Radiological environmental monitoring at the ESS facility

Annual report 2022

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Radiological environmental monitoring at the ESS facility – Annual report 2022

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SUMMARY

Environmental monitoring of surroundings of the European Spallation Source (ESS) commenced in 2017, and in the current report results for 2022 are presented. Sample matrices include grass, fruits and berries, crops, bioindicators, milk, various water bodies and fish. For gamma-emitting radionuclides, no unexpected levels of anthropogenic radioactivity were identified. Small and varying concentrations of ^{137}Cs were observed in seaweed and samples of sediments (separate report). For tritium as well as ^{14}C, the activity concentrations did not deviate from expected values. We propose new, more suitable sampling sites for the marine environment than previously used. Data on sediments collected in 2022 are presented in a dedicated report, referred to in this report.

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List of abbreviations

d.w.	Dry weight
ESS	European Spallation Source
$F^{14}C$	Fraction Modern Carbon
LSC	Liquid Scintillation Counting
MDA	Minimum Detectable Activity concentration
SDI	Spectrum Dose Index
SSM	Swedish Radiation Safety Authority
STD	Standard Deviation
SUM	Standard Uncertainty of the Mean

1. BACKGROUND

The radiological environmental monitoring programme at the European Spallation Source (ESS) started in 2017, and the results have been presented in annual reports since then [1-5]. Carbon-14 data until 2020 have been summarized in [6]. Results for 2022 are presented in the current report.

1.1. Aim

The report aims to provide radiological environmental data for ESS for year 2022. Compared to previous annual reports, in this report, results from the first gamma spectrometric measurements of fish from Kävlinge river and Höje river are added.

1.2. Current status of the ESS activities involving ionising radiation

In 2022, there were no operational activities at ESS that could lead to emissions of radioactivity to the environment. In the report [7] the progress work is described in more detail: "During the year 2022 ESS had continued operation of klystrons in G02 and testing of cryomodules in Test Stand 2 as well as commissioning of the Normal-Conducting Linac (NCL) with beam up to the Faraday Cup after the Drift Tube Linac 1, with a proton beam energy up to 21 MeV, that started in May 2022."

2. METHODOLOGY

2.1. Description of sampling programme

The outline and results from the sampling programmes for 2017-2021 are described and presented in [1-5]. The measurements performed in 2017-2021 [1-5], including data of relevance from various projects financed by the Swedish Radiation Safety Authority (SSM) [4, 8-10], are summarized in Table 1 (related to airborne releases) and Table 2 (related to liquid discharges). Table 3 presents the sample types (or monitored parameters) and sampling frequencies for the environmental monitoring programme of 2022. New for 2022 is gamma spectrometry measurements on fish. The results of an extended investigation of sediments is described elsewhere [11].

Table 1 Monitored parameters (methods) and frequencies of sampling and measurement for zero-point assessments, related to airborne discharges.

Monitored parameters	Number of sites/frequency for the 2017-2018 report [1]	Annual report year 2018 [2]	SSM report, for year 2018-2019, ref [8]	Annual report year 2019 [3]	Annual report year 2020 [4]	Annual report year 2021 [5]
External radiation						
In situ γ spectrometry	21 sites				4 sites	3 sites (summer and winter)
Mobile	Ambient dose equivalent rate at 29 sites. One car assessment				ESS and MAX IV	1 assessment (summer) 1.5-2 km from ESS
Air, deposition						
Soil, γ-emitting radionuclides	Down to a depth of 20 cm at 22 sites. Down to a depth of 7 cm at 29 sites.					
Soil, ^{129}I					4 sites	
Foodstuff and/or ingestion						
Fruits, berries	^{14}C at 12 sites	^{14}C at 10 sites		^{14}C at 6 sites	γ-emitters at 9 sites, ^{3}H at 10 sites and 8 ^{14}C	γ-emitters and ^{14}C at 7 sites, ^{3}H at 5 sites
Crops	γ-emitters at 12 sites, ^{14}C at 6 sites, ^{3}H at one site.	^{14}C at 2 sites		13 γ and 6 ^{3}H samples	γ-emitters at 16 sites, ^{3}H at 1 site, ^{14}C at 1 sites, 1 sugar beet for γ and ^{3}H	15 samples for gamma analysis, 2 samples for ^{3}H analysis
Milk and forage	γ-emitters, ^{3}H and ^{14}C at one site on one occasion.				1 milk, 1 forage grass for γ, 2 ^{3}H and ^{14}C	2 milk samples for gamma, ^{3}H and ^{14}C analysis
Meat					1 γ, t^{3}H and ^{14}C	
^{14}C in annual tree rings	Years 2012-2016 at 4 sites (2 around ESS, 1 urban background and 1 rural background site).					
^{14}C in fullerene soot monitors	Same sites as tree rings, four 4-week periods.					
Drinking water and/or well water	^{3}H at 4 sites	^{3}H at one site		4 γ, monthly ^{3}H in tap water		
Terrestrial indicators						
Grass	γ-emitters at 20 sites, ^{14}C at 12 sites	^{14}C at 8 sites		γ at 6 sites, ^{14}C at 2 sites	9+1 samples for γ, 13 ^{14}C	9 samples for gamma, 3 samples for ^{14}C analysis
Lichen, moss and other bioindicators	γ-emitters at 13 sites, ^{14}C at 12 sites				3 lichen samples for γ (2 also for ^{129}I) analysis, 1 moss for γ and ^{129}I, 10 other bioindicators for γ	2 samples of lichen, 2 samples of moss, 1 sugar beet for gamma analysis
Honey					1 γ and ^{14}C	2 samples for gamma and 1 sample for ^{3}H analysis
Precipitation and air						
Precipitation		Continuous sampling for ^{3}H analysis. Urban reference site 2018-03-19 to 2018-04-13; ESS site 2018-04-13 to 2018-05-03.	Continuous sampling of precipitation at ESS site for ^{3}H analysis. Monthly basis, start April 2018. Results until April 2019 in [8].		Precipitation at ESS site for ^{3}H analysis. Monthly basis.	
Air humidity		Grab sampling for ^{3}H analysis. 1 at urban reference site, 2 at ESS site.	Grab sampling for ^{3}H analysis. Monthly basis, start May 2018. At ESS site and urban reference site. Results until April 2019 in [8].		Grab sampling for ^{3}H at ESS site and urban reference site. Monthly basis.	

