ARISTOTLE
UNIVERSITY OF
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Radioisotope production using linear accelerators

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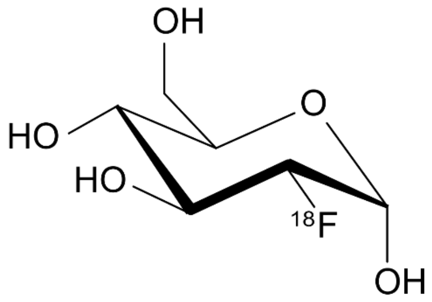
Medical radioisotope production

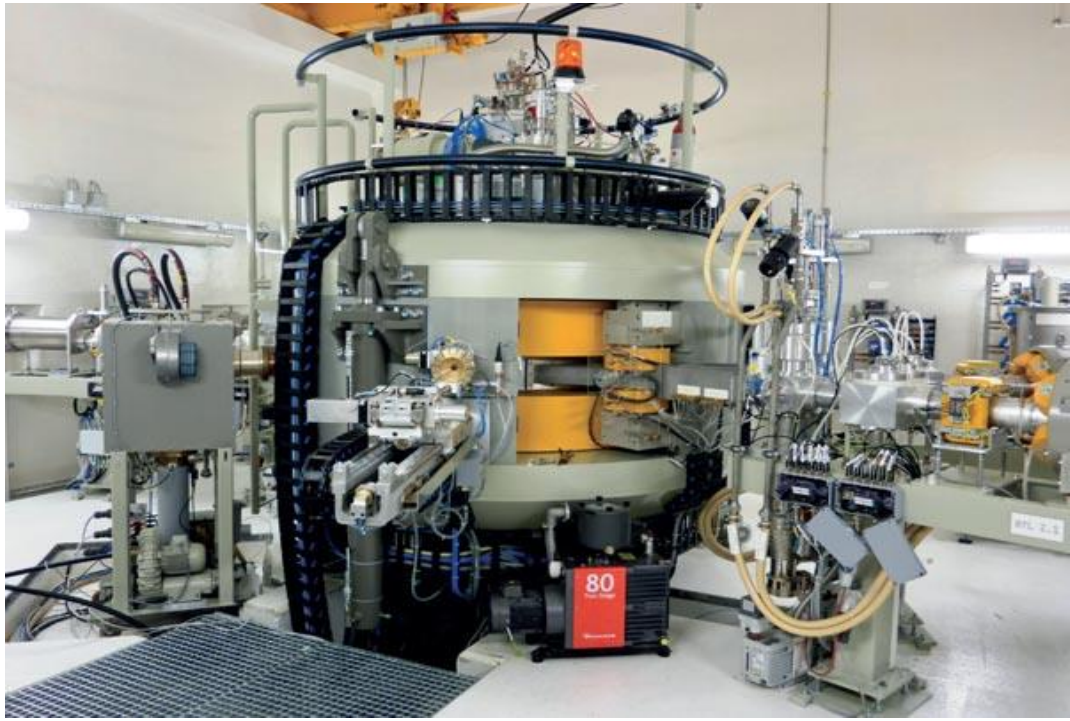
^{18}F-FDG

From radioisotope ^{18}F to the radiopharmaceutical FDG



- ✓ Main topic of bachelor thesis work was to investigate the possibility to use linear accelerators for the production of radioisotopes commonly used for PET imaging.
- ✓ Medical radioisotopes are usually produced by cyclotrons in dedicated facilities and transported to the hospitals for their use.
- ✓ The basic idea is to install a linac-based system for radioisotope production at or near the location where the radioisotopes are used, since linacs may offer many advantages compared to cyclotrons.

