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Report on air activation within bunker

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SUMMARY

The inside of the bunker at the ESS will be an area with high radiation levels. The air contamination that is likely to arise as a consequence of this will need to be considered in the design of the bunker. This report gives an estimation of the levels of air contamination and presents solutions for how this can be mitigated.

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1. BACKGROUND

The inside of the bunker will be an area with high radiation levels. The air within the bunker will potentially become activated. The possible consequences that arise from the air contamination must be considered in the design of the bunker and its potential ventilation system.

The potential activation of the air inside the bunker has to be evaluated in respect to the dose to the worker and the dose the public. To make this evaluation, it is necessary to know the activated air concentration within the bunker and the amount of activated air that could be released to the environment. For this reason, two scenarios have been evaluated:

1. The bunker operated without ventilation, will be the worst-case for the worker operating in the experimental halls.
2. The bunker operated with a ventilation system, and the resulting unmitigated emissions to the environment will describe the worst-case scenario to the public.

This document will estimate these values and discuss how we can mitigate for them.

2. AIR CONTAMINATION IN ESS BUNKER

To determine the Derived Air Contamination (DAC) in the bunker, the incoming neutron beam from the target will be considered as the dominant source term.

The main source term for the air activation in the bunker is due to the neutrons generated in the target-moderator system and emitted from the monolith through the openings in the neutron beam port inserts. While there may be other source terms within the bunker [1], they can be considered second order effects when it comes to activating the air within the bunker. Several isotopes present in air may become activated, however most of these are extremely short-lived. The exception is Ar^{41}, which has a half-life of a few hours [2]. We therefore determine the Derived Air Contamination (DAC) based on the activation of argon (present naturally in air within the bunker) by neutrons entering the bunker.

The calculation is shown in detail in Appendix A with the main conclusion shown in Table 1. It shows that during the steady state operation of the ESS, the inside of the bunker will have a C4 containment area classification [3], if no mitigation measures are implemented. Within 13 hours of beam shutdown, due to the decay of Ar^{41}, the air activation will have decreased far enough that the inside of the bunker can be classified as containment area classification C1. As mentioned above, these levels for air activation are a worst-case scenario, assuming that a significant fraction of the thermal neutrons are not contained within the neutron guides, and that no mitigations have been put in place.

Element	Product	Half-life	Exposure time for activation (10 x half-life)	Activation at shutdown [MBq]	DAC at shutdown*	DAC at shutdown**
Ar^{36}	Ar^{37}	34.8 d	350 d	24.2	$2.98*10^{-7}$	$1.99*10^{-9}$
Ar^{40}	Ar^{41}	1.83 h	24 h	852	13.6	0.09

* No absorber ** With absorber (factor 150)

Table 1: Summary of activation levels within the bunker, with and without mitigation

3. HANDLING OF AIR ACTIVATION

As shown in Table 1, the air contamination inside the bunker in the unmitigated case is on the order of 13 DAC. Without any requirements on the air tightness of the bunker, this poses a risk of elevated air activation in the experimental hall, which would not allow the experimental halls to be operated as supervised areas. In order to ensure that the experimental halls can be operated as supervised areas two mitigations have been investigated.

3.1. Ventilation system

An HVAC system could be installed for the bunker. This would lead to a follow-on requirement on the leak tightness of the bunker. In addition it will not provide any mitigation to decrease the activation of the components within the bunker, making their removal for maintenance or exchange in a timely fashion potentially difficult. The levels of release to the environment, when ventilating without a delay line, are shown in Appendix B.

3.2. Absorber for neutron guides

All neutron guides within the bunker could be wrapped with a neutron absorbing material. With this solution, the air activation levels are reduced by a factor 100-1000. Secondly, this will also significantly reduce the activation of the other components within the bunker, making their removal and maintenance potentially far simpler.

This solution would lead to a requirement to place air activation monitors on the outside of the bunker, in order to monitor possible activated air leakage, and to evacuate the given experimental hall should the air activation level become too high.

Possible accident scenarios have been considered and are documented in [4].

4. CONCLUSION

Based on the presented data, it has been decided to make it a safety requirement to coat the neutron guides within the bunker with a suitable neutron absorber, to mitigate the air activation levels inside the bunker and thereby ensure that the experimental halls can be operated as supervised areas. The requirement on the absorber shall be described in more detail in the NOSG handbook [4]. Air activation monitors will need to be placed on the outside of the bunker, in order to detect potential variances and initiate evacuation from the experimental hall should the activation levels become too high outside the bunker.

