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BEER - H1 and H2 scenarios for radiation shielding

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1. SCOPE OF DOCUMENT

The scope of this document is to define the standard operation and likely accident scenarios, so-called H1&H2 events as defined in [1], of the instrument BEER. This list of defined scenarios will be used for the design of the shielding and will drive the simulation and confirmation strategies to evaluate and approve the shielding efficiency. Basic guidelines for this document set in [2] were adapted to the operations and maintenance dedicated and designed for BEER [3].

1.1. Issuing organisation

Nuclear Physics Institute (NPI) in collaboration with collaborators from Research Centre Rez (Czech Republic).

1.2. Contributors

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1.3. Document structure flow

Situations which are relevant for the shielding design are combinations of the incoming beam and the sample or structure interacting with the beam. After the brief introduction to the BEER instrument in Chapter 2 and its modes of operation (Chapter 3), the definition of the worst-case beams (Chapter 4) and the worst interacting material (Chapter 5) are made separately. Their combination then leads to the definition of the H1 and H2 events listed in Chapter 7. Further down is then presented expected mitigation plan (Chapter 9) for the H2 events and shielding strategies (Chapter 8) based on the preliminary design.

2. BEER INSTRUMENT DESCRIPTION

2.1. General overview

The BEER instrument belongs to the long-instrument family and is located at the beam-port W2 in the E01 hall. Its components pass different buildings, namely D03 (bunker + hall), E02 (guide hall) and E01 (experimental hall). A schematic layout is shown in Figure 1 [3].

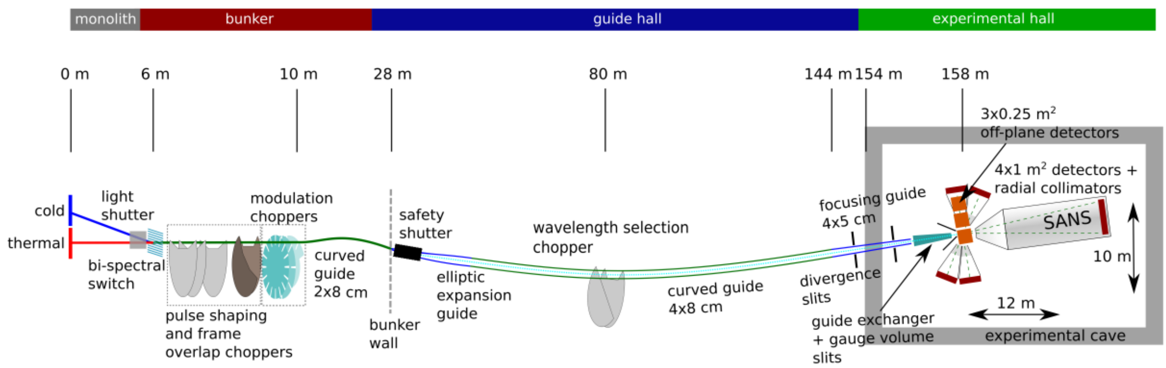

Figure 1 - Schematic layout of the instrument BEER

The double extraction system allows access to both cold and thermal neutrons. To eliminate fast neutrons propagating along with the neutron transport guide, this guide is curved in the S-shape manner. The first curvature starts after the chopper cascade with a radius of 2 km and allows closing of the direct line-of-sight (LOS) for the first time within the bunker wall (see [4], chapter 5.3). The second opposite curvature with a radius of 20 km closes LOS for the second time at about 80 m from the source.

