Radiation Safety at FLUTE
with Special Emphasis on Activation Issues

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Abstract

The accelerator FLUTE (name abbreviation derived from its German name: Ferninfrarot Linac- und Test-Experiment) has been set up in cooperation with DESY and PSI [1]. The electron source and diagnostics has commenced operation.
General safety issues of FLUTE are covered in this paper. The activation of the accelerator and vacuum parts were predicted previously [2]. The attention is given to the activation of aluminum and impurities in the electron absorber of the beam dump. Potential air activation in the experimental hall is also discussed.

1 Introduction

The accelerator FLUTE is currently being set up in cooperation with DESY and PSI and commenced operation in 2018 [1]. So far, an rf-photo-injector driven by a $6\,\mathrm{mJ}$ titanium-sapphire laser and the diagnostics up to $5.5\,\mathrm{MeV}$ were commissioned. Since the FLUTE experimental hall is surrounded by thick concrete walls and no activation whatsoever is expected below $10\,\mathrm{MeV}$, no major radiation protection issues are taken into account. However, when an extension by an accelerator linac and a magnetic bunch compressor will be added, the energy will increase to approximately to $50\,\mathrm{MeV}$. Hence, the activation in accelerator components, as well in air, has to be considered. In the present paper, the activation of accelerator parts will be limited to the dump absorber, as activation in other components, at least in the course of regular operation, will remain manageable.

2 Personal safety

The existing FLUTE experimental hall is surrounded by concrete walls of at least $1.5\,\mathrm{m}$ thickness, that provide extensive radiation protection and simplify remaining safety issues considerably. The access doors to the experimental hall are labyrinthed by thick concrete walls as well. The main revolving door consists of steel and concrete and has a minimum shielding equivalence of $1.5\,\mathrm{m}$ concrete. Nevertheless, some scenarios as, e.g., a direct interaction of the primary beam with matter may make the existing concrete shielding insufficient. Additionally, an activation of the absorber, even if well contained, has to be considered.

The area inside the experimental hall is a temporary exclusion area. No person is allowed to stay in this area during the accelerator operation. This area is protected by a personal interlock system. This has to be set by the operator before starting accelerator operation. The setting procedure requires a visual search of the area and pushing a predefined sequence of search-up buttons. This search process is announced and accompanied by acoustic and light warnings. After the search procedure, the revolving door of the experimental hall is closed by the operator and the temporary exclusion area can be set by pressing a button outside of the experimental hall. If the temporary exclusion area is inactive, the rf cannot be switched on.

A person overlooked in the experimental hall can interrupt the search and disable the temporary exclusion area any time by pressing one of the emergency buttons installed at each wall of the hall. This results in the immediate switch off the main RF drive.

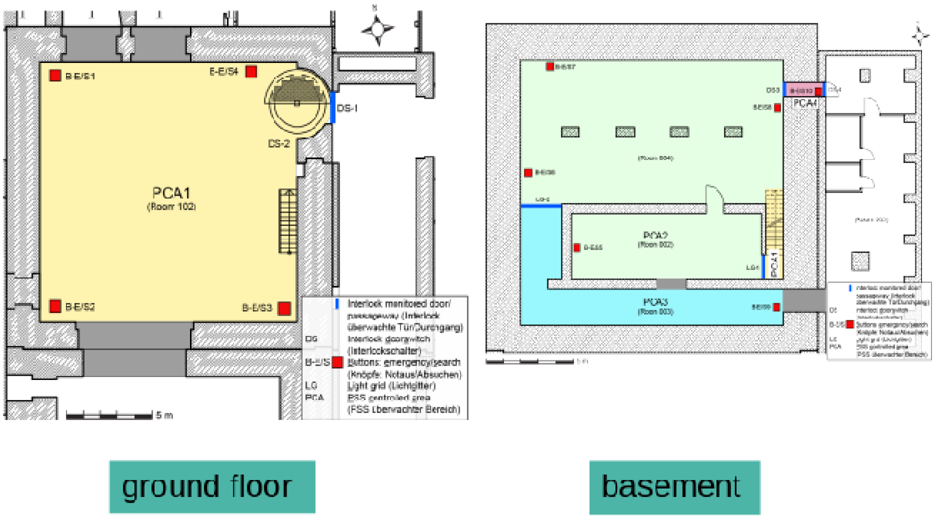

Figure 1: *The personal safety system. Left - ground floor with clearly visible revolving door) and, Right – basement. Both floors are temporary exclusion areas, interlocked during the operation.*

3 Beam dump

The beam dump was identified as the most pronounced source of radiation. In the following, the equivalent radiation dose originating from the bremsstrahlung in the beam dump, its activation, as well air activation originating from the dump are elaborated.

