ESS status - focusing on the perspectives for international research, and the challenges related to radiation protection for the staff, the public and the environment

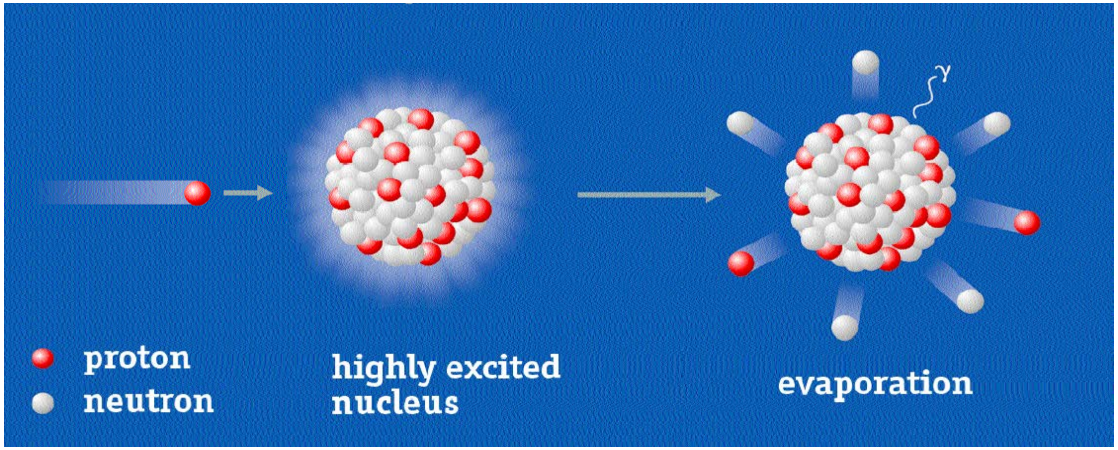
Peter Jacobsson

Head of Environment, Safety & Health

www.europeanspallationsource.se

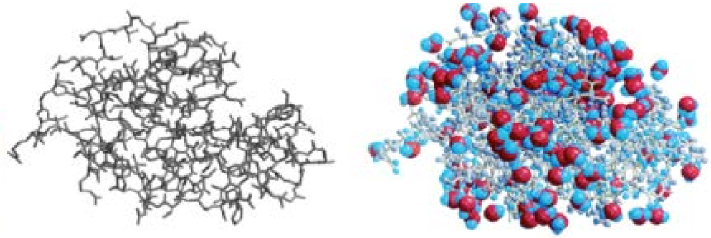
15-09-28

Spallation



Spallation: A nuclear process in which a high energy proton excites a neutron rich nucleus which decays sending out neutrons (and other particles such as protons, muons, pions, neutrionos)

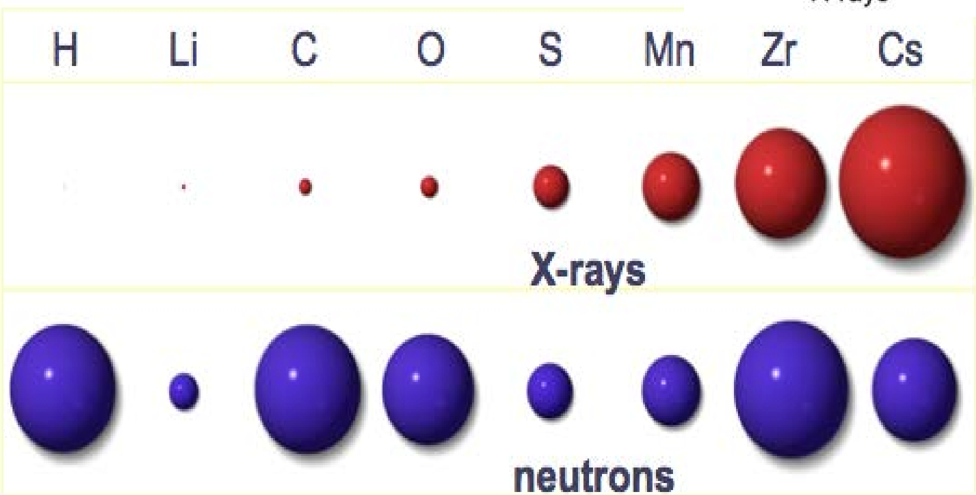
Complementarity between X-rays and Neutrons

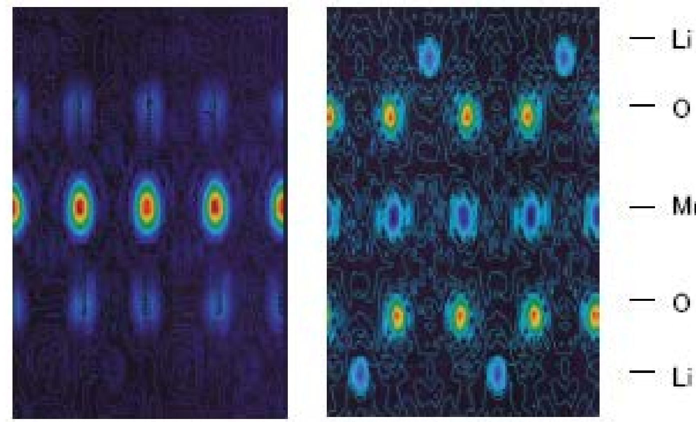


X-rays Neutrons

Water molecules Observed with neutrons

N. Niimura, et al.





Material for Li-battery seen by

X rays (left) and

Neutrons (right)

T. Kamiyama, et al.

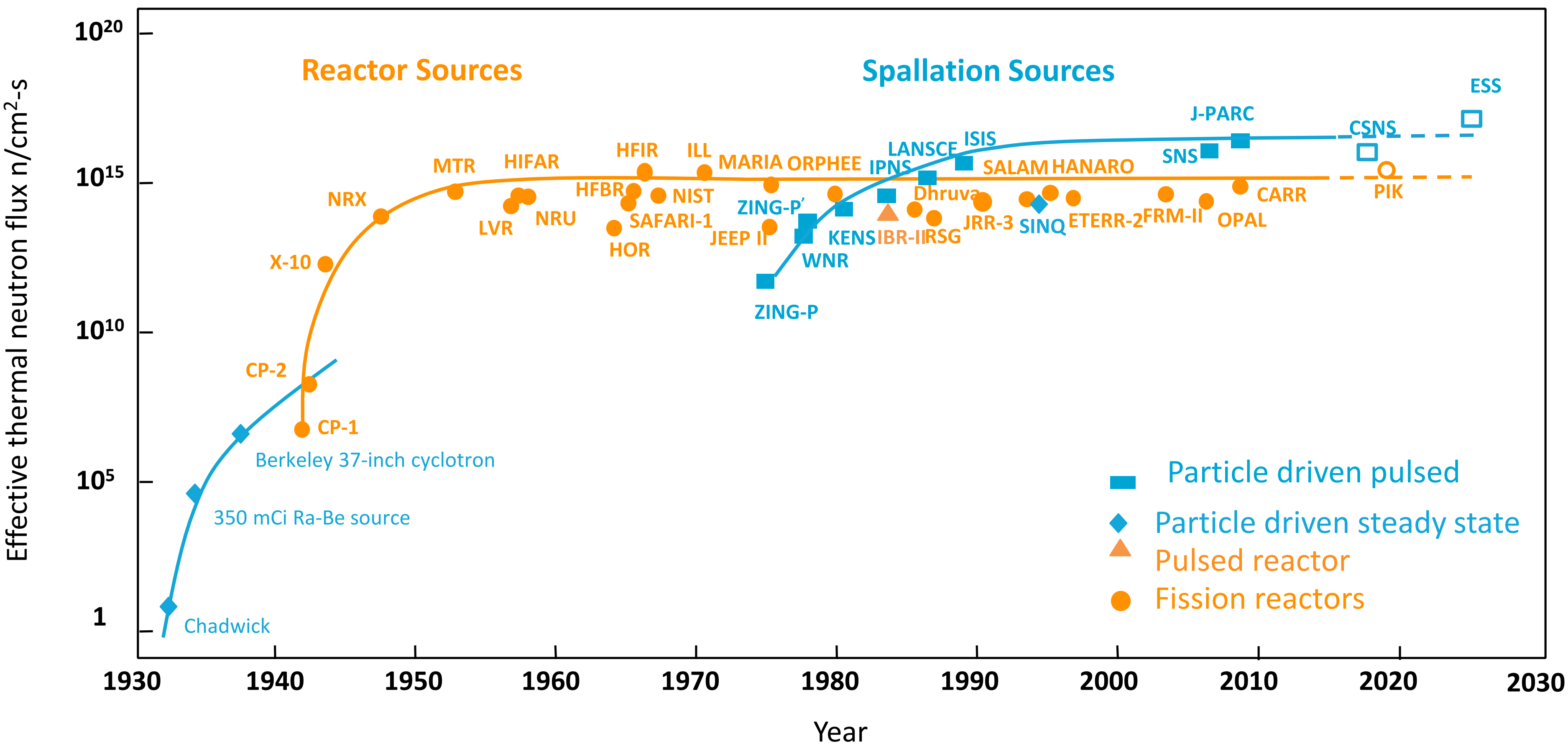
X-rays interact with electrons.

