ESS LINAC
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Subject :

Full error study of ESS linac

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Dose rate and exposure

The maximum dose that a European "highly exposed" worker can absorb in one year is 50 mSv (01/2002). Euratom is recommending 30 mSv, a level that should be adopted in a near future.

The ESS accelerator will operate about 6000 hours a year for the user program. This leaves 2800 hours per year for maintenance. Assuming a worker participates in the full maintenance period, the maximum *average dose rate* is: 50 mSv / 2800 hrs = 18 µSv/h.

Because the instantaneous dose rate decreases with time while the workers are working on the shutdown machine, their *average dose rate* will be lower than the *entering dose rate* defined as the dose rate when they are allowed to enter the linac tunnel. The ratio between the *entering dose rate* and *average dose rate* depends on the decay time of the dose rate, the number of maintenance interventions and the time each intervention takes.

The allowed *entering dose rate* would then be between 200 µSv/h and 20 µSv/h.

Pressure limit for a given energy loss per meter

The stripping of the H^- beam by residual gas depends on the gas type, its pressure and the particle energy.

The stripping cross section in different gases at 10 MeV is plotted in Figure 1. this plot is based on publications compiled in [1] and in [2].

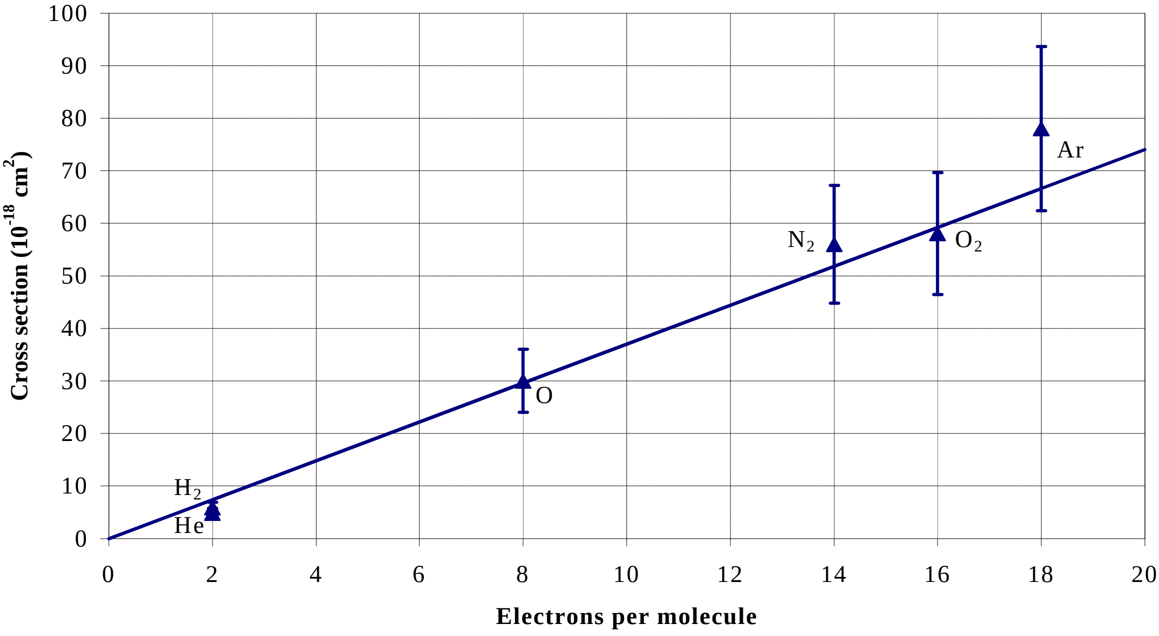

Figure 1 : H^- Stripping cross section at 10 MeV in different gases

The stripping cross section, at 10 MeV, is almost proportional to the number of electrons per molecule. It can be modeled by:

$$\sigma_{10MeV} = 3.75 \cdot 10^{-22} \cdot n_e \cdot f(E).$$

σ_{10MeV} is in m^2,

n_e is the number of electrons per molecule,

$f(E)$ is a dimensionless function of the H^- energy with $f(10MeV) = 1$.

To determine a variation with energy E, one can use the plots given in [2, pp.2-46]. The plots given in [1] have too small an energy extension to establish the variation of the stripping cross section with E. From this information, one finds: $\sigma \propto E^{-3/4}$.
The stripping cross section formula used in the following discussion is:

$$\sigma = 2.1 \cdot 10^{-21} \cdot n_e \cdot E^{-3/4},$$

where s in m^2, E in MeV.

"In normal conducting linac the majority of the residual gas will be water vapour" [2, p.2-46]. In H_2O, the cross section is then :

$$\sigma = 2.1 \cdot 10^{-20} \cdot E^{-3/4},$$

where s in m^2, E in MeV.

The beam power lost per meter P by a beam of energy E by stripping in a pressure Pg is:

$$P = \frac{Pg}{kT} \cdot s \cdot E \cdot \frac{10\,MW}{1334\,MeV}.$$

From this formula, one can determine the gas pressure for a given power loss per unit length.

$$Pg = 2.63\,10^{-7} \cdot E^{-1/4} \cdot P$$

with: Pg in hPa,
E in MeV,
P in W/m.

