Document Type	Report
Document Number	ESS-0068567
Date	Feb 17, 2017
Revision	1
State	Released
Confidentiality Level	Internal
Page	1 (12)

NSS handbook assessment for the contributions of the NSS work areas to the dose at the site boundary through skyshine

	Name	Role/Title
Owner	Stuart Ansell Monika Hartl	Senior Beamline Scientist, NSS Scientist, NSS
Reviewer	Gunter Muhrer Phil Bentley	Group Leader Target Physics, Target Division Group Leader Neutron Optics and Shielding Group
Approver	Arno Hiess Peter Jacobsson	Head of Scientific Activities Division Head of Environment Safety & Health Division

TABLE OF CONTENT **PAGE**

1. PURPOSE

The purpose of this report is to assess the dose contribution from Neutron Scattering Systems (NSS) workspaces to the reference person at the side boundary. The main dose contributions from skyshine to a person at the site boundary will arise from the bunker and instruments. The much smaller contribution that could potentially arise from the remaining NSS workspaces (laboratories and workshops) will be regulated through administrative controls to be less than 1 μSv/year so that the sum of all contribution will not exceed 5 μSv/year.

2. METHODOLOGY

The dose contribution of the bunker and instruments at the side boundary through skyshine was assessed using analytical formulas as described in A.H. Sullivan [1].

3. ACCEPTANCE CRITERIA

In accordance with the ESS General Safety Objectives [2] the combined dose to the public emitted from ESS shall not exceed 50 μSv/year. Of these 50 μSv/year, 5 μSv/year have been allocated for NSS.

4. ASSUMPTIONS

4.1. Contribution areas

4.1.1. Bunker

The bunker sits in the middle of the instruments surrounding the target monolith. The contribution of the bunker to the skyshine can be approximated by assuming the bunker to be a uniform circle section that starts 6 m from the target center (blue area in Figure 1). The target contribution to the skyshine up to the 6 m, inner part of the circle, is accounted for in the target station contribution to the dose at the site boundary (ESS-0065565).

The bunker covers an area of 2x 120° of the circle (white areas in Figure 2), so surface area assumed for skyshine will be 2/3^{rds} of the total area. The radius of the circle is in two sectors 28 m and in the other two sectors 15 m. The bunker surface has a maximum leakage of 1 μSv/hr as stated in [3].

The shortest distance from the bunker center to the respective site boundary is 275 m (measured from [4]).

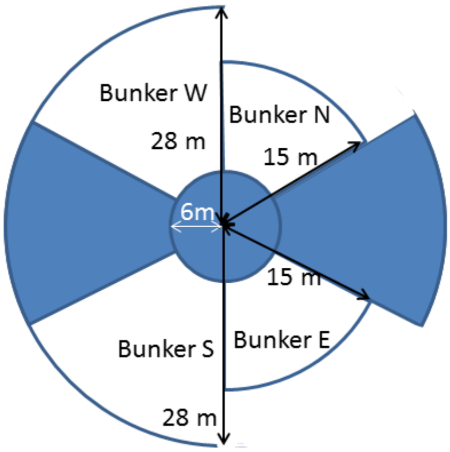

Figure 1: Contribution areas (white) from the bunker. The length of the bunker in the S and W sectors is 28 m, while the length of the bunker in the E and N sectors is 15 m.

4.1.2. Instruments

In order to illustrate the assumptions made for the instruments, Figure 2 shows a layout of the instruments planned in their respective sectors. The number of instruments is given with an indication for the yet unassigned instrument to be added to long sections (West and South) amounting to a total of 22 instruments. This is the most conservative approach since these instruments will contribute most to the skyshine. The shielding of the instruments is designed for 1 μSv/hr (ESS-0052625 - The safety margin for calculating the dose level has a safety factor of 3 for analytical calculations and a safety factor of 1.5 for approved Monte-Carlo packages). At distances longer than 20 m (outside the bunker) the gamma flux will dictate the shielding design and thickness, implying the skyshine will be actually repressed even more than calculated in this document just by the required shielding of the beamline. This is assuming the shielding thickness is constant or increasing along the beamline, which is a reasonable assumption.

