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Assessment of environmental consequences of the normal operations of the ESS facility

- status report -

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Environment - Regulatory aspects

Swedish legal requirements : SSMFS2008:23, SSMFS2010:2 limited/no validity for ESS
New Swedish regulations in 2018
Euratom BSS 2013, ICRP & IAEA recommendations
SSM2015-127 Licensing conditions
Unified methodology under development: PREDO project

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ESS GSO
Facility dose budget to Reference person
No partitioning of direct radiation vs releases
RELEASES < 40 μSv/y as stray radiation dose= 10μSv/y
Radiation Protection Design Criteria
ESS Radiation Safety Officer (RSO)=>
Requirements (design, construction, operations)

➢ Dose constraints

	Linac	Target	Instruments	Waste facility
Emission into Air	AA **X**	TA **X**	IA **x**	WA **X**
Direct Radiation	AB **X**	TB **x**	IB **x**	WB **x**
Activation Gr. water	AC **X**	TC **x?**	IC **-**	WC **-**
Discharge into drains/evaporator	AD **X**	TD **X**	ID **X**	WD **X**

X = major
x= minor
Contribution

Step#1 screening approach => E < 0.1 μSv/y
Step#2 realistic approach

	Linac	Target	Instruments	Waste facility	ESS Total	
Operation & maintenance	0.03	0.01	0.005	0.005	0.05 mSv/y	**H1**
Expected events	0.05	0.35	0.05	0.05	0.1 mSv/event	**H2**
Non-expected events	1.00	1.00	1.00	1.00	1 mSv/event	**H3**
Design Basis Accidents (DBA)	20.00	20.00	20.00	20.00	20 mSv/event	**H4**
Beyond Design Basis Accidents (BDBA)	50.00	50.00	50.00	50.00	50 mSv/event	**H5**

=> 10 μSv/y

SSM 2013/1525
All isotopes giving contribution
➢ 1% to release

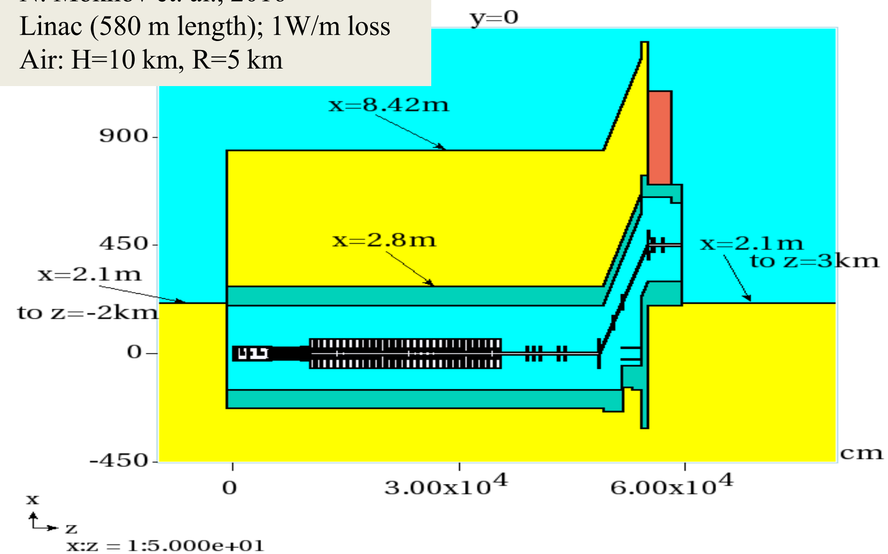
➢ **ALARA**: Justification & Optimization + **BAT** Swedish Environmental Code (DS 2000:61)

De minimis dose < 10 μSv/y => facility is deemed to be justified and optimized

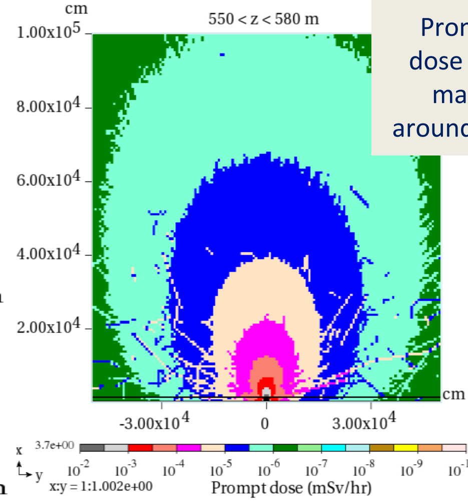
Dose constraint is not a dose limit, but is used as the starting value for the optimization of radiation protection. (SSMFS:14-2480, 2014)

This means that the actual doses to members of the public, via the best possible technique and optimization of radiation protection are, for most cases, expected to be significantly lower

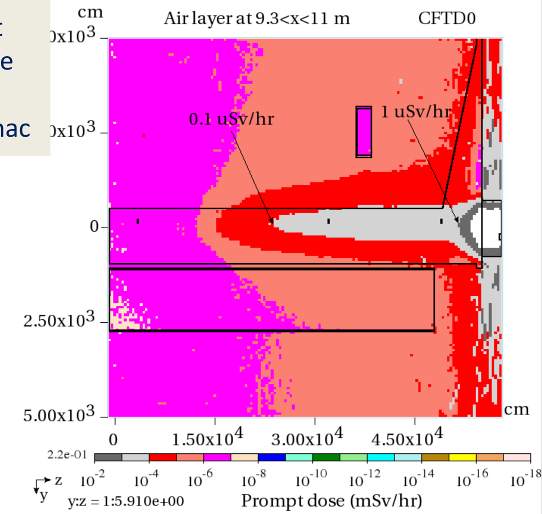
N. Mokhov et. al., 2016
Linac (580 m length); 1W/m loss
Air: H=10 km, R=5 km



Prompt dose rate maps around linac



xy-isocontours at 550 < z < 580 m;



9.3 < x < 11 m air layer above the berm

Effective dose rates for selected locations (receptors) near the ESS site

Linac

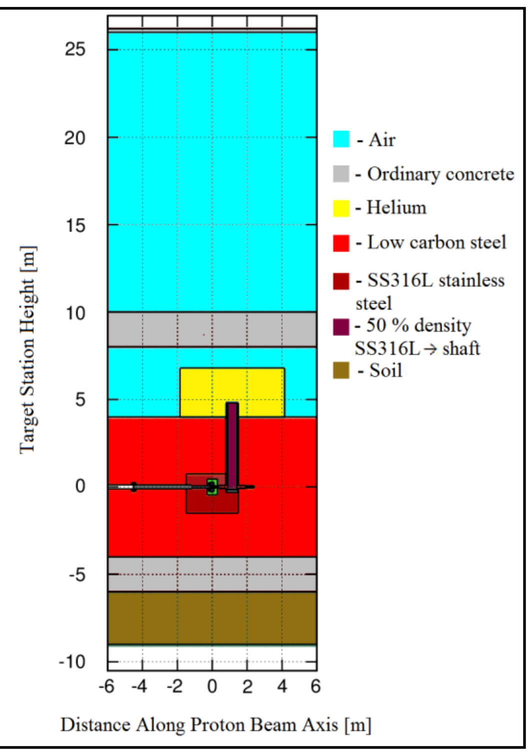
Distance from release (m)	MARS15 estimate*	
	μSv y⁻¹	error (%)
340	7.6	≤ 20
600	1.6	≤ 20

*Integrated over the maximum operating time of 6000 h/y

Target Station

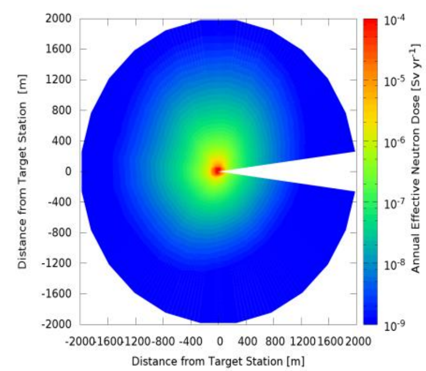
Distance from release	MCNPX estimate**			
	Minimum		Maximum	
(m)	μSv y⁻¹	error (%)	μSv y⁻¹	error (%)
340	0.46	10	0.72	10
600	0.07	18	0.13	13

**Integrated over the operating time of 5000 h/y



Target station model used for skyshine source term estimates.

Neutron effective dose rate map around target station R=2 km



An occupancy factor approaching 1 was considered, as the people settlements are located very closed to the fence.

Stray radiation Skyshine

Airborne releases general considerations

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❑ GRADED APPROACH defining Source Term (ST):

1.**SCREENING**: conservative calculations (IAEA SRS19) for *selection of the radionuclides potentially radiation safety important*
Breakdown of radionuclides -> calculate DF -> Quantification of ST (Bq) (calculations/estimates) -> Ranking & selection via screening analysis using **screening dose rate 0.1 μSv/y per nuclide & summed dose rate of all radionuclides screened out < 1 μSv/y =>** i) important nuclides tbt via realistic analysis; ii) screened-out nuclides;

2.REALISTIC APPROACH (PREDO method) => realistic wind dispersion and realistic radioecological models.