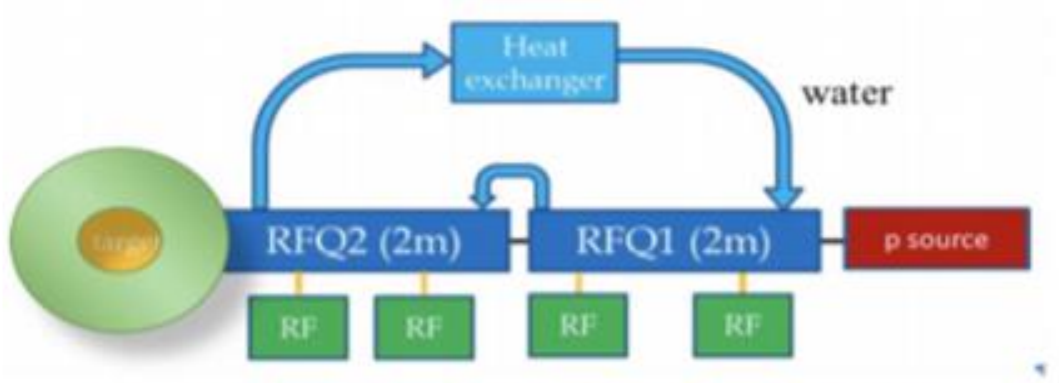
The Cyclone 30 isotope-producing cyclotron, 8.3 tons



Source: https://bit.ly/3l5ihdu

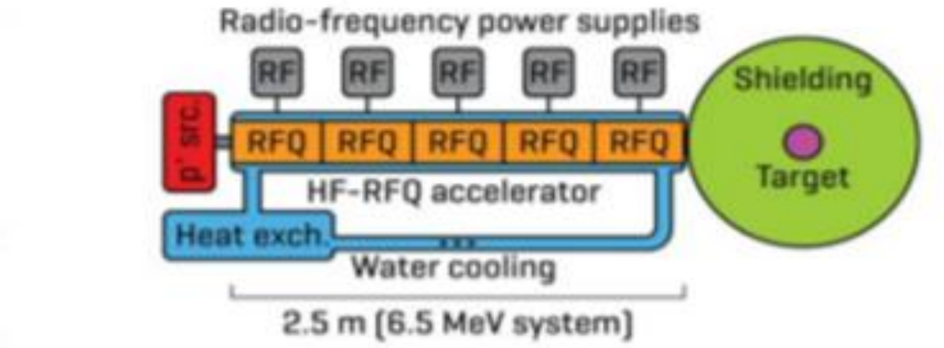
Possible RFQ Linac designs

<u>Source:</u> https://bit.ly/3p0efFQ, M. Vretenar et al.



Option: 10 MeV, 20 microA

Characteristics	
Accelerator length	4 m
Surface	15 m^2
Weight	500 kg
Output Energy	10 MeV
Duty Cycle	10%
Power Consumption	350 kW
Operating Frequency	750 MHz



Option: 6.5 MeV, 30 microA

Characteristics	
Accelerator length	2.5 m
Surface	10 m^2
Weight	350 kg
Output Energy	6.5 MeV
Duty Cycle	4 %
Power Consumption	400 kW
Operating Frequency	750 MHz

Development of numerical calculations

- The production yield of ^{18}F commonly used for PET imaging was estimated in a certain range of energies together with the corresponding number of PET doses.

- Developed a method of numerical calculations for radioisotope production to:
  - Search for an energy range in which we can achieve efficient radioisotope production
  - Keep the setup compact and cost effective
  - Investigate the possibility for injection to the synchrotron in the same energy range

Radionuclide Production Yield

$$A = I \cdot \underbrace{\left(1 - e^{-\lambda \cdot t}\right)}_{} \cdot \underbrace{\frac{N_A \cdot \rho}{M}}_{} \cdot \underbrace{\int_{E_i}^{E_{th}} \frac{\sigma\,(\mathrm{E})}{\frac{dE}{dx}} \cdot dE}_{}$$

- Yield
(mCi or GBq)

- Beam current
(μA)

