Ferrofluidic Rotary Passthrough

Flange to Flange

- Direct Connection with a flange
  - No vibration or movement isolation, sometimes more simple support design. Simple geometry, no extra space requirement. The cheapest.
- Connection with flexible joint
  - Vibration isolation only in the direction of the beam, but easier to install than the direct flange
- Connection with bellow
  - The best for isolation. The most expensive. (Welded bellow is preferable to hydro-formed, because more flexible)



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Positioning I
Getting it right

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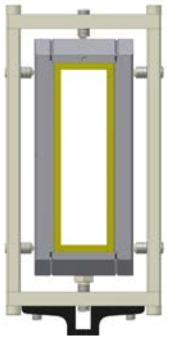
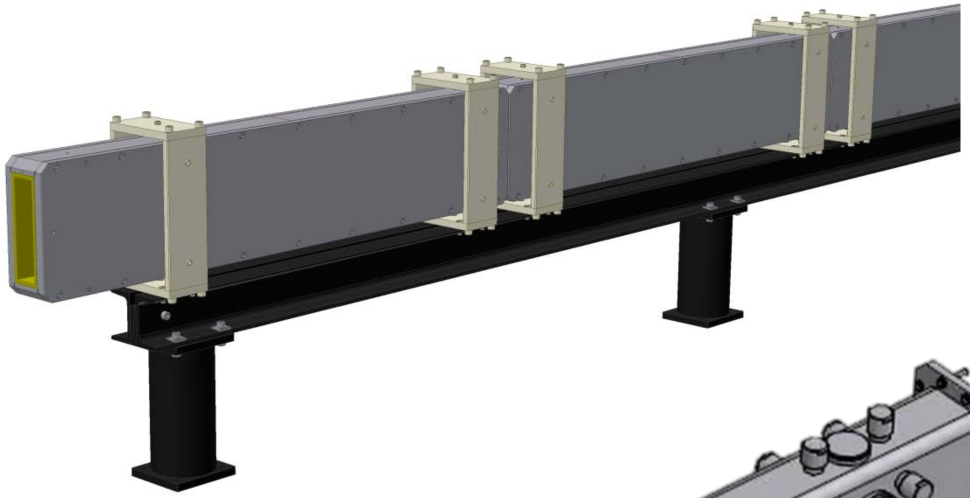
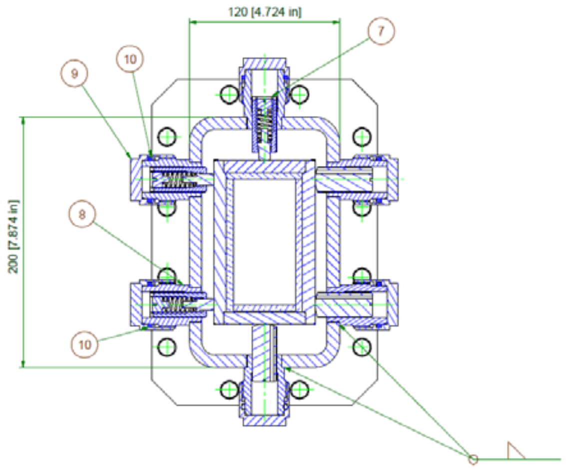
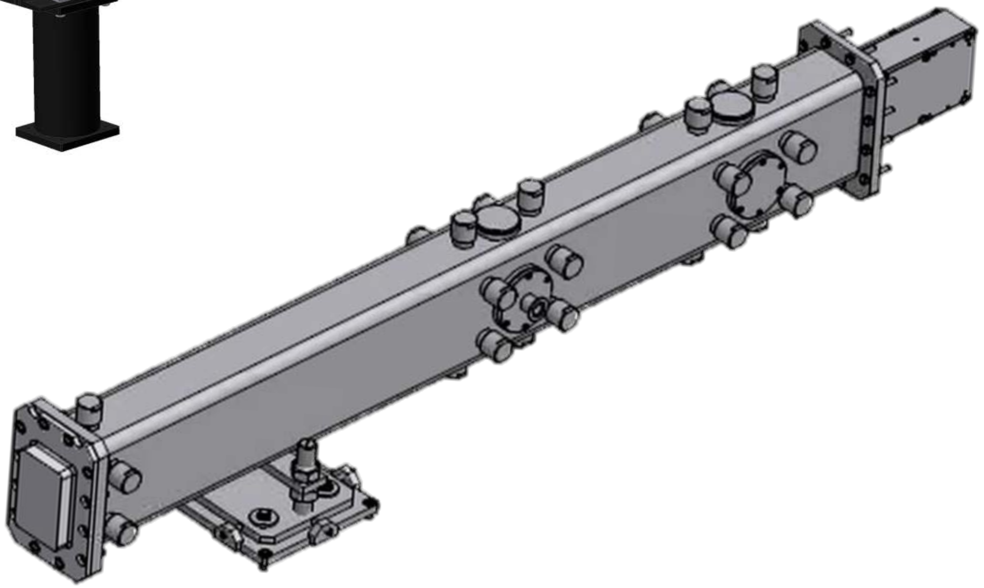
Positioning classical