H_2O Pressure limit for a given linac activation

The relation between energy loss per meter and the corresponding activation has been calculated for the SNS project [3]. A curve showing activity one foot distant from the structure after 4 hours as a function of the beam energy for 1W/m energy loss is plotted in Figure 2. After 4 hours, all the short-life isotopes have decayed in long life isotopes. This means that activation would probably not decrease very fast during the following days!

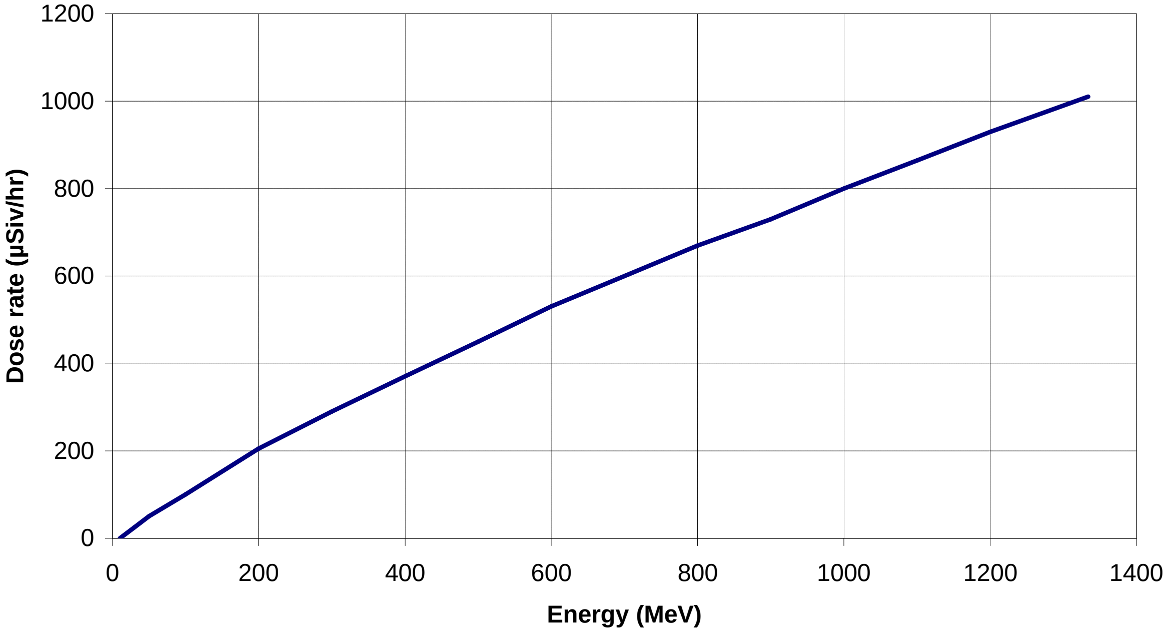

Figure 2 : Dose rate at 1 ft after 4 hours corresponding to 1W per meter

The maximum allowed water vapour gas pressure is represented in Figure 3. This limit on pressure depends on the allowed dose rate. Given dose rates are in µSv per hour at 1 foot after 4 hours cooling.