→ X-rays see high-Z atoms.

Neutrons interact with nuclei.

→ Neutrons see low-Z atoms.

Neutron facilities – reactors and particle driven



(Updated from *Neutron Scattering*, K. Skold and D. L. Price, eds., Academic Press, 1986)

ESS on the map

The ESS Project

- 22 “public” instruments (16 included in the construction budget)
- 5 MW accelerator capability
- One target station with tungsten (W) as target material
- Organization form: ERIC (European Research Infrastructure Consortium)
- Cost Book construction cost of 1,843 $B€_{2013}$
- Cost Book annual operations cost target of 140 $M€_{2013}$
- ***“Neutrons in this decade”***

The ESS Facility Layout

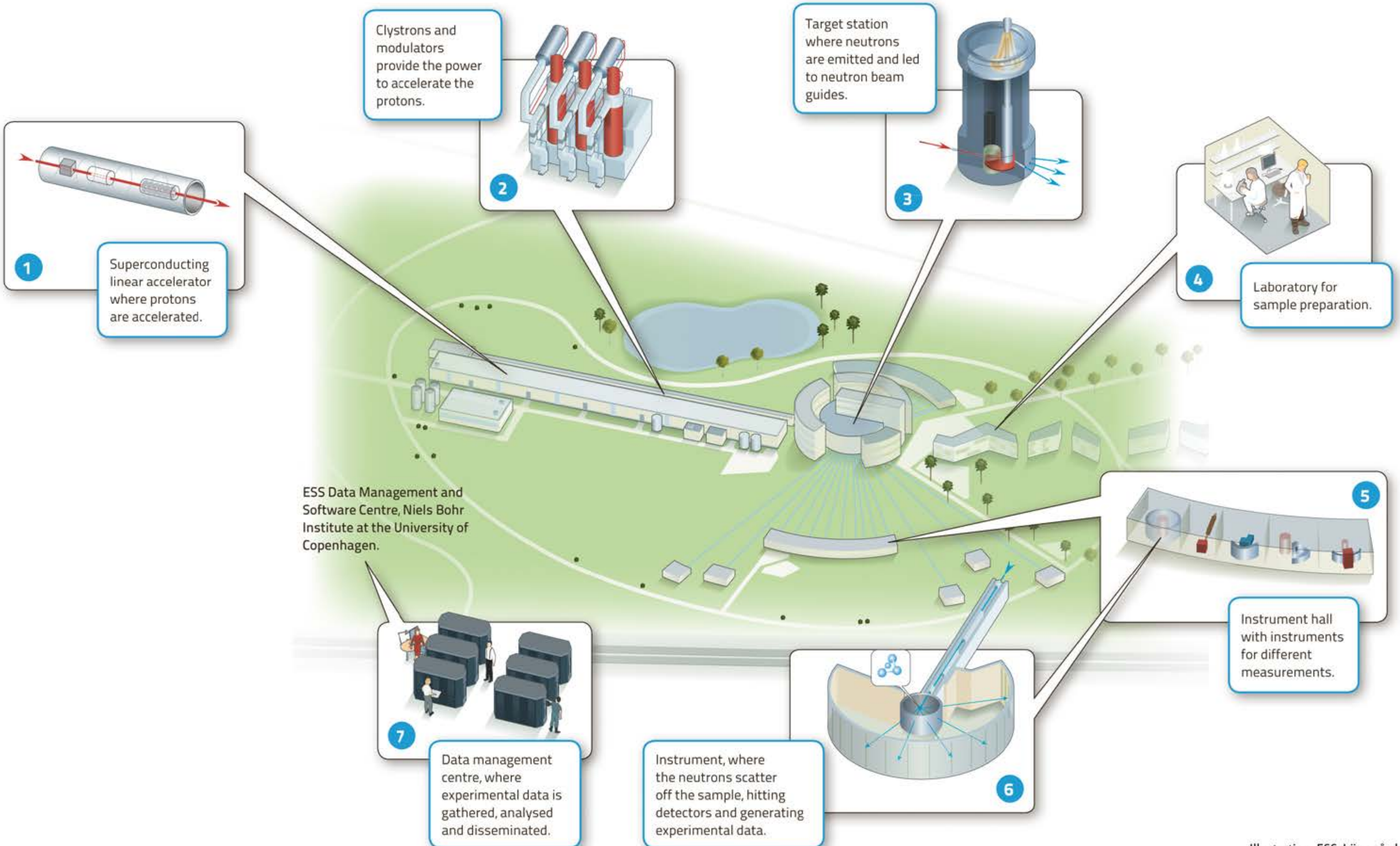


Illustration: ESS, Lönegård

Financing includes cash and deliverables

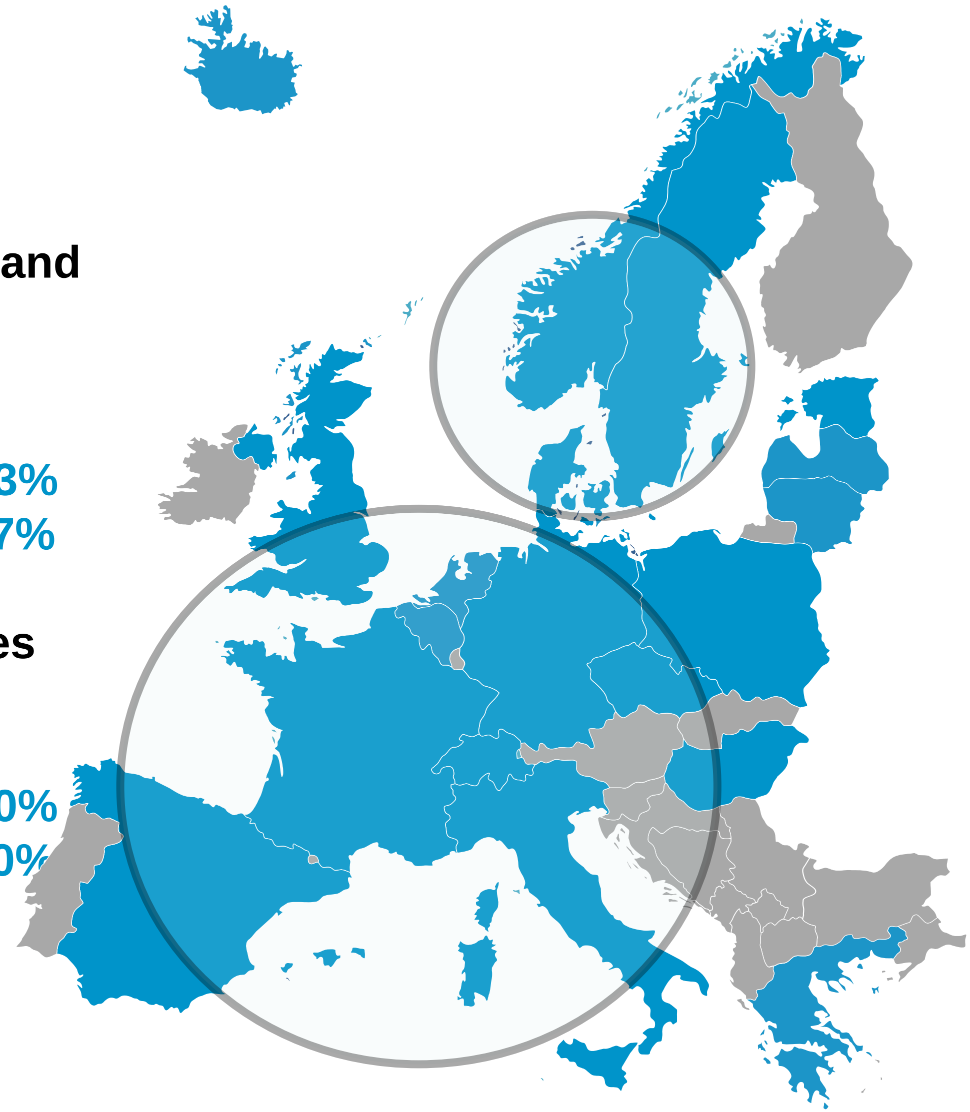