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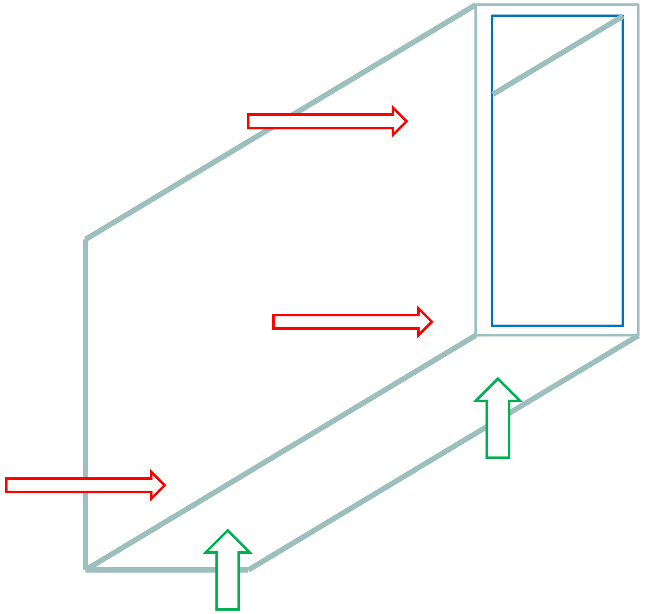
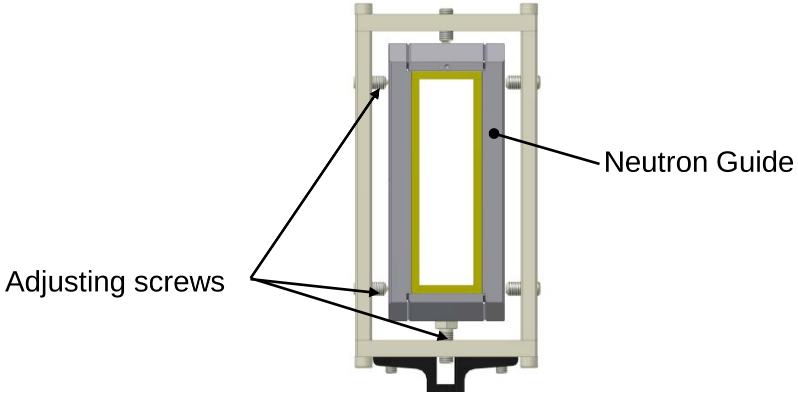
Positioning





Simple Guide positioning:

- Three screws from the side, two from below

Design considerations:

- The more apart the screws the better, because:
  - More angular accuracy with the same alignment method
  - The closer the screws to the end, the less the swinging of the end.
  - The screws should not be able to bend or break the guide.
- The longer the guide unit, the better
- (Alignment accuracy (pitch))