2.2. Shielding structures

Outside the bunker as the main shielding structure nearby the monolith, the instrument consists of four shielding structures which are relevant and need to be considered for the H1&H2 scenarios:

- **Shutter pit** is located at the outer bunker wall and contains the heavy shutter. It protects the D03 hall environment mainly from neutrons (including high energy spectrum) escaping from the bunker and neutrons and gamma radiation emitted by the heavy shutter in both the open and closed positions. The shutter is linked with the Personnel Safety System (PSS) switches for the closed position. No operation or maintenance is allowed down-stream when the shutter is open. When the shutter is closed, the maintenance actions (guide alignment, chopper maintenance) and operations (sample exchange) after the shutter pit are possible.
- **Neutron guide shielding** connects the shutter pit with the experimental cave, passing from D03 to the far end of E02. It should protect mainly from the prompt γ radiation produced by the interaction of neutrons with the super-mirror layers and the substrate of the neutron guide. It should also protect from neutrons and prompt γ radiation caused by the interaction of the neutron beam with the jaws of the first slit system at 152 m from the source.
- **Chopper pit** is located in E02 at about 80 m from the source. It holds the two wavelength-selection choppers. Interaction of the neutron beam with the chopper disks is the main source of scattered neutrons and prompt γ radiation to be shielded by the chopper pit, in addition to the radiation generated in the guide coating and substrate.
- **Experimental cave** is located in E01 hall and has to provide biological shielding from neutrons as well as prompt-γ radiation produced by scattering or absorption of the neutron beam by the sample, sample environment or other equipment in the experimental cave. The cave has two entrances, one for large equipment (service entrance) and one for the personnel access. These doorways will be protected by the shielding doors (service entrance) or inner labyrinth (personnel entry). Both entrance door systems will be connected with the PSS system, which disables the access to the cave when the heavy shutter is open.

3. INSTRUMENT OPERATION MODES DESCRIPTION

3.1. Beam modes description

The incoming neutron beam will be tuned by several optical (focusing neutron guide, adjustable apertures) or mechanical (choppers) devices to prepare the beam necessary for the experiment. From the users’ perspective, the main operational scenarios are described in the instrument *Concept of Operations* [3]. A list of typical instrument setup modes with beam characteristics is given in *Optics Report for the BEER instrument* [4]. Basic setting parameters of the choppers and beam optics for the modes relevant from the radiation safety perspective (those producing the most intense beams) are summarised in Table 1. The beams ***F0*** and ***F1*** are not required for normal operation; they are considered only for **H2** scenarios.

Table 1 – Worst-case instrument modes considered for the H1&H2 scenarios. The frequency of the choppers is given in Hz and the slit settings in mm. The choppers not shown in the table (PSC2, FC1b and FC2b) or marked with '-' are considered to be stopped in the open position. The slit width and height marked with 'o' means fully open (as removed). The beam modes considered for H1 and H2 scenarios are marked by green and red fill colour, respectively. The modes shown here are a subset of the modes listed in the *Optics Report for the BEER instrument* [4].

ID	Description	Choppers						Slits			
		Pulse shaping		Modulation		Frame overlap		SL1		SL3	
		PSC1	PSC3	MCA	MCC	FC1a	FC2a	w	h	w	h
Maximum beams											
F0	Maximum white beam	-	-	-	-	-	-	o	o	o	o
F1	Accident full beam	-	-	-	-	28	14	o	o	o	o
F2	Maximum operational beam	-	-	-	-	28	14	o	o	10	20
Diffraction modes											
PS0	Maximum pulse shaping	168	168	-	-	28	14	o	o	10	20
M0	Maximum modulation	-	-	70	-	28	14	o	o	10	20
Imaging mode											
IM0	Maximum imaging	-	-	-	-	28	14	10	10	o	o
SANS modes											
SANS	Maximum SANS	-	-	-	-	28	14	20	20	10	10
DS0	Modulation + SANS	-	-	-	70	14	7	40	40	5	10

3.1.1. Chopper modes

Depending on the status of the choppers, four categories of the beam were identified:

