# Vacuum system basics for Instrument Engineers

ISNIE Summer School

2018

# A word from our sponsor  ISNIE ;)

How this course works …

maybe

# Overall objectives

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To increase the **awareness** of engineers to the importance of considering the engineering constraints and **best practices** related vacuum systems as part of the design of neutron instruments.

....such that, designers are aware of **important issues**, may **avoid commonly occurring mistakes**, and **communicate effectively with system experts**,

....in order to produce neutron instruments which provide **superior scientific capability** at **lower installation and operational costs** (through improved maintainability).

# Our approach to learning in this course

Make it real …. And work from there

- Relevance
- Interaction
- Engagement

Real life examples

Exploration
Worked examples

Technique
And applied theory

# In each implementation we will consider

Installation specific

System Requirements

- Vacuum level
- Pumped volume
- Cycles

Constraints

- Radiation hardness
- Serviceability

Installation specific

Analysis

- Techniques
- Theory

Solutions

- Equipment choice
- Packaging
- Sealing

# Game plan

**Part 1**
**Introduction** (Iain)
30mn
- Context
- Case studies

**Part 2 (Marcello & Lothar)** 45mn + 30mn
Approach & Solutions
Vacuum technology

**Part 3 Wrap up**
(Marcello) 15mn
Take away

# Neutron instruments
# an introduction (?)

# A typical neutron scattering instrument ...

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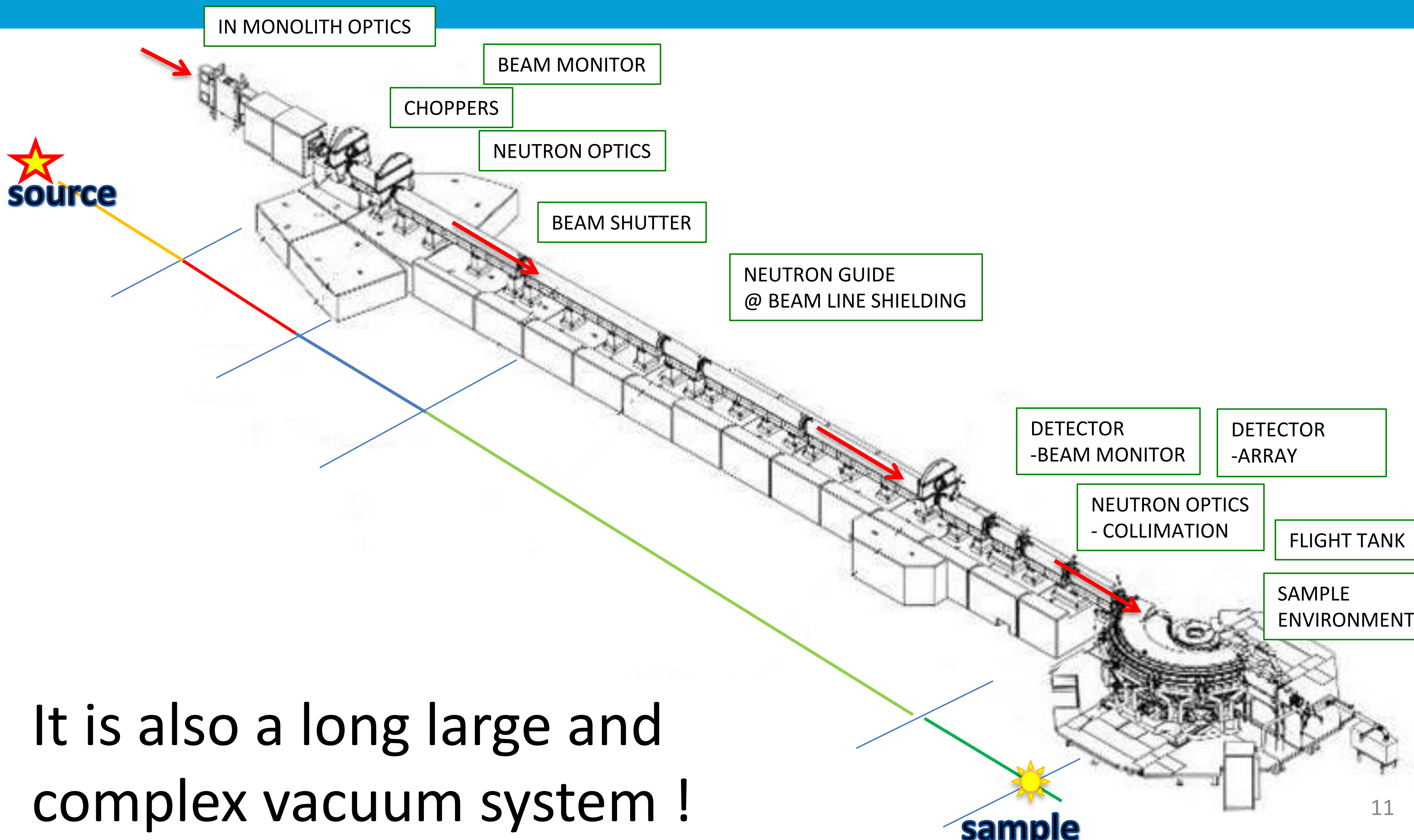
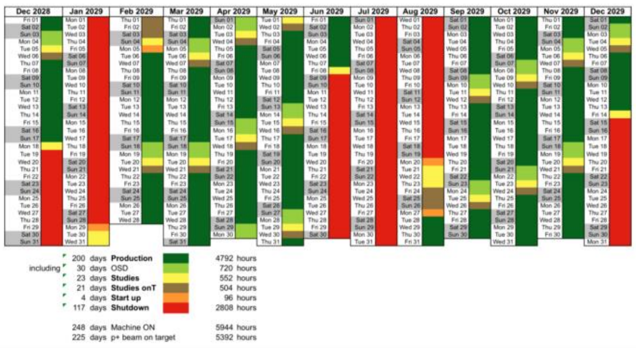



It is also a long large and complex vacuum system !

