# Source Term Estimates for the Environmental Impact Analyze of the European Spallation Source Facility.

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As other accelerator based facilities, the European Spallation Source (ESS) facility will not be a totally isolated system. It will interact with the environment. One can distinguish four types of radiological impacts: i) releases of activated air, ii) discharges of activated water, iii) activation of soil and groundwater, iv) stray radiation in the environment. The Swedish legislation requires a demonstration that the sum of the doses resulting from the exposure of any member of the public to ionizing radiation dose does not exceed the specified limit. A radiological assessment has been produced to provide that demonstration [1]. This evaluation was based upon the actual status of the ESS design as given in the Ref. [2]. This paper reports the source term estimates for the radiological assessment of the dose that would arise: i) from the routine discharge of gaseous and aqueous radioactive waste for ESS facility as well as from ii) the groundwater activation around the linac tunnel and the target station monolith foundations. Additionally, estimates of the stray radiation effects were done by coupling the results of the deep penetration calculations with analytical formula [4, 5]. Only results corresponding to routine operation conditions are reported here.

## Releases of activated air

The source term for atmospheric releases was separated into two distinct release operations: i) on-line emissions, and ii) emissions resulting from processing. Emissions through the stack into the atmosphere were derived from both accelerator tunnel (AT) and target station (TS). As basic assumption: nuclides that are emitted at a rate of 25 MBq $y^{-1}$ were accounted in the analysis.

### On-line emissions

*Table 1. Source term from the accelerator tunnel.*

| Nuclide | Chemical form | | Source Term (Bq/year) Sealed tunnel | Source Term (Bq/year) r=1/day | Source Term (Bq/year) r=0.5/day |
|---|---|---|---|---|---|
| $^{3}$H | $H_2O$ | gas | 8.80E+06 | 8.80E+06 | 8.80E+06 |
| $^{15}$O | $O_2$ | gas | 0 | 1.50E+12 | 7.50E+11 |
| $^{41}$Ar | Ar | gas | 6.60E+08 | 4.10E+10 | 2.00E+10 |
| $^{11}$C | $CO,CO_2$ | gas | 1.20E+09 | 2.60E+12 | 1.30E+12 |
| $^{7}$Be | $BeO_2$ | aerosol | 1.00E+07 | 1.00E+07 | 1.00E+07 |
| $^{13}$N | $NO_2$ | gas | 3.50E+07 | 2.70E+12 | 1.30E+12 |
| $^{7}$Be | $BeO_2$ | aerosol | 1.00E+07 | 1.00E+07 | 1.00E+07 |
| $^{32}$P | | aerosol | 2.50E+05 | 6.9E+05 | 6.9E+05 |
| $^{33}$P | | aerosol | 5.61E+05 | 1.1E+06 | 1.1E+06 |
| $^{35}$S | | aerosol | 1.57E+05 | 2.0E+05 | 2.0E+05 |

The justification for setting the cut-off at this level of activity is that the most radiotoxic nuclide in the facility is $^{148}$Gd, and a release of 25 MBq/y of $^{148}$Gd would give a dose of 10μSv to the nearest neighbour. Other isotopes have significantly lower dose factors for all pathways and the highest dose due to 25MBq $y^{-1}$ release of any potential radionuclide considered for airborne dose assessment is from $^{125}$I, at 0.2 μSv. However, in case of a future agriculture critical group $^{32,33}$P and $^{35}$S were accounted also. Table 1 gives the source term for the AT derived from the activation calculations of the air [3] and conservative assumptions upon the ventilation rate. On-line emissions through the stack into the atmosphere from the TS are supposed to be negligible (helium cooling loop of the target is a closed circuit, see Fig.1). A very conservative assumption of 0.1% per day leakage rate from the cooling loop was used for the first rough estimates. For this value the source term for critical isotopes is given in the Table 2.

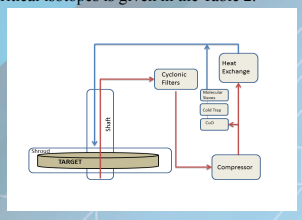


*Figure 1. Schematic view of the He cooling loop.*

*Table 2. Source term from the target station.*

| Nuclide | Activity in He loop (Bq) | Source Term (Bq $y^{-1}$) |
|---|---|---|
| $^{3}$H | 2.00E+11 | 4.16E+10 |
| $^{125}$I | 9.00E+10 | 1.87E+7* |

* A filter effect with (99.9%) was considered for $^{125}$I leaked from the He loop

### *Processing* emissions

Main contributions to atmospheric releases from processing operations are given in Table 3.