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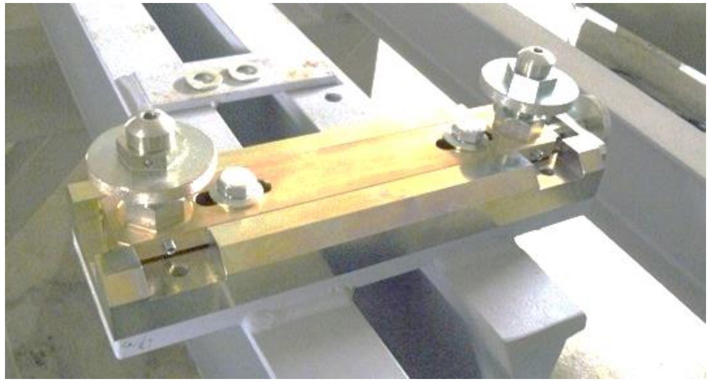
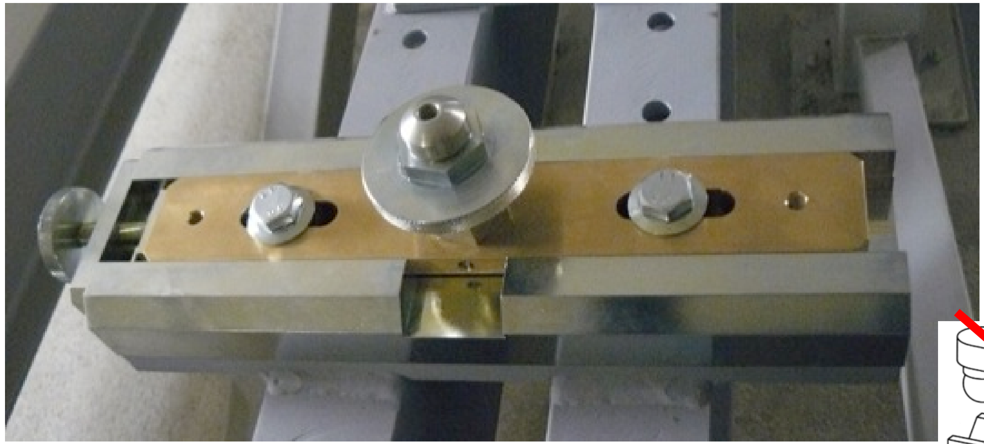
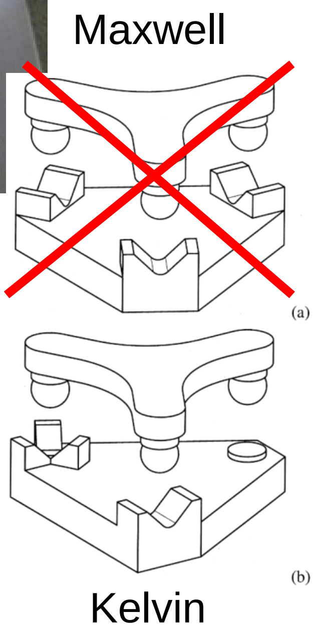
Positioning uni-jacket

- 3 points on each housing
  - Front fixed
  - Rear floating
- Not hyper static
- High rigidity required (vac loads)
- Bolt down







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positioning strategy

(Travel +/- 15mm)