# Building blocks of neutron scattering instruments

- Neutron Source
- Neutron transport
- Neutron conditioning
- Sample exposure
- Detector
- Shielding
- Control
- Data collection
- Data Treatment

# There to be used
# High performance + high maintainability




Complex Installed systems

Hazardous environment

Limited access opportunities

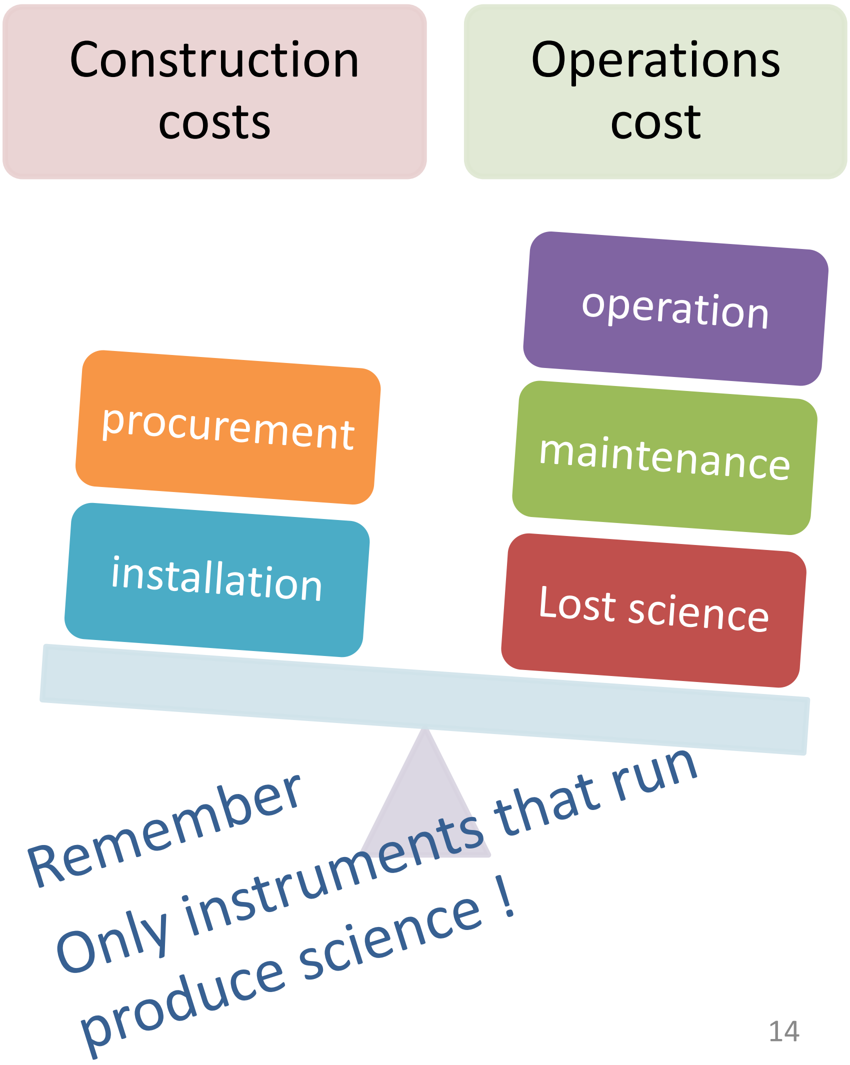
A challenging environment to operate equipment

# A engineering balancing act

Construction cost /
Operating cost

Scientific Performance /
Availability

- Vacuum systems represent
  - 5-10% of the construction cost
  - But also 5-10% of maintenance costs



# Down time

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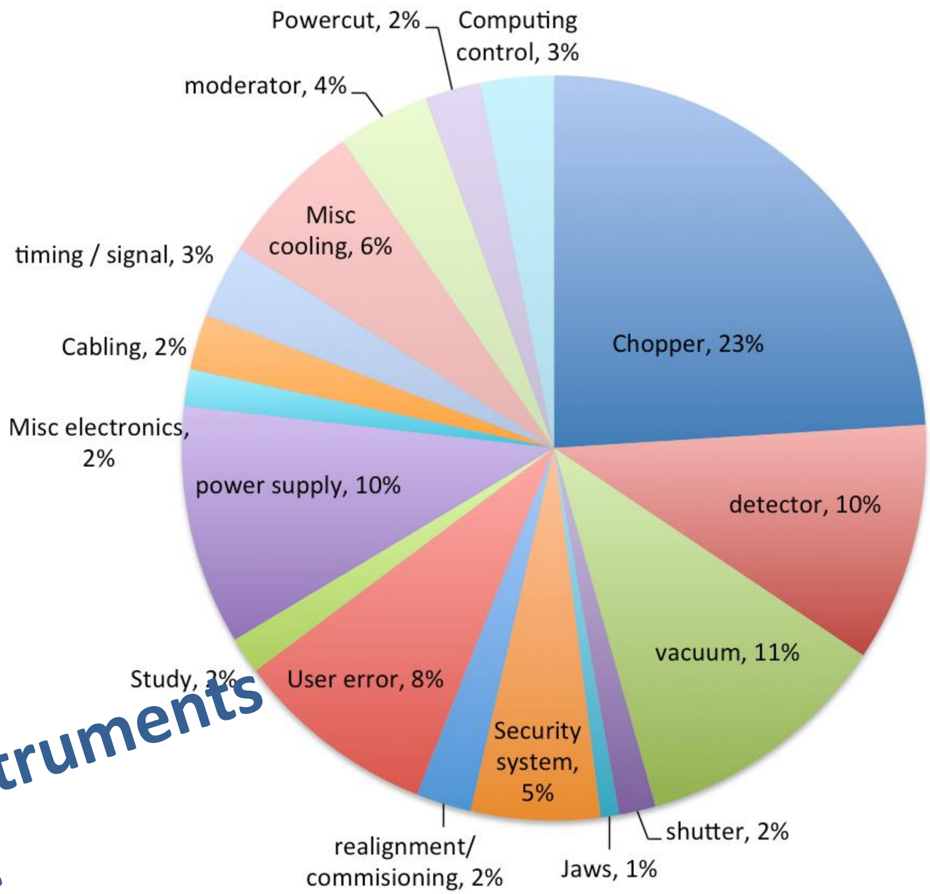
- Issues with vacuum are the #2 or #3 most frequent ‘cause’ of instrument shutdown.

- A significant part of downtime




**Remember only operating instruments produce science !**

# Why vacuum?

Because …

Increased instrument Performance

- Reduced transmission losses
  - Source – Sample
  - Sample - Detector

Increased Safety

- Reduced air activation

Increased operability

- Avoid corrosion

Vacuum systems make instruments better and helps keep them that way

Consideration of vacuum related issues in the design process is vital.