EUROPEAN SPALLATION SOURCE

Host Countries of Sweden and Denmark

47,5% Construction
15% Operations
In-kind Deliverables ~3%
Cash Investment ~97%

Non Host Member Countries

52,5% Construction
85% Operations
In-kind Deliverables ~ 70%
Cash Investment ~ 30%



Ground Break and Foundation Stone Celebrations

Ground Break Event

- 2 September 2014 (200 guests)
- Hosted by Danish Minister for Science and Higher Education and Swedish Minister of Education and Research
- Recognized progress with member country commitments
- Official start of the construction!

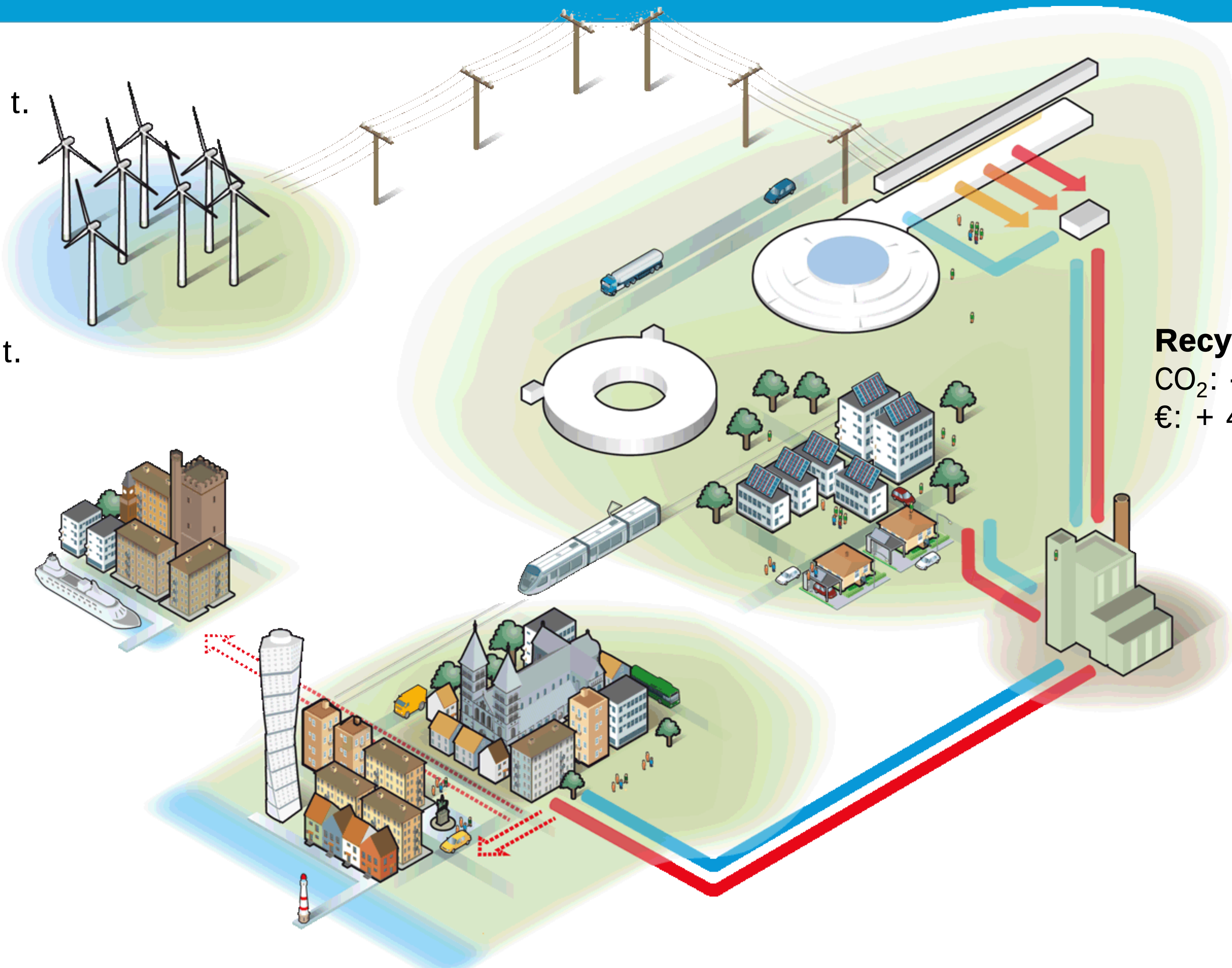
Foundation Stone Ceremony

- 9 October 2014 (700 guests)
- Programme on site including speeches, partner video, walking tour and reception
- Science Symposium in Lund
- Mobilized partners and stakeholders for construction!

