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# IMG technical specification

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# 1. INTRODUCTION

The imaging systems will measure the two-dimensional distribution of the proton beam current. Three imaging systems will be deployed: one for the Target Wheel, one for the Proton Beam Window (PBW) and one for the Tuning Dump. The imaging systems shall consist of luminescent coatings on designated surfaces at or near target and dump components, together with optical systems that measure the proton beam induced luminescence.

The density distribution shall be measured for each pulse. Based on this measurement, the next pulse will be enabled or disabled. The most important parameter to measure will be the maximum current density within the beam footprint.

To support imaging and calibration without beam, illumination systems shall be installed that covers the entire fields of view of the imaging systems. Near the edges of the field of view, fiducials shall allow alignment, determination of scale factors, and optionally, correction of distortion.

To support background suppression and diagnostic studies, the imaging systems shall provide adjustable spectral selectivity over the visible and near IR range. Diagnostic equipment shall also be provided to measure spectra, power, and other characteristics of the emission without interrupting the operation of the primary imaging cameras.

# 2. TECHNICAL DESCRIPTION

## 2.1. General information

The IK partner shall design the full imaging systems required to fulfill the requirements in section 2. This includes (but is not limited to) fluorescent coatings on the surfaces that will imaged, alignment fiducials and illumination on the same surfaces, optics assemblies to be installed in the proton beam instrumentation plug, and cameras and any other necessary optical equipment.

All parts of the design will be chosen and developed in collaboration with ESS. The final choice of design must be approved by ESS.

## 2.2. Overview

### 2.2.1. Target region

The two surfaces that shall be coated and imaged are the proton beam window and the target wheel. The proton beam window is a thin metal sheet that separates the high vacuum of the final part of the accelerator from the helium or vacuum environment in the target region. The target wheel is tungsten surrounded by a steel shell.

See figure 1 for an overview of the target region. The instrumentation and electronics will be at the other end of the instrumentation plug.