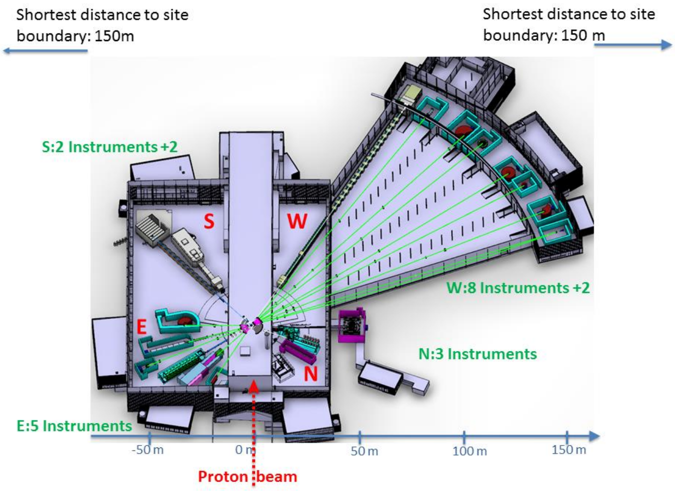

*Figure 2: Instrument layout for the planned instruments in the four sectors (**N**orth, **E**ast, **S**outh, **W**est) with the minimum distance to the site boundary on each side of 150 m. The number of instruments is given in green with the not yet decided instruments (4) being assumed to be in the long sectors (+2 in W, +2 in S).*

The contribution of the instruments to the skyshine can be approximated by assuming that the shielding on each beamline will be in average 1m wide x 1m tall. Summing up the surfaces, each beamline has an effective surface area width estimated conservatively at 3 m (two sides with 1 m plus one roof with 1 m -see Figure 3).

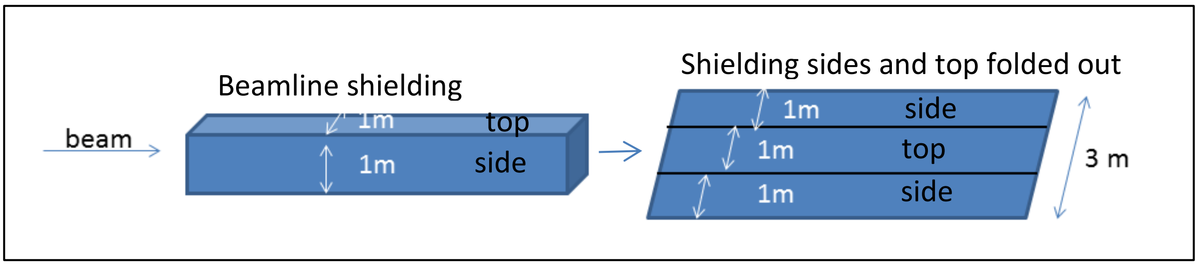

Figure 3 : Scheme to describe the effective surface area width of 3m assumed for the instruments

For the non-straight instruments the bent occurs at 40 m or less (get lost point of bender). Once the instruments are out of line of sight from the moderator the transported beam will no longer contain any significant fraction of high energy hadronic particles that cause the skyshine. It can therefore safely be assumed that the contribution from the bent beamlines to the skyshine after this point can be neglected.

In the case of a straight beamline, the high energy hadronic flux transported by the beamline falls off following the inverse square law, with the moderator being the point of origin. At the same time, the beam line shield thickness, as mentioned above, will not change significantly from 20 m outward because the shielding configuration will be driven by the guide losses and the gamma captures resulting from these losses. Outwards from 20 m the contribution to skyshine become dominated by gamma. For the purpose of this estimate, it is therefore fair to assume, that the leakage of high energy hadrons will fall of following the inverse square law $\phi \sim \frac{1}{R^2}$ (R: distance) at each point along the beamline. Thus we integrate the contribution from the beamline assume that 100% of the dose come from high energy neutron up to 20 m and then the dose is proportional to $1/R^2$ relative to the 20 m point (i.e. at 40 m we assume that ¼ of the dose is from high energy neutrons). This is continued to either the end of the beamline or to the get lost point of the bender.