Table 2 Monitored parameters (methods) and frequencies of sampling and measurement for zero-point assessments, related to liquid effluents.

Monitored parameters	Number of sites/frequency for the 2017-2018 report [1]	Annual report year 2018 [2]	SSM report, for year 2018-2019, ref [8]	Annual report year 2019 [3]	Annual report year 2020 [4]	Annual report year 2021 [5]
Water bodies						
Groundwater	^3H at 12 sites			γ in 4 samples	1 at reference site Grevie (^3H)	3 samples for gamma analysis, 1 sample from Grevie (background)
Surface water	^3H at 8 sites			^3H in monthly samples from 3 ponds, and from Källby pond.	Monthly grab sampling of pond water at 3 sites for ^3H analysis. 11 ^3H in water from streams and rivers	Monthly grab sampling of pond water at 3 sites (ESS, MAX IVand 1 urban reference site) for ^3H analysis. 3 samples for ^3H in water from streams and rivers
Tap water					8 samples of Lund tap water (^3H)	12 samples of Lund tap water (^3H)
Sewage sludge	γ-emitters and ^3H at Källby: Monthly samples from April 2017 – April 2018.	γ-emitters and ^3H at Källby: two occasions		γ-emitters and ^3H in 2 samples	13 samples for γ and 11 for ^3H	8 samples for gamma and ^3H analysis
Seaweed					SSM project SSM2019-5225 [9]	2 samples for gamma and ^{14}C analysis
Sediment						1 test sample for gamma, site 31.6 (ESS pond 4), ~5 months sampling with bottom trap

Table 3 Monitored parameters (methods) and frequencies of sampling and measurement for zero-point assessments 2022.

Discharge	Monitored parameters	Number of sites/frequency
Airborne	*External radiation*	
	In situ gamma spectrometry	7
	Mobile	1
	Air, deposition	
	Soil	N/A (to be continued during ESS operation)
	Fruits, berries	5 samples for gamma and 13 samples for ^{14}C analysis, 3 samples for ^{3}H analysis
	Crops	7 samples for gamma analysis (4 pooled for each type of crops), 3 samples for ^{3}H analysis
	Milk and forage	2 milk samples for gamma, ^{3}H and ^{14}C analysis
	Meat	N/A (to be continued during ESS operation)
	Grass	6 samples for gamma, 5 samples for ^{14}C analysis
	Honey	N/A
	Lichen, moss and other bioindicators	2 samples for gamma analysis
	Precipitation and air	
	Precipitation	Continuous sampling of precipitation at ESS site for ^{3}H analysis. Monthly basis.
	Air humidity	Grab sampling for ^{3}H analysis at ESS site and urban reference site. Monthly basis.
Liquid	*Water bodies*	
	Groundwater	1 sample from Grevie (background)
	Surface water	Monthly grab sampling of pond water at 3 sites (ESS, MAX IV and 1 urban reference site) for ^{3}H analysis. 8 samples for ^{3}H in water from streams and rivers.
	Tap water	Monthly grab sampling of Lund tap water (^{3}H)
	Sewage sludge	N/A
	Seaweed	2 samples for gamma and ^{14}C analysis
	Sediment	11 (sites) samples for gamma analysis, described in [11]
	Fish	2 samples for gamma analysis

2.2. Sampling sites

Sampling sites and sample/measurement types for 2022 are listed in Table 4.

Table 4 Sampling sites and type of measurements performed during year 2022.