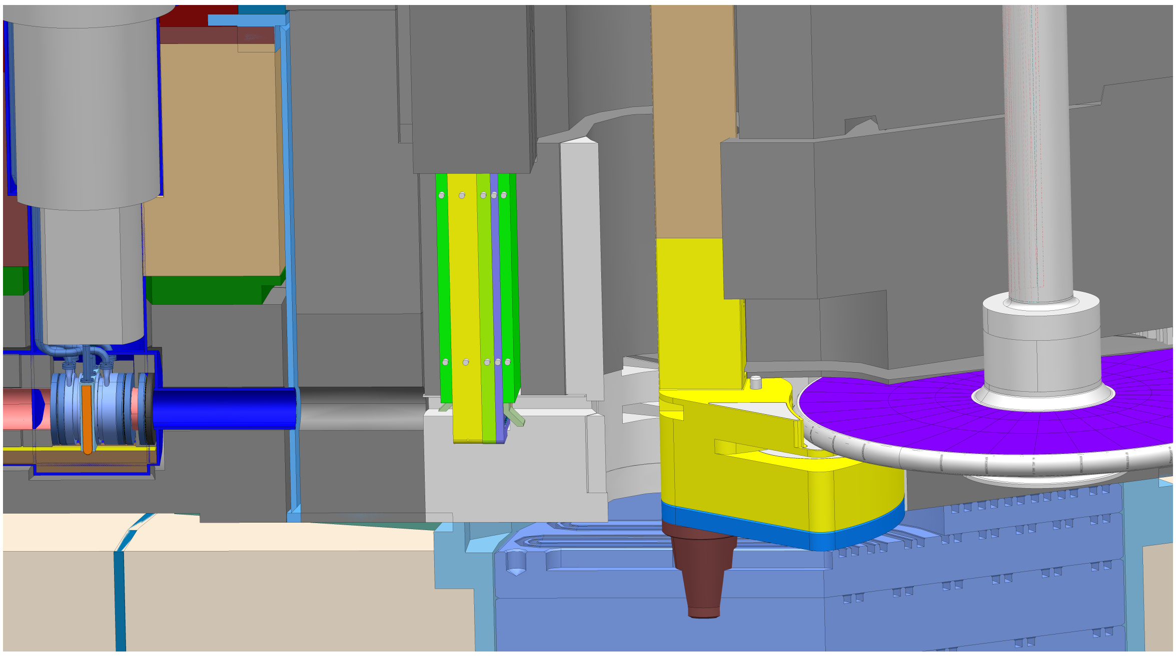

**Figure 1; Target region overview. A part of the proton beam instrumentation plug can be seen (in green and yellow) in the center, with two schematic mirrors at about 45 degrees. To the left is the proton beam window in its tube, and to the right is the target wheel.**

#### 2.2.2. Tuning dump region

The surface that shall be coated and imaged is on the tuning dump surface that faces the incoming beam. The tuning dump will be the beam destination during start-up and tuning of the accelerator. An alternative/addition is to provide a luminescent screen just upstream of the tuning dump surface.

### 2.3. Geometry

ESS shall provide CAD files that fully describe the geometry of the relevant regions and the allowed volume envelopes for the imaging systems.

The design of the imaging systems shall comply with these CAD files.

### 2.4. Luminescent coating

The photon sources shall be luminescent coatings on the imaged surfaces. The IK partner shall develop the coating and design the coating process. The coating shall be designed so that the emission intensity, spectrum, and decay time of the proton beam induced luminescence is sufficient for the imaging systems to fulfill the requirements in section 3.

### 2.5. Alignment systems

Each imaging system should be equipped with an alignment system. The alignment systems shall consist of illumination together with fiducials.

The fiducials shall be placed within the field of view of the imaging system. The illumination system should be designed so alignment can be done without the proton beam.

### 2.6. Optics assembly and equipment

In the target region, an optics assembly shall be designed and placed in the proton beam instrumentation plug to transport the image through the target monolith.

Similarly, in the tuning dump region, an optics assembly shall be designed to transport the image from the tuning dump to an area suitable for the camera and other imaging equipment.

The IK partner shall choose the imaging equipment (cameras, spectrometers, etc) that is necessary to image and characterize the proton beam induced luminescence. This equipment will also be used to measure the relative positions of components.

## 2.7. Control systems and data transfer

The imaging systems will be integrated into the accelerator control systems. The input-output control (IOC) shall control the camera, acquisition settings, processing and data transfer. See image 3 for an overview. Not shown are the interfaces to other global systems such as the beam interlock system and to the timing system (see next section).

Detailed control interfaces and data formats are not yet decided. They shall be developed and provided by ESS in collaboration with the IK partner.