Total Dose = Σ realistic dose + Σ *dose of the radionuclides screened out*

❑ Threshold values:

Radioisotopes with $T_{1/2}$ < 10 sec will not be included in the analysis.
The traveling time from the stack until the closest potential Reference Group is about 2 min.
No unique threshold value of radioactivity= > **Graded approach**

❑ Criteria for selection of the radionuclides of the source terms:

- are significant in terms of radiological impact;
- are significant in terms of quantity of radioactivity discharged, whether or not are significant for radiological impact;
- have long radioactive half-lives, that may persist and/or accumulate in the environment and that may contribute significantly to the dose.

❑ Additional processes used for derivation of releases to the stack:

- Ventilation system rate (VR);
- "Filter" effectiveness (F) | *"filter" is used here as generic for all devices able to: filter, absorb and/or delay the isotopes from their production to the stack.*
- Radioactive decay (l).
- *No retention*

❑ Two cases of release rates were considered:

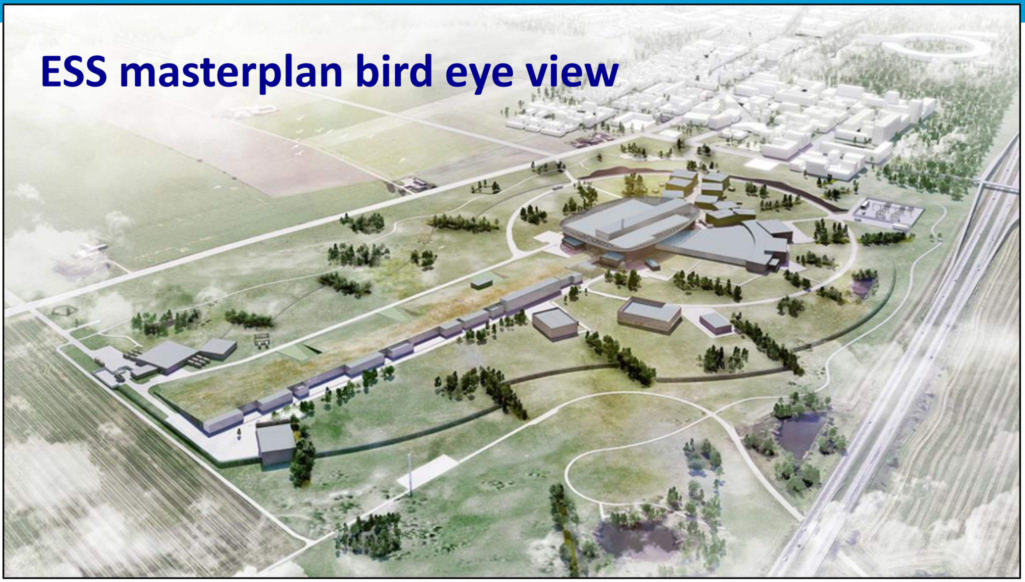
-*pessimistic release*, that assumes the maximum that the facility can potentially release (no credit to the filtration equipment at the main stack);
-*optimal release* asuming that all abatement equipment works optimally

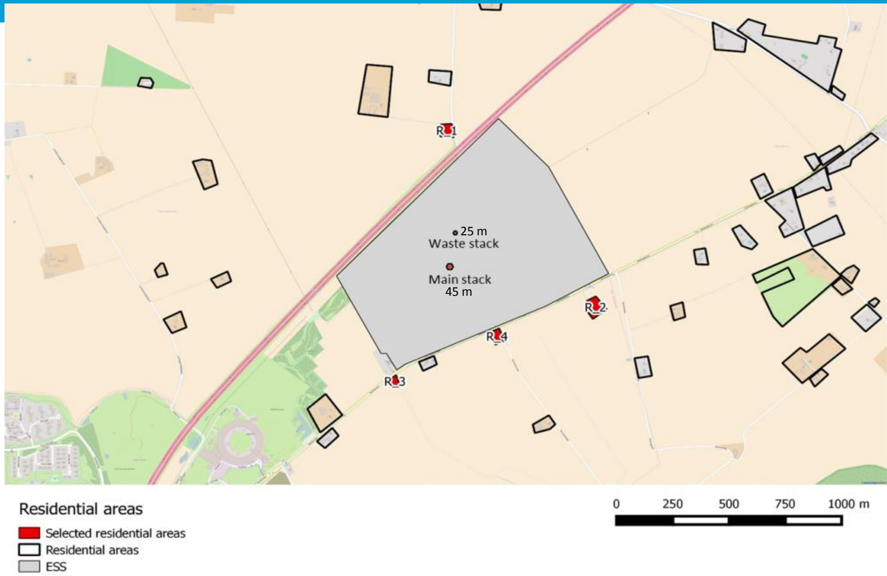
❑ Two main scenarios:

1. chronic long-term release corresponding to a normal operation of the facility: i) uniform release during 50 years of the facility operation and ii) averaged weather conditions

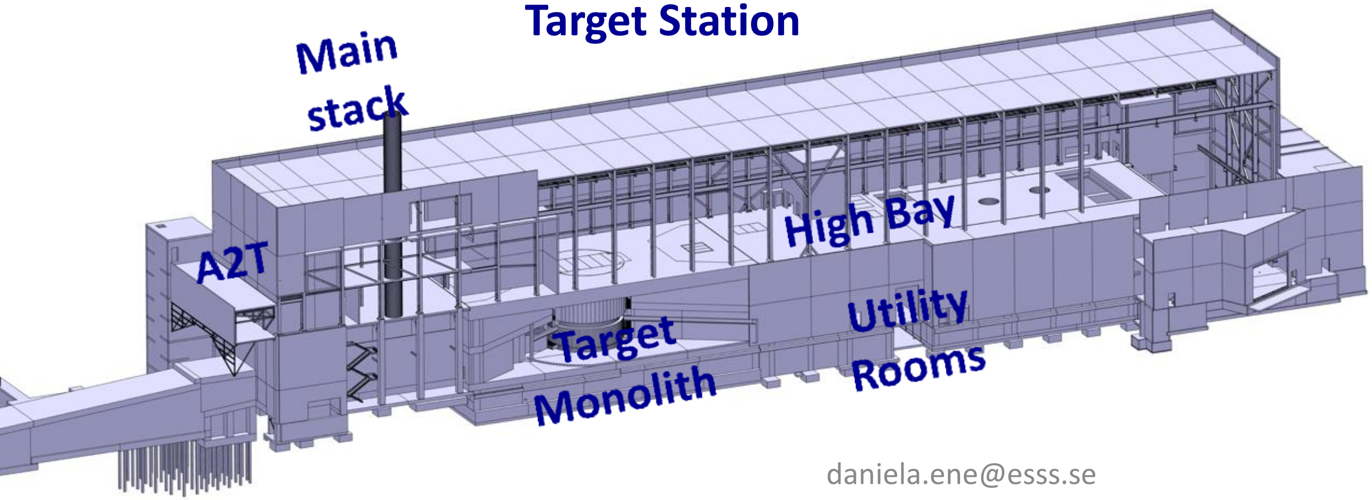
2. short-term release : short-term planned interventions on the facility, when significant amounts of radioactivity may be released at once and the most adverse and unchanging weather conditions assumed.

ESS site plan





Release points & locations of the reference groups



Airborne Release

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Atmospheric release
Source term from Linac