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# Reality
# Case studies

# Typical vacuum system implementations

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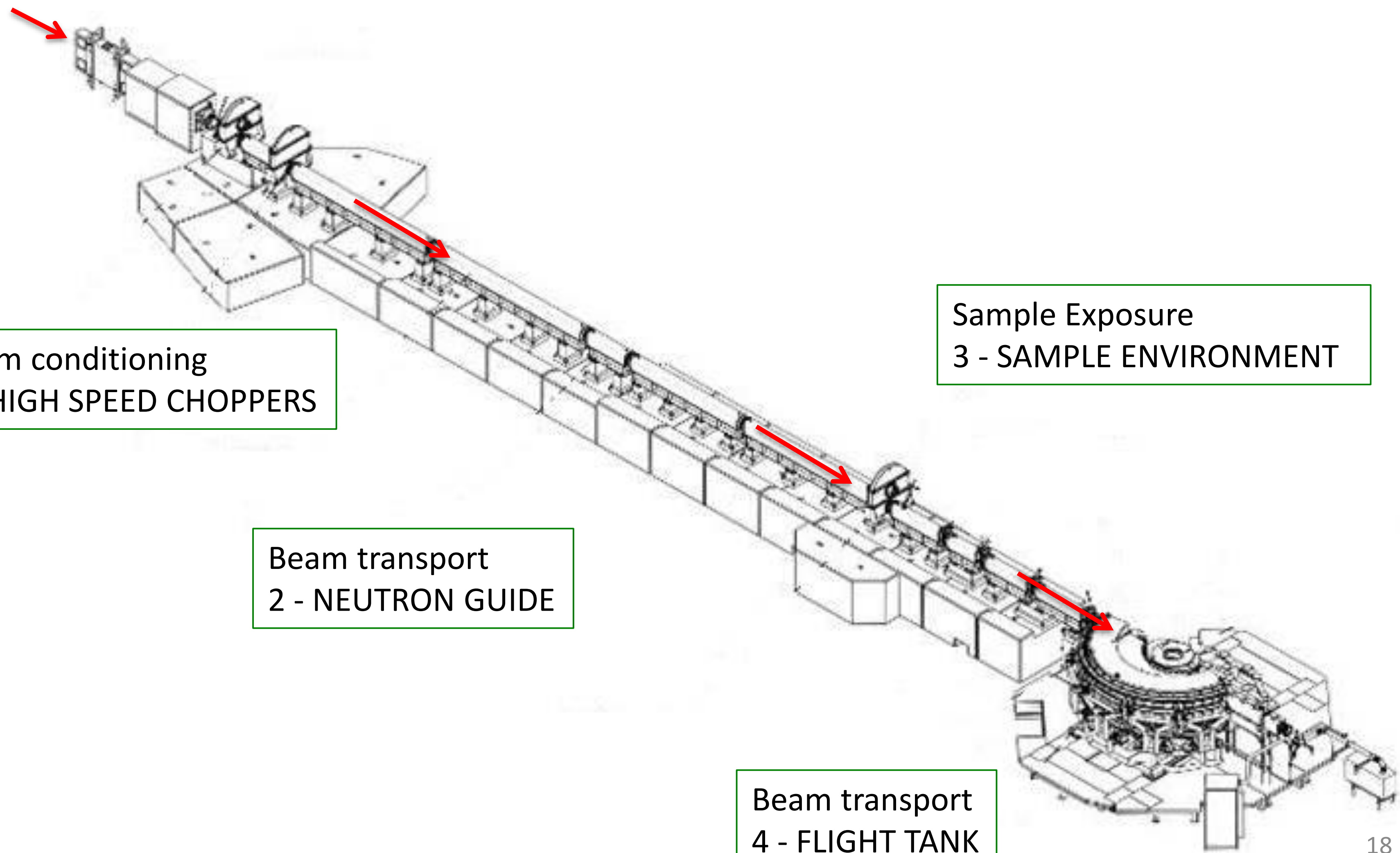


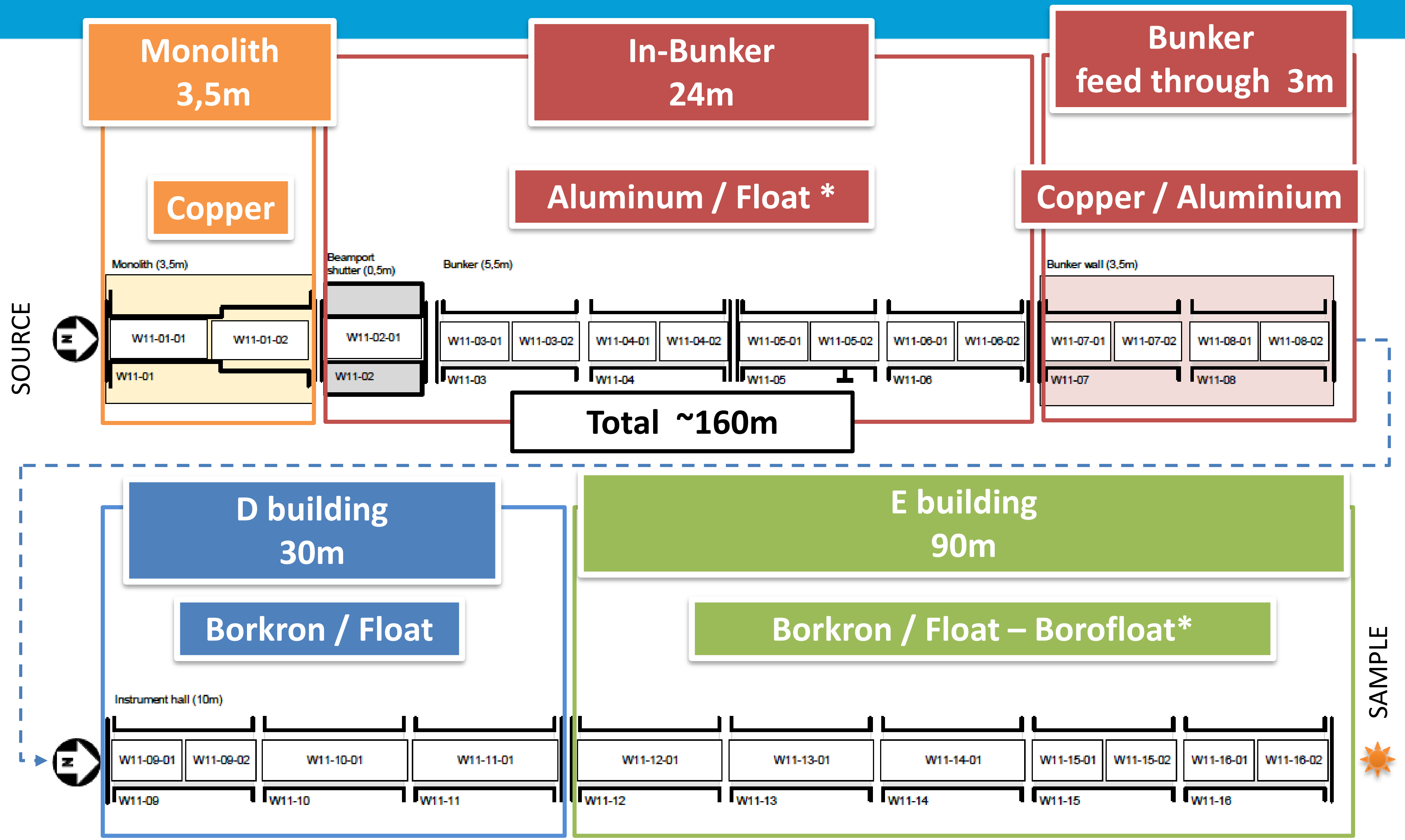
# Instrument vacuum systems
# Case study – Neutron guide systems