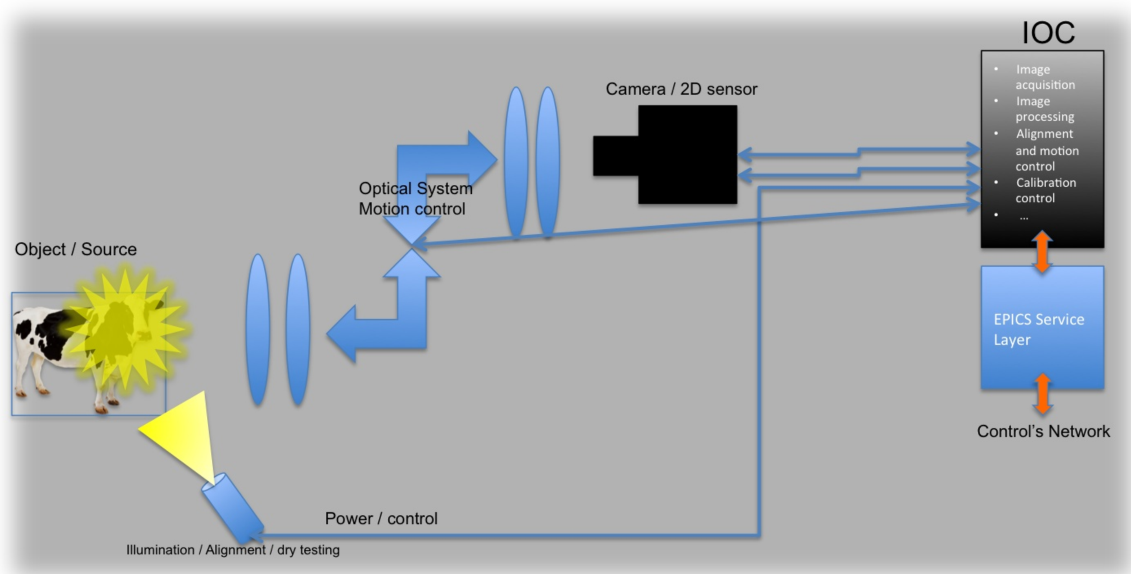


**Figure 3; Control of imaging systems**

## 2.8. Electronic interfaces

### 2.8.1. Interlock system

The imaging systems shall interface with the beam interlock system according to the specifications in ref 2 (tbd).

### 2.8.2. Timing system

The imaging systems shall interface with the ICS timing system to provide triggered data acquisition, timestamps, buffered data on demand, and other features required to support system verification/calibration as well as machine commissioning, startup and operations.

# 3. TECHNICAL REQUIREMENTS

## 3.1. ESS requirement types

ESS requirements are divided into top-down requirements and interface requirements. Top down requirements are named by a level number, and are specific for a certain section. The IMG instrumentation is a level 5 component, and is formally a part of the level 4 accelerator discipline “PBI”, proton beam instrumentation. Accelerator sections, e.g. A2T or DmpL, are level 3.

The level 4 requirements (listed in this section) are set by the accelerator sections onto the instrumentation in the specific sections. They are maintained in the ESS requirement database DOORS. This document contains copies of the relevant requirements with references to DOORS.

Interface requirements between the IMGs and other accelerator disciplines can be found in DOORS. This document contains copies of the relevant requirements with references to the sources.

Interface requirements between the IMGs and target disciplines can be found in ICD-R documents. This document contains copies of the relevant requirements with references to the sources.

Level 5 requirements are all requirements on specific implementations of the measurement system, in this case the different imaging systems.

## 3.2. Formal component names and types

The imaging system components have formal ESS names and type IDs according to the table below.

**Table 3.1 Device names and IDs.**

| **Device name** | **DOORS type ID** | **Description** |
|---|---|---|
| MNLT-PBDPLG:PBI-IMG-001 | IMG1 | Mounted upstream in PBIP, observes the proton beam window. Optical set B. |
| MNLT-PBDPLG:PBI-IMG-002 | IMG2 | Mounted downstream in in PBIP, observes the target wheel. Optical set A. |
| DMPL-050DRF:PBI-IMG-001 | IMG3 | Mounted in DMPL section, observes tuning dump. |

## 3.3. Level 4 requirements

### 3.3.1. Level 4 requirements for the A2T accelerator section

Table 3.2 contains the relevant L4 requirement for the A2T section. DOORS-IDs and traceability information is tbd.

**Table 3.2 L4 requirements for PBI in the A2T section (extract relevant for IMG systems)**

| DOORS-ID | Name | Description | Clarification | Traced Up To | Verify Method | Development Phase |
|---|---|---|---|---|---|---|
| | A2T PBI energy range | Proton beam instrumentation in the A2T section shall function over a proton beam energy in the range of 180 MeV - 2100 MeV. | Sufficient tolerances shall be added on the instrument level. All instruments must not cover the entire range. | | inspection | design, operation |
| | A2T PBI energy range, near target | Proton beam instrumentation downstream of the neutron shield wall shall function over a proton beam energy in the range of 180 MeV - 2.5 GeV. | Maximum energy on target due to heat fatigue is 2.2GeV. 10% tolerance is added. | | inspection | design, operation |
| | A2T PBI peak current range | Proton beam instrumentation in the A2T section shall function over a peak beam current range of 3 mA to 65 mA. | Sufficient tolerances shall be added on the instrument level. | | inspection | design, operation |
| | A2T PBI pulse length range | Proton beam instrumentation in the A2T section shall function over a proton beam pulse length range of 5µs to 2.980 ms. | Sufficient tolerances shall be added on the instrument level. | | inspection | design, operation |
| | A2T PBI pulse-by-pulse measurement update rate | Unless specifically stated, all instrumentation shall be able to perform the measurements and report the relevant PV data at a repetition rate of 14 Hz. | Sufficient tolerance shall be added on the instrument level. | | inspection | design, operation |