- **Maximum white-beam** – the maximum physically possible beam with all choppers stopped and slits open, considered only as **an H2 scenario**. The corresponding setting is *F0* in Table 6 of [4].
- **White-beam modes** – only wavelength frame selection choppers (FC) are running (used in white-beam SANS, imaging). The corresponding settings are *F1*, *F2*, *IM0* and *SANS* in Table 6 of [4].
- **Pulse shaping modes** – pulse shaping (pair of choppers) and FC choppers are running (used for diffraction, strain scanning, diffraction + SANS). The corresponding settings are *PS0* to *PS3*, *IM1* and *DS1* in Table 6 of [4].
- **Modulation modes** – modulation chopper(s) and FC choppers are running (strain scanning, diffraction, diffraction + SANS). The corresponding settings are *M0* to *M3* and *DS0* in Table 6 of [4].

During the normal operation, the wavelength frame selection choppers (FC1a[1] at 28/14 Hz and FC2a[1] at 14/7 Hz) will be running permanently. There is ***no*** planned scenario when t*hey will be* ***parked open*** *during normal operation*.

3.1.2. Optics modes

The chopper modes defined above can be combined with various settings of neutron optics (slits and focusing guide). There are three main **operation scenarios** defined in the *Concept of Operations* [3] - diffraction, imaging and SANS. They require different beam geometries as described below. For each geometry, the most intense operation beam mode is considered for H1 events:

- **Diffraction mode** – a *convergent beam* defined by two adjustable divergence slits (SL1[1] and SL2[1]) and the sample slit (SL3[1]) defining a gauge volume. The maximum intensity setting in this mode corresponds to ***F2*** in Table 6 of [4] and Table 1. The beam cross-section of 10x20 mm^2 is the maximum SL3 opening allowed by design.
- **Imaging mode** – a *divergent beam* defined by a pin-hole (SL1[1] reduced). The sample slit (SL3[1]) and the last focusing guide section (GEX1[1]) are removed for a maximum field of view. The maximum simulated intensity in this mode corresponds to ***IM0*** in Table 6 of [4] and Table 1.
- **SANS mode** – a *collimated beam* defined by collimation produced by reduction of both slits, SL1[1] and SL3[1], with the last focusing guide section (GEX1[1]) removed, suitable for SANS measurements. The maximum simulated intensity in this mode corresponds to ***DS0*** in Table 6 of [4] and Table 1.

3.2. Changing the modes – the worst-case scenarios

Switching between operation modes involves the stopping of one set of choppers and starting of another one, as well as changing slit openings and changing the guide exchanger position. The change of the operation mode is usually performed at the beginning of the user experiment, and it is done by trained instrument-responsible personnel. A dedicated manual for the process of switching between modes will be provided. The worst-case situation during the improper switching between operation modes leads to the ***F1*** beam conditions; this is considered as an **H2** event (Table 1).

Before the experiment starts, some additional adjustment of the chopper cascade could be needed. It concerns mainly the *diffraction pulse shaping mode* and includes, for example, tuning of resolution (move of the PSC1 and PSC2 choppers), adjustment of the wavelength band centre (setting of chopper delays), etc. These adaptations have to be considered as routine operation procedures. For example, all PSC choppers have 144˚ opening, while two disks always rotate in optically blind mode. Even a small out-phasing can lead to a wide time window as if they are stop-open. This situation may or may not happen during chopper adjustment. Therefore, such a scenario has to be considered as an **H1** event. It will lead to the ***F2*** beam mode (Table 1) considered as the worst **H1** event.