# Neutron guides
# What is it ?

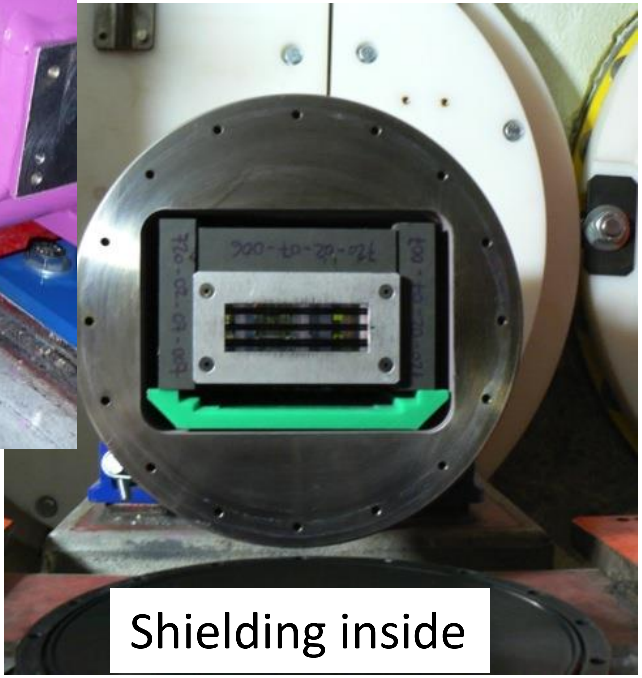
- Function
  - Beam transport
  - Energy selection
- How do they operate ?
  - reflection of neutron beam
- Why vacuum ?
  - Neutron transmission

# Neutron guides
# What is it ?

# Neutron guides



# Details


# Examples
# A range of requirements and challenges for vacuum systems

| Criteria | Neutron Guide |
| --- | --- |
| Vacuum level | Poor |
| Pumped volume | Moderate |
| Cycle time | V.Slow |
| Radiation hardness | High/Mod |
| Servicability | V.Low |

| | | |
| --- | --- | --- |
| Component type | Neutron guide system | |
| Example | ILL / H14 | |
| Operating vacuum level | 1e10-1 | mbar |
| Pumped volume | 5 | m3 |
| Cycle time | 6 months | |
| Pump down | 1 day | |
| Materials | Steel housing | |
| | Painted surfaces | |
| | Glass neutron guide | |
| | Rubber seals | |
| Radiation level | High | |
| Maintenance period | 5 years | |

Particularity

Housing has a section of 100cm2 and a length of 100m

# Vacuum systems case study
# - high speed neutron choppers

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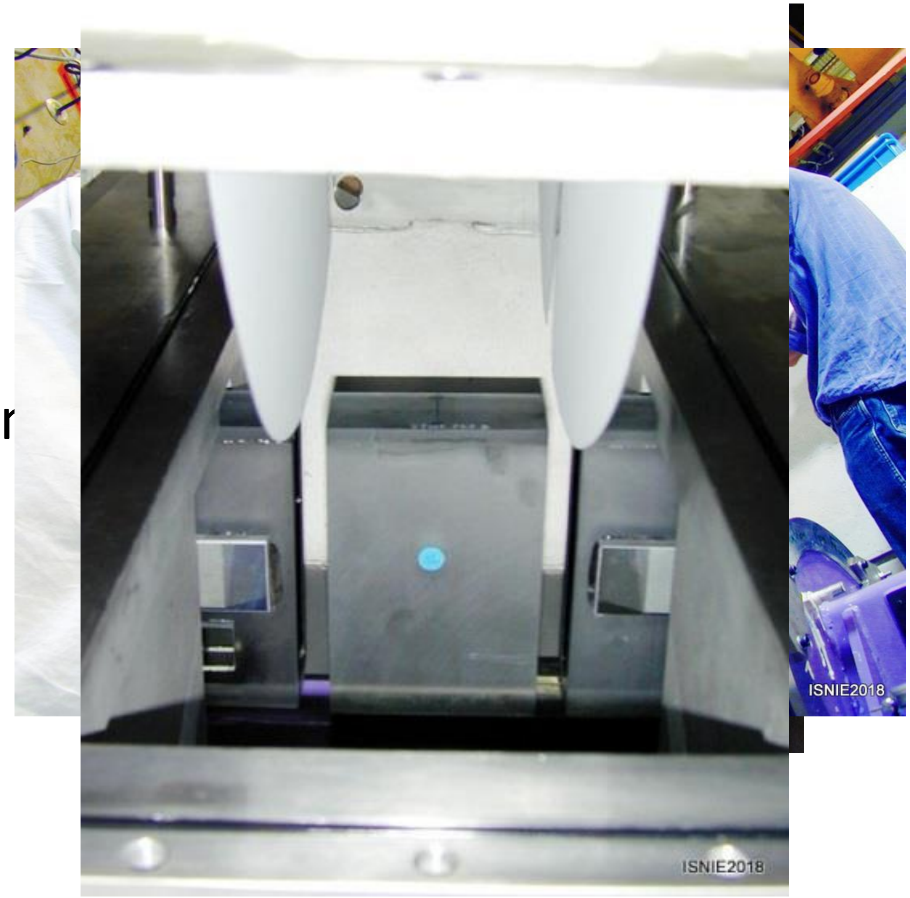
# Neutron chopper
# What is it ?