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| | A2T PBI measurement error limit definition | Unless specifically stated, instrumentation shall be designed so that less than 1 measurement in 2.4e8 is allowed to be outside the specified allowed error limits for each requirement. | This is one pulse per year. The limits correspond to hard limits of a uniform distribution, or a margin of approximately 6 sigma for a two sided interval of a normal distribution. | | inspection, analysis | design, operation |
| | A2T instrumentation measurement aperture | All measurements in the A2T section shall function for beam distributions within the area of the beam pipe in the section. | This corresponds in most cases to the clear aperture of the beam. Suggest: "measurement made for all beam distributions within the aperture" | | inspection | design, operation |
| | A2T instrumentation clear aperture | The clear aperture of the instrumentation in the A2T section must be designed so that no part of the frames of the instrumentation absorb more energy than 1 W/cm3, averaged over a pulse period. | A "pulse period" is defined as 1/14 s regardless of the used pulse repetition rate of the accelerator. The value corresponds to 71 mJ/cm3/pulse. | | inspection, analysis | design, operation |
| | A2T damaging beam detection and mitigation | Beam conditions that are potentially damaging to machine components shall be detected by the instrumentation and reported fast enough so that the conditions can be mitigated before damage occurs. | A component is considered damaged if it requires inspection according to the standards described in ESS-TBD. | | inspection | design, operation |
| | A2T PBI beam start up measurements | Proton beam instrumentation shall be capable of measuring all beam parameters needed that allow for a safe start-up of beam power, from no beam to the full nominal beam. | The different beam modes are described in ESS-0038258 R2. | | inspection | design, operation |
| | A2T invasive measurements beam modes | All invasive measurements in the A2T section shall be possible for beam pulse lengths of 5 microseconds at 14 Hz and 50 microseconds at 1 Hz. | This corresponds to the slow and fast beam tuning modes (duty cycle of approx. 0.005%). This does not include transients that can reach up to 2 times 20 microseconds. | | inspection | design, operation |

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| | A2T beam centroid position measurement | The beam centroid position shall be measured in at least 7 locations in the A2T section, including at the location of the target wheel surface. | | | inspection, demonstration | design |
| | A2T beam centroid position horizontal measurement error, target wheel | The beam centroid position on the target wheel, averaged over one pulse shall be measured with a total horizontal measurement error of less than ±1.5 mm. | This refers to the centroid of the beam footprint after expansion and rastering. | | inspection, analysis | design, operation |
| | A2T beam centroid position vertical measurement error, target wheel | The beam centroid position on the target wheel, averaged over one pulse shall be measured with a total vertical measurement error of less than ±1 mm. | This refers to the centroid of the beam footprint after expansion and rastering. | | inspection, analysis | design, operation |
| | A2T beam current density measurement | The proton beam current density map over the physical aperture of the beam, averaged over one pulse shall be determined at the locations of the proton beam window and the target wheel. | The size of the nominal beam 99.9% footprints can be found in ESS-0003310R1. | | inspection, demonstration | design |
| | A2T beam current density measurement range. | The proton beam current density shall be measured in the range 0 to 160 µA/cm2. | This is twice the expected nominal current density at the PBW, averaged over one pulse period (defined as 1/14s). | | inspection, measurement | design, operation |
| | A2T beam current density measurement error | The beam current density, averaged over one pulse, shall be measured with a total measurement error of less than ±20% in each point. | | | inspection, analysis | design, operation |
| | A2T beam current density measurement resolution | The beam current density shall be measured with a spatial resolution of ≤ 2 mm. | | | inspection, measurement | design, operation |
| | A2T beam current density time resolution. | The beam current density measurement time resolution, defined as the interval between independent reported measurement readouts, shall be once per pulse. | | | inspection, measurement | design, operation |

### 3.3.2. Level 4 requirements for the DMPL accelerator section

Table 3.3 contains the relevant L4 requirement for the DMPL section. These are an extract from baseline xxx, DOORS.