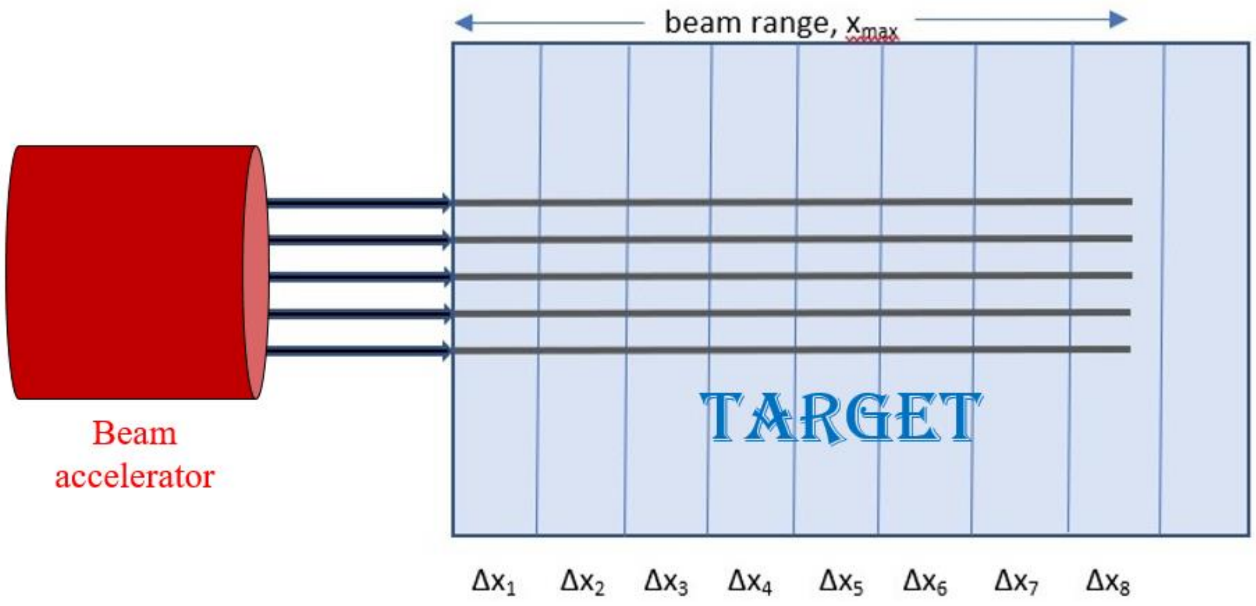
- Irradiation time
- λ decay constant of the radionuclide

- Number of target atoms per unit volume

- E_i is the beam energy,
- E_{th} is the reaction threshold energy,
- σ(E) is the excitation function,
- dE/dx is the stopping power of the target material.

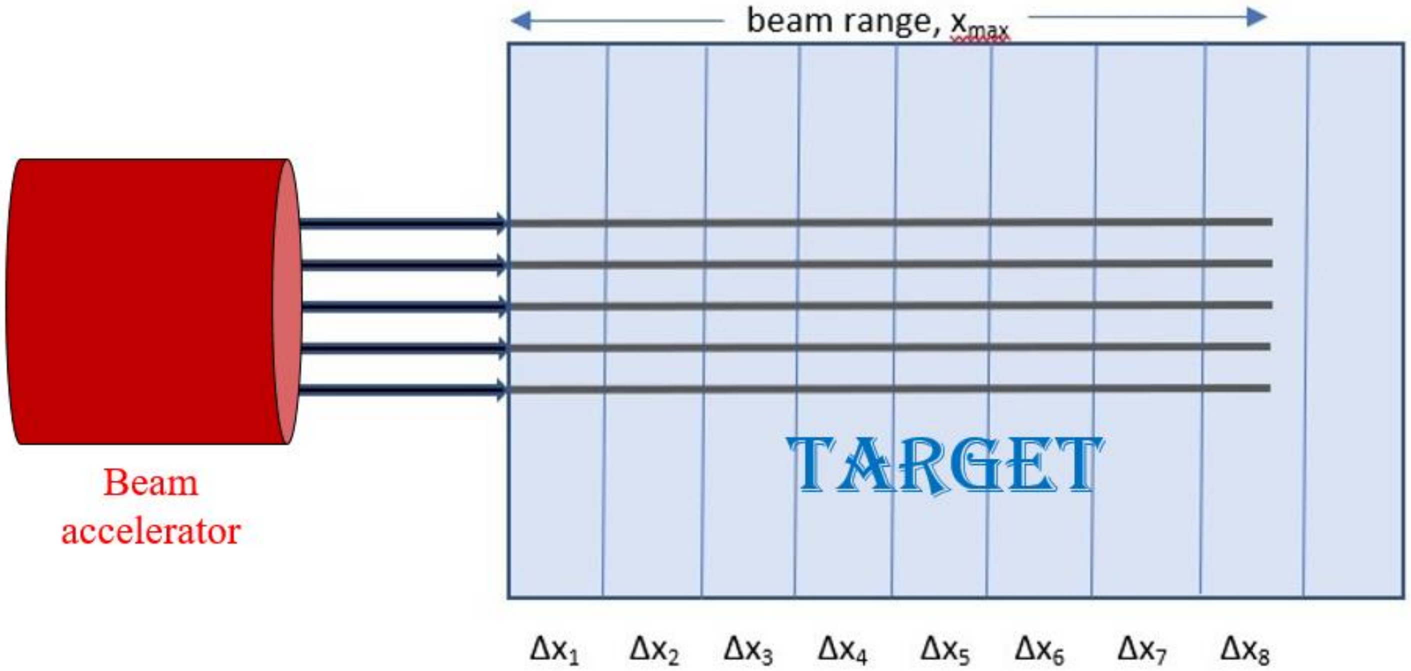
❑ For practical reasons, saturation factor, λ, is considered at 3.5 $T_{1/2}$ of the radioisotope.