The length of instrument covered by the bunker is 28 m for the W and S sector and 15 m for the N and E sector.

Below, the shortest distance from the end of the instrument hall to the respective site boundary is given. The distances can be measured from [4]:

W-sector: 180 m	N-sector: 310m
E-sector: 220 m	S-sector: 216 m

It can be stated, that this is a conservative approach, because of constraints of the highway E22 and the science village not being allowed to house permanent residents, the closest permanent resident will life about 500 m from the origin of the target coordinate system (ESS-0035090).

W sector: 10 instruments with a total surface of 360 m^2 at a minimum distance of 290 m from the site boundary.

The instrument length for the ten long, bent instruments in the W sector is 150 m. For the calculation an instrument length of 40 m from the target will be considered since all ESS instruments will be out of line of sight from the moderator at 40 m (get lost point of the bender). So the instrument contribution to skyshine not covered by the bunker calculation that will be considered results from a length of 40m-28m=12m resulting in 12m*3m*10=360m^2 surface. That also means that the instruments are all at least 180 m (instrument hall to site boundary) + 150 m -40 m (distance from 40 m to end of hall) = 290 m distance from the site boundary.

N sector: 3 instruments with a total surface area of 225 m^2 at distance of 320 m from the site boundary.

The maximum instrument length for the 3 bent instruments in the N Sector is 50 m. For the calculations, the instrument length considered is 40 m (get lost point of bender). The resulting length of instrument outside the bunker is 40m -15m = 25 m. The surface area of the instruments is 25m*3m*3=225m^2. The distance from the end of the instrument hall to the site boundary is 310 m, so the shortest distance from the end of the instrument to the site boundary is 320 m (310 m + 50m -40m).

E sector: 5 instruments with a total surface area of 435 m^2 at a distance of 250 m from the site boundary.

The instrument length for the four bent and one straight instruments in the E sector is 60 m. For these instruments, the instrument length for the skyshine calculation will be 40 m from the target (get lost point of bender). The instrument contribution to skyshine not covered by the bunker calculation that will be considered results from a length of 40m-15m=25m for the bent instruments and 60m-15m=45m for the straight instrument leading to a surface area of (25m*3m*4) + (45m*3m*1)=435 m^2. The instruments are all at least 250m distance from site boundary: 220m (instrument hall to site boundary) + 60m -30m (average distance from end of the four instruments to the end of hall) = 250 m distance from the site boundary.

S sector: 4 instruments with a total surface area of 744 m^2 at a minimum distance of 275 m from the site boundary.

The instruments in the S sector are straight (4x 90m). For these instruments, the instrument length for the skyshine calculation will be 90 m from the target. The instrument contribution to skyshine not covered by the long bunker section will be 90m-28m=62m leading to a considered surface area of 62m*3m*4=744 m^2. The instruments are all at least 275 m from the site boundary: 216m (instrument hall to site boundary) +

90m -28m (distance from bunker wall to end of hall) = 275 m distance from the site boundary.

4.2. Distance to the site boundary

Distances to the site boundaries have been determined using [4].For the purpose of this report, we will consider the skyshine at two sets of points:

(1) It is assumed that the reference person is located right at the site boundary at the closest position (Figure 4, blue arrows). We will construct a map showing the skyshine across the ESS site and the site boundary.

(2) The coordinates given by D. Ene are depicted as blue stars in Figure 4. These coordinates are called “ESHcoordinates” in this document and labelled according to input by D. Ene.