Responsible – Renewable – Recyclable

Responsible
CO_2: - 30 000 t.
€: + 3 M

Renewable
CO_2: -120 000 t.
€: + 8 M

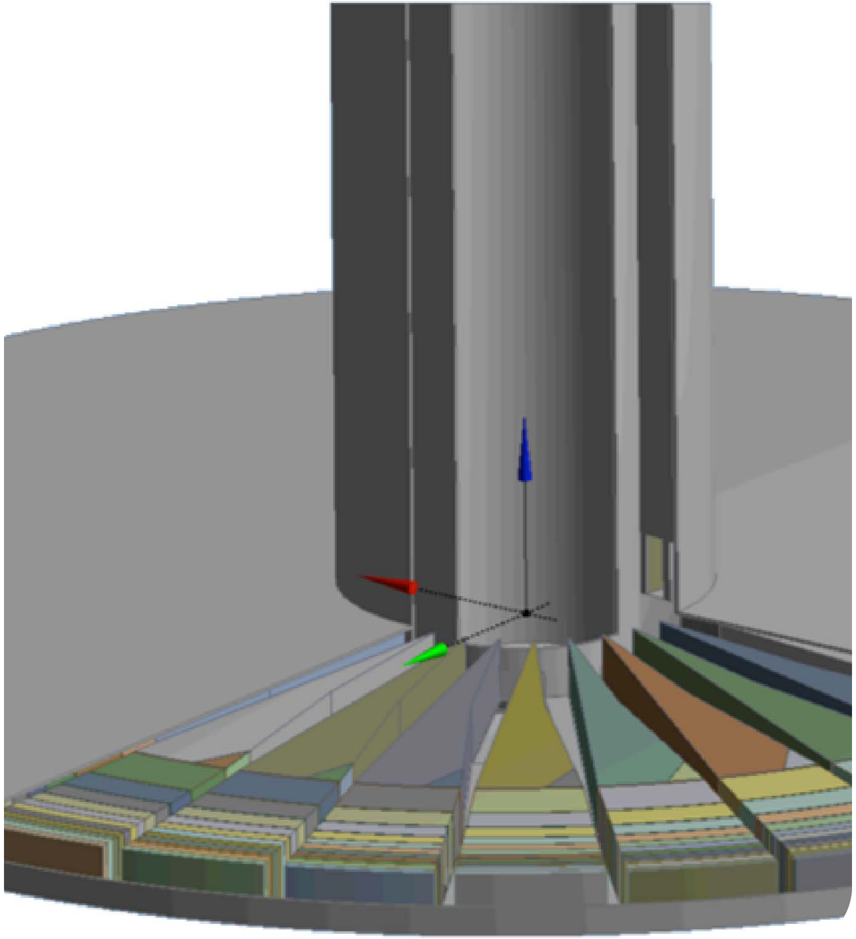


Recyclable
CO_2: - 15 000 t.
€: + 4 M

Accelerator

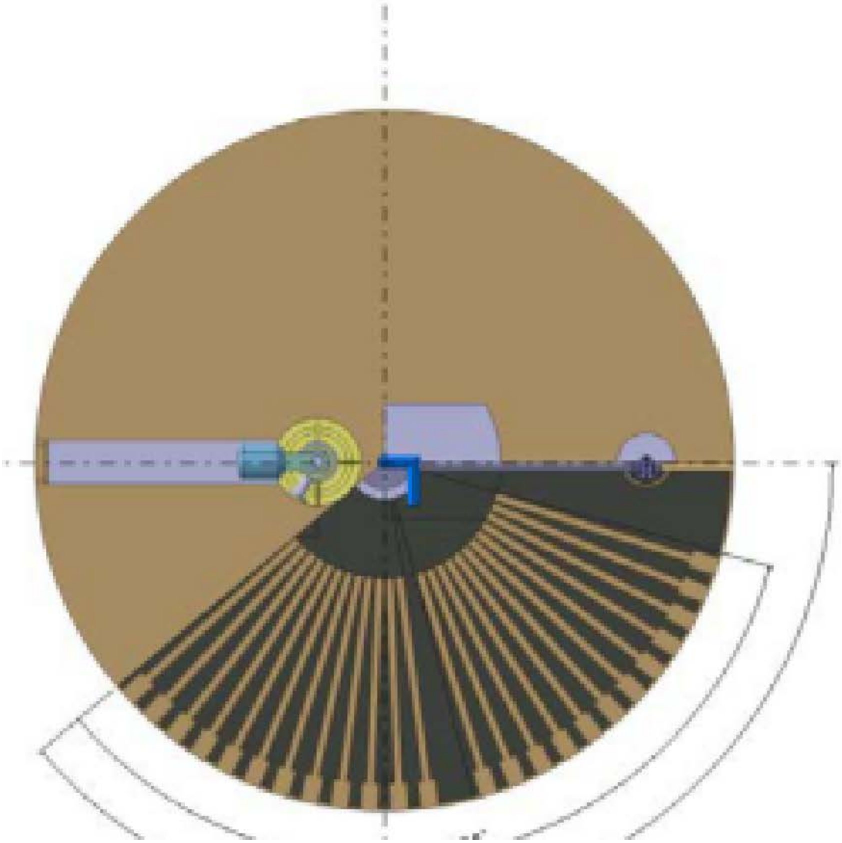
- Superconducting Proton Linear Accelerator (500 m)
- 2.0 GeV Proton Energy
- 2.86 ms pulse length
- 14 Hz pulse frequency
- 71.4 ms periods between pulses
- 5MW proton beam power

