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Published in:
Fusion Science and Technology

Link to article, DOI:
10.13182/FST14-T21

Publication date:
2015

Document Version
Peer reviewed version

MANAGEMENT OF TRITIUM IN EUROPEAN SPALLATION SOURCE

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The European Spallation Source (ESS) will produce tritium via spallation and activation processes during operational activities. Within the location of ESS facility on Lund, Sweden site it is mandatory to demonstrate that the management strategy of the produced tritium ensures the compliance with the country regulation criteria. The aim of this paper is to give an overview of the different aspects of the tritium management in ESS facility. Besides the design parameter study of the helium coolant purification system of the target the consequences of the tritium releasing into the environment were also analyzed. Calculations shown that the annual release of tritium during the normal operations represents a small fraction from the estimated total dose. However more refined calculations of migration of activated-groundwater should be performed for higher hydraulic conductivities, with the availability of the results on soil examinations. With the assumption of 100% release of tritium to the atmosphere during the occurring of the extreme accidents it was found as well that the total dose complies with the constraint.

I. INTRODUCTION

The European Spallation Source (ESS) is the European common effort in designing and building a next generation large-scale user facility for studies of the structure and dynamics of materials. The ESS facility is based on a linear driver (linac) directing the proton beam (5 MW of 2.5 GeV) of 2.8 ms long pulses with a 20 Hz on a tungsten target where neutrons are produced via spallation reactions. Further the neutrons moderated to thermal and subthermal energies in a couple of moderators placed around the target will be guided through 22 beamlines to the scattering instruments.

II. TRITIUM PRODUCTION

Estimation of the tritium production were performed using MCNPX2.6.0, Monte Carlo program (Ref. 1) based on CEM3k nuclear reaction model coupled with CINDER'90 activation cod (Ref. 2). The obtained results were used to characterized and classify the waste arising from the facility and to derive the source terms needed for environmental impact analysis.

The total inventory of tritium (^{3}H) in the tungsten target accumulated within 1 year (5000 hours) of operation is about 600 TBq (Ref. 3). While, after 5 years of irradiation, the lifetime of the target, the ^{3}H contribution to the total activity is shown in the Figure 1.

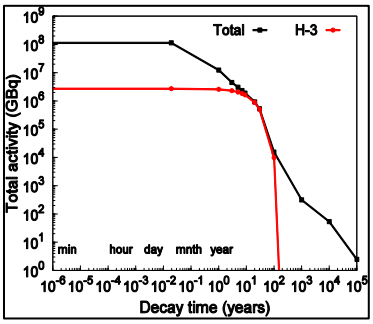

Fig. 1. Total activity in the target wheel and the ^{3}H contribution as a function of the decay time after 5 years of irradiation.

Similar estimates were obtained in Ref. 3 for other components of the target station, such the moderator reflector plug, proton beam window plug, neutron guides, shielding etc. Activation calculations were performed as well in the Ref. 4 for the linac machine, air inside the tunnel, its wall and the surrounding soil, assuming a beam loss of 1 W/m, and standard shielding (1 m of concrete). Using the same assumption the source terms (Ref. 4) for the environmental impact assessment were also estimated. Potential ^{3}H release from the accelerator tunnel

conservatively estimated has the level of 1 GBq while the maximum specific activity of ^{3}H in the first 20 cm of soil around the concrete wall of the linac is about 0.6 Bq/g.

III. CALCULATION OF THE HELIUM LOOP PERFORMANCE

The target is a wheel of 2.5 m diameter that rotates during irradiation with a revolution speed of 25 rpm. The maximum temperature of the front of the target is estimated at about 600^{o} C. The heat is removed by a helium flow (3 bar, 3 kg/sec).

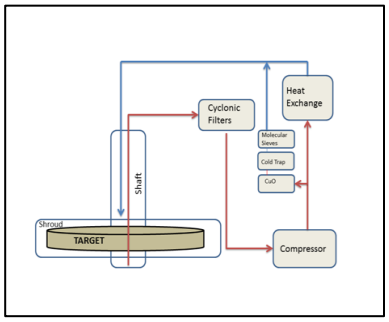

Fig. 2. Schematic view of the helium cooling loop

The tritiated water is subsequently removed by trapping on cold molecular sieve components, see the Figure 2. The release of ^{3}H from the tungsten target was conservatively assumed to be 100% from production. Derived amount of tritiated water to be extracted from the system and its specific activity were calculated accounting for two parameters: i) the purification rate and ii) the hydrogen addition to the helium loop (Ref. 5). Amounts of tritiated water extracted and the specific activity are provided in the Table I and II.