[1] For the abbreviation see *BEER Optics Specification* (ESS-0478295)

4. INCOMING NEUTRON BEAM

4.1. At the sample position

Beam intensities at the sample position for the beam modes described in the preceding section are summarised in Table 10 of [4]. Three of them are considered for the H1&H2 scenarios as described below:

- **Maximum operation beam (MOB**, *F2* in Table 1**):** pulse-shaping high-intensity mode, the last slit fully open (10x20 mm^2), wavelength band centre at 2.1 Å, proton beam at 5 MW, **neutron flux: 2.87·10^8 n·s^{-1}·cm^{-2}**, **integrated intensity** over the beam size and wavelength band of 1.7 Å: **5.73·10^8 n·s^{-1}**.
- **Accidentally full beam (AFB**, *F1* in Table 1)**:** all choppers stopped except FC choppers, divergence slits open, the last slit removed, the last focusing guide GEX1 on (beam size at sample approx. 40x18 mm^2 using FWHM), wavelength band centre at 3.1 Å, proton beam at 5 MW, **neutron flux in the centre: 2.94·10^9 n·s^{-1}·cm^{-2}**, **integrated intensity** over the beam size and for wavelength range 0.2-8.2 Å: **2.26·10^{10} n·s^{-1}**.
- **Maximum whitebeam (MWB**, *F0* in Table 1**)**: maximum physically possible beam intensity that can be delivered to the sample: like AFB, but all choppers including FC are parked open. **Neutron flux in the centre: 5.3·10^9 n·s^{-1}·cm^{-2}**, **integrated intensity** for wavelength range 0.2-8.2 Å: **4.07·10^{10} n·s^{-1}**.

Provided abbreviations are used further in the text and in the definition of H1 and H2 events in Table 2 and Table 3.

The maximum operational beam *(MOB)* yields the highest intensity out of all operation modes from Table 1. Beams with lower intensities are therefore not considered for further investigation. The *AFB* is considered as a likely accident scenario which can occur during improper switching between operation modes or by the accidental opening of the slits system during the imaging or SANS experiment. The *MWB* is considered as a severe accident when everything fails. This is the maximum neutron intensity which can be transported to the sample position.

4.2. Along with the neutron guide

Interaction of non-reflected thermal neutrons with the neutron guide coating and the substrate is the main source of radiation which defines requirements for neutron guide shielding after the bunker and shutter pit. The non-reflected thermal neutrons are either (i) captured in the NiTi multilayer, giving raise to prompt-γ radiation from Ni and Ti, or (ii) escape (by transmission and/or scattering) and are captured in the substrate or interact with other components of the neutron guide system and shielding. Neutron guides after the shutter pit have Borkron glass substrate and are protected by B_4C shielding at the gaps. Therefore, prompt-γ radiation from boron is the main source of gamma radiation in the case (ii). The worst-case scenario for both H1 and H2 events is therefore defined by the neutron capture rates in the guide coating and substrate under the conditions of the maximum whitebeam (MWB) at 5 MW source power. The capture rates shall be determined by ray-tracing simulations of non-reflected neutrons using the method described in [https://doi.org/10.1016/j.nima.2018.12.069] and [https://doi.org/10.3233/JNR-190123]. In the following text, this neutron intensity is denoted as **Neutron Guide Escape Beam (NGEB)**.

4.3. At the chopper and slit systems

The intensities of the neutron beam, inside the neutron guide, decrease along the path downstream from the source. The simulated intensities across the neutron guide cross-section at a specific point which need to be considered for shielding design at chopper pit (80 m from the source) and at the slits systems (at about 145 m) are listed in Table 11 of the *Optics Report for the BEER instrument* [4] and are depicted below. As the FC chopper will spin all the time and the slit system will be adjusted frequently, the interaction with these neutron intensities is considered as H1 event.

- **BM6** – integral intensity simulated at 80 m from the source at the position of the FC choppers: $\mathbf{5.87 \cdot 10^{10}\ n \cdot s^{-1}}$
- **BM7** – integral intensity simulated at 144.5 m from the source at the start of focusing section: $\mathbf{5.24 \cdot 10^{10}\ n \cdot s^{-1}}$

4.4. In the shutter pit

The H1 and H2 scenarios and the shielding design for the shutter pit are driven by the presence of fast neutrons leaking through the bunker wall. As the shutter pit is located just after the bunker and the first close of LOS is within the bunker wall, the possible fast neutron leakage needs to be considered as an H1 event. The incoming neutron spectrum across the wide energy range will be simulated as part of the neutronics calculation for the guide shielding in the common shielding project. For the purpose of this document, we call this beam as **Bunker Exit Beam (BEB)**.