Development of numerical calculation for radioisotope production



- Obtain the “range” of the particle beam inside the target from the literature.
- We divide the “range” that the particles of the beam will reach, x_{max}, in the target in several thin slices of equal thickness Δx.
- Knowing the initial kinetic energy $E_{input} = E_1$ of the particle beam impinging on the first slice, we can get from the literature the value of the stopping power $S_1 = S(E_1)$ for this energy, which is valid in the whole slice, assuming that the stopping power is approximately constant for small variations of energy.
- The energy loss of particles passing this slice must be equal to $\Delta E_1 = S_1 \cdot \Delta x_1$, and the energy of particles exiting this slice and entering into the next will be equal to $E_2 = E_1 - \Delta E_1 = E_1 - S_1 \cdot \Delta x_1$.
- We proceed in the same way to the following slices, the particle energy in each slice is decreasing in small but unequal steps, until it reaches zero (in the figure this happens somewhere into the 8th slice).

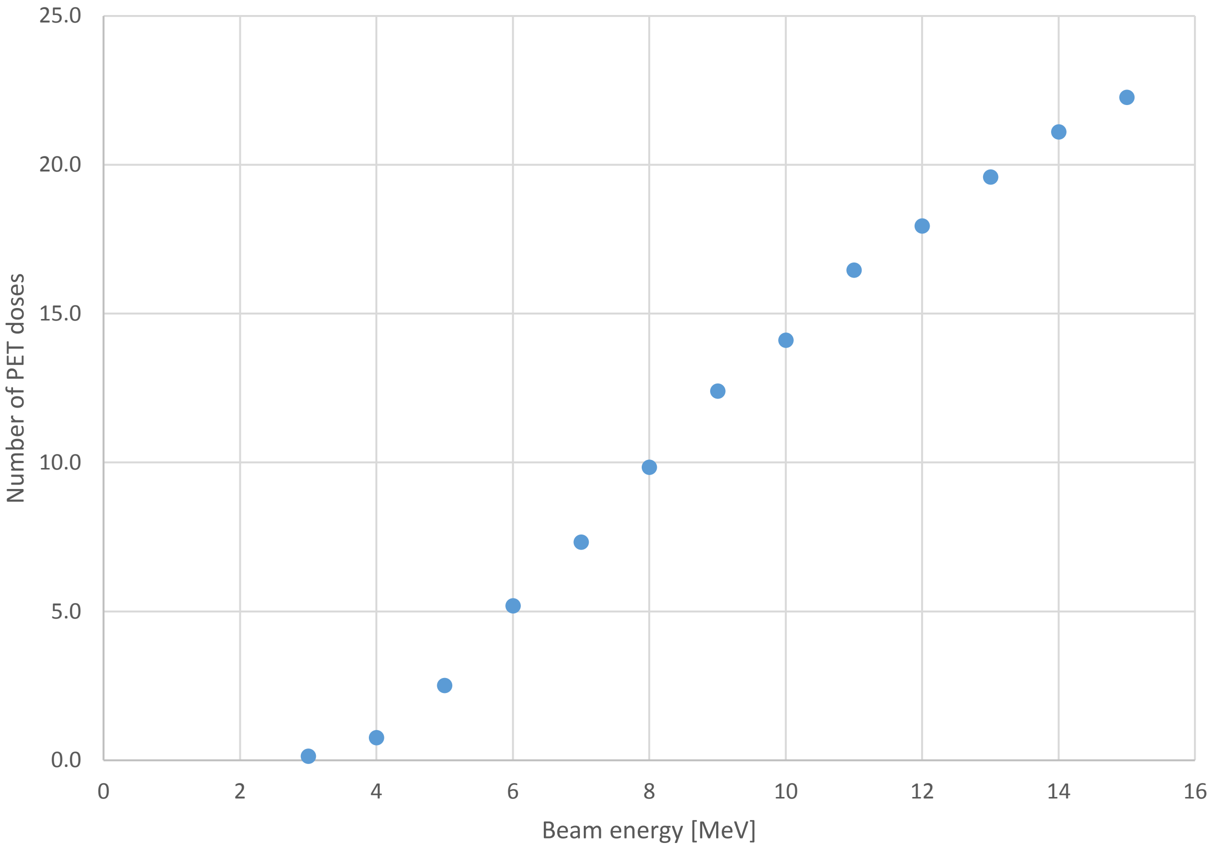
Development of numerical calculation for radioisotope production