**Table 3.3 L4 requirements for PBI in the DMPL section**

| DOORS-ID | Name | Description | Clarification | Traced Up To | Verify Method | Development Phase |
|---|---|---|---|---|---|---|
| | DMPL PBI energy range | Proton beam instrumentation in the DMPL section shall fulfil the requirements for a proton beam energy in the range of 75 MeV - 2100 MeV. | Sufficient tolerances shall be added on the instrument level. All instruments must not cover the entire range. | | inspection | design, operation |
| | DMPL PBI peak current range | Proton beam instrumentation in the DMPL section shall function over a peak beam current range of 3 mA to 65 mA. | Sufficient tolerances shall be added on the instrument level. | | inspection | design, operation |
| | DMPL PBI pulse length range | Proton beam instrumentation in the DMPL section shall function over a proton beam pulse length range of 5µs to 2.980 ms. | Sufficient tolerances shall be added on the instrument level. | | inspection | design, operation |
| | DMPL PBI pulse-by-pulse measurement update rate | Unless specifically stated, all instrumentation shall be able to perform the measurements and report the relevant PV data at a repetition rate of 14 Hz. | Sufficient tolerance shall be added on the instrument level. | | inspection | design, operation |
| | DMPL PBI measurement error limit definition | Unless specifically stated, instrumentation shall be designed so that less than 1 measurement in 2.4e8 is allowed to be outside the specified allowed error limits for each requirement. | This is one pulse per year. The limits correspond to hard limits of a uniform distribution or a margin of approximately 6 sigma for a two sided interval of a normal distribution. | | inspection, analysis | design, operation |
| | DMPL instrumentation measurement aperture | All measurements in the DMPL section shall function for beam distributions within the area of the beam pipe in the section. | This corresponds in most cases to the clear aperture of the beam. Suggest: "measurement made for all beam distributions within the aperture" | | inspection | design, operation |

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| | DMPL instrumentation clear aperture | The clear aperture of the instrumentation in the DMPL section must be designed so that no part of the frames of the instrumentation absorb more energy than 1 W/cm3, averaged over a pulse period. | A "pulse period" is defined as 1/14 s regardless of the used pulse repetition rate of the accelerator. The value corresponds to 71 mJ/cm3/pulse. | | inspection, analysis | design, operation |
| | DMPL damaging beam detection and mitigation | Beam conditions that are potentially damaging to machine components shall be detected by the instrumentation and reported fast enough so that the conditions can be mitigated before damage occurs. | A component is considered damaged if it requires inspection according to the standards described in ESS-TBD. | | inspection | design, operation |
| | DMPL PBI beam start up measurements | Proton beam instrumentation shall be capable of measuring all beam parameters needed that allow for a safe start-up of beam power, from no beam to the full nominal beam. | The different beam modes are described in ESS-0038258 R2. | | inspection | design, operation |
| | DMPL invasive measurements beam modes | All invasive measurements in the DMPL section shall be possible for beam pulse lengths of 5 microseconds at 14 Hz and 50 microseconds at 1 Hz. | This corresponds to the slow and fast beam tuning modes (duty cycle of approx. 0.005%). This does not include transients that can reach up to 2 times 20 microseconds. | | inspection | design, operation |
| | DMPL beam centroid position measurement | The beam centroid position shall be measured in each linac warm unit in the DMPL section, including at the tuning dump surface. | | | inspection, demonstration | design |
| | A2T beam centroid position horizontal measurement error, dump surface | The beam centroid position on the tuning dump surface, averaged over one pulse, shall be measured with a total measurement error of less than ±1 mm. | | | inspection, analysis | design, operation |