Fine stage
(screw)
Resolution 0.01mm

+ 10mm
Nominal aligned
- 10mm

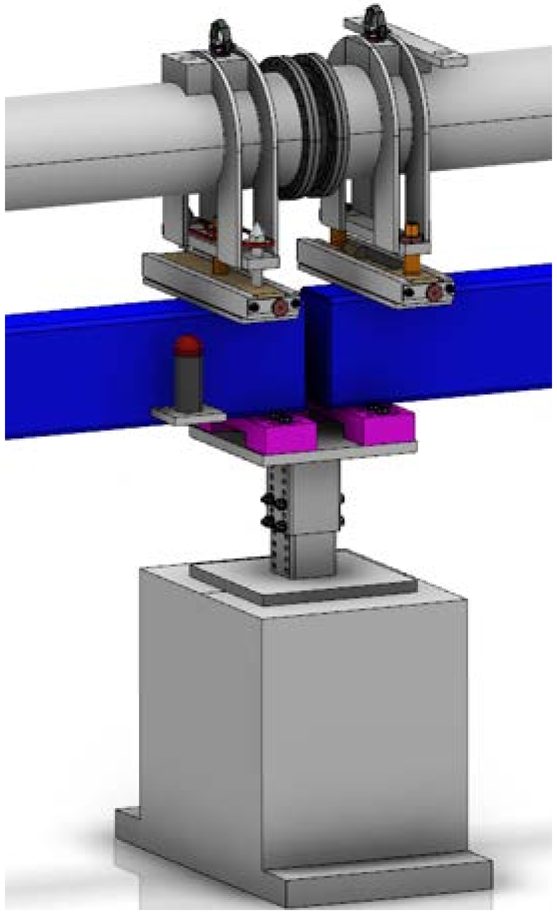
Use : alignment / realignment

Course stage
(shim or slide)
Resolution 2mm

+ 10mm
- 10mm

Use: Installation & OSS

Objective
Only the fine stage will be touched in the life of the instrument



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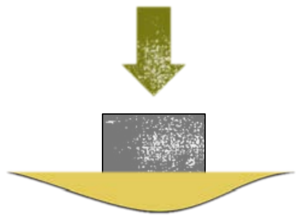
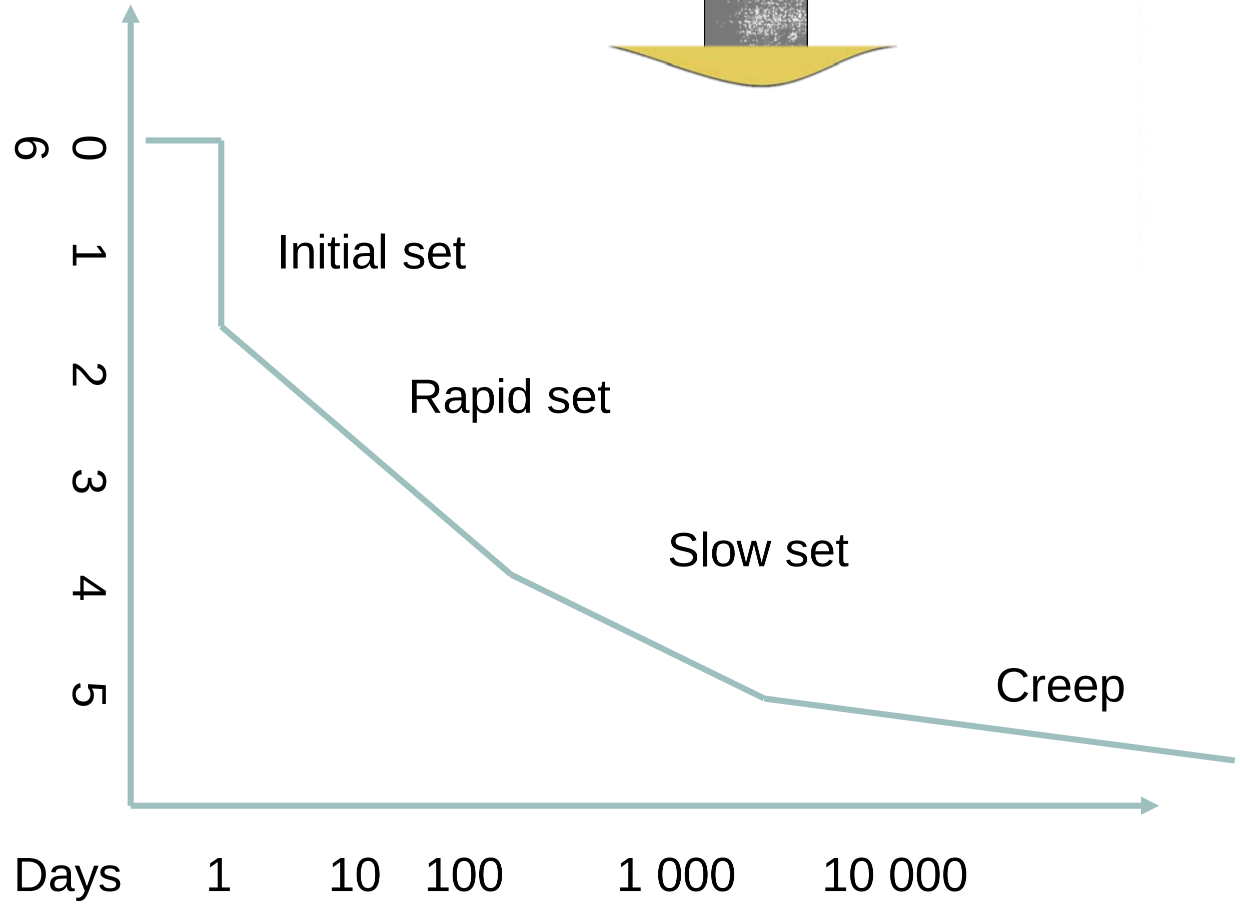
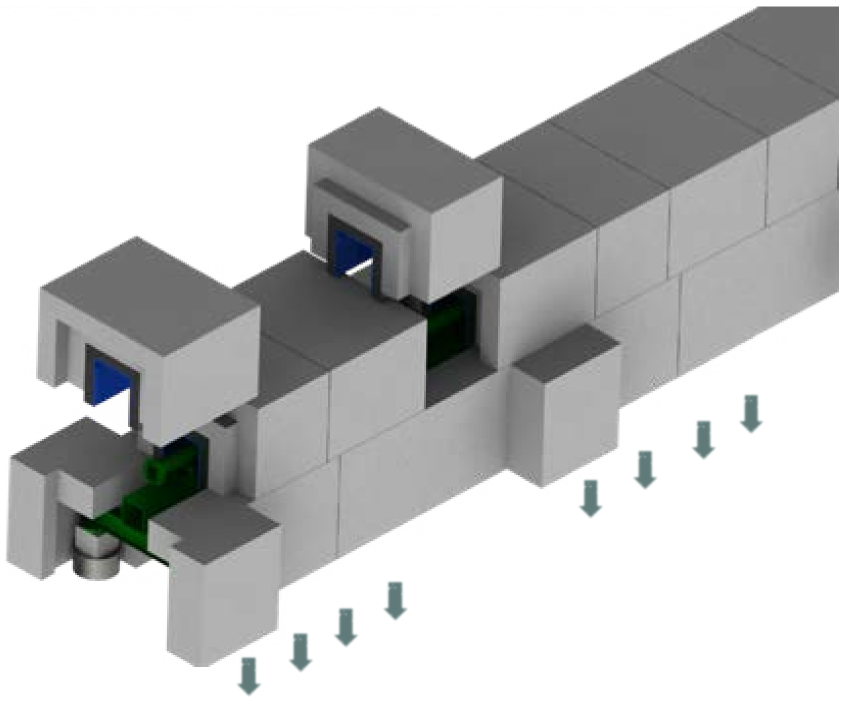
Position II
keeping it right