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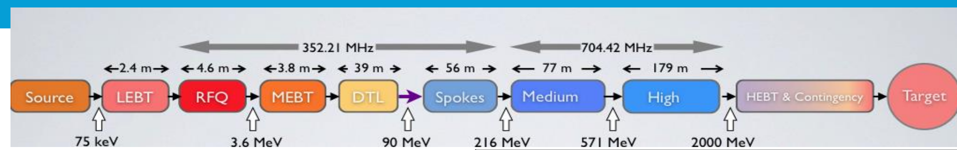
Radionuclide	Activity to stack* (Bq/y)	Screening approach SRS19 Dose factors (Sv/y per Bq/y)	Annual effective dose** (Sv/y)
H-3	6.21E+07	1.73E-18	1.07E-10
Be-7	6.33E+05	2.09E-16	1.32E-10
Be-10	3.48E-02	6.29E-14	2.19E-15
C-11	4.09E+12	5.27E-19	2.16E-06
C-14	1.06E+07	1.24E-16	1.32E-09
N-13	7.70E+12	6.02E-19	4.63E-06
O-14	7.88E+11	1.86E-21	1.47E-09
O-15	8.29E+12	2.27E-19	1.88E-06
O-19	1.45E+09	1.32E-17	1.91E-08
F-18	8.53E+09	2.09E-18	1.79E-08
Ne-23	3.50E+09	9.36E-20	3.27E-10
Ne-24	7.12E+08	2.01E-23	1.43E-14
Na-22	9.21E+01	8.20E-14	7.56E-12
Na-24	2.11E+05	8.19E-17	1.73E-11
Na-25	1.85E+06	3.18E-19	5.87E-13
Mg-27	2.27E+06	3.81E-19	8.66E-13
Mg-28	3.00E+04	4.97E-16	1.49E-11
Al-26	4.56E-04	6.60E-12	3.01E-15
Al-28	9.93E+06	4.78E-19	4.74E-12
Al-29	4.62E+06	2.03E-18	9.38E-12
Si-31	1.25E+06	4.24E-19	5.29E-13
Si-32	6.09E-01	9.47E-13	5.77E-13
P-30	2.87E+06	2.84E-19	8.15E-13
P-32	9.30E+04	1.65E-15	1.53E-10
P-33	3.78E+04	2.61E-16	9.87E-12
P-35	3.63E+06	1.92E-19	6.95E-13
S-35	1.46E+04	2.28E-15	3.32E-11
S-37	1.14E+07	1.72E-20	1.97E-13
S-38	1.55E+06	4.00E-18	6.18E-12
Cl-34	3.73E+09	1.78E-18	6.64E-09
Cl-36	9.90E+01	7.32E-15	7.25E-13
Cl-38	1.30E+11	1.68E-18	2.19E-07
Cl-39	1.87E+11	1.94E-18	3.63E-07
Cl-40	4.64E+10	2.08E-21	9.67E-11
Ar-39	4.48E+05	1.45E-21	6.49E-16
Ar-41	1.24E+12	7.59E-19	9.42E-07
K-38	6.89E+09	1.75E-18	1.21E-08
K-40	2.05E-03	2.13E-13	4.37E-16
Total	**2.25E+13**		**1.03E-05**
No filter effect:			
Total	**2.26E+13**		**1.16E-05**



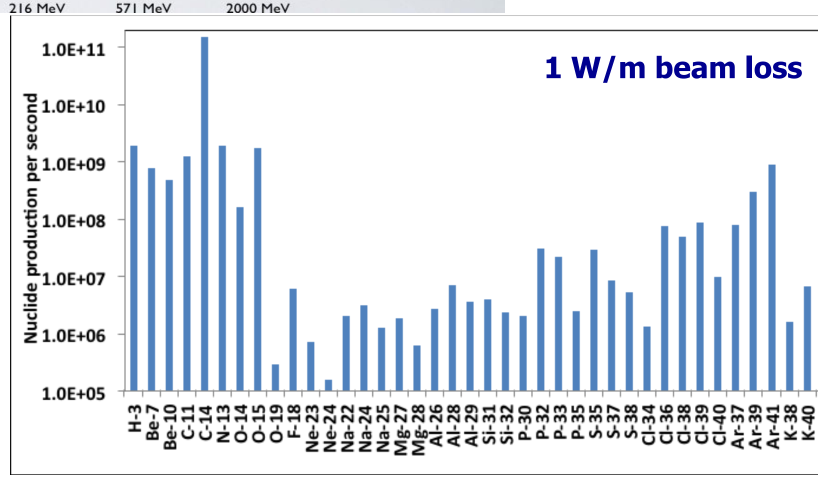
A_{out} = 23 TBq

for 6000 h continuous operation

* Filter effect (99.97%)

Main isotopes:

^{13}N, ^{11}C, ^{15}O, ^{41}Ar, ^{14}O



Radionuclide production yields in the air of the tunnel of accelerator (Mokhov et. al 2016)

Baseline parameters of the air release from the accelerator tunne

Function	Air exchange rate* (hr^{-1})	Stack diameter (m)	Exhaust speed (m/ s)	HEPA filter	Controlled exhaust
Tunnel on-line vent	1	1.8 - 1.9	12	On main stack	yes
Flush mode	2.5 - 3	1.8 - 1.9	12	On main stack	yes
Tunnel access	2	1.8 - 1.9	12	On main stack	yes

calculated to a hypothetical group located at 350 m from the release point.

By using realistic wind dispersion and realistic radio-ecological models it is expected the conservative screening dose result reported will be substantially lesser.

ATMOSPHERIC PATHWAY
Target Station

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Breakdown of radionuclides with potential of releasing into the ambient air

Two main ways of ST generation are considered:

- ❑ spallation and activation of the air & cooling water and
- ❑ contamination of air with gaseous and volatile elements as well as dust (erosion and/or corrosion products).

3 important contributors to radioactive releases in locations where HVAC will be implemented:

-Helium cooling loop (**HeL**) of the tungsten (W) target;

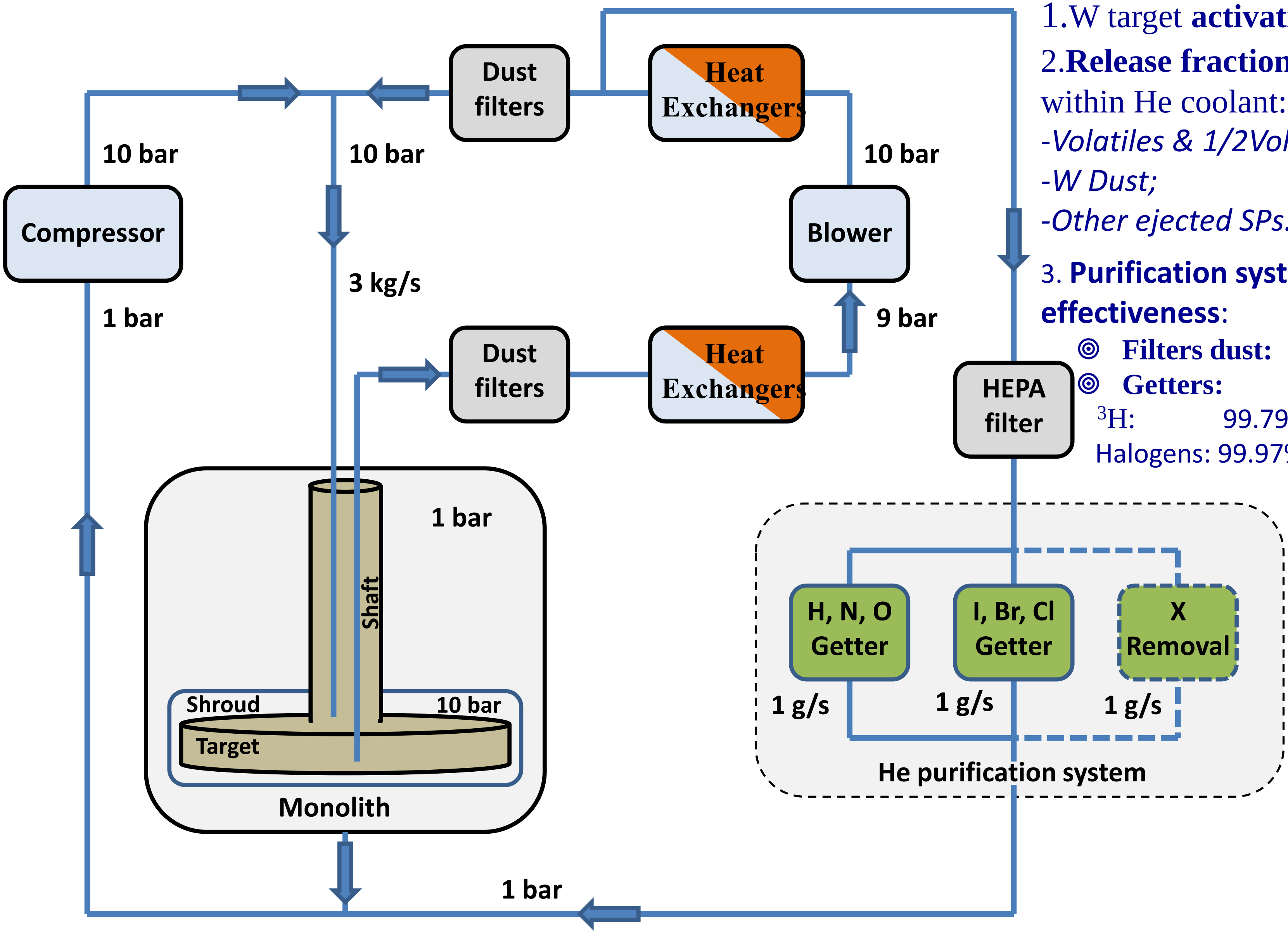
-Gas-liquid separator (**GLS**) tanks of the main cooling water circuits;

} Continuous long-term release

Main stack

-Processing hot cell (**HC**). → Short-term release

HeL scheme| Helium purification system (HePS)



1.W target **activation**

2.**Release fractions** of isotopes within He coolant:

-Volatiles & 1/2Volatiles;

-W Dust;

-Other ejected SPs.