5. MATERIAL INTERACTING WITH THE NEUTRON BEAM

Besides the incoming neutron flux and integral intensity, requirements on the shielding design depend on the samples and other materials interacting with the neutron beam, such as beam stopper, slit jaws, chopper discs or parts of the sample environment. There are two main important interactions – **prompt-γ radiation** from neutron capture by atom nuclei and **scattering of neutrons**. The type and intensity of radiation emitted to the environment depend on the chemical composition, structure and geometry of these materials.

5.1. Sample

Taken into consideration possible samples which will be measured on BEER, the worst γ emitter is Ni. Ni produces harder γ radiation [5] than Cd proposed in [2] as a worst-case sample. Moreover, Cd has a very strong self-shielding effect, and its geometry is very crucial. Thanks to its geometry effects and particularities in the γ emitted spectrum, the Cd sheet in the beam should be still considered among the worst-case samples. As an example of common samples measured on the engineering diffractometers, we can mention stainless steels (8-18% of Ni) or Ni-based superalloys for turbine blades (around 80% of Ni) with the sample size covering the whole incoming beam.

The worst neutron scattering sample considered for BEER is water. There is no intention to measure water directly except of small amounts used for the calibration of SANS. However, neutron beam can also accidentally interact with hydrogen e.g. in a sample environment (SE) cooled by water or during measurements of samples containing parts with plastic or liquids with high hydrogen content. The shape of the water sample is crucial because water itself has a very strong shielding effect. To minimise the influence of the sample shape, in the case of simulations, the worst-case neutron scattering sample should be replaced by an ideal neutron point source with isotropic distribution and total intensity equal to the time-averaged integral intensity of the whole cross-section of the incident beam.

The size of the sample also plays an important role. BEER will handle the samples of very various sizes starting at millimetre up to the meter scale. The most problematic are the samples of the size similar to the beam size. A bigger sample causes a stronger self-shielding effect where a part of the sample, which is not irradiated, shields the irradiated part. A bigger sample doesn't imply worse dose rates.

For the purpose of the definition of H1 and H2, three "worst-case" samples in the sense of composition and size were selected, and their characteristics are described below:

- **The worst γ emitting sample (WGE)** – pure Ni sample with the size of 4.4x4.4x1.5 cm^3 (1.5 cm is the thickness along the beam) considered in combination with the maximum beam cross-section (AFB and MWB) or with the size of 1.2x2.2x1.5 cm^3 (1.5 cm is the thickness along the beam) considered in combination with MOB.
- **The worst neutron scattering sample (WNS)** – an ideal isotropic neutron point source with intensity and spectrum equal to the integral intensity and spectrum of the full cross-section of the incoming beam.
- **Cd sheet in the beam (CDB)** – 1 mm thick Cd sheet covering the beam size and rotated by 45˚ in both directions.

The above-mentioned samples cover all the other possibilities in the sense of composition and size. No other samples need to be therefore considered for the shielding simulations.

5.2. Sample environment

The measurements on the BEER instrument include different sample environments (SE). They can be made from different elements. The design of SE is such that only a very small part of the SE is directly in the beam. Mainly it deals with the outer walls made preferably from aluminium.

In the accident scenario, it is assumed that the SE is misaligned and the bigger part of the SE is in the beam. Taking into the consideration usual materials from which the SE is constructed, the worst-case samples described above cover any hazardous situations with misaligned SE. Then **misaligned SE is therefore not considered** in the H1 and H2 scenarios.