Site	Site	Latitude	Longitude	Gamma	^{3}H	^{14}C
1	Västra Odarslöv 341	N55.7431	E13.2477	Apple		Apple
2	Östra Odarslöv 651	N55.7380	E13.2736	Pear		Pear
6	Möllegården	N55.7304	E13.2441	Apple, grass, lichen, *in situ*		Grass, apple
14.2	Kävlingeån, Gårdstånga kyrka	N55.7589	E13.3267		Surface water	
27.2	Kärrpengavägen bus stop, east side of the road	N55.7344	E13.2603			Grass
27.3	ESS SE corner (at stones)	N55.7346	E13.2597	Grass, *in situ*		
30	Kopparstaden windmill	N55.7385	E13.2543	Grass, *in situ*		Grass
31.6	ESS area (6) (ESS offical pond 4)	N55.7358	E13.2442	Sediment [11]	Surface water	
31.20	ESS area (20), weather station	N55.7366	E13.2455		Precipitation, air humidity	
32.2	Dammstorpsvägen 16 (field 1)	N55.7279	E13.2574	Autumn wheat		
32.4	Dammstorpsvägen 16 (field 3)	N55.7288	E13.2520	Malt grains		
34.4	MAX IV area (4)	N55.7270	E13.2363	Pear		Pear
34.5	MAX IV area (5), pond	N55.7283	E13.2376		Surface water	
35.4	Källby, Höje å, Drömbron	N55.6980	E13.1552	Sediment [11]		
35.5	Källby, pond 1	N55.5927	E13.1624	Sediment [11]		
35.6	Källby, pond 5	N55.6991	E13.1527	Sediment [11]		
35.7	Källby, pond 2	N55.6962	E13.1589	Fish		
36.2	Svenstorp's gods, farmland (2) field "6-0"	N55.7583	E13.2508	Autumn wheat		
36.3	Svenstorp's gods, farmland (3) field "8-0"	N55.7449	E13.2442	Autumn wheat		
36.4	Svenstorp's gods, farmland (4) field "5-0"	N55.7515	E13.2397	Autumn wheat		
36.5	Svenstorp's gods, farmland (5) field "21-0"	N55.7400	E13.2671	Rapeseed		
36.6	Svenstorp's gods, farmland (6) field "25-0"	N55.7446	E13.2808	Rapeseed		
36.7	Svenstorp's gods, farmland (7) field "10-0"	N55.7509	E13.2597	Spring grains		
36.8	Svenstorp's gods, farmland (8) field "24-0"	N55.7465	E13.2707	Rapeseed		
36.9	Svenstorp's gods, farmland (9) field "8-1"	N55.7378	E13.2416	Spring grains		
36.10	Svenstorp's gods, farmland (10) field "22-0"	N55.7422	E13.2594	Rapeseed		
36.11	Svenstorp's gods, farmland (11) field "9-0"	N55.7445	E13.2529	Autumn wheat		
36.17	Svenstorp's gods, farmland (17)	N55.7665	E13.2413	Sugar beet		
42	Ladugårdsmarken (cell tower)	N55.7347	E13.2283	Apple		Pear
48	Timjanvägen 5, Lund	N55.7186	E13.1828		Air humidity	Apple
52	Professorsgatan 1, Lund	N55.7097	E13.2047		Tap water	Rowan berries
54	Active Biotech	N55.7169	E13.2206			Rowan berries
59	Gamla Bjärred, Pilevägen	N55.7071	E13.0334	Seaweed		Seaweed
60	Skillinge	N55.47	E14.28	Seaweed		Grass, seaweed
61	Hyltemossa	N56.10	E13.32			Grass, blueberry, rowan berries, blackberry
62	Grevie PV5 well	N55.6131	E13.1970		Ground water	
63	Monument park	N55.7182	E13.1851		Surface water	
64	Södervidinge 302-36	N55.827	E13.098	Milk	Milk	Milk
74.1	Glomsjön, inlet, at bridge, cow's drinking spot	N55.7206	E13.2661		Surface water	
76	Höje river, Trolleberg	N55.7022	E13.1439		Surface water	
77	Höje river, Lomma kyrka	N55.6878	E13.0781	Sediment [11]	Surface water	
79	Lödde river (Kävlinge river), Strömnäsvägen	N55.7357	E13.0050		Surface water	
80	Kävlinge river, Högs mölla	N55.7798	E13.0775		Surface water	
81	Kävlinge river, Håstad	N55.7769	E13.2350		Surface water	
82	Kävlinge river, Flyinge kungsgård	N55.7500	E13.3550		Surface water	
83	Kävlinge river, Revinge by	N55.7299	E13.4670		Surface water	
84	Vomb bridge	N55.6986	E13.5543		Surface water	

88:2	Åhus, Helge å, Mölleholmen	N55.9148	E14.2838	Sediment [11]	
89.3	Lundaslättens drift, field C	N55.7368	E13.2346	Rapeseed	
89.5	Lundaslättens drift, field E	N55.7239	E13.2443	Rapeseed	
89.8	Lundaslättens drift, field H	N55.7372	E13.2278	Grains	
90	Getinge bridge	N55.7645	E13.3145	Sediment [11]	
91	Pegasus trädgård	N55.7625	E13.0544	Sediment [11]	
92	Örtofta	N55.7762	E13.2455	Sediment [11]	
93	Kävlinge scoutgård	N55.7914	E13.1392	Sediment [11]	
94.1	Kävlingeån, outlet Sularpsbäcken, upstream	N55.750	E13.338	Sediment [11]	Surface water
94.2	Kävlingeån, outlet Sularpsbäcken, downstream	N55.751	E13.337	Sediment [11]	
95	Höje å, Bjällerup	N55.658	E13.260	Sediment [11]	
96	Viderup slott	N55.78	E13.29	Fish	

Positions of the sampling sites, for measurement with laboratory gamma spectrometry, and sites for *in situ* gamma spectrometry are shown in Figure 1 (coordinates are provided in Table 4). Sites 6 (Möllegården), 27.3 (ESS SE corner) and 30 (Kopparstadens windmill) were used for repeated *in situ* gamma spectrometry and samplings of grass during summer 2022 and winter 2023.

Figure 1 Sampling sites for gamma spectrometry measurements for year 2022. See Table 4 for more information. The lower figure is zoomed around the Lund area.

Figure 2 shows the positions of the sampling sites of ^{3}H in 2022 (coordinates are provided in Table 4). Sites 48 and 63 are urban reference sites, used for sampling of air humidity and surface water. Water from the deep well "Grevie PV5" (depth 71-72 m) at site 62, operated by VA Syd, was used as background water (a previous study has reported a ^{3}H concentration of about 0.02 TU, corresponding to 0.002 Bq L^{-1} [12]).