Ground movement







Some causes

- Elastic deflection
- Plastic deformation
  - Closing gaps
  - Pile tip breakage
  - Plastic flow

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Reducing ground deflection

Options	**Constraint**
Reduce mass of shielding	Laws of Physics
Increase distance	add Mass or Complexity = additional cost
Spread load	limited effectiveness
Decouple	Complexity

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Load spreading Rafts

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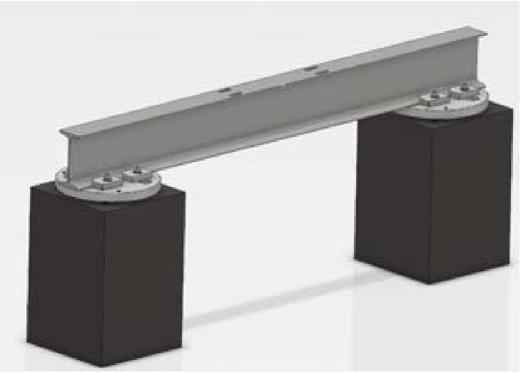
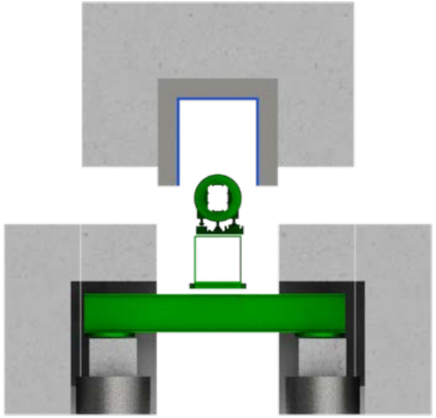
Decoupling