3. **Purification system effectiveness**:

◎ **Filters dust:** 99.999%

◎ **Getters:**

^{3}H: 99.79%

Halogens: 99.97%

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Target Station | **HeL**

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Elements released from W target to HeL

Gases	Volatiles	Semi-volatiles	Others ejected spallation products (particles)
Noble gases: Ne, Ar, Kr, Xe	Halogens: I, Br, F, Cl	As, Se, Sb, Te, Ru, P, S, Cs, K	**Alkali metals**: Li, Na, Rb; **Alkaline earths:** Be, Mg, Ca, Sr, Ba; **Boron group:** B, Al, Ga, Te, In; **Transition metals:** Sc, Ti, V, Cr, Mn, Fe, Co, Ni, Cu, Zn, Y, Zr, Nb, Mo, Tc, Rh, Pd, Ag, Cd, Hf, Ta, W, Re, Os; **Metalloids:** Be, Si, Ge, Rb, Sn, Sb; **Lanthanides:** La, Ce, Pr, Nd, Pm, Sm, Eu, Gd, Tb, Dy, Ho, Er, Tm, Yb, Lu.
O, C*, N	H		

*CO or CO_2

Three main mechanisms responsible for releasing of the radionuclides from the W target within the HeL:

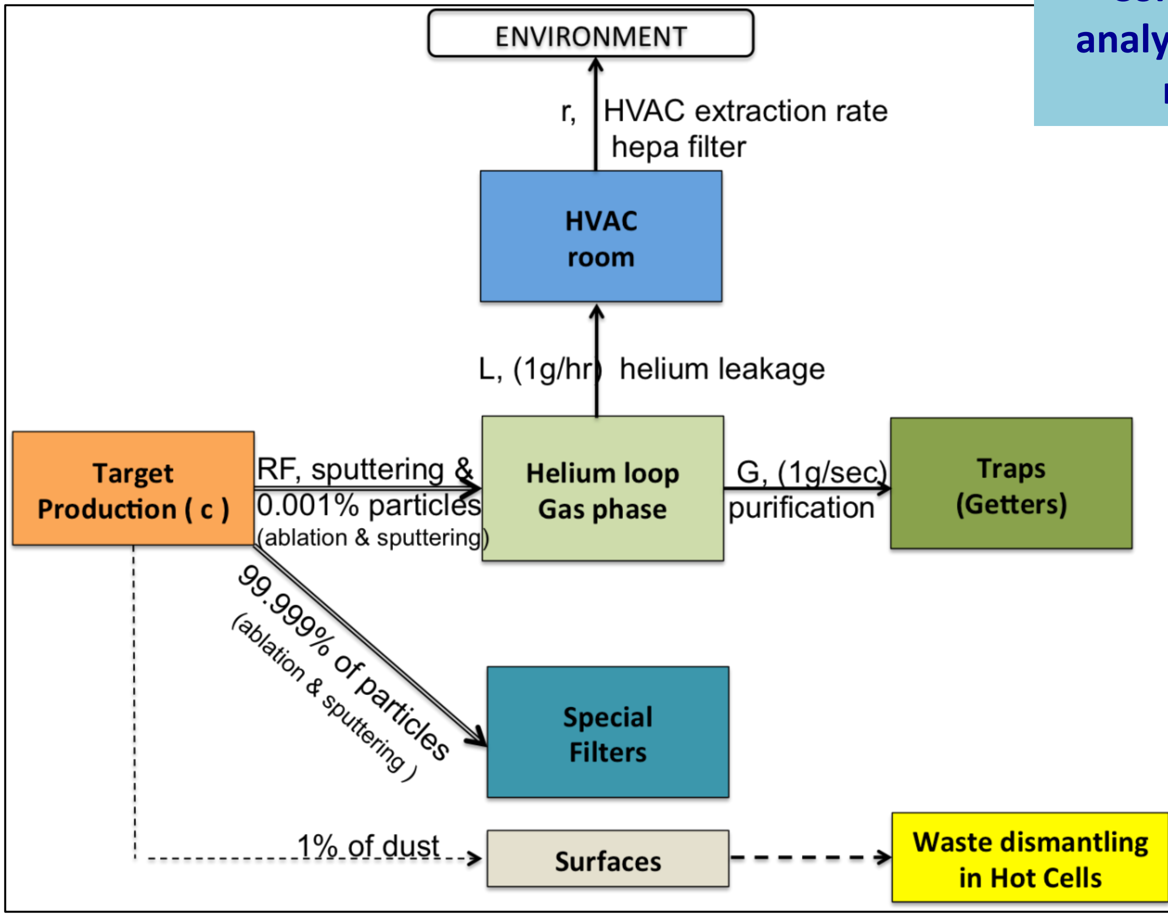
- **sputtering or direct ejection (dominant),**
- **diffusion,**
- **ablation.**

Class of radionuclides	"Filter" type within HePS
Noble Gases, N, O, C, F, Cl	no
³H and halogens	specialized getter.
Semivolatiles (As, Se, Sb, Te, Ru, P, S, Cs, K)	dust & aerosol special filters but with potential to escape the filters and to be gettered.
Non-volatiles (mainly metals) ejected from target & W dust	dust & aerosol special filters.

Species	RFs	
	Ejection fraction & Diffusion (E. Pitcher, 2015)	Conservatism Factor*
Noble gases (He-Ne-Ar-Kr-Xe)	3E-4; 1E-4; 3E-5	5
H	1	1
Volatiles (F-Cl-Br-I)	3.00E-04	10
Semi volatiles (C thru Zr)	1.00E-04	5
Semi-volatiles (Nb thru Os)	3.00E-05	2

*a conservatism factor applied to account for the calculations uncertainty.

Compartment model for developing the analytic expressions governing radioactivity releases from helium cooling loop



Parameters used		
Release Fraction Iodine	RF	3.00E-03
Getter_Iodine (1/sec)	G	3.00E-05
Leakage (1/sec)	L	9.26E-09
HVAC_rate (1/sec) room: D02.115.4003	r	1.39E-03
Irradiation time (sec)	T_{irrad}	1.80E+07

Radionuclide	$T_{1/2}$ (sec)	λ (1/sec)	Annual production in target (Bq)	Annual release (based on Eq. 11 & parameters above) (Bq)
I 117	1.38E+02	5.02E-03	9.29E+13	1.11E+05
I 118	8.20E+02	8.45E-04	1.21E+14	2.39E+06
I 118*	5.10E+02	1.36E-03	5.51E+12	5.57E+04
I 119	1.15E+03	6.05E-04	1.45E+14	4.42E+06
I 120	4.86E+03	1.43E-04	1.85E+14	2.70E+07
I 120*	3.18E+03	2.18E-04	1.41E+12	1.37E+05
I 121	7.63E+03	9.08E-05	1.78E+14	3.84E+07
I 122	2.18E+02	3.18E-03	2.10E+14	5.53E+05
I 123	4.75E+04	1.46E-05	1.90E+14	1.17E+08
I 124	3.61E+05	1.92E-06	7.17E+11	6.22E+05
I 125	5.20E+06	1.33E-07	1.66E+14	1.53E+08
I 126	1.12E+06	6.16E-07	6.43E+11	5.82E+05
I 128	1.50E+03	4.62E-04	3.27E+11	1.38E+04
I 129	4.95E+14	1.40E-15	1.17E+03	1.08E-03
I 130	4.45E+04	1.56E-05	1.56E+10	9.39E+03
I 130*	5.40E+02	1.28E-03	7.13E+09	7.84E+01
I 131	6.93E+05	1.00E-06	9.79E+09	8.75E+03
I 132	8.26E+03	8.39E-05	3.05E+09	7.01E+02
I 132*	5.02E+03	1.38E-04	5.46E+08	8.20E+01
I 133	7.49E+04	9.25E-06	1.33E+09	9.33E+02
I 133*	9.00E+00	7.70E-02	1.56E+08	9.97E-04
I 134	3.15E+03	2.20E-04	1.56E+08	1.50E+01
I 134*	2.21E+02	3.13E-03	6.82E+02	1.84E-06
I 135	2.37E+04	2.93E-05	7.80E+07	3.57E+01
I 136	8.34E+01	8.31E-03	1.96E+00	9.35E-10
I 136*	4.69E+01	1.48E-02	1.82E+00	2.93E-10
TOTAL				3.44E+08

Differential equations governing the system:

$$\frac{dA_T}{dt} = c(1 - R_S) - (\lambda + D + \varepsilon_F + \varepsilon_H)A_T \qquad \text{Target activity} \qquad (1)$$

$$\frac{dA_H}{dt} = A_T(D + \varepsilon_H) - (\lambda + G + L)A_H \qquad \text{Helium gas phase activity} \qquad (2)$$

$$\frac{dA_r}{dt} = LA_H - (\lambda + r)A_r \qquad \text{HVAC room activity} \qquad (3)$$

$$A_{out}(t) = r\,A_r(t) \qquad \text{Activity to the stack} \qquad (4)$$

$$A_{out} = r\int_0^T A_r(t)dt \qquad \text{Annual released activity} \qquad (5)$$

$$A_{out} = r\int_0^T A_{rH}(t)dt = P\,N\,r\left[\mathrm{a} - \frac{\mathrm{a}-\mathrm{b}}{\mathrm{k1\,T}}\left(1 - e^{-\mathrm{k1\,T}}\right) - \frac{\mathrm{b}}{\mathrm{k2\,T}}\left(1 - e^{-\mathrm{k2\,T}}\right)\right]$$

where:

c	radionuclide prod. rate	per radionuclide	Bq/sec
R_S	Release fraction sputtering	per radionuclide (3E-3 Iodine)	
λ	radiation decay constant	per radionuclide	1/sec
D	diffusion rate	per radionuclide	1/sec
ε_H	unfilterable dust form. rate	1.67E-16	1/sec
ε_F	filterable dust form. rate	1.67E-11	1/sec
G	purification rate	3E-5	1/sec
L	leakage rate	9.3E-9	1/sec
r	Vent. syst. exchange rate	per room (1.4E-3 as example)	1/sec
T	Operation time	1.8E+7	sec