- Function
  - Pulse shaping
  - Energy selection
- How do they operate ?
  - Interception of neutron bear
- Why vacuum ?
  - Neutron transmission
  - Air friction




ILL IN5 CRD

# Typical vacuum requirements
# High speed choppers

| Criteria | HS Choppers |
|---|---|
| **Vacuum level** | Good |
| **Pumped volume** | Small |
| **Cycle time** | V.Slow |
| **Radiation hardness** | High |
| **Servicability** | Low |

Instrument vacuum systems

| | | |
|---|---|---|
| Component type | Sample environment | |
| Example | | |
| Operating vacuum level | 5e10-6 | mbar |
| Pumped volume | 0.1 | m3 |
| Cycle time | 1 day | |
| Pump down | 1 hour | |
| Materials | Steel housing aluminium | |
| Radiation level | High | |
| Maintenance period | months | |

# Instrument vacuum systems
# Case study – Sample environment

# Sample environments
# What is it ?

- Function
  - Environmental conditioning
- How do they operate ?
  - Various !
- Why vacuum ?
  - Neutron transmission
  - Heat insulation
- Access
  - Good

- Cyrostat
- Furnace
- Cryomagnet
- Pressure cell
- …..

# Sample environment Installation context

- Where are they located in a beamline
- What is the installation context
- What are radiation levels
- How easy it is to access
- Why are they operating under vacuum?
- What are typical vacuum requirements for this type of system

# Typical vacuum requirements
# Sample environment

| Criteria | Sample environment |
| --- | --- |
| **Vacuum level** | Very good |
| **Pumped volume** | V.Small |
| **Cycle time** | Fast |
| **Radiation hardness** | High |
| **Servicability** | High |

| | | |
| --- | --- | --- |
| Component type | High speed neutron chopper | |
| Example | ILL / IN5 CRD M-Chopper | |
| Operating vacuum level | 5e10-4 | mbar |
| Pumped volume | 0,1 | m3 |
| Cycle time | 6 months | |
| Pump down | 1 day | |
| Materials | Steel housing | |
| | Painted surfaces | |
| | Glass neutron guide | |
| | Aluminium rotor | |
| Radiation level | High | |
| Maintenance period | 5 years | |

# Instrument vacuum systems
# Case study – Flight vessel

# Flight vessels
# What is it ?

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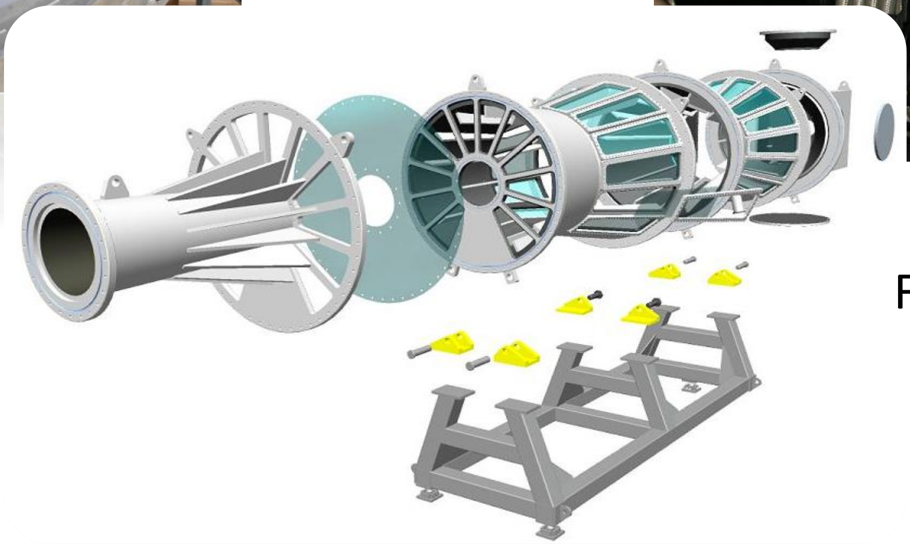
- Function
  - Avoid air scattering
- How do they operate ?
  - Evacuate flight path
- Why vacuum ?
  - Neutron transmission
- Access
  - Poor


# Flight vessel
# Issues

Thin windows



geometry


Full of 'stuff'