Figure 2 Sampling sites for ^{3}H samples for year 2022. See Table 4 for more information. The lower figure is zoomed around the Lund area.

Sites used in 2022 for sampling for ^{14}C analysis are presented in Figure 3. Site 60 (Skillinge) is used as marine reference station and 61 is the rural Swedish ICOS/ACTRIS[1] station Hyltemossa (N56.0976, E13.4189, 115 m above sea level). Hyltemossa is a combined atmosphere and ecosystem station, located in the forest 46 km NNE of Lund. The Hyltemossa station is used within ICOS to collect biweekly samples of atmospheric CO_2 at a sampling height 150 m above ground. The ^{14}C data from Hyltemossa, as well as from several other such European research infrastructures, are available from the ICOS data portal[2]. As discussed in [6] small regional as well as local differences may exist at different reference sites, e.g. due to varying influence from local sources of combustion of fossil fuels, and from varying degrees of soil respiration (releasing stored bomb-^{14}C back to the atmosphere). Four sample types (grass, blueberries, rowan berries and blackberries) were collected in the forest at Hyltemossa in 2022, to aid in assessing the representativeness of the biweekly ICOS ^{14}C data (from atmospheric CO_2 collected at 150 m above ground) to vegetation growing at ground level.

[1] ICOS: Integrated Carbon Observation System, https://www.icos-cp.eu/; ACTRIS: the European Research Infrastructure for the observation of Aerosol, Clouds, and Trace gases, https://www.actris.eu/
[2] https://www.icos-cp.eu/

Figure 3 Sampling sites for ^{14}C samples for year 2022. See Table 4 for more information. The lower figure is zoomed around the Lund area.

2.3. Methods for sample collection and analysis of gamma emitting radionuclides

The collection and sample preparation procedures for gamma spectrometry measurements of various sample types, also included in the monitoring programmes of previous years, are described in Refs [1, 8]. Sediment collection and sample preparation are described in a separate report [11]. Methods for gamma analysis of seaweed samples are described in [13].

Fish were caught by rod fishing in September in Kävlinge river close to Site 96 Viderup slott (3 individuals of *Perca fluviatilis* (perch) and 1 individual of *Esox lucius* (pike), total weight >2 kg). The fish were filleted (extracting 888 g pure fish meat), cut into smaller pieces and freeze-dried in open zip-lock bags (gaining 185 g of dried fish meat, i.e. the dry-weight to wet-weight ratio was 21%). Additionally, 24 individuals of tench (*Tinca tinca*) were caught in cages and collected from pond 2 at Källby waste-water treatment plant (Site 35.7). The 10 largest fish (3.8 kg, average weight 377 g, average length 30 cm) were filleted. The other 14 smaller fish (1.5 kg, average weight 109 g, average length 20 cm) were frozen whole for possible later analysis. From the 10 largest fish, 1049 g of pure meat (wet weight) was obtained. The dry weight after freeze-drying was 216 g (dry-weight to wet-weight ratio 21%). The dried fish meat from both sites were separately grinded into powders and were packed into 200 ml containers for gamma spectrometry analysis. Parts of the sample preparation stages are shown in Figure 4.

Figure 4 Sample preparation for fish samples prior to gamma spectrometry analysis. a) Tench (*Tinca tinca*) prior to filleting. b) Fillets cut to smaller pieces. c) Freeze-drying in zip-lock bags. d) Freeze-dried pieces of fish fillets. e) Powdered freeze-dried fish meat in 200 ml beaker.

In previous annual reports in this series of environmental monitoring the ^{238}U daughter ^{226}Ra has been reported among the gamma emitting radionuclides in the analysed samples. However, since the branching ratio of the single gamma emission from ^{226}Ra is low, gamma spectrometry is not an optimal method for quantification of the low concentrations of ^{238}U generally found in natural samples unless a special sample preparation method is utilized. The method requires special sample containers and a storage time between sample preparation and measurement. Since all samples are stored for future reference, such analysis can be prepared when needed. In this report, although equilibrium cannot be ascertained, the activity concentration of ^{214}Bi is reported.

2.4. Method for *in situ* and mobile gamma spectrometry around ESS

The methods for *in situ* and mobile gamma spectrometry are described in Ref [1, 8]. *In situ* gamma spectrometry was repeated at three specific sites (same as used for grass sampling) close to the ESS, in different directions: south, east, and north, corresponding to Sites 6, 27.3 and 30, respectively, using a p-type HPGe detector (Canberra) with a relative efficiency of 25%, on a tripod 1 m above the ground. The gamma spectrometry acquisition times were at least 40 minutes. As during previous years of the monitoring program, a car-borne mapping of the gamma dose rate (including spectrometry) in terms of spectrum dose index (SDI, see [14] for definition) was carried out during the autumn 2022 on the available roads within 1.5-2 km around the ESS.

2.5. Methods for tritium and ^{14}C

Methods for sampling, sample preparation and analysis of tritium from various sample types are presented in [3] and in references therein. Seaweed samples for ^{14}C analysis were pre-treated and analysed as described in [9]. For determination of the ^{14}C content of other sample types, the collection, preparation, measurement, and analysis were performed according to previous annual reports [1-4] and in [6].