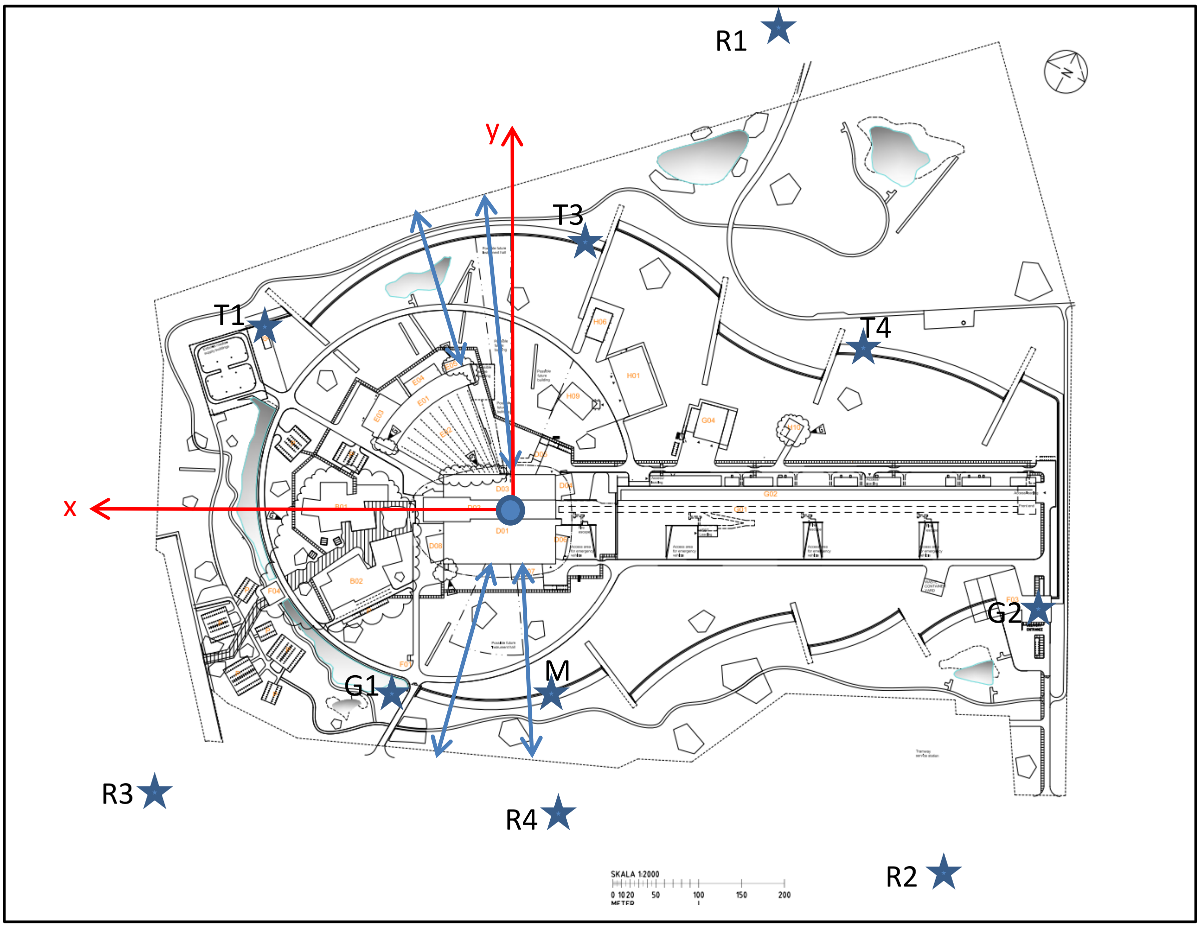

Figure 4: ESS-site with the site-boundary drawn as dashed line [4]. Blue arrows are indicating the shortest distance between the instrumental hall and the site boundary for all four sectors. Blue stars indicate the coordinates given by D. Ene and are labelled according to table 1.