Feed throughs

# Typical vacuum requirements
# Flight vessel

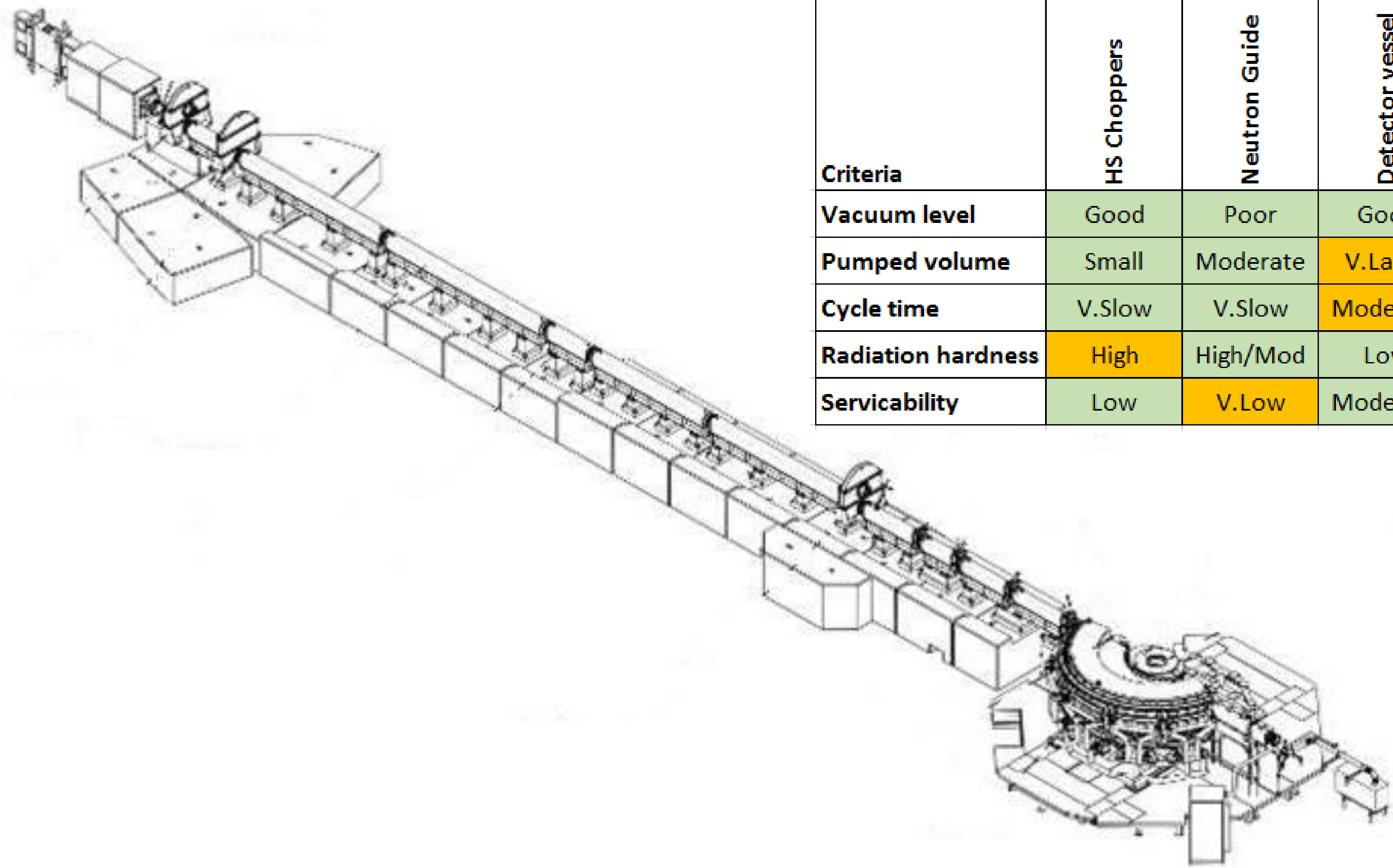
| Criteria | Detector vessel |
|---|---|
| **Vacuum level** | Good |
| **Pumped volume** | V.Large |
| **Cycle time** | Moderate |
| **Radiation hardness** | Low |
| **Servicability** | Moderate |

Instrument vacuum systems

| | | |
|---|---|---|
| Component type | Flight vessel | |
| Example | | |
| Operating vacuum level | 1e10-3 > 10e-6 ? | mbar |
| Pumped volume | 30m3 | m3 |
| Cycle time | 1 month | |
| Pump down | 1 day | |
| Materials | Steel<br>aluminium<br>boron carbide<br>rubber<br>polyethene | |
| Radiation level | High | |
| Maintenance period | months | |

# A range of requirements and challenges for vacuum systems

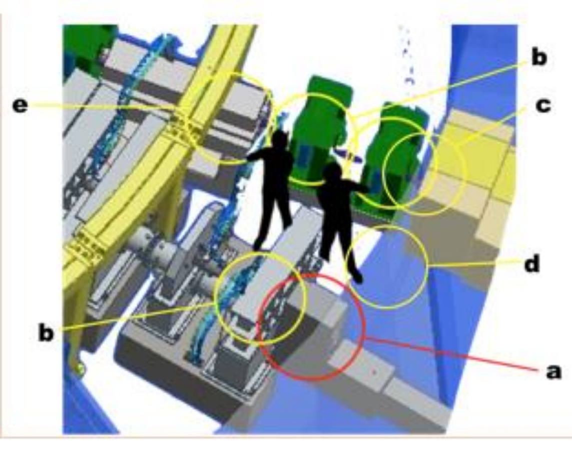
| Criteria | HS Choppers | Neutron Guide | Detector vessel | Sample environment |
|---|---|---|---|---|
| **Vacuum level** | Good | Poor | Good | Very good |
| **Pumped volume** | Small | Moderate | V.Large | V.Small |
| **Cycle time** | V.Slow | V.Slow | Moderate | Fast |
| **Radiation hardness** | High | High/Mod | Low | High |
| **Servicability** | Low | V.Low | Moderate | High |