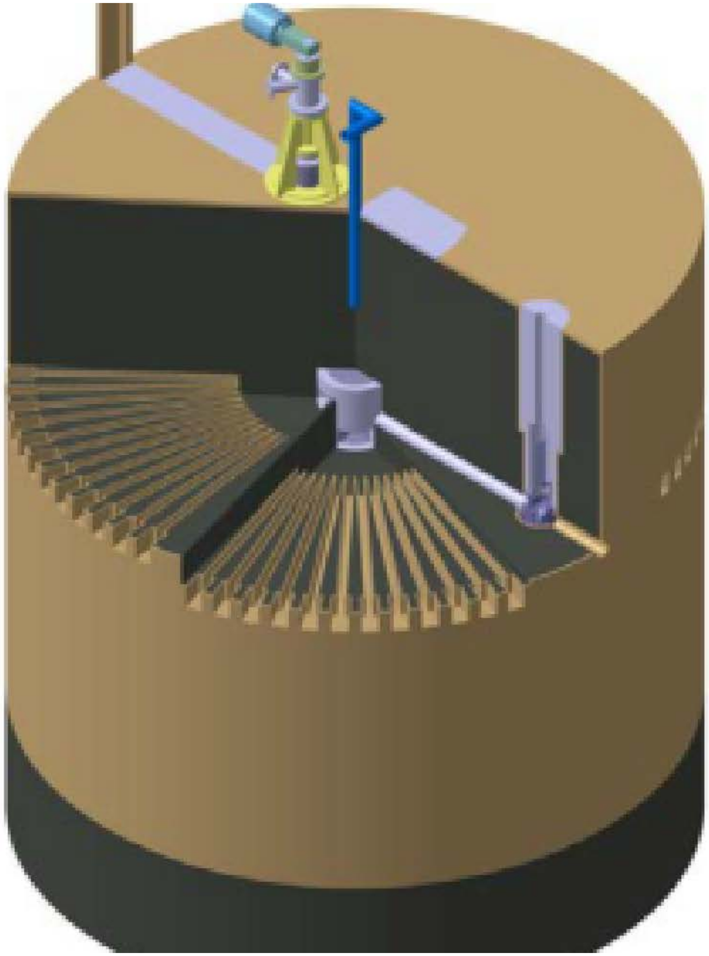
Target



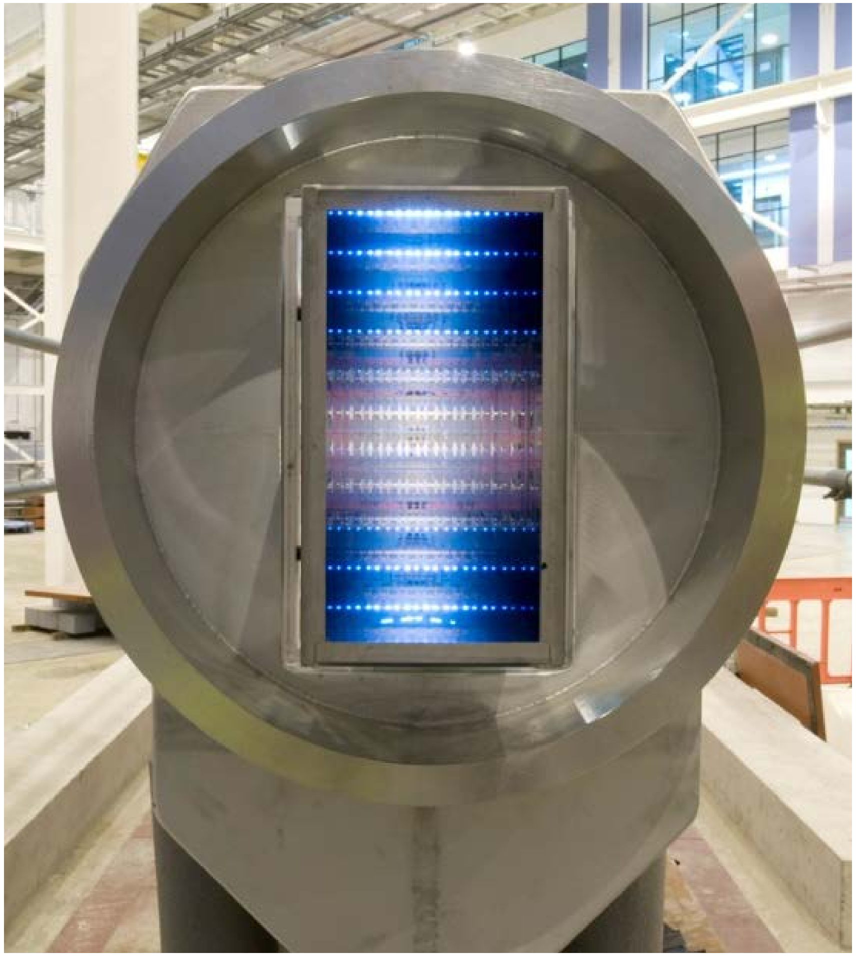
- Target Material; Tungsten (W)
- Rotating wheel, He cooled
- Pre-Moderator; H_2O
- Moderator; H_2 (l)
- Reflector; Be
- Proton Beam Window; Al

Target





Instruments

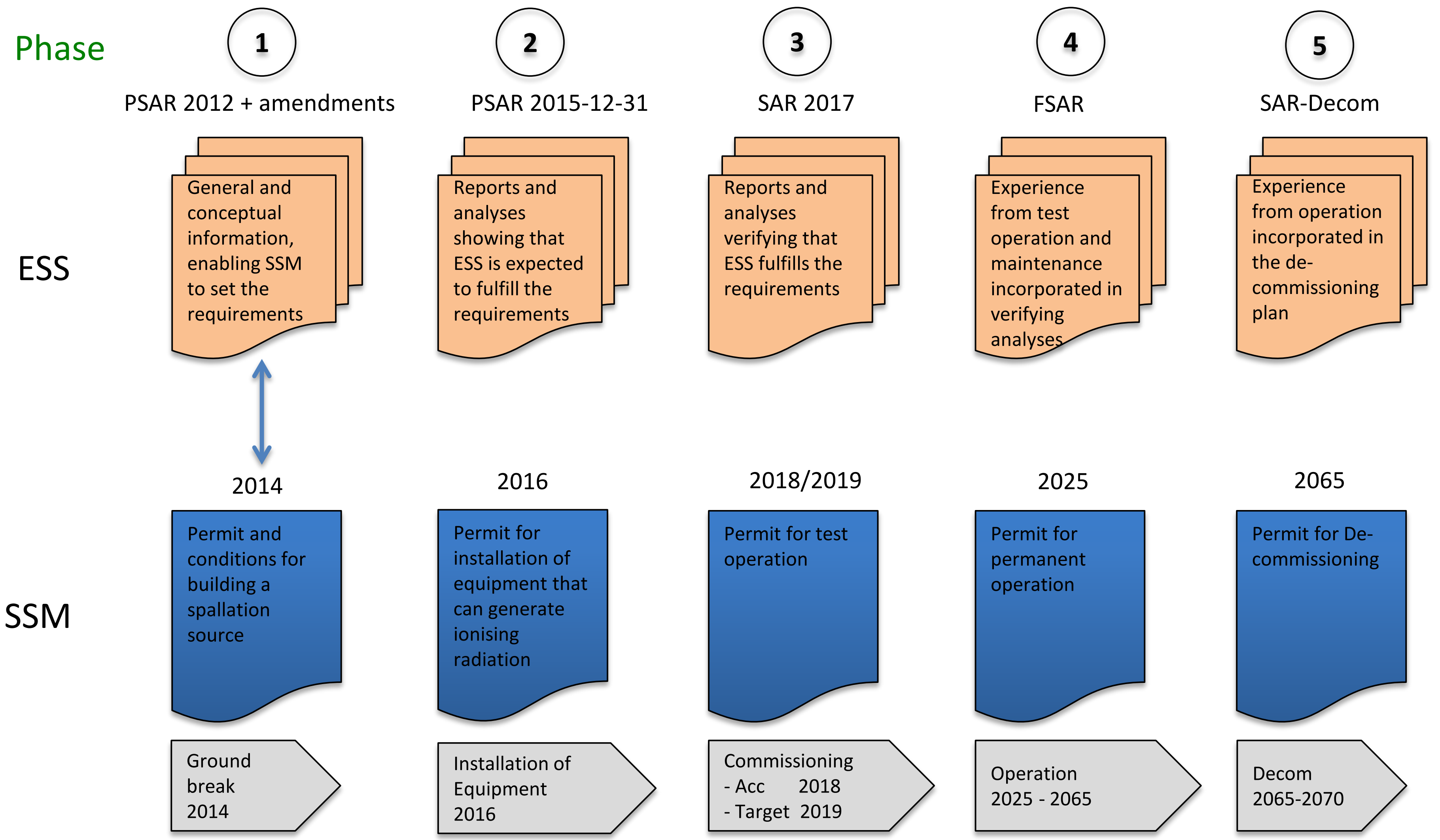


- 22 instruments planned in the project
- 44 beam ports
- Three instrument halls in the project
  Possibilities to build "long" instruments

Legal Aspects and Permits

- Environmental Code
  - Permissibility for construction & operation
- Radiation Safety Protection Act
  - Permit for Construction (step 1)
  - Permit for Installation (step 2)
  - Permit for Commissioning (step 3)
    - Permits given for different levels of beam power and production of neutrons.
  - Permit for permanent operation (step 4)
  - Permit for Decommissioning (step 5)
- Planning & Building Act
  - Detailed Plan
  - Building Permit
    - Permits to be given as a graded approach
- The Act on Flammable Materials and Explosives
  - Agreement with the Local Fire Brigade
- National Heritage Act
  - Archeological investigation

Graded approach SSM - Schedule



Licensing status

- General Hearing at the Regional Environmental Court 2014-04-24—25. Decision, with permit and conditions received 2014-06-12.
- Permit #1 from the Swedish Radiation Safety Authority (SSM) received 2014-07-17. Over 300 conditions to be applied.
- Notification process in accordance with the Euroatom Treaty, article 37 finalised 2015-02-26. The European Commission concluded that the ESS facility does not constitute any threat or hazard to any nearby state.