FLUTE operation is limited to the electron energy of less than $10\,\mathrm{MeV}$ so far. A downscale version of a dump is used for this purpose. The electron beam is fully absorbed in an aluminum cylinder (thickness=$15\,\mathrm{mm}$) mounted on the inner side of the vacuum flange terminating the electron beam guidance. There is an unsubstantial amount of bremsstrahlung- x-rays and gammas transmitted through the vacuum system tubes and flanges, accompanied by a minor neutron flux, both measured inside the experimental hall. The presence of neutron flux is yet unexplained and still under investigation. This neutron flux during the operation is not related – as reasonably explained by beam energy not reaching the activation energy of any typical nuclear reaction – by any post-irradiation activation.

The situation will most probably change when the energy will increase by $40-50\,\mathrm{MeV}$, when using a linac extension. For minimizing the potential activation in the absorber a material was chosen with low susceptibility for nuclear reactions. A pure aluminum block (chemical purity better than 99.995%) was chosen, surrounded by a led shielding (Figure 2).

The dump was intentionally over-dimensioned to accommodate the higher total beam load in the dump related to potential high dark currents originating from the cathode or the $2\frac{1}{2}$ cell rf-cavity. In addition, the shielding is designed and constructed in a way, that its modular extension with standard lead bricks will be anytime possible. The next Section will cover the activation issues in the dump.

Table 1: *Summary of saturation activity for the aluminum of the dump absorber. The nuclear activation data was taken from [3]. Column 2 specifies the daughter nuclide considered, columns 4-6 give the threshold energy for the reaction and the specific saturation activation coefficients per* kW *e-beam power As for two electron energies, approximately corresponding to electron energies in different operational regimes of FLUTE.*

1	2	3	4	5	6	7
target	nulclide	$T_{1/2}$	Threshold [MeV]	A_S GBq/kW at e-beam energy [MeV]		activity at 35 MeV Bq
				10	35	
Al	Na-24	14.96h	23.71	0	1.1	1.2
	Al-26m	6.37s	13.03	0	325	341.3

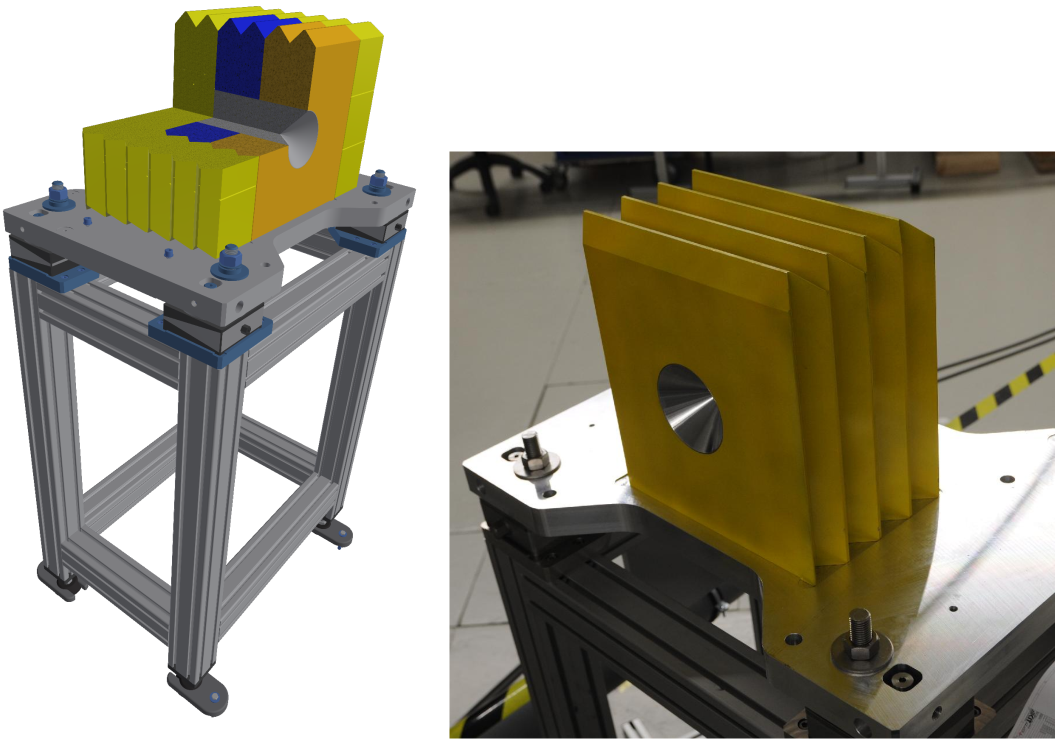

Figure 2: *The electron beam dump. Left – CAD drawing, Right – realization of its core elements. The lead shielding can be added on demand. This option of a modular shielding extension is kept open if unexpectedly high beam currents (as, e.g., increased dark currents originating from the cathode and rf-cavity) have to be handled.*

4 Activation in the dump at higher energy electron beam

For coarse estimations, a saturation activation of typical reaction products was chosen. For pure aluminum, two most prominent daughter nuclides were considered after [3]: Al-26m and Na-24. The latter originates from a sophisticated (n,α) reaction with a considerable cross section [4]. The overview is given in Table 1.