Guide supported piles

Constraint

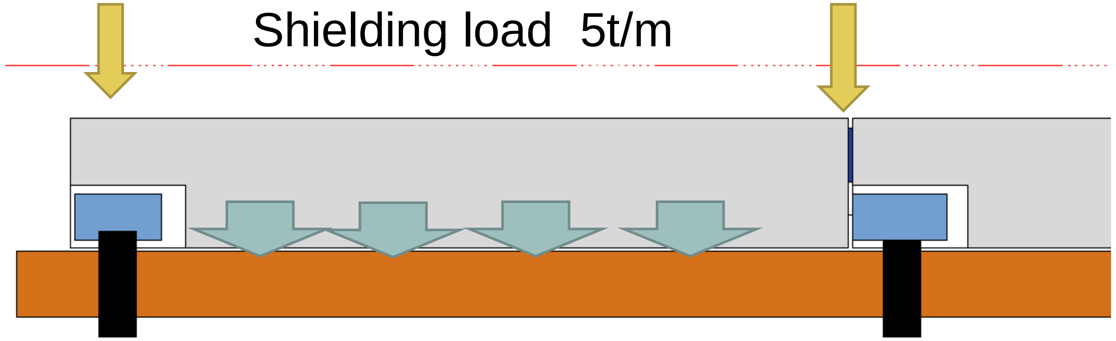
- Trajectory
- 4m ‘step’
- logistics





Equipment load 500kg / point

Shielding load 5t/m



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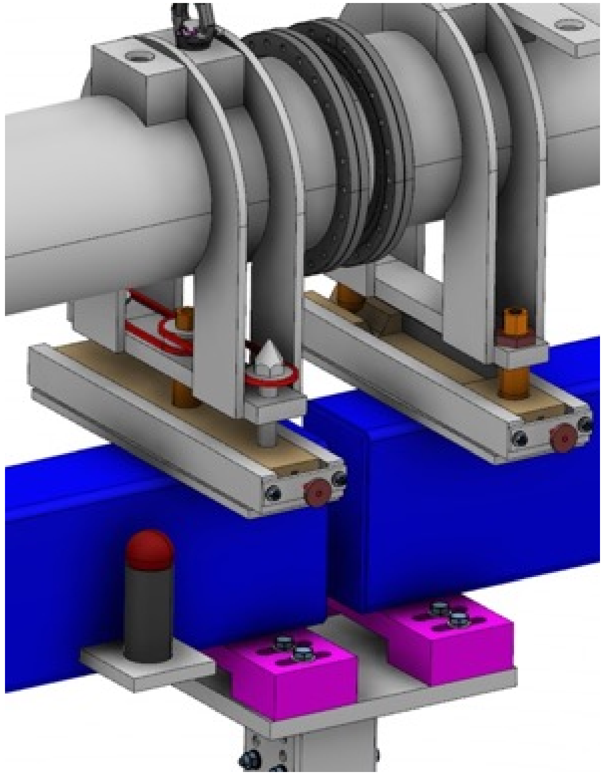
strategy