Nuclide Inventory – Airborne emissions Normal operation

Accelerator

Nuclide	Chemical form	Source Term (Bq/y)
H-3	H_2O gas	8.8×10^{6}
Be-7	BeO_2 aerosol	1.0×10^{7}
C-11	CO, CO_2 gas	2.6×10^{12}
N-13	NO_2 gas	2.7×10^{12}
O-15	O_2 gas	1.5×10^{12}
Ar-41	Ar gas	4.1×10^{10}

Target Station

Nuclide	Chemical form	Activity (Bq)	Release fraction	Source term
H-3	H_2O gas	5×10^{14}	1×10^{-2}	5×10^{12} Bq/y
I-125	HI, HIO_3	1×10^{8}	1×10^{-2}	1×10^{6} Bq/y
H-3	Gas	5×10^{14}	1×10^{-3}	5×10^{11} Bq/5y
W-181	Dust/aerosol	1×10^{16}	4×10^{-8}	4×10^{8} Bq/5y
Ta-179	Dust/aerosol	8×10^{15}	4×10^{-8}	3×10^{8} Bq/5y
Gd-148	Dust/aerosol	8×10^{11}	4×10^{-8}	3×10^{4} Bq/5y

Dose contribution – Airborne emissions

- ECOSYS-87 model (DTU/Andersson, Nielsen)
- Pathways
  - Intake (via inhalation, ingestion and skin absorption) of tritiated water vapour in the air
  - Inhalation of contaminant particles (during plume passage and from re-suspension)
  - External exposure from the contaminated plume during its passage
  - External exposure from deposition of airborne contaminants on surfaces
  - External exposure following deposition of airborne contaminants on humans
  - Ingestion of locally produced contaminated food products

Dose contribution – Airborne emissions (2)

EUROPEAN SPALLATION SOURCE

Nuclide	Source term (Bq/year)	Annual air conc. avg. (Bq/m^3)	Dose 1-year old (µSv/year)	Dose adult (µSv/year)
H-3	5.0×10^{12}	0.32	0.04*	0.04*
Be-7	1.0×10^{7}	6.3×10^{-7}	0.00003*	0.00001*
C-11	2.6×10^{12}	0.14	0.2	0.2
N-13	2.7×10^{12}	0.13	0.2	0.2
O-15	1.5×10^{12}	0.029	0.03	0.03
Ar-41	4.1×10^{10}	0.0027	0.004	0.004
I-125	1.0×10^{6}	6.3×10^{-8}	0.0003*	0.00007*
TOTAL			**0.4**	**0.4**

Nuclide	Release (Bq)	Dose 1 year-child (µSv)	Dose Adult (µSv)
W-181	4.0×10^{8}	0.06	0.01
Ta-179	3.0×10^{8}	0.02	0.001
Gd-148	3.0×10^{4}	0.003	0.002
Lu-172	5.0×10^{6}	0.003	0.0006
W-185	2.0×10^{7}	0.002	0.0003
Hf-172	5.0×10^{6}	0.002	0.0008
Lu-173	8.0×10^{6}	0.002	0.0004
Ta-182	3.0×10^{6}	0.001	0.0002
Hf-175	2.0×10^{6}	0.0002	0.00003
TOTAL		**0.1**	**0.02**

Nuclide Inventory Target (after 5 years of operation) larger than 1 x 10^{15} Bq

Nuclide	$T_{1/2}$ (s)	Bq
W-187	8.54×10^{4}	1.58×10^{17}
W-183m	5.20×10^{0}	1.24×10^{17}
W-185	6.49×10^{6}	7.63×10^{16}
Re-186	3.26×10^{5}	1.96×10^{16}
W-181	1.05×10^{7}	1.78×10^{16}
Re-188	6.12×10^{4}	1.68×10^{16}
W-179	2.25×10^{3}	5.49×10^{15}
Ta-178	5.59×10^{2}	4.55×10^{15}
W-185	1.00×10^{2}	4.18×10^{15}
Ta-179	5.75×10^{7}	3.65×10^{15}
W-178	1.87×10^{6}	3.62×10^{15}
Ta-177	2.04×10^{5}	3.49×10^{15}
H-3	3.89×10^{8}	3.19×10^{15}
Hf-175	6.05×10^{6}	2.61×10^{15}
Ta-176	2.91×10^{4}	2.60×10^{15}
Ta-175	3.78×10^{4}	2.11×10^{15}

Nuclide	$T_{1/2}$ (s)	Bq
W-177	8.10×10^{3}	2.01×10^{15}
Ta-183	4.41×10^{5}	1.98×10^{15}
W-179	3.84×10^{2}	1.94×10^{15}
Hf-173	8.64×10^{4}	1.88×10^{15}
W-176	8.30×10^{3}	1.60×10^{15}
Ta-174	4.25×10^{3}	1.55×10^{15}
Ta-180	2.94×10^{4}	1.54×10^{15}
Yb-169	2.77×10^{6}	1.47×10^{15}
Ta-182	9.89×10^{6}	1.45×10^{15}
Ta-173	1.13×10^{4}	1.37×10^{15}
Lu-171	7.12×10^{5}	1.34×10^{15}
Hf-179	1.87×10^{1}	1.32×10^{15}
Hf-171	4.36×10^{4}	1.16×10^{15}
Lu-173	4.32×10^{7}	1.14×10^{15}
Lu-170	1.73×10^{5}	1.11×10^{15}
Ta-182	2.83×10^{1}	1.07×10^{15}

Defining the target material

- Tritium & Noble gases H, He, Ar, Kr, Xe
- Aerosols Na, K, Zn, Ga, Se, Rb, Cd, In, Sn, Te, Cs
- Volatiles N, O, F, P, S, Cl, I, Br
- Other All the other elements

- Tritium & Noble gases 100%
- Aerosols 0.5%
- Volatiles 0.2%
- Other 0.001%

Pathways

- Committed effective dose from inhalation during plume passage
- Effective dose from external exposure from the plume during plume passage (1 h)
- Effective external dose from ground deposited nuclides for time integrals 0-30 days, 0-70 years and until infinity.
- Committed effective dose from internal exposure from intake of locally produced food the first year and integrated dose from a 70-year period and until infinity.

Dose caculations

EUROPEAN SPALLATION SOURCE

Parameter	Value	Reference
Duration of release	3600 s	SSM, Reference [67]
Transportation time within the building	300 s	ESS, Reference [27]
Wind Speed	3 m/s	SSM, Reference [67]
Inversion	150 m	SSM, Reference [67]
Initial dispersion (horizontal and vertical)	20 m	Default in Lena-code [68]
Surface roughness	0.1 m	SSM, Reference [67]
Dispersion parameters	See equations	SSM, Reference [67 and 68]
Relative concentration (300 m from Release point)	3×10^{-5} s/m^3	Stability Class D, Reference [67]
Relative concentration (40 000 m from Release point)	5×10^{-7} s/m^3	Stability Class D, Reference [67]
Meandering factor	0.03	Default in Lena-code [68]
Time integrated deposition velocities:		SSM, Reference [67]
Noble gases	0 m/s	
Particles	0.002 m/s	
Organic Iodine	0.02 m/s	
Inorganic Iodine	0.0002 m/s	
Dry deposition velocities		SSM, Reference [67]
Noble gases	0 m/s	
Particles	0.001 m/s	
Organic Iodine	0.01 m/s	
Inorganic Iodine	0.0001 m/s	