5. GLOSSARY

Term	Definition
DAC	Derived Air Contamination
NIST	National Institute of Standards and Technology
HVAC	Heating ventilation air conditioning
NSS	Neutron scattering systems

6. REFERENCES

[1] ESS Document ‘Neutronic design of the bunker’: ESS-0052649
[2] LA-14407-ENV ‘Environmental Surveillance at Los Alamos during 2008’
[3] SS-ISO 17873:2011
[4] ESS Document ‘European Spallation Source Neutron Optics Guidelines, Requirements and Standards’: ESS-0039408
[5] CRC Handbook of Chemistry and Physics 96th Edition, Section 14-20
[6] https://www.ncnr.nist.gov/resources/activation/
[7] IAEA Safety Standards Series No. GSR Part 3 (2014)
[8] MCNP(x) model 0aa7c76cc (S. Ansell)

DOCUMENT REVISION HISTORY

Revision	Reason for and description of change	Author	Date
1	First issue	Melissa Sharp	2016-04-02

APPENDIX A

Steady state production of Ar^{41}

The production term is obtained from the flux at point of interest Φ [n/cm^{2}s], the absorption cross section σ_{abs} of the elements in the material [barn], the atomic density of the material ρ [atoms/barn*cm], the volume of material hit by the beam [cm^3]

$$P\left[\frac{atoms}{s}\right] = \phi\ \sigma_{abs}\ \varrho\ V$$

The flux can be expressed as:

$$\phi = \frac{J_{total}}{V}\bar{d}$$

With J_{total} being the total flux in [n/s], V being the volume [cm^3] and $\bar{d}$ being the average distance that a neutron can cover in the volume V.

$$P\left[\frac{atoms}{s}\right] = J_{total}\ \bar{d}\,\sigma_{abs}\ \varrho$$

The activation is calculated as follows with $t_{1/2}$ being the half-life of the respective isotope:

$$A(t)=P*\left[1-e^{-\lambda t}\right] \quad \text{with } \lambda = \frac{ln2}{t_{1/2}}$$

The activation in [Bq] becomes equal to the production term when the time of exposure t goes towards infinity ($t \to \infty$) and $e^{-\lambda t}=0$.

For ($t \to \infty$): A[Bq] = P

The absorption cross section σ_{abs} is isotope specific and taken from accepted references.

The following assumptions have been made:

1. The ESS has one bunker, split into 2 halves (with each half containing 2 sections), see Figure 1.

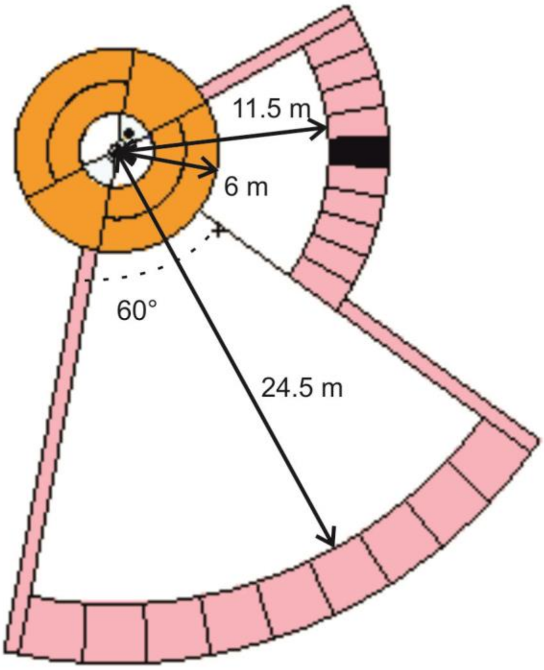

Figure 1 Sketch of the bunker layout

2. Each bunker half contains 21 beamports, giving a total of 42 beamports
3. Each beamport has dimensions 10x10 cm^2
4. The neutron flux exiting each beam port is approximately $3*10^{10}$ $n/cm^2/s$ [8]
5. This means the total flux, entering each bunker half is:

$$J_{total} = 21 \times (10\times10)cm^2 \times 3*10^{10}\ n/cm^2/s = 6.3*10^{13}\ n/s$$

6. Most neutrons will travel along the neutron guides, which are under vacuum. For this calculation we will assume that the guides have a reflectivity coefficient of 90%, such that 10% of the neutrons escape and enter the air of the bunker. This gives a total neutron flux of $J_{corr.total}$=$6.3*10^{12}$ n/s entering each bunker half.
7. The maximum distance the neutrons could travel within the bunker is $\bar{d}$=1200 cm (12 m), based on the geometry of the bunker.
8. Since the mass density of air is 1225 g/m^3 (i.e. $1.225*10^{-3}$ g/cm^3) and the fraction of argon in air is 0.934 percent by volume [5], this means the mass density of the argon, is:

$$\rho = 1.225*10^{-3}\ g/cm^3 \times (0.934 / 100) = 1.14*10^{-5}\ g/cm^3$$

With the molecular weight M(Ar)=39.95 g/mol and Avogadro's number being $6.022*10^{23}$ atoms/mol, we obtain for the atomic density:

$$\rho = 1.14*10^{-5}\ \text{g/cm}^3 / 39.95\ \text{g/mol} \ * 6.022*10^{23}\ \text{atoms/mol}$$

$$= 1.7*10^{17}\ \text{atoms/cm}^3$$

$$= 1.7*10^{-7}\ \text{atoms/(barn*cm)}$$

since 10^{24} barn = 1 cm^2

The abundance of Ar^{36} is 0.3365%, so ??(Ar^{36}) = $5.7*10^{-10}$ atoms/(barn*cm).