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|---|---|---|---|---|---|---|
| | DMPL beam current density measurement | The proton beam current density map over the physical aperture of the beam, averaged over one pulse shall be determined at the locations of the surface of the tuning dump. | The size of the nominal beam 99.9% footprints can be found in ESS-0003310R1. | | inspection, demonstration | design |
| | DMPL beam current density measurement range. | The proton beam current density shall be measured in the range 0 to 60 μA/cm2. | This is twice the current density based on the maximum pulse space charge requirement ESS-0034025R2.5: ACCSYS-209, averaged over one pulse period (1/14s). | | inspection, measurement | design, operation |
| | DMPL beam current density measurement error | The beam current density shall be measured with a total measurement error of less than ±20% in each point. | | | inspection, analysis | design, operation |
| | DMPL beam current density time resolution. | The beam current density measurement time resolution, defined as the interval between independent reported measurement readouts, shall be once per pulse. | | | inspection, measurement | design, operation |

### 3.3.3. PBIP IMG Interface requirements

The imaging systems in the target region are mounted into the proton beam instrumentation plug. The tables below are an extract from table 2.2.1 in the ICD-R document ESS-0060563, rev1.2, describing the interface requirement.

The PBIP section is the same as in revision 1 that was released for the PBIP preliminary design review (PDR), but verification information has been added. Items not relevant for the IMGs have been cut out. Information from other tables in ESS-0060563 has been added to the column “Comments”. In case of conflicts between this document and ESS-0060563, the latest version of ESS-0060563 takes precedence.

**Table 3.4 Interface requirements between the PBIP IMG and Monolith systems. Extract from ESS-0060563R1.2**

| Interface ID | Description | Value or Reference | Verify by/Phase | Comments |
|---|---|---|---|---|
| PBI-2.1 | The instrumentation slices shall have the possibility to be removed individually. | | Inspection /Design | |
| PBI-2.2 | Clear aperture of the PBIP slices. | 200x80 mm | Inspection /Design<br>Measurement/Installation | W 260 mm, H 140 mm, T 25 mm<br>Detailed mechanical drawings TBD before PBIP CDR. |
| PBI-2.4 | Positioning tolerances of in-beam PBI parts in the x and y directions. | ±0.5 mm with regard to the theoretical beam axis. | Inspection /Design<br>Measurement/Installation | A rigid extension with printed circuitry and dimensions (XxYxZ) shall extend from the in-beam part or the APTM up through the slice. Cables are connected to the upper end of the extension.<br>The APTM assembly shall be mounted to PBIP slice. Method to be agreed before CDR.<br>Detailed mechanical drawings TBD before PBIP CDR. |

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| PBI-2.5 | Geometry of optical envelopes routed inside the optical slices A and B and the optical blocks A and B. | See drawing/model:<br>Optical Set A (downstream) – ESS-0050446<br>Optical Set B (upstream) – ESS-0050447<br>These are preliminary at the PBIP PDR. | Inspection /Design<br>Measurement/Installation | See table for an extract of tables.<br>The cables routed in the slices are supplied by PBI. Monolith systems shall provide an aperture in the structure that can accommodate the cables. |
| PBI-2.6 | Position tolerance of attachment points for optical components in the imaging slices and blocks. | ±0.1 mm<br>Drawings TBD before CDR of PBIP | Inspection /Design<br>Measurement/Installation | |
| PBI-2.7 | Position tolerance of the optics blocks relative to the correponding imaging slices. (Optics block A relative to Imaging slice A, optics block B relative to imaging slice B). | ±0.1 mm<br>The relative alignment is critical as the optical slices and block contains parts of the same optical assembly. | Inspection /Design<br>Measurement/Installation | |
| PBI-2.8 | Displacement of optical mounts in the imaging slices and blocks due to mechanical and/or thermal stress. | ±0.1 mm | Inspection /Design<br>Measurement/Installation | |
| PBI-2.9 | There shall be a clear line of sight between the mirror at the bottom of IMG slice upstream and the observed area at the PBW. The observed area is X x Y mm, centered on the theoretical beam axis. | See optical Set B (upstream) – ESS-0050447 for the mirror placement. (Preliminary at the PBIP PDR.) | Inspection /Design<br>Measurement/Installation | |
| PBI-2.10 | There shall be a clear line of sight between the mirror at the bottom of IMG slice downstream and the observed area at the target wheel. The observed area is X x Y mm, centered on the theoretical beam axis. | See optical set A (downstream) – ESS-0050446 for the mirror placement. (Preliminary at the PBIP PDR.) | Inspection /Design<br>Measurement/Installation | |