5.3. Neutron guide

The supermirror coating of the neutron guide is made from Ni/Ti layers. Prompt-γ radiation is produced by the capture of neutrons in the supermirror coating and glass substrate containing boron. Prompt γ radiation from neutron capture by Ni nuclei makes a dominant contribution to the total dose rate behind neutron guide shielding due to the large fraction of high energy photons in the emitted spectrum. The geometry of the neutron guide, together with substrate materials and the m-values along the whole distance is described in the *Optics Report for the BEER instrument* [4] and in the *Neutron optics specification table* [6].

5.4. Chopper, beam-stop and slit system

The usual material used for stopping the thermal-neutron beam on choppers, jaws or beam-stops is boron-containing material, mainly compounds with high boron content like B_4C. After the interaction of neutrons with boron, prompt-γ radiation is emitted. In the case of the beam-stop, the borated material is embedded in the lead structure, which shields prompt-γ radiation emitted from boron. The above-mentioned neutron-stopping systems are designed to be used during the normal instrument operation, and so they need to be considered for the H1 events.

5.5. Heavy shutter

The purpose of the heavy shutter is to stop full neutron beam (thermal and fast) coming downstream from the bunker. The heavy shutter has been designed a sandwich of 1 cm of B_4C, 50 cm of copper and 10 cm of HDPE with 5% of boron. Because the heavy shutter is planned to be used during the standard mode of operation, it is considered to be in the position blocking the beam for H1 events when users are allowed to access the experimental cave.

6. ESS SHIELDING DESIGN REQUIREMENTS

The instrument shielding will be designed to be in accordance with *General Safety Objectives* [1], *ESS procedure for designing shielding for safety* [7], and also satisfy the dose limit requirements for the non-designated zones and supervised areas mentioned in *Radiological requirements and guidelines for instrument shielding design* [8].

7. H1 AND H2 EVENTS FOR BEER

The operational scenarios (H1) of the BEER instrument and the possible accidents (H2) have been identified and assessed and are listed in Table 2 and Table 3, respectively. They include the scenarios for all the shielding structures described in 2.2.

The scenarios H1.1-H1.6 listed in Table 2 have to be considered and evaluated for the design of the shielding structures of the heavy shutter pit, chopper pit and neutron guide tunnel. The scenarios H1.7-H1.10 are than relevant for the cave shielding design.

Table 2 – List of H1 scenarios for BEER.

#	Cause	Event	Notes:
H1.1	Fast neutrons at 5 MW leaking from the bunker.	The **BEB** is hitting the closed heavy shutter.	Part of the simulation of the guide shielding.
H1.2	Fast neutrons at 5 MW leaking from the bunker.	The **BEB** enter the shutter pit when heavy shutter is open.	Part of the simulation of the guide shielding.
H1.3	Fast neutrons at 5 MW leaking from the shutter pit.	The **BEB** hitting the closed heavy shutter and propagates out of the shutter pit.	Part of the simulation of the guide shielding.
H1.4	White-beam chopper setup[2].	The **NGEB** interact with the neutron guide.	Part of the simulation of the guide shielding.

[2] For description of "White-beam chopper setup" see 3.1.1.

#	Cause	Event	Notes:
H1.5	White-beam chopper setup[2], the FC2 choppers are closed.	The **BM6** hits the B_4C on the chopper disk.	Part of the simulation of the guide shielding.
H1.6	White-beam chopper setup[2], the first slit is closed.	The **BM7** hits the B_4C on the slit's jaws of SL1.	Partially closed slits for imaging and SANS.
H1.7	White-beam chopper setup[2], the sample slit (SL3) is closed.	The **AFB** hits the B_4C on the slit's jaws of SL3.	Definition of gauge volume in the sample.
H1.8	White-beam chopper setup[2], sample slit (SL3) installed, all slits open, neutron scattering sample.	The **MOB** hits **WNS**.	Expected during standard diffraction measurement tune-up. It supersedes all other samples and modes.
H1.9	White-beam chopper setup[2], sample slit (SL3) installed, all slits open, γ emitting sample.	The **MOB** hits **WGE**.	It supersedes H1.7. Expected during standard diffraction measurement tune-up. It supersedes all other samples and modes.
H1.10	White-beam chopper setup[2], sample slit (SL3) installed, all slits open, no sample.	The **MOB** hits the beam stop.	Expected during beam analysis procedures.