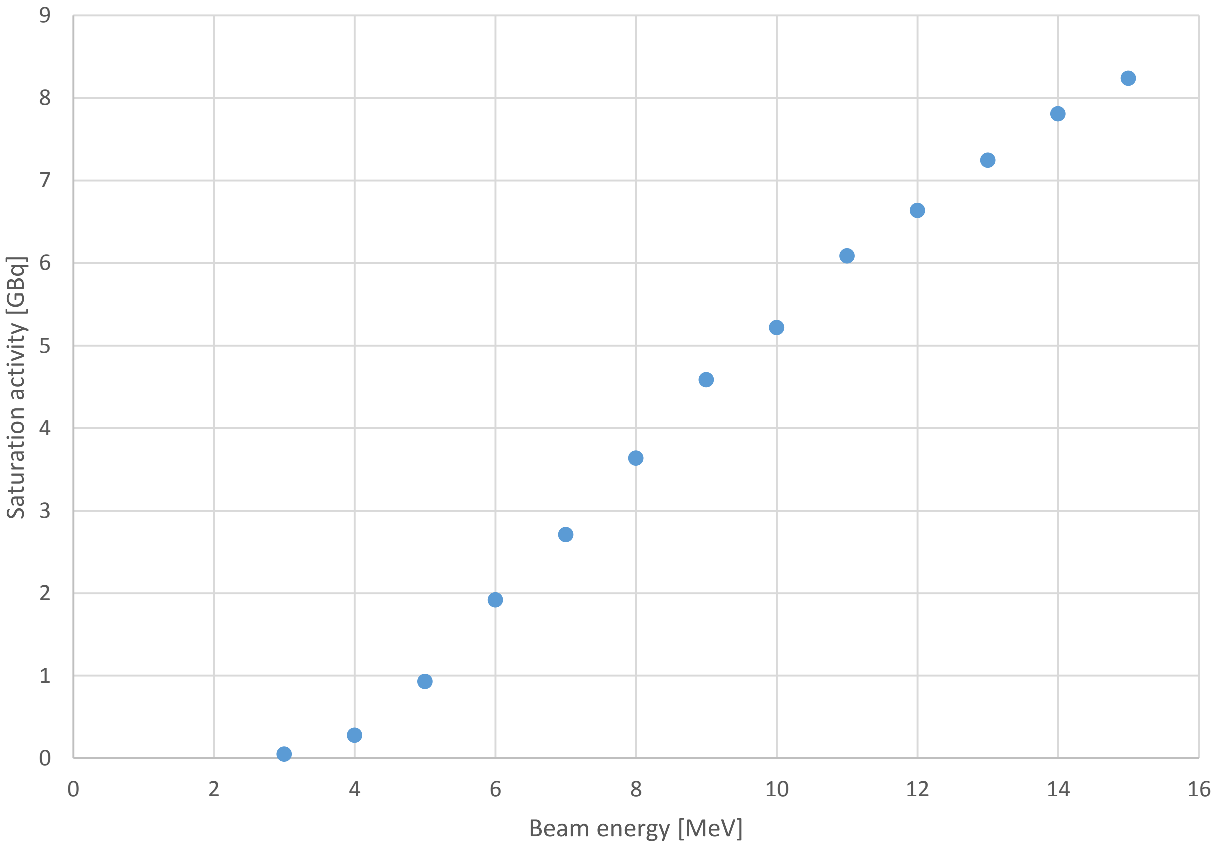
- In order to calculate the yield in each slice, y_i, we need in addition the values of the cross section $\sigma_i = \sigma(E_i)$ for energy E_i of the particles in each slice.
- We need also the number of nuclei of the surface's density for each slice $n = (\rho \cdot \frac{N_0}{M}) \cdot \Delta x$, the particle flux (i.e. the beam current I), the irradiation time t and the decay constant λ of the produced radioisotope.
- At the end, we find **the yield** as the sum of the yields in each slice: $Y = \Sigma y_i$.