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| PBI-2.12 | Specification of equipment (cables etc.) that requires routing through the Plug. | See table 2.2.5 in ESS-0060563R1.2. (Table 3.4 below). | Inspection /Design | |
| PBI-2.13 | Cables and cooling water shall be routed so that no (activated) return water is running next to cables. | This affects the lifetime of cables. | Inspection /Design<br>Inspection /Installation | |
| PBI-2.14 | All in-beam PBI parts shall be conductivly cooled through the mechanical interfaces with the respective PBI slices. | This includes the bottom mirrors of the imaging slices. | Inspection /Design<br>Demonstration/Installation | |
| PBI-2.15 | There shall be a possibility to access/replace the PBI parts on individual PBIP slices with 6 month intervals. | | Inspection /Design | |
| PBI-2.16 | Minimum lifetimes of the PBI parts. | See table 2.2.6 in ESS-0060563R1.2. | Analysis /Design | PBIP IMG minimum lifetime: 2 years |
| PBI-2.17 | In the direction of the beam, the slice order shall be optical slice upstream, BPM, GRD, PBIP APTM, optical slice downstream | | Inspection /Design | |

**Table 3.5 Cables for mirror control in imaging slices and blocks (placeholder for cable routing). Extract from ESS-0060563R1.2**

| System | Cable type | Ø (mm) | Quantity | User defined cable class | Connector type PBIP side |
|---|---|---|---|---|---|
| IMG upstream looking at Proton Beam Window | 15C24OSRS232* | 15 | 4 | E | Multi-wire for mirror motion control |
| | K-type thermocouples | 5 | 10 | A | Thermocouples on mirrors in the slice |
| IMG downstream looking at Target Wheel | 15C24OSRS232* | 15 | 6 | E | Multi-wire for mirror motion control |
| | K-type thermocouples | 5 | 10 | A | Thermocouples on mirrors in the slice |

### 3.3.4. DMPL IMG interfaces

The DMPL IMG system is mounted in the DMPL section near the tuning dump drift tube part DMP-050DRF.

The IMG system is mounted with a DN250 flange onto a vacuum instrumenta shown in ESS-0044812R6 (planned revision), DMP-BP5, part 4 and 6.

The DMPL VAC interface is defined as the surface of the mounting flange as s 0044812R6.

All IMG parts exposed to vacuum shall be compliant with the vacuum pressur DMPL section. See DOORS requirement DMPL.SyR-14 for requirements on ma allowable pressure.

## 3.4. Other requirements

### 3.4.1. Documentation

For each major design review, and for the final design, the IK partner shall pr with CAD files and documentation that fully describe the design of the imagir

The dates for the design reviews, and for when the documentation should be ESS for each review, are listed in the technical annex.

# 4. REFERENCES

[1] "Description of Modes for ESS Accelerator Operation", ESS-0038258R2
[2] Beam interlock specification, tbd.

# DOCUMENT REVISION HISTORY

| Revision | Reason for and description of change | Author | Date |
|---|---|---|---|
| 1.1 | Initial template | N/A | 2015-11-16 |
| 1.2-7 | Development versions. | Johan Norin | 2015-12-04 |
| 2.4 | Requirements updated | Johan Norin | 2016-09-13 |