Table 3 – List of H2 scenarios for BEER. Lighter shade of the scenarios (H2.1-H2.3) signify that those have likelihood of occurrence more than once a year. The darker shade (H2.4-H2.7) represent sever accident with a very low probability.

#	Cause	Event	Notes:
H2.1	White-beam chopper setup[2], sample slit (SL3) installed, all slits open, neutron scattering sample.	The **AFB** hits **WNS**.	It supersedes H1.8. Expected during mode switch.
H2.2	White-beam chopper setup[2], sample slit (SL3) installed, all slits open, γ emitting sample.	The **AFB** hits **WGE**.	It supersedes H1.9. Expected during mode switch.
H2.3	White-beam chopper setup[2], sample slit (SL3) installed, all slits open, no sample.	The **AFB** hits the beam stop.	It supersedes H1.10. Expected during mode switch.
H2.4	All choppers stopped-open, sample slit (SL3) not installed, all slits open, neutron scattering sample.	The **MWB** hits **WNS**.	This supersedes H2.1. Severe accident scenario.

#	Cause	Event	Notes:
H2.5	All choppers stopped-open, sample slit (SL3) not installed, all slits open, γ emitting sample.	The **MWB** hits **WGE**.	This supersedes H2.2. Severe accident scenario.
H2.6	All choppers stopped-open, sample slit (SL3) not installed, all slits open, γ emitting sample.	The **MWB** hits **CDB**.	Severe accident scenario.
H2.7	All choppers stopped-open, sample slit (SL3) not installed, all slits open, no sample.	The **MWB** hits the beam stop.	It supersedes H2.3 Severe accident scenario.

8. SHIELDING STRATEGIES FOR BEER

All the shielding structures (see Chapter 2.2) will be designed in such a way that they will provide sufficient **passive biological shielding** to satisfy the **supervised area** requirement within all relevant halls (D03, E02 and E01) according to [9] for **all H1** on all surfaces **except roof**. The explanation is provided below.

Passive shielding to supervised area limits will also be provided for H2 events with a likelihood of occurrence of more than once a year (H2.1-3 and H2.7). Less likely H2 events (H2.4-6) will also be covered by passive shielding as much as reasonably possible. When not possible, due to technical and financial reasons, the possible mitigation strategies described below will keep the exposure doses below the 1 mSv limit set for the H2 event [8].

8.1. Experimental cave roof

The preliminary cave design and shielding calculation reveals that it will be very difficult (if possible, at all) to satisfy the E01 hall requirements for the floor load (20 t/m^2) [10] when the roof is designed to fulfil the supervised area requirement. Therefore, the shielding strategy for the **roof surface** will be relaxed to the **blue-controlled zone** according to [9] which will not affect the radiation dose limits of non-designated zones as it is explained and proposed by *Radiological requirements and guidelines for instrument shielding design* [8]. The access to the roof will be controlled by locked fence with a PSS key management and administrative measures to ensure safety considerations. There are no planned activities such as sample storage or sample preparation related to the cave roof. This space will be kept empty during instrument operation.