We will use the center of the bunker as origin for our coordinate system and the direction of the beam towards the target as (x,0,0). This is the target coordination system (ESS-0030590). The origin of the “ESHcoordinates”given by D. Ene is the entrance of the front end of the accelerator. We changed the axes of the system of D. Ene to be x=z(D. Ene), y=-y(D.Ene), z=x(D.Ene). The “ESHcoordinates” x and y are given in the first two columns of Table1. Now we can shift the origin of the “ESHcoordinates” to the center of the bunker. The entrance of the accelerator is located relative to the new origin at (-590, 13,0) which is the target coordination system (see x” and y” in columns 4 and 5 of Table 1).

Table 1: Coordinates of locations of interest for skyshine.

Receptor	**ESH coordinates (original)**		**target coordinates (new origin= bunker, x-direction along accelerator in direction of beam)**			
	x/m	**y/m**	**x"/m**	**y"/m**	**distance from center/m**	**angle of vector /°**
R1	272	576	-318	589	669.36	-118.36
R2	112	-448	-478	-435	646.30	-137.70
R3	1024	-280	434	-267	509.55	-31.60
R4	552	-368	-38	-355	357.03	-96.11
G1	712	-224	122	-211	243.73	-59.96
G2	0	-128	-590	-115	601.10	-168.97
M	552	-224	-38	-211	214.39	-100.21
T1	864	192	274	205	342.20	-36.80
T3	376	248	-214	261	337.52	-129.35
T4	200	152	-390	165	423.47	-157.07

4.3. Operating hours

In the case of NSS, maximum annual operation of the bunker and instruments is limited to 5400 h [5]. The remaining workspaces will possible operated year round.

5. LIMITATIONS

The estimated skyshine is limited to normal operation.

6. COMPUTER HARDWARE AND SOFTWARE

- No hardware requirements.
- The C++ code used for integrating over the whole area is attached to this documentation as a compressed file containing the source code as well as the make file. The center of the bunker is the origin of the coordinate system and the target coordination system is used. The (1,0,0) vector runs in the same direction as the protons travel and positive x is after the proton-target impact point. Vector (0,1,0) is in the horizontal plane, pointing towards North.

7. CALCULATIONS

In accordance with [1] the skyshine of an accelerator driven facility can be estimated with the following formula (equation 2.41 in [1]):

$$H = 7 * 10^4 \frac{e^{-\frac{R}{600}}}{R^2} \sum_{1}^{n} H_i A_i,$$

where H is the dose at the side boundary in [μSv/h]. R is the distance between the end of the beamline and the side boundary in [m]. $\sum_1^n H_i A_i$ is the combined hadron dose equivalent rate in [Sv/h] at the leakage surface times the surface area in [m^2], with H_i being the hadron dose equivalent rate in [Sv/h] emitted by the surface area A_i in [m^2].

7.1. Skyshine

The calculated dose levels are shown in Table 2. The locations are marked in Figure 3 and the coordinates are listed in Table 1.

As can be seen, all locations inside and outside the contribution of skyshine from NSS to the ESS site and boundary are below a yearly dose of 4 μSv.

Table 2: Locations and their yearly respective dose calculated using conservative assumptions.

Location	dose / μ Sv/y
R1	0.175
R2	0.16
R3	0.34
R4	0.89
G1	2.3
G2	0.21
M	3.21
T1	0.98
T3	1.1
T4	0.58

A complete skyshine map shows the dose rates at each point of the ESS site (Figure 5).