TABLE I. Amount of tritiated water extracted (kg/y)

f/F (%)	^{2}H in He (%) 0.01	0.1	0.2	0.5
0.01	9.5	95	190	475
0.05	47.5	475	950	2375
0.1	95	950	1900	Irrelevant high

TABLE II. Specific activity (MBq/ml) of the water removed

f/F (%)	^{2}H in He (%) 0.01	0.1	0.2	0.5
0.01	6.30E-2	630	315	125
0.05	1.25E-3	125	60	25
0.1	6.00E-3	60	30	n.a

For the reference parameters set to 3 g/s purification-loop flow and 100 ppm hydrogen addition to the helium, the system will generate roughly 100 liters of tritiated water per year (6 TBq/l). The reference management solution for this waste water is the cementation on site. However waste acceptance criteria of the disposal facility are required to be set for this option.

The steady state ^{3}H activity in the helium is about 200 Gbq. This value was estimated analytical based on the block diagram in the Figure 3 that shows the possible locations where activity can reside, and the ways in which it can move.

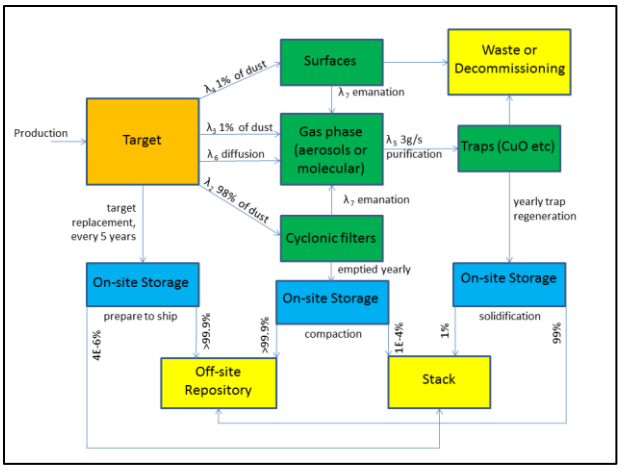

Fig. 3. Compartment model activity movement in the target cooling loop.

Additionally, the purification loop, see Figure. 2, contains a cyclonic filter of the potential dust (assumed to be 0.07% of the total target per year) arising from ablation.

IV. EVALUATION OF ENVIRONMENTAL IMPACT OF THE TRITIUM RELEASE

IV.A. Routine operations

IV.A.1. Source terms

The source term (ST) for routine atmospheric releases can be separated into two distinct release operations: i) on-line emissions, and ii) emissions resulting from processing.

The on-line ^{3}H emissions via stuck were derived accounting for two main sources: i) activated air in the tunnel of the linac, and ii) leakage of the helium gas from the cooling loop of the target.

The tunnel will be sealed during the beam-on and vented only two hours after the beam is off. Based on ESS operation schedule (Ref. 6) it was derived a ^{3}H ST of 8.8E+6 Bq/year. As the helium-cooling loop of the target is a closed circuit, the single potential source of releasing was assumed to be the leakage of the helium gas that is further vented through the stuck. With the assumed conservative value of 0.1% per day leakage rate the resulting ^{3}H source term from the target station is 4.16E+10 Bq/year.

The main contribution to atmospheric releases arising from processing operations is the on-site cementation of tritiated water. This water is the result of the helium purification loop of the target and may be generated directly from activated cooling water systems. In agreement with (Ref. 8) the cementation shall release 1% (evaporation loss) of volatiles. It is assumed that the cementation takes place once after at least 1200 days of decay-time. Under above assumptions the derived ^{3}H ST is 6.00E+12 Bq/year. Finally, hot cell operations, occurring every five years, that will cut the target shaft will generate small releases of activated steel as aerosols, along with small amounts of aggregated and activated tungsten dust. A ST of 2E+9 Bq/5years was estimated based on a release fraction of 4E-8 %. This value was obtained assuming that 1% of all tungsten dust is present in the dismantled region and taken through the ventilation (99.9% efficiency) into the atmosphere.

IV.A.2 Effective dose assessment.

The dose estimate for the ^{3}H airborne release was based on the assumption (Ref. 9. and 10) that all water entering the body of an exposed person has the same ^{3}H concentration. The total intake of an adult of water containing ^{3}H is assumed here to be 965 liters/year. This amount comes from 600 l drinking water plus 365 l water in food. The drinking water comes from the local wells. A fraction of the well water may originate from activated soil underneath facility, during ESS operation. Some isotopes from the soil can leach and be transported via groundwater to the receptor. This component is called here 'horizontal source'. Another part originates from airborne isotopes released from ESS facility during operation. This is called 'vertical source' since after dispersion into the environment isotopes may fall down on the site via precipitations.