3. RESULTS AND DISCUSSION

3.1. Activity concentration of gamma emitting radionuclides in various types of samples year 2022

The reported activity concentrations for some samples of crops were pooled in 2022. Gamma analysis for individual samples of the same type of crop, growing on nearby farmlands and belonging to the same farmer, are reported as one average activity concentration and range of minimum detectable activity (MDA). Crops of only one type per farmer is reported with its individual activity concentration and MDA. The results are similar compared to 2021, with activity concentrations above the MDA only for ^{40}K and with the highest values for rapeseed. The results of the gamma analysis of crops are given in Table A1.1.

Samples of grass were collected at three sites (6, 27.3, 30) in summer 2022 and in winter 2023. One sample (Site 6) had an ^{228}Ac activity concentration of 13±3 Bq kg^{-1} (±1σ), just above the MDA (11 Bq kg^{-1}), apart from which, only ^{40}K was above the MDA in all samples. As before, the activity concentration in the grass is higher in winter as compared to the summer. The results of the gamma analysis of grass are presented in Table A1.2.

Five samples of fruit, from five different sites, were collected and analysed in 2022. No unexpected levels of radioactivity were observed in these samples. The results of the gamma analysis of these samples are presented in Table A1.3.

Various types of bioindicators were collected and analysed (lichen, seaweed, sugar beet, fish). The seaweed samples (*Fucus vesiculosus*) had activity concentrations above the MDA for all the reported radionuclides, and as in 2021, with a higher ^{137}Cs concentration at site 60 (Skillinge) as compared to Site 59 (Gamla Bjärred). New for 2022 was the analysis of the activity concentration in fish, from site 35.7 (Källby pond 2) and in Kävlinge river (close to site 96). None of the samples contained any unexpected levels of radioactivity. The results of the gamma analysis of the bioindicators are presented in Tables A1.4 and A1.5.

Two samples of milk were collected and measured in 2022, one collected in June and one collected in November. As previously, the activity concentration in the milk samples were below the MDA except for small levels of ^{40}K, 71±5 Bq kg^{-1} and 74±6 Bq kg^{-1}, respectively. The results of the gamma analysis of the milk samples are presented in Table 1.6.

Furthermore, in 2022 it was not feasible to collect sewage sludge at Källby treatment facility (site 35). As this indicator is important for describing the radiation environment in the catchment area of Lund it is recommended to continue to follow long- and short-term changes in the sewage sludge further. The results of the gamma spectrometry measurements of the sediment samples are reported elsewhere [11].

3.2. *In situ* and mobile gamma spectrometry around ESS

As in previous reports in the series, *in situ* gamma spectrometry surveys were conducted at the same three sites (6, 27.3 and 30), one in summer 2022 and one in winter 2023. Small levels of ^{137}Cs were observed at two of the sites, but not at site 6 (Möllegården). Since 2021, a large part of the ground surface at site 6 has been renovated and new landfill materials added. This may explain the absence of the ^{137}Cs peak at that site in the *in situ* measurements in 2022. The results of the *in situ* gamma spectrometry are presented in Table A1.7.

The average SDI dose rate from the 5905 individual measurement points (acquisition time 1 s) during the mobile mapping (Figure 4) was 0.07 μSv h^{-1} with a standard deviation of the mean of 20%. The SDI dose rate is based on a cross calibration with a calibrated dose rate instrument at the start position of the measurement, and should hence not be observed as exact for each position. The measurement data should rather be viewed in terms of the variation over the mapped area, which for the data in Figure 4, corresponds to a span between 0.045-0.162 µSv h^{-1} (with a median value of 0.06 µSv h^{-1}).

In Figure 4 it can be observed that the radiation background along the small gravel and asphalt roads surrounded by fields with crops is low and homogenous. Areas with slightly elevated levels were close to construction sites with new ground layers or under bridges.