Robust design

- Decoupled loads
- Strategic breaks
- Paired supports
- Adjusters
- Access

If you have done all this … don´t worry – be happy



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Structural Supports

Support and alignment

20 slides

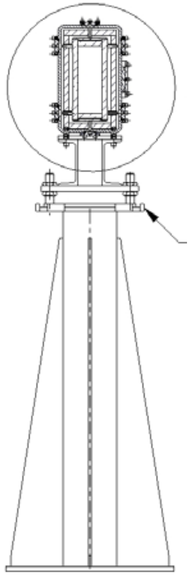
Supports

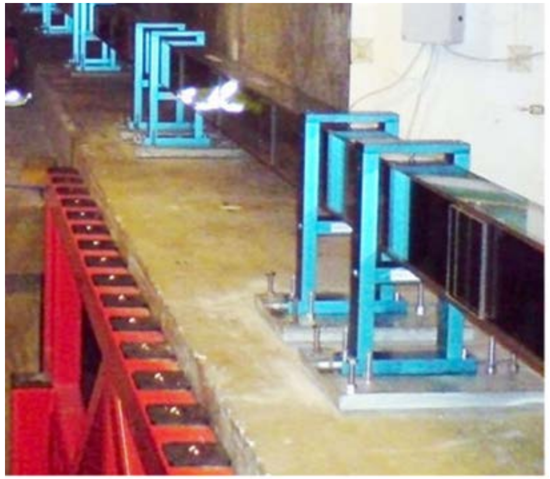
Types

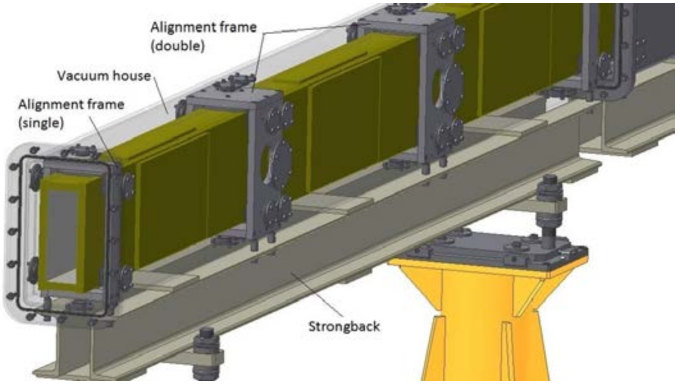
- Slab (concrete)
- Pedistal
- Strongback

Considerations:

- Shielding
- External forces
- Positioning







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Take away

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LESSONS LEARNED (DON)

- Lessons Learned don't have to come at the expense of your own mistakes.
- Technology has made the world smaller and has opened up networks and lines of communication. Use the resources that ISNIE membership and the annual DENIM events offer to reach out to fellow engineers and sponsors for help in your design endeavors – don't work in a vacuum.
- Reliability should be weighted equally with initial performance in the design of neutron guide systems – downtimes cause large losses in neutron availability.
- Guide system design must consider accessibility for repair and maintenance.
- If feasible, consider vacuum jackets for the entire length of guide systems

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Recommendations (iain)

Construction

- Separate your loads
- Design to be installed / maintained

Alignment

- Best done in the lab
- Purchase the longest sections of guide practical (1-2.5m)
- For best in service results align the housing not the guide

Jackets

- One per guide one (if you can)
  - Cheap /Quick & easy to install / Alignment under vacuum
- Aluminium is cheaper than steel in the end

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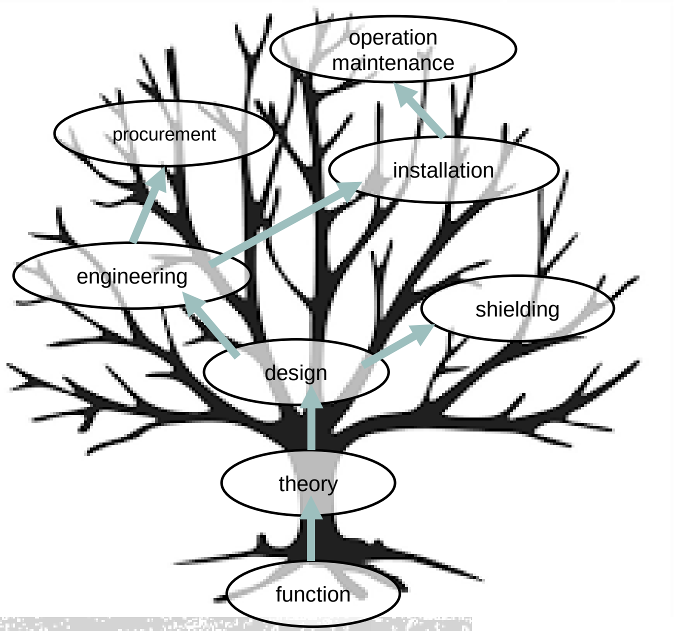
End of the line engineering



Thanks for participating

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