⇨ Numeric integration

ATMOSPHERIC PATHWAY
Target Station | **Hot Cells**

1. Tungsten Dust (pasted-up on the surfaces of the structures and pipes) => spread =>HVAC=> environmnent

Ablation rate 3E-4/year formation of W dust

$$A_{1y} = \frac{q_s}{\lambda}\left[1 - e^{-\lambda T_{irrad}}\right]$$

q_s = P e f_{pu} is the plated up rate of the W dust derived using: P = annual production, e = ablation rate, f_{pu} = fraction and T_{irrad} is the operation time

at the end of the 5th annual run:

$$A_{5y} = A_1 \sum_{i=1}^{5} \left[e^{-\lambda T_1}\right]^{i-1}$$

annual release to the environment:

$$A_{HC\_W} = \frac{A_5\ r}{\lambda + r}\left[1 - \frac{1}{T_{HC}(\lambda + r)}\left(1 - e^{-(\lambda + r)T_{HC}}\right)\right]$$

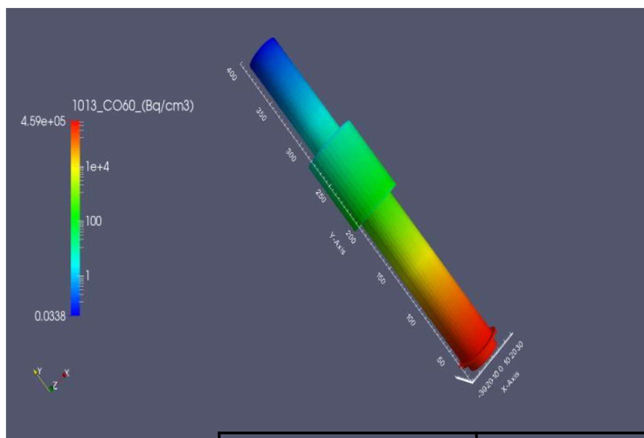
T_{ActC} = time needed for dismantling (2 months) & r is the HVAC exchange rate

$$RF_{H3}^{60degC} = 1E\text{-}4$$

ST from ActCs: short term release

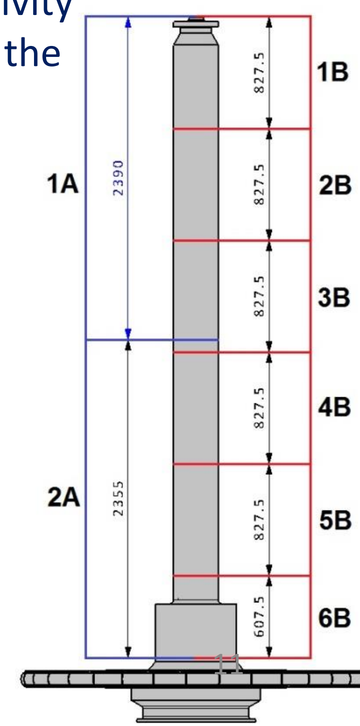
Nuclide class	Pessimistic release	Optimal release	^3H
SS dust	4.59E+08	1.38E+05	*2.01E+08*
W dust	1.06E+08	3.17E+04	*6.24E+11*
Total dust	5.65E+08	1.70E+05	
Total from ActC	**6.25E+11**	**6.24E+11**	

Release during dismantling



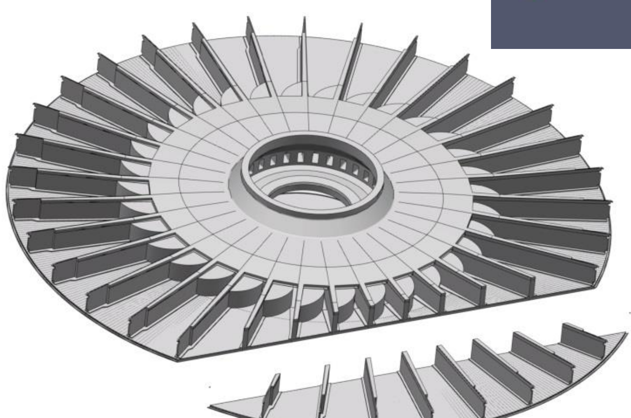
Distribution of radioactivity of ^{60}Co integrated over the entire shaft geometry (T. Mora et. al, 2016)

∫ over all shaft volume



2. Stainless Steel Dust

$$RF_{H3}^{60degC} = 0.5$$



	Stainless steel dust fractions* (%)			
	Min		Max	
	Shaft	Shroud	Shaft	Shroud
Stainless steel dust	0.20	1.13	0.42	2.24

***Estimated fractions of the stainless steel dust arising from the cutting of the target system**

Atmospheric releases

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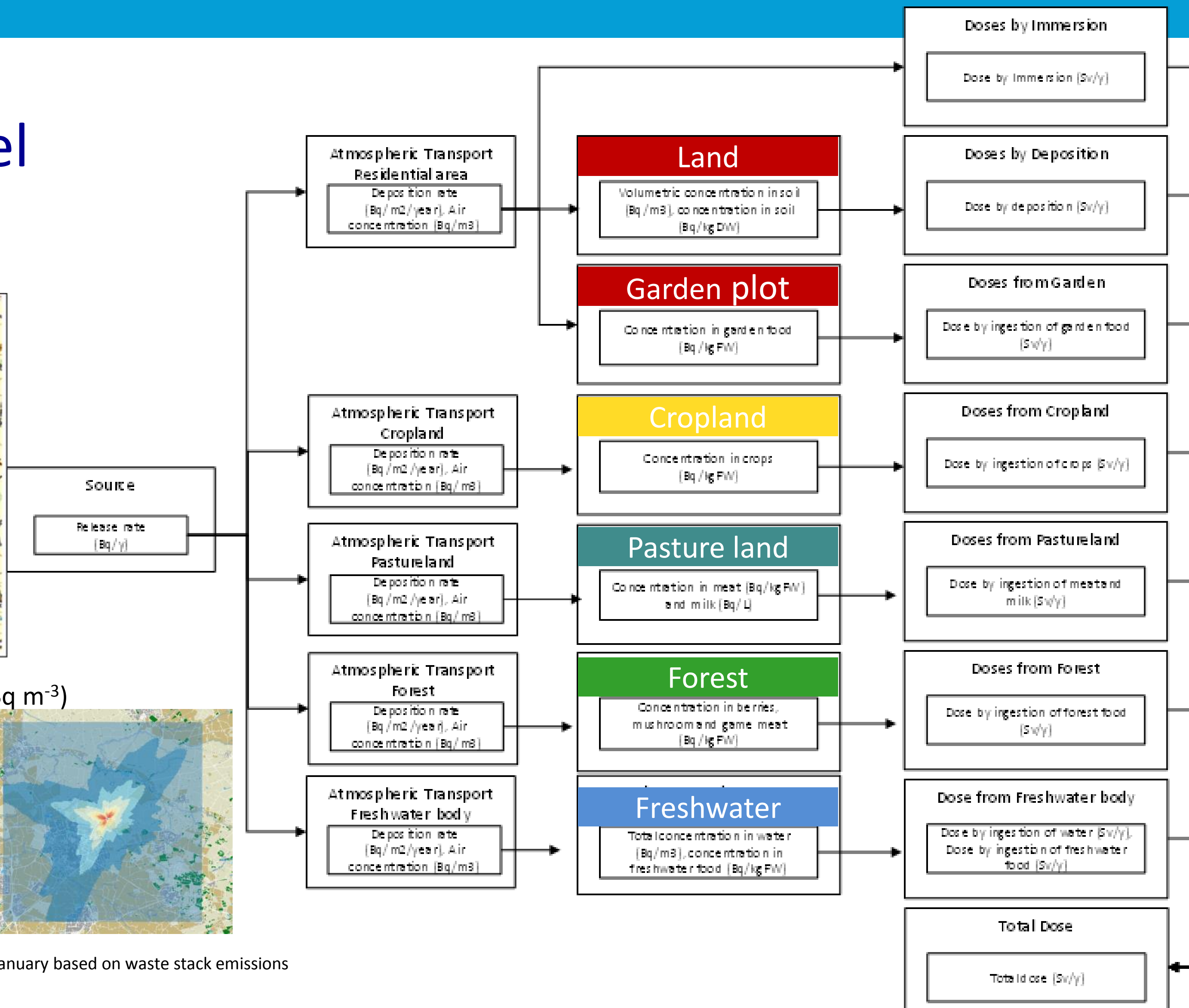
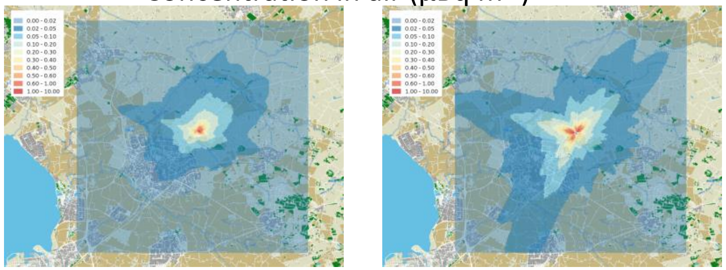
Realistic Model structure