The abundance of Ar^{40} is 99.60%, so ??(Ar^{40}) = $1.7*10^{-7}$ atoms/(barn*cm).

9. The absorption cross section σ_{abs} are: $\sigma_{abs}(Ar^{36})$ = 5.2 barn and $\sigma_{abs}(Ar^{40})$ = 0.66 barn.
10. The production term for both nuclei is calculated and listed in Table 2:

$$P\left[\frac{atoms}{s}\right] = J_{total}\,\overline{d}\,\sigma_{abs}\,\varrho \quad = 6.3*10^{12}\ \text{n/s} * 1200\ \text{cm} * \sigma_{abs} * \rho$$

Element	Product	Half life	0 hrs *(24 hrs)*	0 hrs *(24 hrs)*
			µCi	MBq
Ar^{36}	Ar^{37}	34.8 d	652.8 *(639.9)*	24.1 *(23.7)*
Ar^{40}	Ar^{41}	1.83 h	$23.0*10^3$ *(2.60)*	852 *(0.096)*

Table 2: Activation levels within the bunker right after shutdown (0 hrs) and 24 hours after shutdown (24hrs)

11. Each bunker half has an air volume of 1383 m^3 leading to an activated air concentration at shutdown of $1.7*10^4$ Bq/m^3 and $6.2*10^5$ Bq/m^3 for Ar^{37} and Ar^{41}, respectively.
12. Using the immersion dose rate for Argon [7], see Table 3, we see that the concentration needed to produce 20 mSv during one working year of 2000 hours is:

$DAC_{equiv}(Ar^{37})$=0.02Sv/(immersion dose rate *2000 h)= $5.85*10^{10}$ Bq/m^3
$DAC_{equiv}(Ar^{41})$=0.02Sv/(immersion dose rate *2000 h)= $4.53*10^4$ Bq/m^3

Product	Activation at shutdown [MBq]	Activated air conc. at shutdown [Bq/m^3]	Immersion dose rate [Sv/day][Bq/m^3]	Immersion dose rate [Sv/h]/[Bq/m^3]	DAC$_{\text{equivalent}}$ [Bq/m^3]
Ar^{37}	24.1	**$1.7*10^4$**	$4.1*10^{-15}$	$1.7*10^{-16}$	**$5.85*10^{10}$**
Ar^{41}	852	**$6.2*10^5$**	$5.3*10^{-9}$	$2.2*10^{-10}$	**$4.53*10^4$**

Table 3: Summary of factors for activation calculation

13. Comparing the DAC$_{\text{equivalent}}$ with the activated concentration of the respective argon isotopes, it can be seen that we only need to be concerned about the presence of Ar^{41}. The DAC at shutdown that arises from Ar^{41} has a value of:

$$6.2*10^5/4.53*10^4 = 13.6$$

14. Within 24 hours of shutdown the DAC value has dropped to a level of $1.46*10^{-3}$, see Table 4.

Product	Activation at shutdown [MBq] *(Activation 24 hrs after shutdown [MBq])*	Activated air conc. at shutdown [Bq/m^3] *(Activated air conc. 24 hrs after shutdown [Bq/m^3])*	DAC at shutdown without the use of absorbers on guides *(DAC 24 hrs after shutdown* without the use of absorbers on guides*)*	DAC at shutdown with the use of absorbers on guides* *(DAC 24 hrs after shutdown* with the use of absorbers on guides**)*
Ar^{41}	852 *(0.09)*	$6.2*10^5$ *(69.6)*	13.6 *($1.5*10^{-3}$)*	0.09 *($10.2*10^{-6}$)*

** With absorber (factor 150)

Table 4: Summary of DAC values within the bunker

15. If the guides are coated in an absorber, the neutron flux entering the air of the bunker is reduced by a factor 100-1000. This results in a DAC value at shutdown of 0.13 – 0.013. Using an absorber of factor 150, one can therefore bring the DAC value to 0.09, making the inside of the bunker a containment area classification C1.

Caveats:

(2) not all beamports will be in use

(3) most beamports will be smaller than this

(6) this is an overestimate. With proper coating of the neutron guides, this number will be reduced by a factor 100-1000.

(7) It is very unlikely that the neutrons would travel such a long distance in air

(10) not all the neutrons entering the air will have the right energy to activate Argon

APPENDIX B

Total yearly production of Ar-41

Using the same input as above, the total amount of Ar^{41} produced in a year can be estimated by taking the amount produced in a 1-second time span (90 kBq) and scaling it up. During 200 days of operation this leads to a total release of 1.55 TBq, assuming no absorber is used to reduce the air activation levels.

It should be noted that this is the amount of Ar^{41} that could be released to the environment, if the bunker was to be ventilated.