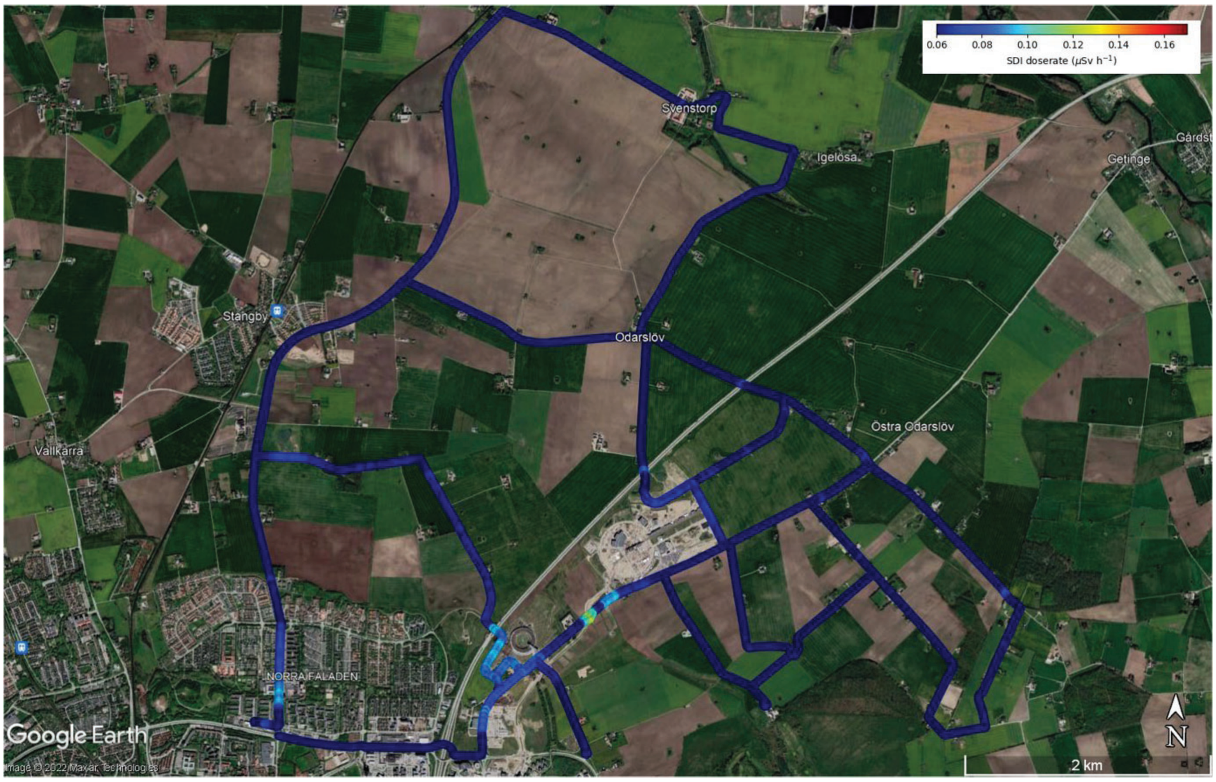

Figure 5 Dose rate map (Google Earth as of March 2022) in terms of SDI-dose rate (µSv h^{-1}) around ESS as measured by a carborne 2×4 litres NaI(Tl) detector system on 2022-10-25.

3.3. ^{3}H analysis year 2022

The results of the tritium measurements of samples of precipitation, air humidity, surface water, Lund tap water and streams collected in 2022 are shown in Tables A1.8-A1.13 in Appendix 1. Results from measurements of crops and fruits are presented in Table A1.14. Two measurements on milk samples from the dairy farm at site 64 are reported in Table A1.15.

For the majority of the samples, the measured activity concentration was below the MDA of 1.65 Bq L^{-1}. Slightly elevated levels of tritium were measured in some samples from the monitored ponds during the coldest and warmest months of the year. Tritiated water has a higher melting and boiling point than water. It induces a fractionation of tritium when evaporation is high or when the temperatures are below 0 °C. Thus, values above the 1.65 Bq L^{-1} detection level were measured but they are still within the expected range of environmental levels. Similar observations can be done for air humidity and precipitation samples. The highest value observed this year was 3.81 Bq L^{-1} measured in precipitation in March. This phenomenon has also been observed previously [8], and seasonal variations are expected [15]. In particular, elevated levels may be observed in spring, since water vapour from the stratosphere (where tritium is produced and hence has a relatively higher tritium activity concentration than in the troposphere) enters the troposphere each spring when the tropopause breaks up between 30° and 60° north [15]. The low amount of precipitation during this period (30 g instead of the usual > 1000 g sample mass) most likely amplifies this effect.

This year no samples of milk, fruits or crops presented activity concentrations higher than 1.65 Bq L^{-1}.

All of the measured activity concentrations of tritium in the samples are at expected environmental levels.

3.4. ^{14}C analysis year 2022

Table A1.16 in Appendix 1 presents the results of the ^{14}C analysis of 18 terrestrial samples (grass, fruits, berries and milk). The results of the 2 brown seaweed (*Fucus vesiculosus*) samples are presented in Table A1.17 in Appendix 1. The results are expressed as $F^{14}C$ [16, 17], see Ref [1] (p. 92-94) for definition and conversion to other activity concentration units[3].

Figure 5 shows the $F^{14}C$ values for the various samples at the different sites. The average $F^{14}C$ value of the terrestrial ^{14}C samples analysed for year 2022 samples was 1.004 (STD: 0.004; SUM:< 0.001), corresponding to a specific activity of 225 Bq kg^{-1} C using $\delta^{13}C$= - 25 ‰ (see Annex B4 in Ref [1]). The terrestrial data is normally distributed with no significant outlier according to Grubb's test. No significant difference can be observed between the mean values of ^{14}C in the 4 Hyltemossa samples and the rest of the terrestrial samples (two sample t test).

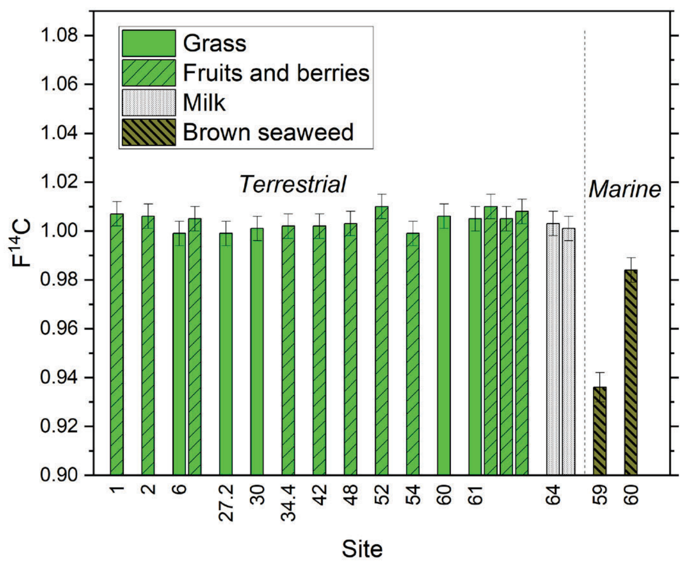

Figure 6 Results of the ^{14}C measurements from 2022. Uncertainties represent 1 standard deviation.