The dispersion was derived applying the standard Gaussian dispersion formula (Ref. 11). The main parameters and assumptions used (Ref. 12) were:

- Atmospheric stability class D, assuming no buoyancy in release;
- Reference effective release (stack) height of 45 m;
- Height of inversion of 150 m (applied in one reflection at the height of inversion and one reflection on the ground;
- Receptor is placed on the plume centerline;
- Receptor height of 1 m above ground;
- Wind speed of 3 m s^{-1};
- The wind is blowing from ESS towards the local population groups during 10% of the year (this probability is based on analysis of the wind data;
- Radioactive decay during transport in air from stack to representative person accounted;
- No entrainment effect (the building size/structure effect on dispersion of the plume) was accounted.

Using this model, a dispersion factor of 2E-5 s m^{-3} (σ_y = 50 m, σ_z = 30 m) was calculated at the critical group location, 660 m from the ESS release point. A dose factor of 5.82 10^{-21} Sv/Bq release of ^{3}H at the reference person (adult) was further derived using this value and the assumption that 80% from the intake water comes from local precipitation.

Thus, the annual dose from routine release of ^{3}H to air during normal operations amounts to 3.2E-8 Sv/y, a small fraction of the total dose estimated at 1.5E-5 Sv/y.

Preliminary calculations have been made (Ref. 13) of the migration of activated-groundwater towards the ESS site border (distance 300 m). It was combined with the groundwater migration model Trace/Partrace, extended to radioactive nuclide transport. The results indicate that ^{3}H, requires several hundred of years to reach the site boundary and therefore its contribution to the environmental impact is negligible. As this estimate was based on a very low hydraulic conductivity ($10E^{-6}$ m/s) further examinations considering higher hydraulic conductivities will be necessary to be done. An extended campaign of hydrogeological measurements on soil samples from the ESS site is under way, and migration calculations will be repeated if deviating soil parameters are found.

The consequence of the discharge of 1 TBq/y ^{3}H from ESS to the sewer system was also assessed (Ref. 14) shown negligible effective dose to the general public.

IV.B. Extreme accidents

The definition of the ST of Design Basis Accidents (Ref. 6) assumes that ^{3}H will be 100% released to the atmosphere, whereas the amounts of volatiles and aerosols will vary depending on the exact scenario. The whole ^{3}H inventory in the target after five years of operation is 3.2E+15 Bq. The dispersion was derived using the same method described in the chapter IV.A.2 considering that the wind blows towards the representative persons all the time (100%). With these assumptions the ^{3}H annual dose consequently to the major accidents is about 1.8E-4 Sv. For a small volatile release fraction of 0.001 % ^{3}H gives the major contribution to the total dose (0.33 mSv). While, under a larger volatile release fraction (0.5%) scenario the ^{3}H contribution is only 3% of the total dose estimate (5.9 mSv) see Ref. 9.

V. "BAT" STATEMENT FOR TRITIUM REDUCING

Development of a Best Available Technique (BAT) statement for ^{3}H reducing (Ref. 7), as requested by the Swedish legislation, to optimize protection of people and the environment, taken into consideration a wide range of matters. Listed below are the options, which have been identified for potentially minimizing radioactive discharges and disposal from ESS facility operation and maintenance: i) Reference: capture of ^{3}H gas in purification system based on molecular sieves, ii) capture ^{3}H gas in purification system based in zeolite traps, iii) in-line emissions through the stack of all radioactive gas. The options for minimization discharges previously identified will be assessed against a number of criteria. Assessment criteria developed for this example are: i) ^{3}H discharge to air, ii) ^{3}H discharge to water, iii) radioactive solid waste generated, iv) cost, v) timescale for implementation, vi) operator hazard, vii) security implications, viii) social and economical considerations.

Identified options should be assessed against the criteria given above and comparison has to be made vs the reference option. Thus, any given option may be identified as performing: i) better than, ii) worse than, iii) substantially the same, as the reference option, when assess against each criterion.

Quantification of this comparison is necessary and it will be done in the future based on more detailed information upon various analyzed options. Qualitative relative merit may be a preliminary mean to be used, for discarding since the beginning, the options whose performances are all worse.

VI. CONCLUSIONS

The key management tritium issues of the ESS facility were analyzed and it was demonstrated that can be solved. As far as the tritiated water extracted from the cooling purification system is regarded the cementation solution needs still to be verified in the future.

It is clear from the results of this work that safe ^{3}H management is easily achievable, and that the feasibility of ESS as a whole is not compromised by the production of ^{3}H on site.

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