The value for Na-24 is manageable, especially as well contained in the absorber and attenuated by lead shielding (see Section 3). The initial activation with Al-26m seems high, but cools down, due to the short decay half time (6.35 s) by a factor of 106 within three minutes. This time is substantially shorter than the opening time of the massive revolving door, separating the FLUTE experimental hall from the foyer and control room (see Section

Table 2: *Summary of saturation activity for impurities in the dump absorber. Column 7 gives the activation values for three daughter products originating of stable Iron. They are scaled down with the spurious iron concentration in the absorber. Due to high purity of the absorber, the values are very low. See caption for Table 1 for more details.*

1	2	3	4	5	6	7
target	nulclide	$T_{1/2}$	Threshold	A_S GBq/kW at e-beam energy [MeV]		activity at $35\,\mathrm{MeV}$
			[MeV]	10	35	Bq
Fe	Mn-54	303d	20.42	0	22	570.6
	Mn-56	2.57h	10.57	0	1.23	1.1
	Fe-53	8.51m	13.62	0	27	700.2

2 and Figure 1). The machining, decommissioning and disposing of the dump is prohibited for operators and technicians and can be managed only by qualified radiation safety staff. Hence, the exposition of staff with activation products in the absorber is excluded. The activation numbers are based on an energy of $35\,\mathrm{MeV}$, as known in the literature and given in [3].

Table 2 summarizes the saturation activation originating from iron impurity concentration in the aluminum absorber. Due to chemical analysis of the aluminum block, the spurious iron content is $24.7\,\mathrm{ppm}$. Its reciprocal value corresponds to a factor, in which the saturation activity scales down in relation to a (hypothetically) pure iron material.

5 Prediction of the hall air activation at higher energy electron beam

The quantification of expected experimental hall air activation during operation with up to $90\,\mathrm{MeV}$ electron energy (more than ever envisaged) was requested by the competent Authority as a document accompanying the application for the operational license for FLUTE. The estimations were provided using a straightforward and easily to be followed method, based on consideration of potential nuclear reactions in air. The most gamma radiation was expected to origin from the shielded dump absorber. The estimations were presented prior to this paper [2]. The activations during the future operation, using design parameters of FLUTE, were compared to an activation budget given by regulations, concluding, that only a total fraction of 3% was exploited (see Table 3).

6 Conclusion

In the present early stage of operation of FLUTE no activation of any accelerator component or air was predicted nor measured. The consideration of the potential activation in later stages at higher energies have also been considered. The activation of components, especially the beam dump, remains manageable.

Special attention was given to the activation of air. A closed air circulation in air potentially increases risk of concentrating the reaction products with run time. Despite this specific feature of FLUTE, which was financial budget-related, the activation of air remains far below exemption limits, defined by the regulations.

References

[1] M.J. Nasse, A. Bernhard, A. Böhm, E. Bründermann, S. Funkner, B. Härer, I. Kriznar, A. Malygin, S. Marsching, W. Mexner, G. Niehues, R. Ruprecht, T. Schmelzer, M. Schuh, N. Smale, P. Wesolowski,

Table 3: *Calculated total and specific activations (3rd and 4th columns) of the hall air with chosen daughter isotopes originating from reactions with air components [2]. Comparison with limits given in the Appendix VII of StrlSchV (German Radiation Protection Ordinance) are shown, according to a scheme defined ibidem for determining their exemption in a particular case (last column); see [2] for details. Please note that total exploitation of activation budget (lower right number) is lower than 3%*

				limits			
Nulcide	**$T_{1/2}$** h	**activation** Bq	**activation** Bq/m^3	**inhalation** Bq/m^3	**submersion** Bq/m^3	**after App VII** Bq/m^3	**exploited**
^{13}N	1.66E-01	1.00E+05	5.90E+01	n.a.	2.00E+03	2.00E+04	2.95E-03
^{15}O	3.39E-02	1.07E+04	6.30E+00	n.a.	1.00E+03	1.00E+04	6.30E-04
^{14}C	4.99E+07	5.15E+00	3.03E-03	6.00E+00	n.a.	6.00E+01	5.05E-05
^{41}Ar	1.83E+00	6.94E+04	4.08E+01	n.a.	2.00E+02	2.00E+03	2.04E-02
^{11}C	3.39E-01	3.77E+04	2.22E+01	6.00E+02	3.00E+03	6.00E+03	3.69E-03
Sum							0.028

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