8.2. Shielding simulation

Based on the above-mentioned analysis of the possible operation and accident scenarios, following scenarios or situations are proposed for further detailed analysis during the process of the shielding design and to be considered as basis for the dedicated radiation report:

#	Cause
Shutter pit	

H1.1	Fast neutrons with the heavy shutter closed
H1.2	Fast neutrons with the heavy shutter open
H1.3	Fast neutrons with the heavy shutter open in the guide after
Chopper pit	
H1.5	Chopper disk in the beam
Neutron guide tunnel	
H1.4	Beam in the neutron guide
H1.6	Beam hits the closed slits
Experimental cave	
H2.1	Worst neutron scattering sample in the maximum useful beam
H2.2	Worst γ emitting sample in the maximum useful beam
H2.3	Maximum useful beam on the beam-stop
H2.4	Worst neutron scattering sample in the maximum beam
H2.5	Worst γ emitting sample in the maximum beam
H2.6	Cd sheet in the maximum beam
H2.7	Maximum beam on the beam-stop

9. MITIGATION STRATEGIES FOR H2 EVENTS

The expected H2 events listed in Table 3 can be grouped by their severity and probability. The scenarios dealing with **AFB** (H2.1-H2.3) are considered as likely accidents which are expected to occur several times a year. And the designed instrument shielding will be able to shield them passively. The other H2 scenarios (H2.4-H2.7) deal with **MWB**, which is the worst-case scenario when all choppers are stop-open and all slits are fully open or removed, hitting the worst-case samples. Those are considered as severe accidents.

The mitigation actions in a case of the H2 events are linked to preventing the situation that the instrument is in the **AFB** or **MWB** mode. Mitigating the worst-case sample in the beam is more difficult as those samples will be commonly measured on the BEER instrument.

The mitigation actions have two aspects. One is prevention that **AFB** or **MWB** mode happens, and the other one deals with its quick detection. Below is a list of some possible actions that could be applied:

- Proper design of the instrument control software which should mainly
  - **Not** allow **changing** the **FC** setup with the **shutter open**
  - Raise the **alarm** if FC chopper is malfunctioning (stop or not in phase)
  - Raise a **warning** when SL1 is changed to fully open state in imaging mode
  - Allow **access** to the setup of the FC choppers only **to privileged users**
  - **Not** allow the **opening** of the **shutter** when **FC** is **malfunctioning**
  - ...
- The output of the sample monitor readout above the threshold set on 1.2x**AFB** should raise the **alarm** in the instrument control hutch

- When setting up an imaging experiment (switching to the imaging mode), the **permanent presence** of qualified personnel in the control hutch will be required to survey the process.

The final decision about the mitigation actions applied in reality will be taken based on the engineering design and are not in the scope of this document.

10. GLOSSARY

Term	Definition
AFB	Accidentally Full Beam
BEB	Bunker Exit Beam
CDB	Cadmium in the beam
FC	Wavelength selection chopper
GEX1	Neutron guide on exchanger – focusing nose (option 1)
LOS	Line-of-sight
MC	Modulation chopper
MOB	Maximum Operational Beam
MWB	Maximum white beam
NGEB	Neutron Guide Escape Beam
PS	Pulse shaping chopper
PSS	Personal Safety System
SANS	Small angle neutron scattering
SE	Sample environment
SL1, 2, 3	Slit system 1, 2 or 3
WGE	Worst prompt-γ emitting sample
WNS	Worst neutron scattering sample

11. REFERENCES

[1] General Safety Objectives for ESS (ESS-0000004)
[2] NOSG phase 2 guidelines for designing instrument shielding for radiation safety (ESS-0052625)
[3] BEER – Concept of operations (ESS-0124310)
[4] Optics Report for the BEER Instrument (ESS-0238217)
[5] https://www-nds.iaea.org/pgaa/pgaa7/index.html
[6] BEER Optics Specification (ESS-0478295)
[7] ESS Procedure for designing shielding for safety (ESS-0019931)

[8] Radiological requirements and guidelines for instrument shielding design (ESS-1108220)

[9] ESS Handbook for Radiation Protection Chapter 2. General Radiation Protection Rules (ESS-0239718)

[10] ESS – Instrument Technical Interfaces (ESS-0403282)

DOCUMENT REVISION HISTORY

Revision	Reason for and description of change	Author	Date
1	First issue	Premysl Beran	2019-07-29