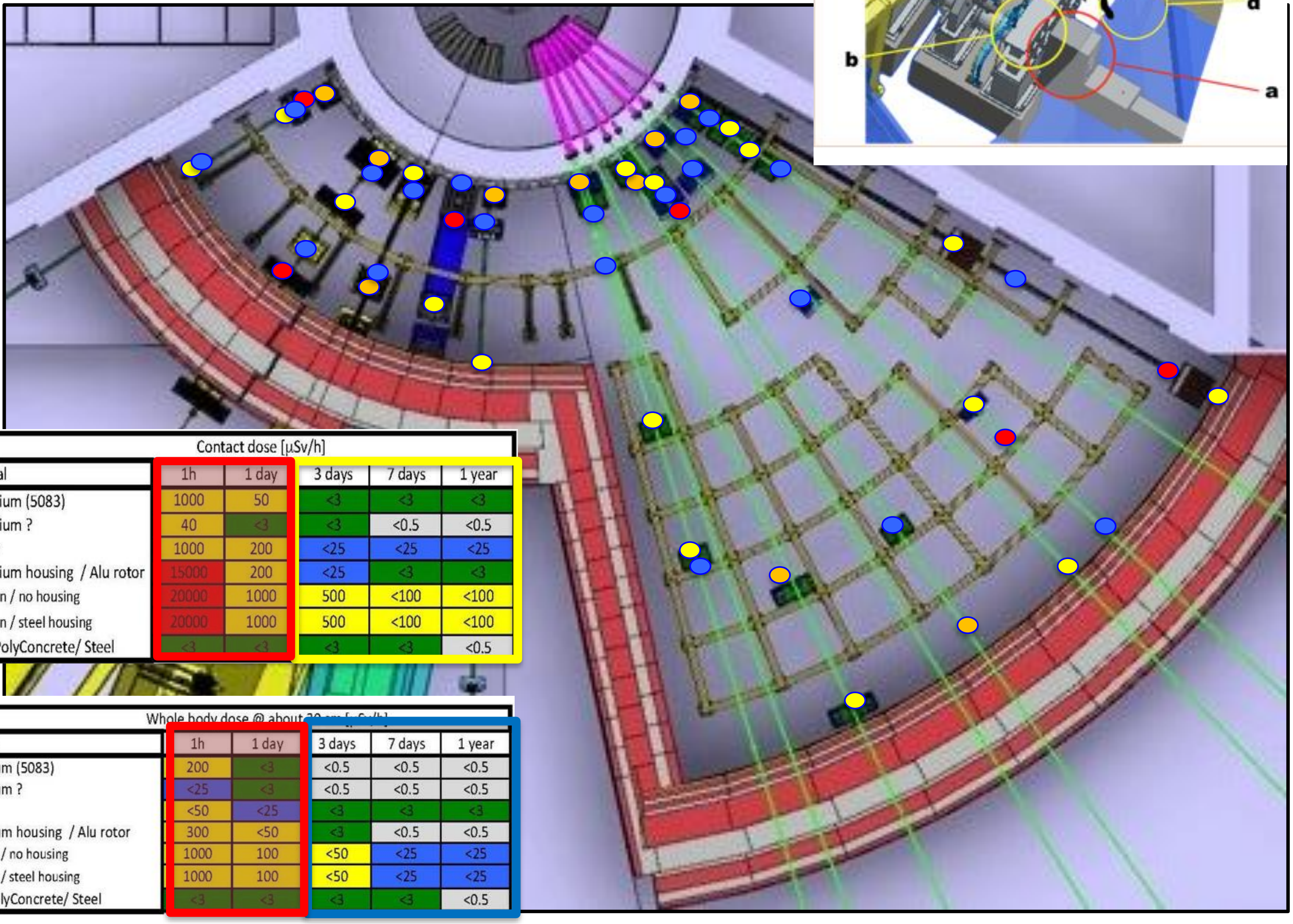


# Technical challenges
# Radiation

Activation & Damage

# Neutron Irradiation Damage & Activation



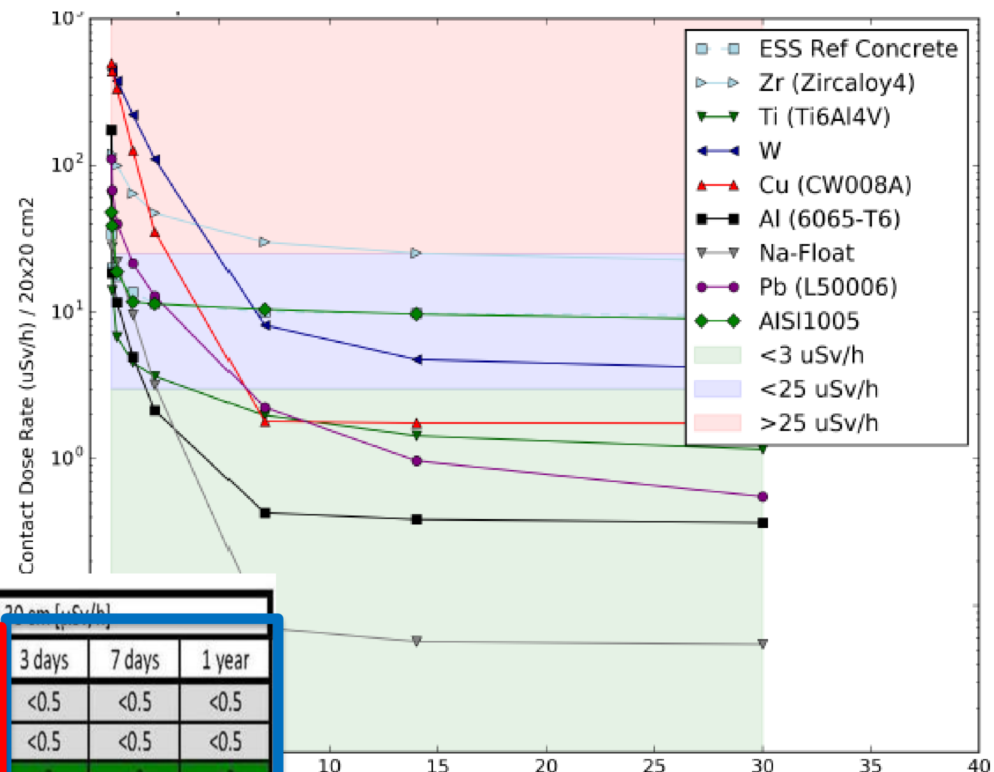
| Contact dose [μSv/h] | | | | | | |
|---|---|---|---|---|---|---|
| Delay following beam shutdown | Material | 1h | 1 day | 3 days | 7 days | 1 year |
| Guide upstream of the 1st chopper | Aluminium (5083) | 1000 | 50 | <3 | <3 | <3 |
| Guide downstream | Aluminium ? | 40 | <3 | <3 | <0.5 | <0.5 |
| Collimator (streaming) | Copper | 1000 | 200 | <25 | <25 | <25 |
| Chopper (no steel) | Aluminium housing / Alu rotor | 15000 | 200 | <25 | <3 | <3 |
| Heavy shutter | Tungsten / no housing | 20000 | 1000 | 500 | <100 | <100 |
| $T_0$ chopper (Tungsten hammer) | Tungsten / steel housing | 20000 | 1000 | 500 | <100 | <100 |
| Inside rear bunker wall (with lead) | Lead /PolyConcrete/ Steel | <3 | <3 | <3 | <3 | <0.5 |

| Whole body dose @ about | | | | | | |
|---|---|---|---|---|---|---|
| Delay following beam shutdown | Material | 1h | 1 day | 3 days | 7 days | 1 year |
| Guide upstream of the 1st chopper | Aluminium (5083) | 200 | <3 | <0.5 | <0.5 | <0.5 |
| Guide downstream | Aluminium ? | <25 | <3 | <0.5 | <0.5 | <0.5 |
| Collimator (streaming) | Copper | <50 | <25 | <3 | <3 | <3 |
| Chopper (no steel) | Aluminium housing / Alu rotor | 300 | <50 | <3 | <0.5 | <0.5 |
| Heavy shutter | Tungsten / no housing | 1000 | 100 | <50 | <25 | <25 |
| $T_0$ chopper (Tungsten hammer) | Tungsten / steel housing | 1000 | 100 | <50 | <25 | <25 |
| Inside rear bunker wall (with lead) | Lead /PolyConcrete/ Steel | <3 | <3 | <3 | <3 | <0.5 |