[3] $F^{14}C$ values corresponding to naturally produced ^{14}C are close to 1. Maximum $F^{14}C$ values observed in 1963 due to testing of atmospheric nuclear weapons in the late 1950s and early 1960s was around 2. $F^{14}C$ in atmospheric CO_2 is currently approaching the pre-bomb levels.

The $F^{14}C$ values of the marine samples are significantly lower than $F^{14}C$ of the terrestrial samples. This is not unexpected since $F^{14}C$ in surface waters can be affected by upwelling of old water with lower $F^{14}C$ in its dissolved inorganic carbon (which is absorbed by marine plants and algae) [9]. Coastal waters can also be affected by inflow of freshwater and groundwater, and river runoff may be depleted in ^{14}C due to contact with carbonate-bearing bedrock [18]. A previous study (in 2020) of $F^{14}C$ in seaweed collected at 45 sites along the Swedish coast has shown that $F^{14}C$ in seaweed can vary significantly [9]. The lowest value of $F^{14}C$ reported in [9] (0.969 ± 0.006) was actually in a *Fucus* samples collected at site 59 (Gamla Bjärred, i.e. the same site as with the lowest value in the current report). Figure 7 presents $F^{14}C$ for sites 59 and 60 for 2020 [9], 2021 [5] and 2022. The interannual variations in $F^{14}C$ are not unexpected (see [9]).

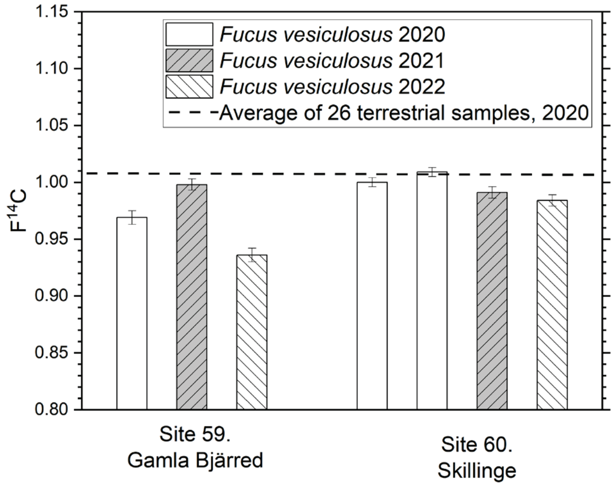

Figure 7 $F^{14}C$ in *Fucus vesiculosus* collected at site 59 (Gamla Bjärred) and site 60 (Skillinge) in 2020 [9], 2021 [5] and 2022.

Figure 6 demonstrates the average $F^{14}C$ values of all terrestrial samples analysed within the ESS environmental monitoring programme, along with ^{14}C data in atmospheric CO_2 from rural background stations at high altitude in central Europe and at Hyltemossa [19-23]. The decreasing trend in $F^{14}C$ is absorption of remains of atmospheric bomb-^{14}C into the oceans, combined with dilution due to releases of fossil (^{14}C-free) CO_2 (see section 3.4 in Ref [3]).

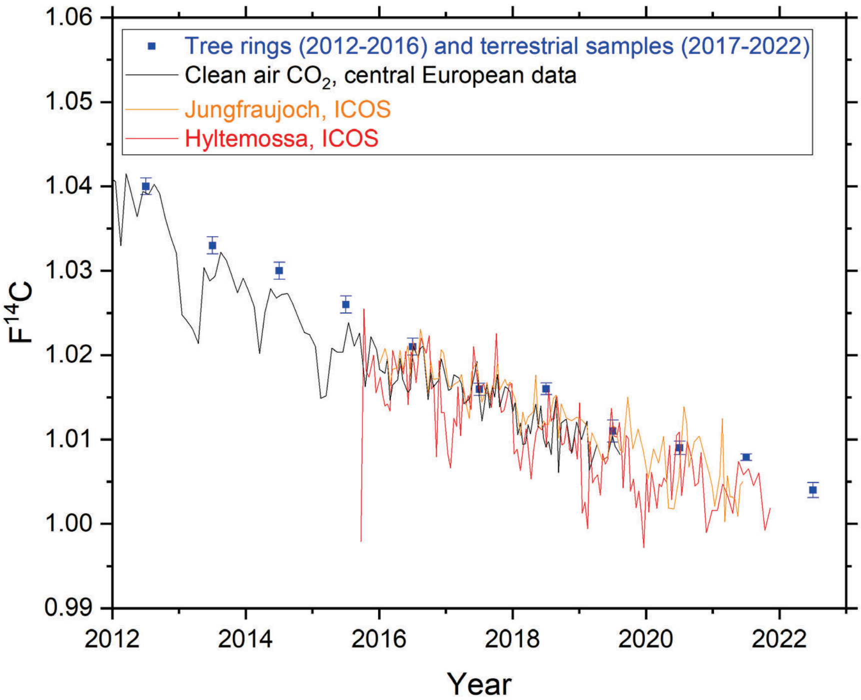

Figure 8 Average $F^{14}C$ values (uncertainty represented by the SUM) obtained for all ESS zero point assessments so far (terrestrial samples), along with ^{14}C data in atmospheric CO_2 collected at rural background stations in central Europe [19-22], Jungfraujoch (Switzerland, N46.5475, E7.9851, 3580 m above sea level, 5.0 m above ground) [24] and at the Swedish ICOS station Hyltemossa [25].