Concentration in air (µBq m^{-3})



5 year averaged based on main stack emissions

averaged January based on waste stack emissions

Annual effective dose to the reference Averaged Man Results from Linac, HeL and Hot Cells

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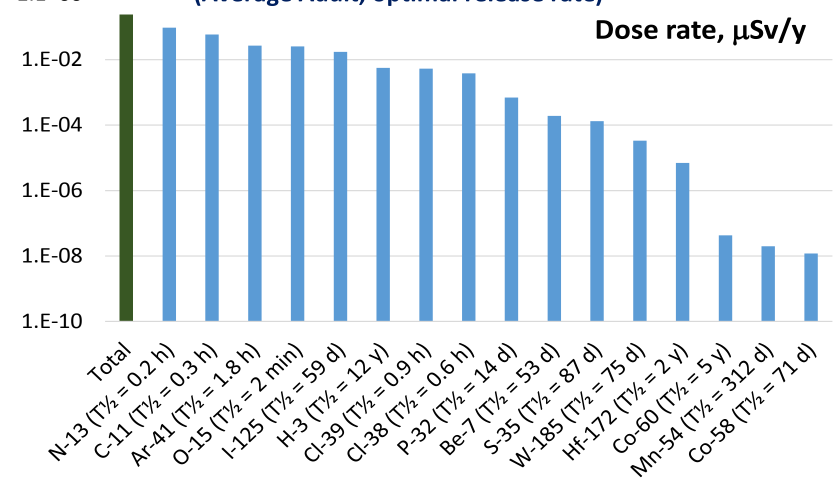
Annual Dose (µSv/y) to the Average Adult and contributions for the two analyzed release cases. (Main stack)

	Component	Released activity (Bq/y)		Effective dose (µSv/y) SCREENING APPROACH		Effective dose (µSv/y) REALISTIC APPROACH	
		Pessimistic	Optimal	Pessimistic	Optimal	Pessimistic	Optimal
Continuous release	**Linac**	2.26E+13	2.25E+13	1.16E+01	1.02E+01	2.84E-01	2.82E-01
	Helium Loop						
	Iodine	1.35E+09	1.35E+09	1.20E+01	1.20E+01	5.57E-02	5.57E-02
	other halogens	5.94E+07	5.94E+07	1.98E-03	1.98E-03	1.98E-03	1.98E-03
	H-3	6.24E+11	6.24E+11	1.08E+00	1.08E+00	5.60E-03	5.60E-03
	gases(O, N, CO)	7.33E+03	7.33E+03	7.53E-09	7.35E-09	3.83E-09	3.83E-09
	Noble gases	6.60E+09	6.60E+09	1.28E-03	1.28E-03	1.28E-03	1.28E-03
	Metaloids_1	2.72E+05	8.17E+01	9.20E-04	2.76E-07	3.26E-07	2.45E-07
	Metaloids_2	5.29E+07	1.59E+04	2.06E-01	6.19E-05	1.02E-04	6.20E-05
	Total	6.32E+11	6.32E+11	1.33E+01	1.31E+01	6.47E-02	6.47E-02
	bunker	-	-	-	-	-	-
	Total @ stack	**2.33E+13**	**2.31E+13**	**2.49E+01**	**2.33E+01**	**3.48E-01**	**3.47E-01**
Short term release	**Dismantling in ActC**						
	W dust	6.24E+11	6.24E+11	1.26E+00	1.08E+00	2.94E-02	2.92E-02
	SS dust	6.60E+08	2.01E+08	7.44E-01	5.71E-04	2.18E-03	6.54E-07
	Total @ stack	**6.25E+11**	**6.24E+11**	**2.01E+00**	**1.08E+00**	**3.16E-02**	**2.92E-02**
	Maximum release each 5 years						
	TOTAL @ stack	**2.39E+13**	**2.37E+13**	**2.69E+01**	**2.44E+01**	**3.80E-01**	**3.76E-01**

Pessimistic release = abatement equipment @ stack =>down

Optimal release = abatement equipment @ stack works optimally

Total dose rate and contributions from different radionuclides (Average Adult, optimal release rate)



Total dose rate and contributions from different exposure pathways (Average Adult, optimal release rate)

RN	Annual dose rate,	Cloud immersion	Deposited radionuclid	Water inges	Food ingestion
Total	3.5E-01	92	1	0	7
N-13	1.1E-01	100	0	0	0
C-11	6.2E-02	98	1	0	0
O-15	4.5E-02	100	0	0	0
Ar-41	2.7E-02	100	0	0	0
I-125	1.7E-02	5	0	0	95
H-3	5.6E-03	19	0	22	60
Cl-39	5.4E-03	97	2	0	0
Cl-38	3.9E-03	98	1	0	0
P-32	2.1E-07	14	0	0	86
Be-7	5.8E-08	7	29	0	64
S-35	4.0E-08	7	0	0	93
W-185	1.0E-08	1	0	0	99
Hf-172	2.1E-09	12	52	0	37
Co-60	1.3E-11	5	81	0	15
Mn-54	6.0E-12	3	59	0	37
Co-58	3.6E-12	9	32	0	59

ATMOSPHERIC PATHWAY
Waste facility: source term

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The waste facility (WF) is a treatment and interim storage facility for radioactive waste. It is complementary to Hot Cells (HC).

Main conditioning processes with potential airborne release:

- Cementation of the waste, such as spent ion exchange resins and activated/contaminated liquid waste;
- Treatment of the waste waters prior to discharging to the sewage system;
- Other treatment/conditioning processes (such as cutting), as well as the temporary storage of the obsolete getters and W dust bags from the Target Station releasing gases, volatiles and/or dust that will be extracted via HVAC through the WF stack to the atmosphere .

Processing activities to be performed periodically during campaigns => short-term release via a WF stack

ST to the atmosphere can be estimates based on:

- Initial radioactive inventory of the waste prior to the treatment;
- Effectiveness of the treatment in terms of releasing (the percentage from the total radioactive inventory of the waste to be treated that will be released through the WF stack into the environment);
- Frequency and duration of the campaign (cementation, water treatment, other with release to the stack).

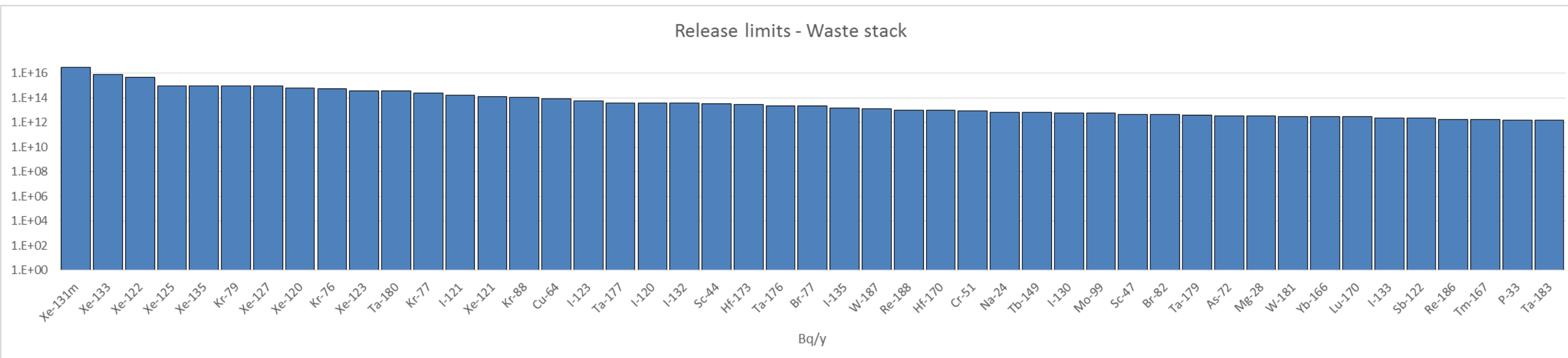
A conservative envelope of radionuclides with potential of releasing from the WF is proposed:

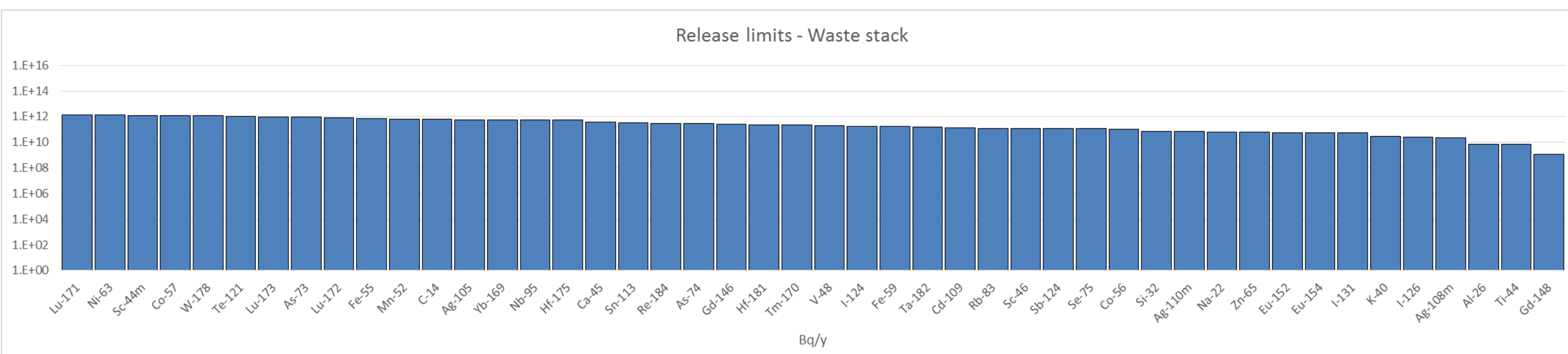
- Radionuclides with potential to be contained in the waste water, produced via activation or contamination during ESS operations;
- Radionuclides of the structural material dust, that were selected based on their radiological impact, as representative isotopes of both: i) corrosion products bound in the ion exchange matrixes and ii) potential dust to be released during the cutting operations;
- Radionuclides of the W dust, as some of the potential contaminated waste from the target station monolith may be hosted in WF, directly or after temporarily HC storage.

Because quantification of the ST is not known it was decided to derive <u>the ESS specific discharge limits for all 93 radionuclides.</u>

Waste stack: Derived Release Limits (Bq/y)

The realistic Dose Factors were used to derive discharged limits by dividing the assumed dose target 10 µSv/y by the Dose Factor





According to SSM, none of the Swedish restrictions on liquid surface discharges: (SSMFS2008:23, 2008) applicable for nuclear power plants (NPP)s or (SSMFS: 2010:2, 2010) applicable for other type of facilities is valid for ESS.
ESS has to agree with wastewater treatment plant (Va Syd Källby Avlopps & Reningsverk) company in Lund the conditions for discharging.

Breakdown of radionuclides with potential of discharging into the sewage system:

A conservative envelope of 72 radionuclides potential contained in the waste water **(ESS-0028551)** :

i) activation of the water (Short lived radionuclides decay inside the close circuits & long lived ones such ^{7,10}Be are removed by the ion-exchangers) ***;***

Activated water of Main Cooling Circuits (MCC) is removed only if the chemistry of the water is damaged or from radiation protection reasons the continuous addition of fresh water within MCC is necessary. The replaced water from the circuit may be discharged after treatment if the activities of the constituents are below the allowed discharged surface water limits.

ii) contamination of water with corrosion products;

iii) contamination with W dust.

(Ion-exchangers clean also activated corrosion products from the metallic pipes & W dust)

Selection of the isotopes was done taking into consideration the existing measurements and experience in management of the wastewater of other spallation facilities, such LANSCE, USA (Borden M., 2014), ISIS, UK (Boyer F., 2011), (Masterson P., 2014), FERMILAB, USA (Vaziri K., 2014), CERN Switzerland (Vojtyla P, 2005).

The treatment, method within Waste Facility of the waste water contributes essentially in defining the ST of discharges. Experience in Swedish NPPs (Hoglund A., 2015) is the use of an evaporator in order to treat the wastewater. In the resulted water to be discharged into environment remains less than 1 Bq/kg of gamma emitters.

Because quantification of the ST is not known & No assumptions on classes of radionuclides (gross beta, gross gamma, others) are available it was decided to derive the ESS specific discharge limits for all 72 radionuclides.

Discharge of radioactive substances to the sewage system

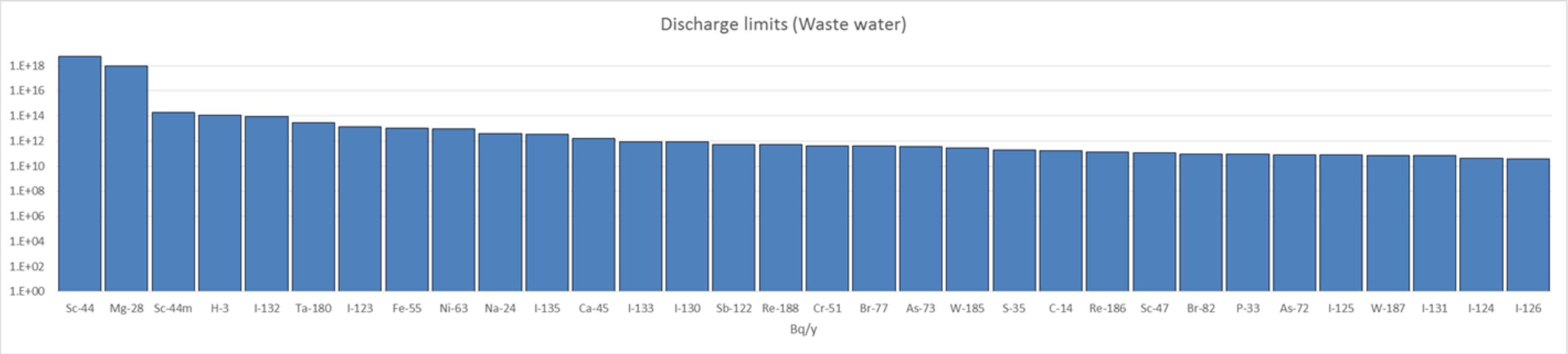
The assessment accounts for exposure to

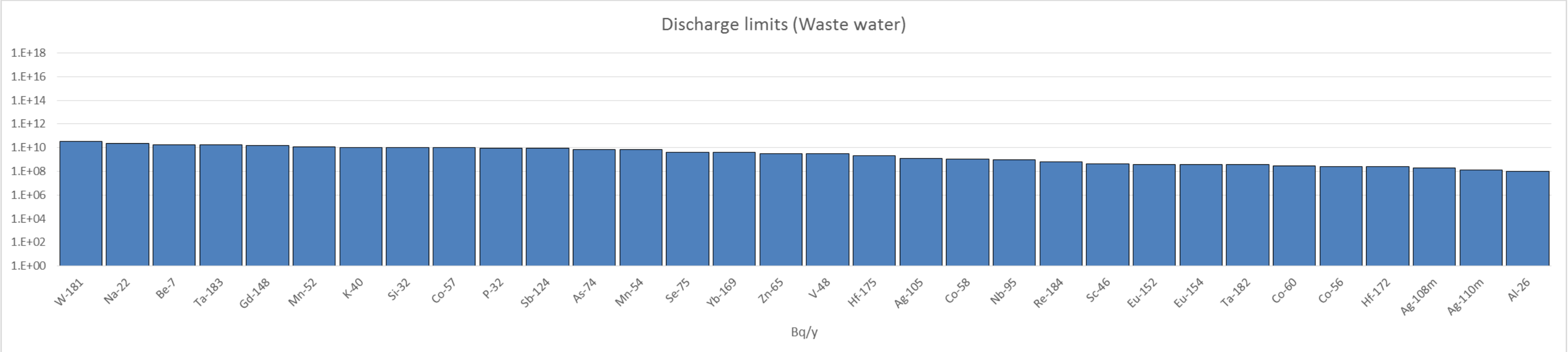
1) **workers in the sewage plant that are exposed to radionuclides in the non-treated water or sewage sludge and**
2) **the general public exposed, either directly (through consumption) or indirectly (though use of water for irrigation or for feeding cattle).**

The realistic Dose Factors were used to derive discharged limits by dividing the assumed dose target 10 µSv/y by the maximum of the Dose Factor for workers and general public

Waste facility outlet:

Derived Reference Discharge Limits for waste water (Bq/y) -72 radionuclides





GROUNDWATER PATHWAY: Source Term & annual dose

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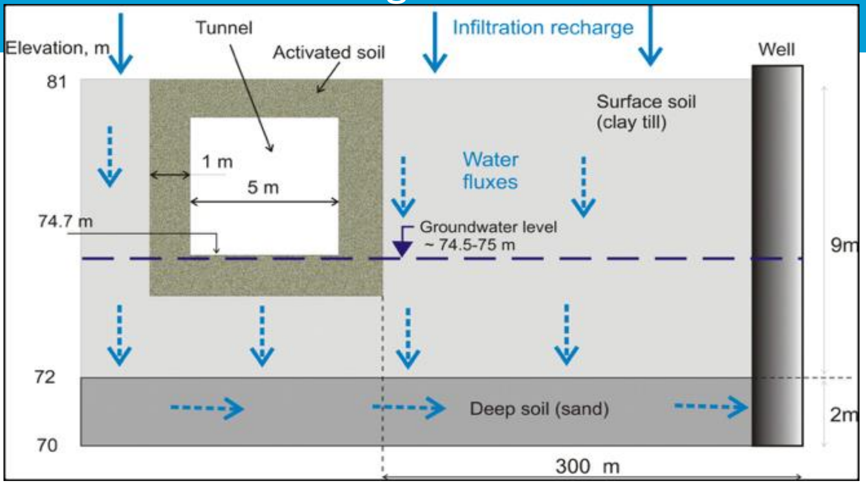
Activity of nuclides produced in the 1st meter thick soil layer around the ESS tunnel wall at shutdown after 40 years of continuous operation.