# Activation Material

Levers to pull

- Design
- Material choice
- … remote handling



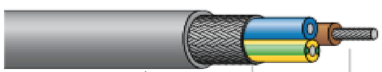

| Whole body dose @ about 30 cm [uSv/h] | | | | | | |
|---|---|---|---|---|---|---|
| Delay following beam shutdown | Material | 1h | 1 day | 3 days | 7 days | 1 year |
| Guide upstream of the 1st chopper | Aluminium (5083) | 200 | <3 | <0.5 | <0.5 | <0.5 |
| Guide downstream | Aluminium ? | <25 | <3 | <0.5 | <0.5 | <0.5 |
| Collimator (streaming) | Copper | <50 | <25 | <3 | <3 | <3 |
| Chopper (no steel) | Aluminium housing / Alu rotor | 300 | <50 | <3 | <0.5 | <0.5 |
| Heavy shutter | Tungsten / no housing | 1000 | 100 | <50 | <25 | <25 |
| $T_0$ chopper (Tungsten hammer) | Tungsten / steel housing | 1000 | 100 | <50 | <25 | <25 |
| Inside rear bunker wall (with lead) | Lead /PolyConcrete/ Steel | <3 | <3 | <3 | <3 | <0.5 |

Cool down

# Damage
# Hardened components

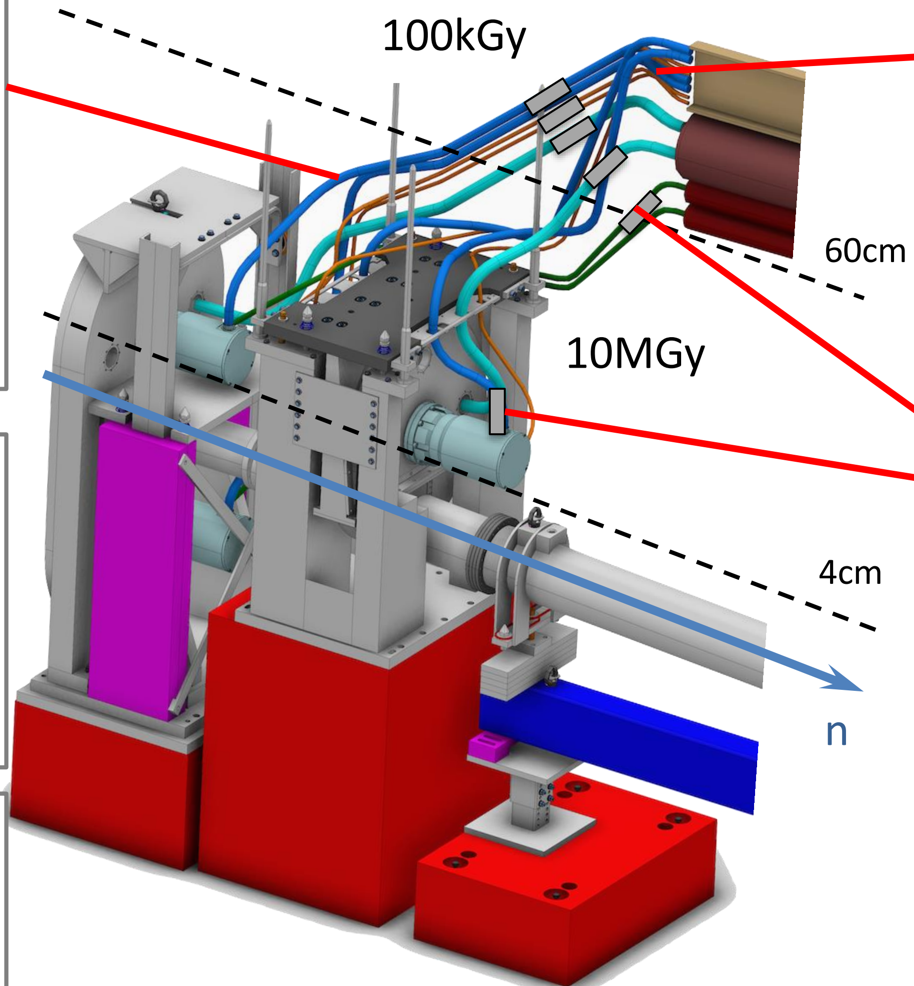
## Cables
Radiation spec cables:
Huber Suhner RADOX 125
**(3 MGy)**

AXON Polyimide TPI
**(20MGy)**



## Sensors
Vibration Sensor:
Vibro-Meter CA901
**(10 MGy)**

## Switches
Mechanical limit switch:
Crouzet 83151 **(10 MGy)**




## Cables
Standard cables, PU isolated
(100 kGy, **to be tested!**)

## Connectors
Push-Pull, RH ability:
Lemo B-series (Materials:
SS AISI 303 + PEEK plastics)
**(10 MGy, to be confirmed!)**

## Positioning Motors
Stepper motors:
Phytron VSS **(1 MGy)**

Brushless DC motors:
Wittenstein MRSR **(10 MGy)**

# Damage
# material options

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0m | 6.05m | 7m | 8m | 10m | 12m

HAYAKAWA 355EB

**MGy**

| | | | | | |
|---|---|---|---|---|---|
| Standard EPDM O-ring (max. 250kGy) | 100 | 86 | 71 | 44 | 10 |
| Rad Hard EPDM O-ring (max. 20MGy) | 10 | 8.6 | 7.1 | 4 | 1 |
| Aluminum Gasket (> 20MGy) | 200 | 170 | 140 | 81 | 20 |

60cm

4cm

2.8cm

Moderator

Neutron beam size 6x6cm

n

Requirement Specs ESS-0059912

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# Thank you for your attention !