Parameter	Value	Reference
Dry soil density	260 kg/m^2	IAEA, reference [69]
Transfer factors for terrestrial food crops	Element specific	IAEA, reference [69] & Oak Ridge National Laboratory reference [70]
Dose coefficient inhalation	Element specific	ICRP, reference [30].
Dose coefficient ingestion	Element specific	ICRP reference [30].
Dose coefficient external cloud	Element specific	Oak Ridge National Laboratory reference [29]
Dose coefficient, activity on infinite planar surface	Element specific	Oak Ridge National Laboratory reference [29]
Inhalation rate adult	2.6×10^{-4} m^3/s	Vattenfall, reference [71]
Inhalation rate infant (1-y child)	6.1×10^{-5} m^3/s	Vattenfall, reference [71]
Root uptake	Element specific	IAEA, reference [69] & Oak Ridge National Laboratory reference [70]
Lumped translocation (surface deposition to edible part of the crop)	0.01 m^2/kg	Studsvik, Reference [72]
Consumption of food from crops	100 kg	Reference group, section 3.4
Duration between contamination and consumption	0.5 years	SSM, Reference [67]
Time of exposure from ground contamination	30 days to 70 years and infinity	SSM, Reference [67]

Doses to the Reference Group – 300 m from the release point 1(4)

EUROPEAN SPALLATION SOURCE

Inhalation

Nuclide	Release (Bq)	Integrated air conc. (Bq s/m^3)	Dose (Sv) 1-year	Dose (Sv) Adult
H-3	3.2×10^{15}	9.6×10^{10}	1.2×10^{-3}	4.4×10^{-4}
Cd-109	1.5×10^{11}	4.6×10^{6}	4.3×10^{-5}	9.5×10^{-6}
In-115	1.2×10^{9}	3.3×10^{4}	6.6×10^{-6}	3.3×10^{-6}
Sn-113	2.2×10^{11}	6.6×10^{6}	1.7×10^{-5}	4.6×10^{-6}
I-125	8.4×10^{11}	2.5×10^{7}	3.4×10^{-4}	9.1×10^{-5}
I-126	2.1×10^{10}	6.2×10^{5}	3.0×10^{-5}	1.6×10^{-6}
Hf-172	7.3×10^{9}	2.2×10^{5}	7.3×10^{-6}	1.8×10^{-6}
Ta-180	1.5×10^{10}	4.4×10^{5}	7.3×10^{-6}	2.9×10^{-6}
Ta-182	1.4×10^{10}	4.3×10^{5}	3.8×10^{-6}	1.1×10^{-6}
W-187	1.6×10^{12}	4.6×10^{7}	1.8×10^{-5}	2.3×10^{-6}
Re-186	2.0×10^{11}	5.8×10^{6}	8.5×10^{-6}	1.6×10^{-6}
TOTAL			$\mathbf{1.6 \times 10^{-3}}$	$\mathbf{5.8 \times 10^{-4}}$

Plume exposure

Nuclide	Release (Bq)	Integrated air conc. (Bq s/m^3)	Dose (Sv)
Ar-41	7.7×10^{11}	1.9×10^{7}	1.1×10^{-6}
Kr-76	5.3×10^{12}	1.5×10^{8}	2.9×10^{-6}
Kr-77	1.0×10^{13}	2.2×10^{8}	9.8×10^{-6}
Kr-79	1.9×10^{13}	5.5×10^{8}	6.1×10^{-6}
Kr-87	1.8×10^{12}	3.9×10^{7}	1.6×10^{-6}
Kr-88	9.5×10^{11}	2.5×10^{7}	2.4×10^{-6}
Xe-120	1.2×10^{14}	2.0×10^{9}	3.6×10^{-5}
Xe-121	1.3×10^{14}	2.1×10^{9}	1.8×10^{-4}
Xe-122	1.6×10^{14}	4.6×10^{9}	1.0×10^{-5}
Xe-123	1.4×10^{14}	4.2×10^{9}	1.0×10^{-4}
Xe-125	1.9×10^{14}	5.5×10^{9}	6.0×10^{-5}
Xe-127	1.4×10^{14}	4.2×10^{9}	4.7×10^{-5}
TOTAL			$\mathbf{4.7 \times 10^{-4}}$

Doses to the Reference Group – 300 m from the release point 2(4)

Nuclide	Release (Bq)	Int. surface conc. Dry dep. (Bq s/m^3)	Int. surface conc. Wet dep. (Bq s/m^3)	Dose, 30 days (Sv)	Dose, Infinity (Sv)
Zn-65	9.0×10^{9}	8.2×10^{9}	1.2×10^{11}	$< 1 \times 10^{-6}$	8.8×10^{-6}
Se-75	2.4×10^{10}	1.1×10^{10}	1.6×10^{11}	1.2×10^{-6}	7.8×10^{-6}
Rb-83	5.4×10^{10}	1.7×10^{10}	2.6×10^{11}	3.5×10^{-6}	1.7×10^{-5}
Rb-84	9.3×10^{9}	1.1×10^{9}	1.7×10^{10}	$< 1 \times 10^{-6}$	2.0×10^{-6}
Cd-109	1.5×10^{11}	2.6×10^{11}	3.9×10^{12}	$< 1 \times 10^{-6}$	8.7×10^{-6}
In-114	7.4×10^{9}	1.4×10^{9}	2.0×10^{10}	3.6×10^{-6}	1.1×10^{-5}
Sn-113	2.2×10^{11}	9.4×10^{10}	1.4×10^{12}	8.1×10^{-6}	4.9×10^{-5}
Te-121	2.9×10^{11}	1.8×10^{10}	2.7×10^{11}	1.4×10^{-5}	2.0×10^{-5}
I-120	7.5×10^{11}	1.2×10^{9}	1.7×10^{9}	6.1×10^{-6}	6.1×10^{-6}
I-121	7.0×10^{11}	1.9×10^{9}	2.9×10^{9}	1.5×10^{-6}	1.5×10^{-6}
I-123	7.3×10^{11}	1.4×10^{10}	2.2×10^{10}	4.4×10^{-6}	4.4×10^{-6}
I-124	3.1×10^{9}	4.8×10^{8}	7.2×10^{8}	1.0×10^{-6}	1.0×10^{-6}
I-125	8.4×10^{11}	1.9×10^{12}	2.8×10^{12}	3.5×10^{-5}	1.2×10^{-4}
I-126	2.1×10^{10}	1.0×10^{10}	1.5×10^{10}	7.1×10^{-6}	8.9×10^{-6}
Cs-134	7.1×10^{8}	2.0×10^{9}	3.0×10^{10}	$< 1 \times 10^{-6}$	3.6×10^{-6}
Eu-152	4.3×10^{7}	7.9×10^{8}	1.2×10^{10}	$< 1 \times 10^{-6}$	1.7×10^{-6}
Tb-158	6.5×10^{6}	1.3×10^{9}	2.0×10^{10}	$< 1 \times 10^{-6}$	2.0×10^{-6}
Lu-173	1.1×10^{10}	2.1×10^{10}	3.2×10^{11}	$< 1 \times 10^{-6}$	4.9×10^{-6}
Hf-172	7.3×10^{9}	1.9×10^{10}	2.8×10^{11}	$< 1 \times 10^{-6}$	3.7×10^{-6}
Hf-175	2.6×10^{10}	6.8×10^{9}	1.0×10^{11}	1.2×10^{-6}	4.7×10^{-6}
Ta-179	3.7×10^{10}	9.1×10^{10}	1.4×10^{12}	$< 1 \times 10^{-6}$	5.0×10^{-6}
Ta-182	1.4×10^{10}	6.2×10^{9}	9.3×10^{10}	2.5×10^{-6}	1.5×10^{-5}
W-181	1.8×10^{11}	8.1×10^{10}	1.2×10^{12}	$< 1 \times 10^{-6}$	5.5×10^{-6}
W-187	1.6×10^{12}	5.7×10^{9}	8.6×10^{10}	5.4×10^{-6}	5.4×10^{-6}
TOTAL				$\mathbf{9.2 \times 10^{-5}}$	$\mathbf{2.8 \times 10^{-4}}$

Ground exposure

Doses to the Reference Group – 300 m from the release point 3 (4)