Rn*	$T_{1/2}$	Total accumulated inventory at 40 y (Bq)	Average production rate, Bq/y	Leaching & H_2O content (%)
H-3	12.33 y	2.10E+10	1.32E+09	100 & 16
Be-7	53.12 d	7.40E+09	3.52E+10	
Na-22	2.60 y	4.37E+09	1.17E+09	15 & 16
Na-24	14.96 h	5.01E+10	2.03E+13	
P-32	14.26 d	1.61E+09	2.86E+10	
S-35	87.32 d	5.27E+08	1.53E+09	
Ca-45	162.61 d	4.31E+07	6.71E+07	
Mn-54	312.3 d	1.62E+09	1.31E+09	
Sc-46	83.79 d	9.75E+08	2.94E+09	
Fe-55	2.73 y	1.40E+10	3.55E+09	
Zn-65	244.26 d	1.87E+06	1.94E+06	

* Selection based on (Sullivan, 1992)

2D cross-sectional groundwater flow model



Radionuclide activities (Bq/m³) in the water of the well @ 300 m

Rn	Scenario 1 Reference K_d*	Scenario 1 Conservative K_d**	Scenario 2 Reference K_d*	Scenario 2 Conservative K_d**
H-3	3.57E+04	3.57E+04	1.67E+04	1.67E+04
Na-22	1.45E-32	2.91E-11	1.28E-31	2.01E-10
S-35	1.21E-88	1.10E-43	2.19E-87	1.75E-42

< 100 Bq/L (EU DWD 2015/1787)

*K_d taken from (Sheppard et al., 2011)

** Kd (= Ref K_d/10)

Two scenarios of radioactivity leaching from the soil:

1. assumes an impermeable soil cover (or **membrane**), situated on the top of a tunnel, which **will fail after the end of operations** of the accelerator (the 40th year), leading to the leaching of the accumulated nuclides in the activated soil to groundwater;
2. assumes that there is **no protective cover present**, and a chronic release occurs through the operation life time of the facility (40 years).

Groundwater transport is carried out in two steps:

1. Groundwater flow modeling using **MODFLOW** code and
2. Radionuclide transport modeling using the **NORMALYSA** model library implemented in Ecolego 6.0

Annual dose rate (Sv/y)

Rn	**Scenario 1 Ingestion of water**	**Scenario 1 Total**	**Scenario 2 Ingestion of water**	**Scenario 2 Total**
H-3	2.42E-07	2.45E-07	1.130E-07	1.15E-07
Na-22	1.74E-41	3.22E-41	1.54E-40	1.54E-40
S-35	3.51E-98	6.50E-98	6.34E-97	1.30E-40
Total	**2.42E-07**	**2.45E-07**	**1.13E-07**	**1.15E-07**

Locations on ESS site
(selection of locations outside the fence)

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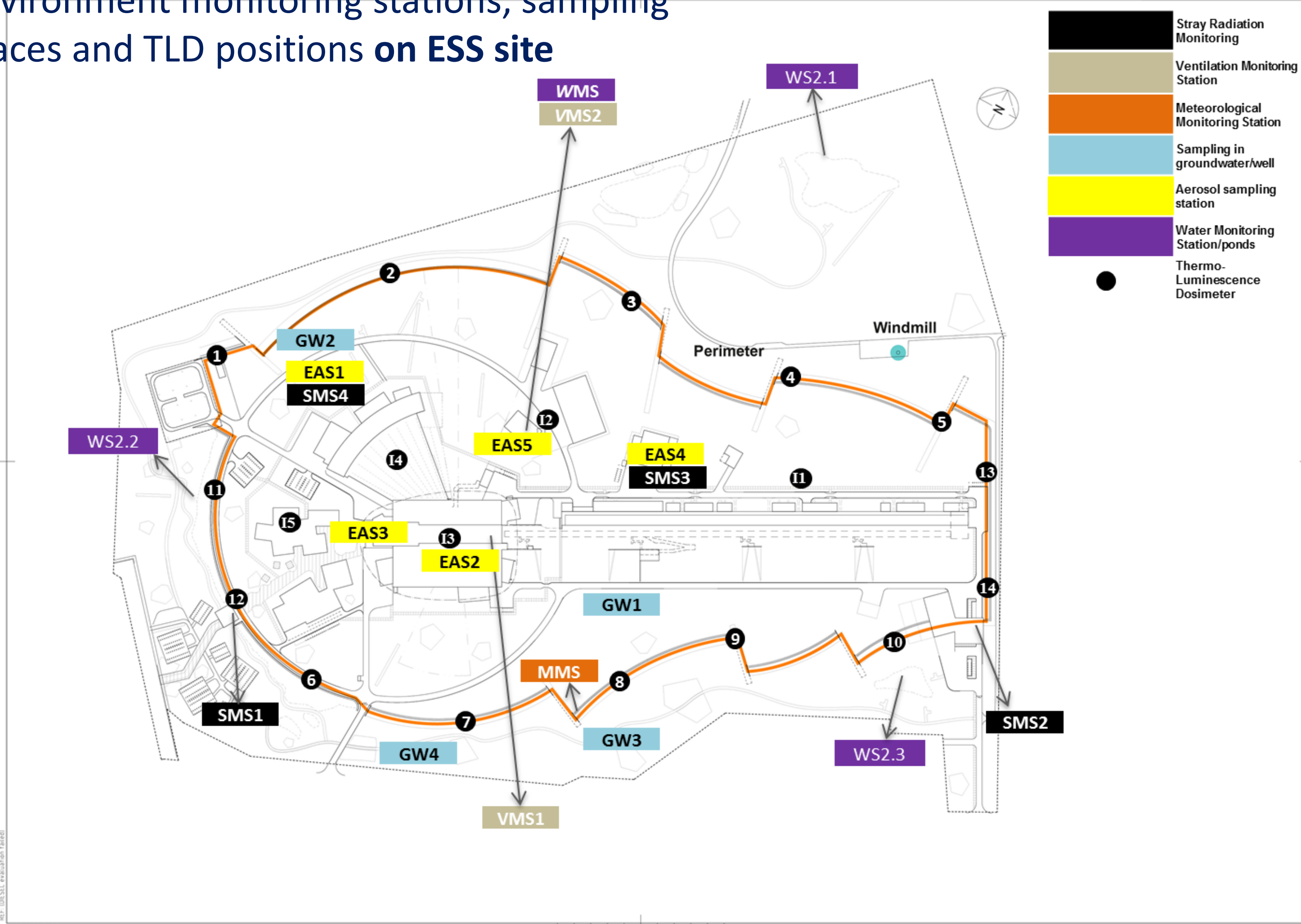
Environment monitoring stations, sampling places and TLD positions **on ESS site**



Summary

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- Annual dose from the direct radiation is less than 10 μSv/y;
- Maximum annual dose for continuous release to the main stack from Linac, HeL is less than 1 μSv/y and the major contribution (80%) is given: ^{13}N, ^{11}C, ^{41}Ar, ^{15}O, ^{3}H, ^{125}I, $^{39,38}Cl$, ^{32}P, ^{7}Be, ^{35}S, ^{185}W, ^{172}Hf, ^{60}Co, ^{54}Mn, ^{58}Co;
- Maximum annual dose for short term release to the main stack is less than 0.1 μSv/y and the major contribution is given by ^{3}H release during dismantling;
- The source term to the waste stack is not known therefore derived activity limits where derived for all 93 radionuclides with potential to be released;
- The source term to the waste facility outlet is not known therefore derived activity limits where derived for all 72 radionuclide with potential of discharging into the sewage system;
- Maximum annual dose due to the migration of the contaminant with the groundwater is less than 1 μSv/y and is due to the drinking water contaminated with ^{3}H;
- Actual results of realistic dose calculations for airborne releases of radionuclides from the main stack show that annual doses to the public are well below the regulatory constraint of 100 μSv/y and even below the exemption level of 10 μSv/y. Obtained results shall be completed with remaining contributors.

This report is conceived according the knowledge that ESS staff has in this stage of the project. The current data are estimations subjected to evolution and update.

An environment monitoring program was defined and it will be implemented gradually during the commissioning of the ESS facility