*Table 3. Source term for airborne release from processing operations.*

| Nuclide | Chemical form | Activity (Bq) | Release Fraction | Source Term |
|---|---|---|---|---|
| $^{3}$H* | H20, gas | 6.00E+14 | 1% | 6.00E+12 Bq/y |
| $^{125}$I* | HI, HIO3 | 1.00E+08 | 1% | 1.00E+06 Bq/y |
| $^{3}$H | gas | Wheel:6E14 | 4.E-5 to 0.1% | 2E+9 to 6E+11 Bq/5y |
| $^{181}$W | Dust/aerosol | Wheel:10E15 | 4.00E-08 | 5.00E+07 Bq/5y |
| $^{179}$Ta | Dust/aerosol | Wheel:8E15 | 4.00E-08 | 3.00E+07 Bq/5y |
| $^{148}$Gd | Dust/aerosol | Wheel:8E11 | 4.00E-08 | 3.00E+04 Bq/5y |

* Cementation after at least 1200 days of decay-time

=>on-site cementation of tritiated contaminated water from He loop| 99% efficiency (IAEA TRS421, 2004)

=> 1% of all tungsten dust (dust accounts for 0.07% of the total target per year) that has been formed due to ablation is assumed to be present in the dismantled region and taken into the ventilation.

## Activation of groundwater & Discharges of activated water

Activity levels in the soil underneath the target station are <1 Bq $g^{-1}$ while for the AT, the results are given in the Table 4.

*Table 4. Activity concentration in first 1 m of soil surrounding the concrete wall of the tunnel @ 40 years of continuous operation (3).*

| Isotope | Specific activity (Bq $cm^{-3}$) | Activity (Bq) |
|---|---|---|
| $^{3}$H | **9.67E-01** | **6.84E+09** |
| $^{7}$Be | 9.77E-02 | 6.91E+08 |
| $^{22}$Na | **1.54E-01** | **1.09E+09** |
| $^{24}$Na | 5.35E+00 | 3.78E+10 |
| $^{32}$P | 8.34E-02 | 5.89E+08 |
| $^{35}$S | 5.86E-03 | 4.15E+07 |
| $^{45}$Ca | 1.05E+00 | 7.43E+09 |
| $^{46}$Sc | 2.02E-01 | 1.43E+09 |
| $^{54}$Mn | 1.59E-01 | 1.12E+09 |
| $^{55}$Fe | 1.94E+00 | 1.37E+10 |
| $^{65}$Zn | 3.15E-04 | 2.23E+06 |

**TRACE**(velocity field)/**PARTRACE**(transport of solutes) codes(5) were used for groundwater migration calculation. Parameters used are:

- homogenous soil with a bulk density of 2.0 g $cm^{-3}$
- hydraulic gradient set to 0.0025
- hydraulic conductivity $K_w$ = 1E-6 *m* $s^{-1}$
- sorption & decay accounted
- of the groundwater flow

For estimated source term => **H*(10) = 4*10$^{-2}$ μSv $y^{-1}$**

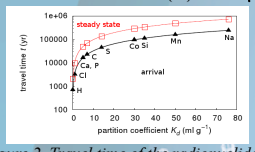


*Figure 2. Travel time of the radionuclides* varying with the partition coefficients soil-water.

***No relevant contamination can occur outside of the ESS site boundary: $^{3}$H needs 900 years.***

**Discharges of $^{3}$H from ESS to public sewers at 1 TBq $y^{-1}$ are shown to cause insignificant doses to representative person from ingestion of contaminated fish (5) .**

## Stray radiation in the environment

For a shielding wall of about 650 m soil following 1 m concrete the calculations (3) shown that the dose rate at the top of the accelerator berm reaches levels of 1 μSv/h.

A dose rate of 1 μSv/h of a 1000 m² emitting surface results in a skyshine dose rate in a distance of 100 m of 6 nSv/h (4).

The results for the target station are based on the estimation of the source term based on the geometric model given in Fig. 3. The resulted doses are presented in the Fig. 4 and the table 5.