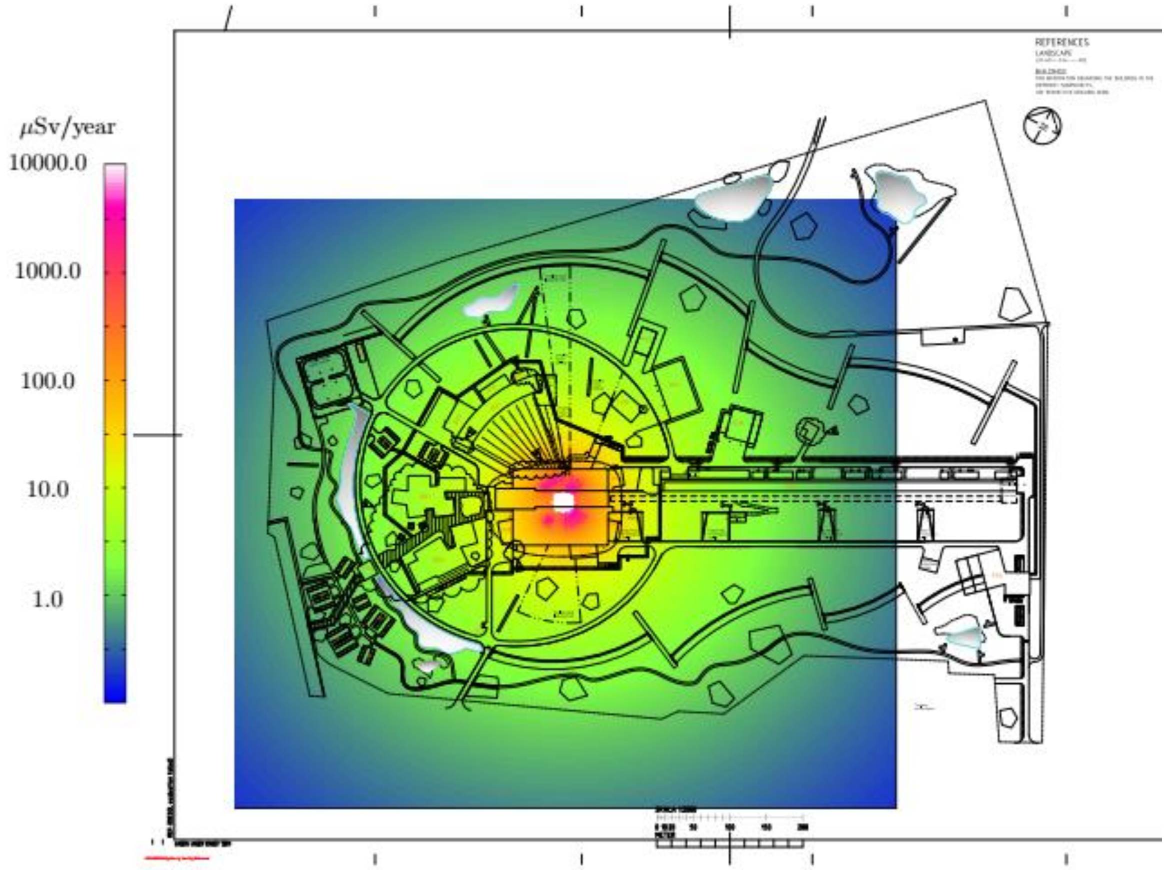

Figure 5: Dose map with skyshine contributions from NSS to the site and site boundary.

8. CONCLUSIONS

A conservative estimate of the skyshine contribution from the Neutron Scattering Systems (NSS) workspaces has been performed using an analytical formula. Since the exact design of instruments is not known at this stage, a very conservative approach has been used to estimate the level of skyshine caused by the instruments and bunker. The handbook estimate describe in this document shows that it is possible to reduce the skyshine at the site boundary with our current shielding policy to less than 3.5 µSv/year coming from the NSS areas. The instruments at their later design stages before hot-commissioning will perform Monte-Carlo simulations to determine their specific skyshine impact.

9. GLOSSARY

Term	Definition
ESS	European Spallation Source
NSS	Neutron Scattering Systems

Term	Definition
ESS	European Spallation Source

10. REFERENCES

[1] A.H. Sullivan, A Guide to Radiation and Radioactivity Levels Near High Energy Particle Accelerators, Nuclear Technology Publishing, 1992.

[2] Thomas Hansson, General Safety Objectives, ESS-0000004.

[3] ESS-0052649, Neutronic Design of the Bunker.

[4] Siteplan-Overview Building Numbers, A01-01---1-A-----002

[5] J. Haines, Updated Report on Operations, ESS-0011768.

DOCUMENT REVISION HISTORY

Revision	Reason for and description of change	Author	Date
1	First issue	Stuart Ansell, Monika Hartl	2016-10-10