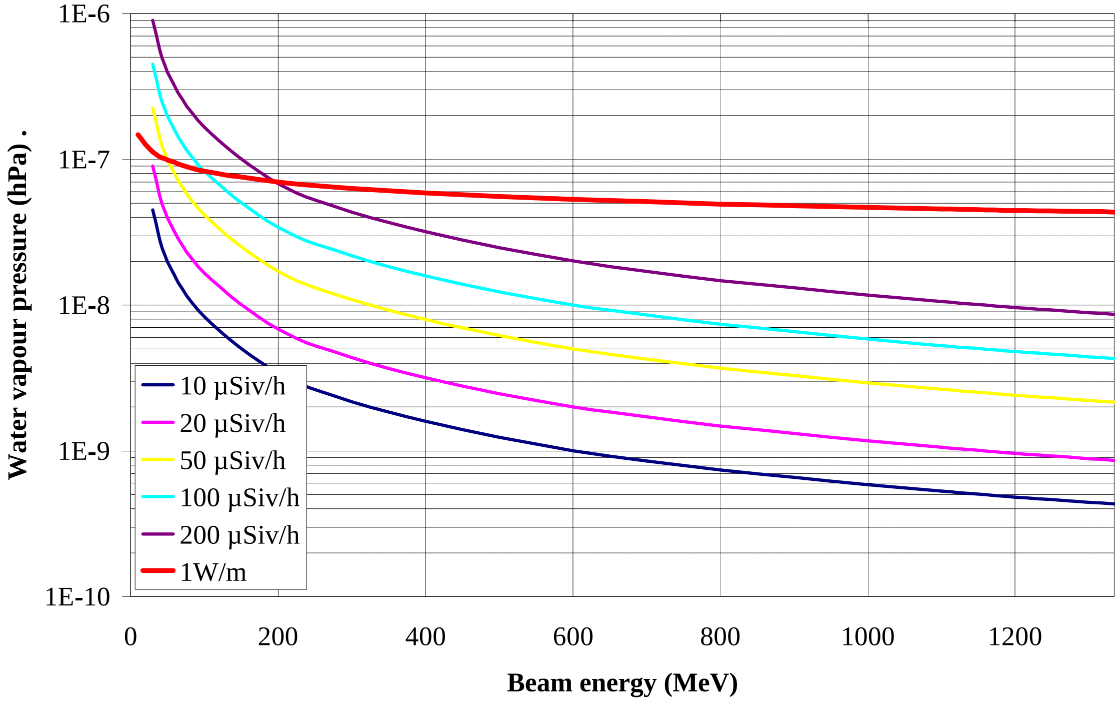

Figure 3 : Maximum water vapour gas pressure for different dose rates or power loss

Estimation of the ESS losses from SNS gas pressure data

SNS team has made some estimation on the gas pressure in their CCL hot model [3]. Table 1 shows the estimated partial pressures of the most common gas and the associated beam loss @ 185 MeV.

Table 1 : Estimation of the SNS CCL gas pressure and beam losses by H^- stripping

Gas	Molecar weight	Partial pressure (Torr)	Electrons per molecule (n_e)	Estimated beam loss @ 185 MeV (W/m)
?	16	$3.0\ 10^{-9}$	8	0.019
H_2O	18	$18\ 10^{-9}$	10	0.144
N_2 + CO	28	$8.7\ 10^{-9}$	14	0.097
O_2	32	$2.4\ 10^{-9}$	16	0.031
Ar	40	$0.43\ 10^{-9}$	18	0.006
CO_2	44	$2.1\ 10^{-9}$	22	0.037
Total, rf off		$39\ 10^{-9}$		0.347
Total, rf on		$50\ 10^{-9}$		0.440

Knowing the SNS beam average current (1.55 mA), one can guess they have used a stripping cross section of $8.7\ 10^{-23} \times n_e\ m^2$. Our formula gives $4.2\ 10^{-23} \times n_e\ m^2$. The formula of the cross section we use is one half (more optimistic!) that used by SNS team. Nevertheless, the order of magnitude is correct.

In a system, the equilibrium pressure scales as:

$$P \propto \frac{Q}{Qv},$$

where Q is the desorbtion. It scales linearly as to the desorbing surface, hence the square of the rf frequency for an rf cavity,

and Qv is the pumping velocity. Assuming the pump velocity is infinite, it is given by the conductance from the pump to the cavity. This conductance of a pipe scales as the cube of the aperture divide by its length.

This is a crude approximation as it depends on the geometry of the linac and the positions of the pumps. Nevertheless, it gives a good order of magnitude estimate.

In SNS, the CCL aperture is 30 mm. The rf frequency is 805 MHz.
In ESS sc-option, the CCL aperture is 35 mm. The rf frequency is 704 MHz. The pressure ratio compared to SNS is then: 0.82.
In ESS nc-option, the CCL aperture is 40 mm, The rf frequency is 560 MHz. The pressure ratio compared to SNS is then: 0.87.
This means that the gas pressure is almost the same whatever option is chosen.

ESS average current is 7.5 mA. The estimated beam loss per meter and activation, for SNS, for ESS sc-option and nc-option are reported on Table 2 and Table 3. The two numbers presented in these tables correspond to calculations done with the cross-section we found, for the first number and with the cross-section used by SNS, for the second number.

Table 2 : H^- stripping beam loss in W/m

	100 MeV	185 MeV	500 MeV	1334 MeV
SNS	?	0.44	<< .44	-
ESS sc-option	0.7 – 1.5	0.8 – 1.7	<< 0.8	<< 0.8
ESS nc-option	0.8 – 1.6	0.9 – 1.85	1.15 – 2.4	1.5 - 3

Table 3 : H^- stripping linac activation in µSiv/hr at 1 foot after 4 hours

	100 MeV	185 MeV	500 MeV	1334 MeV
SNS	?	85	<< 85	-
ESS sc-option	70 – 150	150 - 320	<< 150	<< 150
ESS nc-option	80 – 160	170 – 350	540 – 1100	1500 - 3000

Conclusion

- The higher the energy, the lower should be the gas pressure (the gas pressure should be 10 times lower at 1334 MeV than at 185 MeV).
- To allow an easy maintenance, the gas pressure should be of the order of 10^{-8}-10^{-9} at high energy.
- Residual gas stripping losses can be reduced by a factor 2 by using protons for the long pulse. These protons would allow to work below 1W/m (200 µSv) in the all linac of the sc-option, but not in the high energy part of the nc-option.
- A strong effort needs to be investigated in the vacuum system.

References

[1] C.F. Barnett et al., *Atomic Data for Controlled Fusion Research*, ORNL-5206.
[2] "ESS Accelerator Team", *The ESS Accelerator and Beam Lines with the 280/560 MHz Linac*, TAC Meeting n°1, FZ Juelich, 07-09 January, 2002.
[3] J. Stovall et al., *Final design and expected beam performances of the SNS linac*, SNS ASAC Review, September 19, 2001.