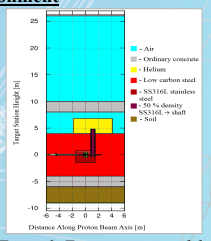


*Figure 3. Target station model used for skyshine source term estimates.*

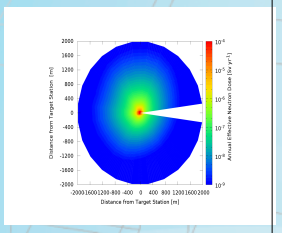


*Figure 4. Neutron effective dose rate map around target station.*

*Table 5. Ambient dose equivalent due to neutron skyshine around ESS TS.*

| Distance | MCNPX | | | | Sullivan (6) | Moritz(7) |
|---|---|---|---|---|---|---|
| | Minimum | | Maximum | | | |
| (m) | μSv $y^{-1}$ | error (%) | μSv $y^{-1}$ | error (%) | μSv $y^{-1}$ | μSv $y^{-1}$ |
| 300 | 0.46 | 10 | 0.72 | 10 | 0.21 | 0.35 |
| 600 | 0.07 | 18 | 0.13 | 13 | 0.03 | 0.006 |

## Conclusion

Methodologies for estimation of the consequences of atmospheric dispersion through the relevant exposure routes have been established and described in the ESS report (see Ref. 8). The resulted maximum annual doses are presented in the Table 6.

Note that results were obtained for reference release height of 45 m. In this case the reference persons are located on a circle with radius of about 650 m. All inhabitants of several existing houses closed to the ESS site border which are exposed due to the presence will receive a dose of 0.34 μSv $y^{-1}$. The reference persons to be exposed additionally due to the agriculture will receive about 3.7 μSv $y^{-1}$.

**Corroborating the obtained results it is evident that the cumulated exposure of the reference person to the operational release of the radionuclides and to the direct radiation is well below the limit of 50 μSv $y^{-1}$, the ESS set safety objective.**

*Table 6. Annual dose contributions (Sv $y^{-1}$) from routine release of radionuclides to air during normal operation at critical group location*

| | Activity* outlet | Tritium | Ingestion | | | Inhalation | | | External | | | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Nuclide | (Bq $y^{-1}$) | (adult) | (1 y) | (15 y) | (adult) | (1y) | (15 y) | (adult) | plume | deposition | skin | Reference person |
| $^{3}$H | 5.50E+12 | **3.20E-08** | | | | | | | | | | 3.20E-08 |
| $^{7}$Be | 1.00E+06 | | **2.50E-11** | 6.73E-12 | 5.38E-12 | **2.30E-13** | 6.79E-14 | 5.48E-14 | 2.90E-14 | 5.10E-12 | 1.70E-13 | 3.10E-12 |
| $^{11}$C | 2.60E+12 | | | | | | | | 1.40E-07 | | | 1.40E-07 |
| $^{13}$N | 2.70E+12 | | | | | | | | 1.30E-07 | | | 1.30E-07 |
| $^{15}$O | 1.50E+12 | | | | | | | | 2.70E-08 | | | 2.70E-08 |
| $^{41}$Ar | 4.10E+10 | | | | | | | | 3.10E-09 | | | 3.10E-09 |
| $^{125}$I | 1.97E+07 | | **4.53E-09** | 1.75E-09 | 1.19E-09 | **4.14E-11** | 1.29E-11 | 9.18E-12 | 1.32E-14 | 2.96E-12 | 1.36E-13 | 4.57E-09 |
| $^{32}$P | 6.90E+05 | | **6.56E-07** | 8.97E-07 | 5.59E-07 | | | | | | | 2.11E-06 |
| $^{33}$P | 1.10E+06 | | **1.54E-07** | 2.20E-07 | 1.21E-07 | | | | | | | 4.95E-07 |
| $^{35}$S | 2.00E+05 | | **2.20E-07** | 4.00E-07 | 1.52E-07 | | | | | | | 7.72E-07 |
| Total | | 3.20E-08 | **1.03E-06** | **1.52E-06** | **8.33E-07** | **4.16E-11** | **1.30E-11** | **9.23E-12** | **3.00E-07** | **8.06E-12** | **3.06E-13** | **3.71E-06** |

## References

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