Hyltemossa ICOS data for 2022 are yet not available. Hence, the comparison between the 4 terrestrial samples collected at Hyltemossa and the ICOS CO_2 will be reported in the upcoming annual report for 2023.

3.5. Quality assurance

The laboratory participates in the annual IAEA intercomparison tests for gamma spectrometry and in 2019 we also participated in the PROCORAD intercomparison test. Our results have, in general, been satisfying during the last years and we are confident in our secure methods for sample preparation, measurements and evaluation. Detailed information about the QA for gamma spectrometry can be seen in previous reports [1-3].

Samples of deep well water (Grevie-Bulltofta-verket, VA Syd) with a well-documented low tritium concentration were used as background and dilutions of tritiated water samples with certified values (from the inter-comparison exercise PROCORAD, 2019) were used as control in the tritium measurements. A quenching curve was also obtained using the method described by the scintillation cocktail provider Perkin Elmer [26].

The ^{14}C data were quality assured by measurement and analysis of secondary standards as described in Ref [1].

4. PROPOSAL OF ALTERNATIVE SAMLING SITES

Fucus is suitable bioindicator in the marine environment due to its long lifetime (several years), its permanent position on the environment (*Fucus* grow on stones and rocks) and its ease of collection. The area of interest for ESS environmental monitoring is at the outlets of Kävlinge river and Höje river in the Öresund Strait. However, this coastal aera is characterized by very shallow water with a sandy bottom and few stones for *Fucus* to attach to. Therefore, it is difficult to find any *Fucus* individuals at all in the area, and gamma spectrometry of these samples has not been possible due to lack of material (only ^{14}C measurements have been performed for Fucus samples within ESS environmental monitoring programme). Further north (e.g. at Barsebäck) and further south (e.g. in Klagshamn), *Fucus* is much more abundant. Since the main water flow is to the north (out of the Öresund Strait), we suggest using a more suitable site for collection of *Fucus* north of the outflow of Kävlinge river. In [9], and also previous studies, Vikhög has been used. The old fort in Vikhög (site 23 in [9]) is proposed for future sample collection of *Fucus* (see Figure 9).

Due to the proximity of Barsebäck nuclear power plant, which is currently under decommissioning, we also propose to sample *Fucus* at Barsebäckshamn Skansen (site 20 in [9], also see Figure 7). In 2003, when Barsebäck nuclear power plant was still in operation, we occasionally observed a relative excess in $F^{14}C$ in *Fucus* from Barsebäckshamn Skansen of up to 12 ± 2 % above the clean air background [27]. This signal from the nuclear power plants was not observed in either of 2 *Fucus* samples collected in Vikhög in 2003 [27]. We therefore suggest replacing sampling site 59 (Gamla Bjärred) with Vikhög fort and Barsebäckshamn Skansen. By including the latter, influence on the Vikhög samples from potential releases from the closed-down nuclear power plant may be detected. The change to these sites will also enable gamma spectrometry, since *Fucus* is thriving at these sites.

Figure 9 **Existing sampling site for marine samples, 59 Gamla Bjärred, and proposed new sampling sites, Vikhög fort and Barsebäckshamn Skansen.**

5. SUMMARY AND CONCLUSIONS

Among the regular samples, and samples of fish, collected and analysed for activity concentration of gamma emitting radionuclides, no unexpected levels of radioactivity were observed. As in 2021, ^{137}Cs was observed in both samples of seaweed. The *in situ* and mobile gamma spectrometry continue to vary slightly between the years due to infrastructure changes in the area.

In 2022 it was not feasible to collect sewage sludge at Källby treatment facility (Site 35). As this indicator is important for describing the radiation environment in the catchment area of Lund it is recommended to continue to follow long- and short-term changes in the sewage sludge further, at least by monthly samples.

For the majority of the samples, the measured activity concentrations of tritium were below the minimum detectable activity (MDA) of 1.65 Bq L^{-1} or at expected environmental levels.
No local anthropogenic contamination of ^{14}C was observed in any of the terrestrial or marine samples collected in 2022. During the summer 2021 a new bicycle path was constructed along Odarslövsvägen. In connection with that, the groundwater well at site number 31.3 (ESS area (3)) was removed.

We propose to abandon the marine site 59 (Gamla Bjärred) due to lack of the suitable bioindicator *Fucus* at site 59. Instead, we propose two new marine sampling sites north of the outflows from Höje river and Kävlinge river: Vikhög and Barsebäckshamn.

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Kristian Nilsson (Lundaslättens drift), Viktor Nilsson (Svenstorps gods) and Ingvar Lindén (private farmer) are gratefully acknowledged for providing crops from their farmlands. Our sincerest thanks also go to VA Syd, for providing background water from the Grevie well and allowing us to collect sediment at Källby waste-water treatment plant. In particular, we thank Peter Blickström (VA Syd) for providing fish from Källby waste-water treatment plant and Viktor Nilsson (Svenstorps gods) for catching fish from Kävlinge river. Alica Bodenhall and Elin Grahm (Procitivas gymnasium, Lund): thank you for helping with the preparation of and gamma spectrometry measurement of the fish samples. We also thank Professor Dan Hammarlund (Department of Geology, Lund University) for valuable advice on sediment sampling.

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APPENDIX 1. DATA FROM MEASUREMENTS 2022

Available from the authors upon request.