EUROPEAN SPALLATION SOURCE

Food uptake

Nuclide	Release (Bq)	Int. surface conc. Dry dep. (Bq s/m^3)	Int. surface conc. Wet dep. (Bq s/m^3)	Dose Transl., 1st year (Sv)	Dose, Root uptake, 1st year (Sv)	Dose, Root uptake, Infinity (Sv)
Cl-36	8.5×10^{4}	3.6×10^{10}	5.4×10^{11}	$< 1 \times 10^{-9}$	$< 1 \times 10^{-9}$	5.9×10^{-5}
Zn-65	9.0×10^{9}	8.2×10^{9}	1.2×10^{11}	1.0×10^{-6}	1.0×10^{-6}	2.0×10^{-6}
Cd-109	1.5×10^{11}	2.6×10^{11}	3.9×10^{12}	1.4×10^{-5}	2.8×10^{-6}	7.9×10^{-6}
Sn-113	2.2×10^{11}	9.4×10^{10}	1.4×10^{12}	3.2×10^{-6}	3.8×10^{-7}	5.7×10^{-7}
I-125	8.4×10^{11}	1.9×10^{12}	2.8×10^{12}	9.3×10^{-4}	7.4×10^{-6}	9.2×10^{-6}
TOTAL				**1.0×10^{-3}**	**1.2×10^{-5}**	**8.3×10^{-5}**

Doses to the Reference Group – 300 m from the release point 4 (4)

Pathway	Dose (Sv) 1-year old	Dose (Sv) Adult
Inhalation	1.6×10^{-3}	5.8×10^{-4}
External exposure from the plume	4.7×10^{-4}	4.7×10^{-4}
External exposure from ground*	2.8×10^{-4}	2.8×10^{-4}
Ingestion/root uptake*	1.2×10^{-4}	8.3×10^{-5}
TOTAL	$\mathbf{2.5 \times 10^{-3}}$	$\mathbf{1.4 \times 10^{-3}}$
Ingestion/translocation, 1st year	3.6×10^{-3}	1.0×10^{-3}

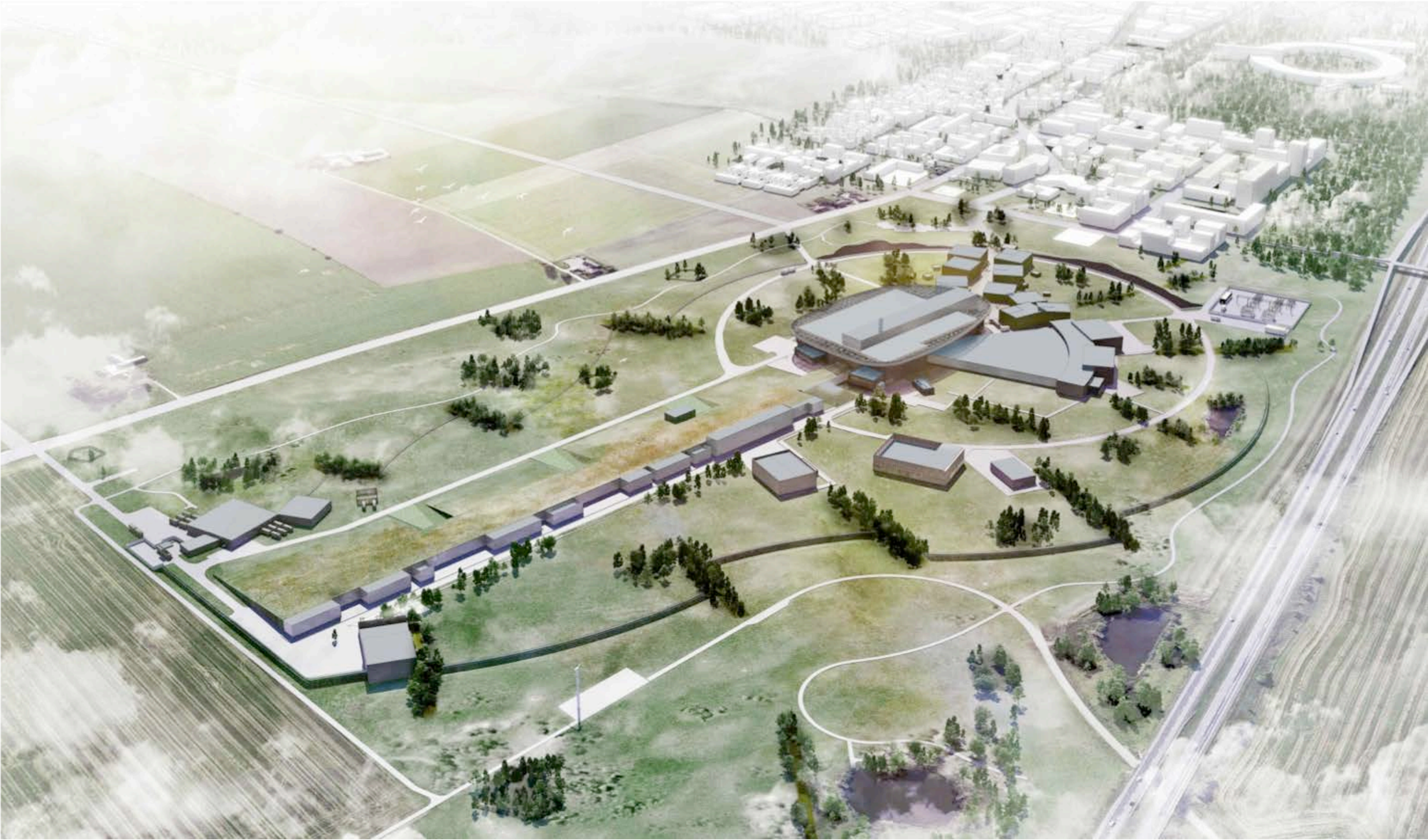
NI (Bq) Target Station

Item	Shut down	1 hour	1 year	10 year	100 year
Target wheel	4.9E+17	3.9E+17	1.2E+16	2.0E+15	1.8E+13
Stainless steel shroud of target wheel	1.9E+16	1.6E+16	2.4E+15	2.9E+14	1.3E+13
Target cooling loop (Helium gas)	6.2E+10	6.2E+10	5.8E+10	3.5E+10	2.2E+08
Pre-moderator (water)	1.3E+14	1.9E+13	1.4E+13	8.3E+12	5.5E+10
Pre-moderator shroud	8.8E+13	8.0E+12	5.9E+12	3.5E+12	2.5E+10
Pre-moderator cooling loop (water)	2.5E+13	2.2E+12	1.6E+12	9.8E+11	6.9E+09
Aluminium cladding of the moderator	8.0E+15	2.6E+14	7.7E+12	2.4E+12	1.6E+10
Moderator (H_2-liq.)	1.6E+11	1.6E+11	1.5E+11	8.9E+10	5.6E+08
Reflector of Beryllium	1.6E+17	5.6E+15	4.7E+15	2.8E+15	1.8E+13
Stainless steel shroud of Be-reflector	1.7E+16	1.5E+16	8.6E+15	7.9E+14	6.2E+11
Total activity in TMRA	**6.9E+17**	**4.3E+17**	**2.8E+16**	**5.9E+15**	**4.9E+13**

Remarks

- Behavior of the Tungsten material during normal operation and incidents, no cladding and Helium cooling
  - Release fractions
  - Chemical behavior in the W material
- Nuclides from the target material that have to be examined
  - Dose coefficients
  - Chemical behavior
- Nuclides in samples
  - Radiation safety reviewing of proposed experiments

ESS looking towards MAX IV



ESS Entrance

Progress on civil construction