Yield calculation for ^{18}F production from $H_2{}^{18}O$ water target.

Number of PET doses for 1 μA



^{18}F Saturation Activity for 1 μA



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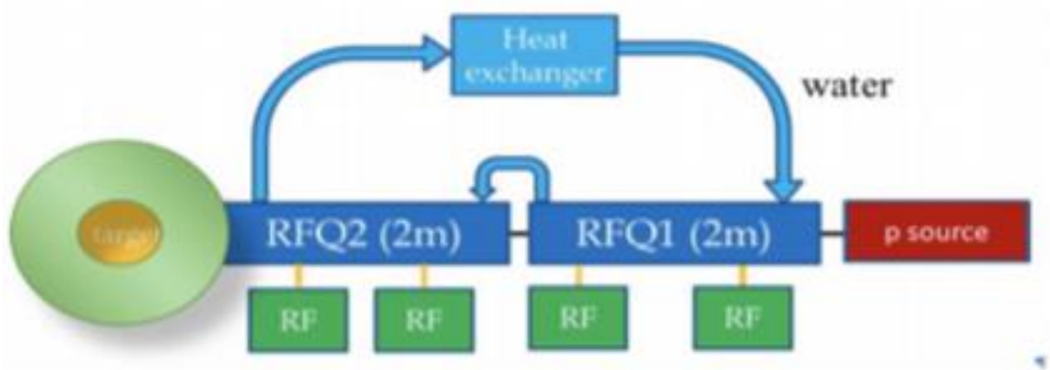
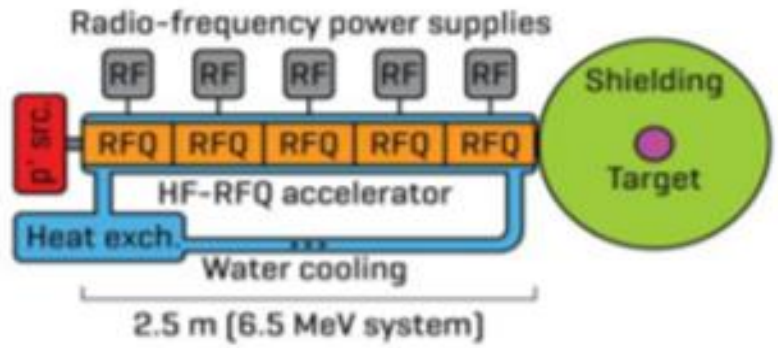


Option: 10 MeV, 20 microA



Option: 6.5 MeV, 30 microA

Saturation yield after 3.5 $T_{1/2} \cong 6$ h:

104 GBq → 282 PET doses

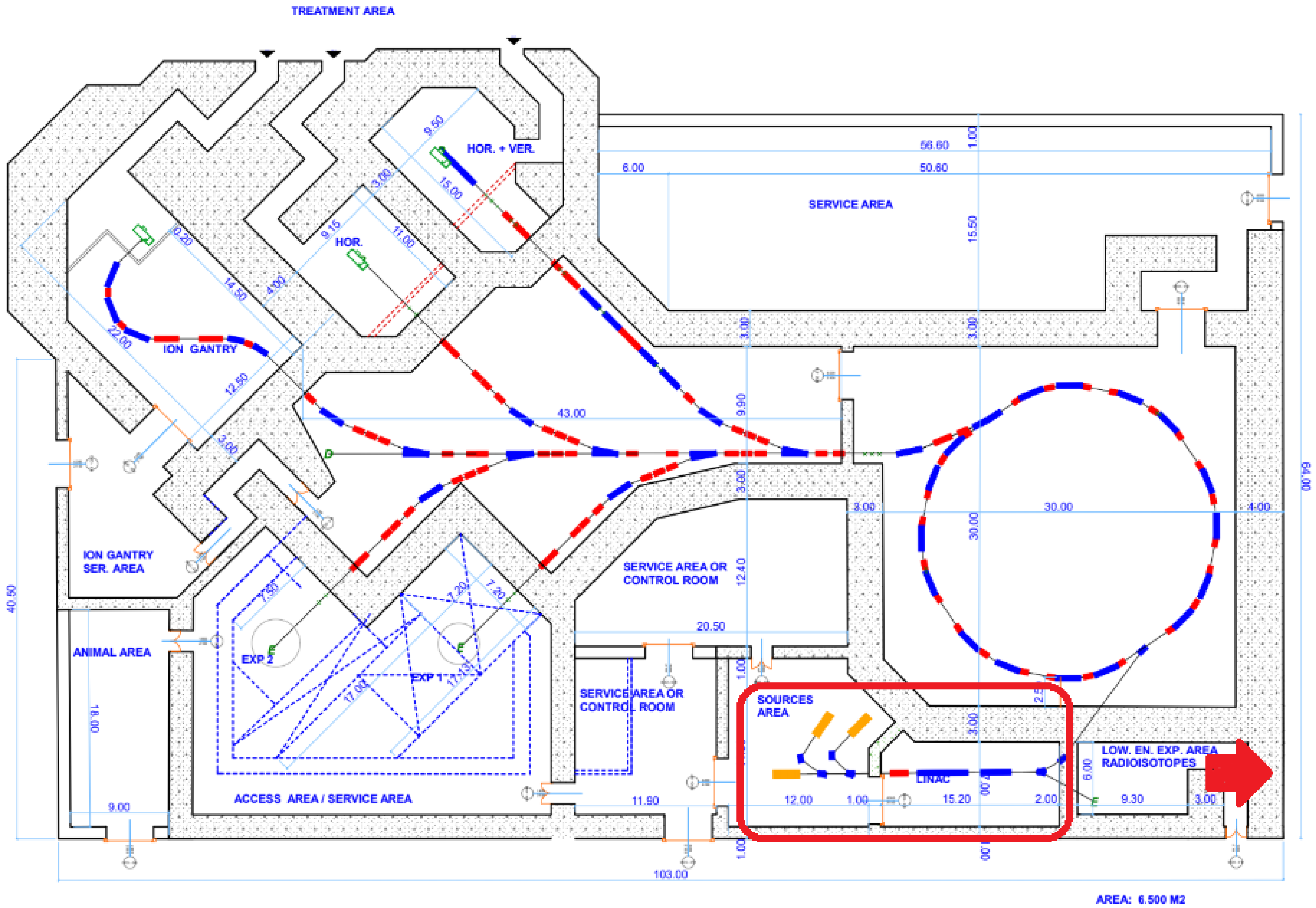
Saturation yield after 3.5 $T_{1/2} \cong 6$ h:

74 GBq → 200 PET doses

- ✓ ^{18}F arriving from Athens, by plane and/or car → Great yield loss.
- ✓ The produced yield at the production laboratory is 120 GBq out of which only 15 GBq reach the hospital (after 5-6 hours) and 4.4 GBq are finaly used.
- ✓ This loss can be avoided with a production unit close to the hospital → Possible linac setup designs.

Possibility of radioisotope production in SEEIIST facility

- ✓ Possibility for an extension to construct a unit dedicated to the extraction of the produced radioisotope from the target and the production of radiopharmaceuticals.
- ✓ The surplus of radioisotope quantities could be made available to other hospitals.
- ✓ Research field for exploring more promising radioisotopes for diagnostic and therapeutic purposes.



Conclusions and Outlook

- The possibility of using linacs for radioisotope production looks promising.

- Study the simultaneous optimization of the parameters needed for the production of these radioisotopes, by a compact cost effective linear accelerating system that could also be used for injection to the synchrotron.

- Optimize the design of this area including efficient radioprotection methods, shielding calculations and appropriate construction materials.

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Thank you!