

HIGH EFFICIENCY [F18]FLUORIDE TARGET SYSTEM FOR THE EFREMOV INSTITUTE CC-18/9 CYCLOTRON

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Abstract

Positron emission tomography (PET) is a nuclear medicine imaging technique that produces a three-dimensional image or a picture of functional processes in a body. The system detects pairs of gamma rays emitted indirectly by a positron-emitting radionuclide (tracer), which is introduced into the body on a biologically active molecule.

If a biologically active molecule chosen for PET is FDG, 2-deoxy-2-[18F]fluoro-D-glucose, an analogue of glucose, concentrations of the tracer imaged then give tissue metabolic activity in terms of regional glucose uptake. Use of this tracer, to explore the possibility of cancer metastasis (i.e., spreading to other sites), results in the most common type of the PET scan in the medical care (95% of current scans).

Due to the short half-lives of the most positron-emitting radioisotopes, the radiotracers have traditionally been produced using a cyclotron in close proximity to the PET imaging facility. The half-life of fluorine-18 is long enough for manufacturing radiotracers labeled with fluorine-18 commercially at offsite locations and transporting to the imaging centers. Since radiochemistry lab in the RRCRST produces FDG for needs of our PET-center and also for two PET-centers in Saint-Petersburg (currently), it is of major importance to produce sufficient amount of fluorine-18 and to obtain FDG with a high radiochemical yield.

The aim of this work was to develop and construct a highly efficient target system for producing fluoride-18 with the Efremov CC-18/9 cyclotron, which is a negative ion system that accelerates 18 MeV ions. The maximum achievable beam current is 100 μ A. The beam profile measured with a scanner indicates that approximately 95% of the beam is distributed within a 20 mm diameter circle.

The former fluoride-18 target system for this cyclotron, supplied by the cyclotron producer, the Efremov Institute, had insufficient productivity, not greater than 1 Ci of fluorine-18 during 2 hour irradiation, and didn't allow achieving high radiochemical yields in producing radiopharmaceuticals due to contamination of irradiated water with metallic impurities from target body.

TARGET CONTRUCTION

The major demerits that caused poor performance were inadequate heat transfer rate of the target body and an inadequate water layer. Since the heat input exceeded the heat removal capability of the target, excessive voiding occurred in the target water. Protons of a given energy have a characteristic range in water which is inversely related to the water density. Since the water

density decreases with the void fraction, the operating void fraction dictates the necessary target depth to prevent the beam from penetrating to the target rear surface. If the proton beam penetrates the water volume and deposits heat in the back wall of the target, the fluoride-18 yield will be reduced due to less proton interactions in the water. Interactions between the beam and the target surface can also release metal ions into water, which react with the ionic fluorine-18 and cause further reduction of the yield.

To prevent the proton beam from striking the back wall of the target, the target must be range thick. The target depth should exceed the range of the protons in the saturated mixture. The range of protons with incident energy between 0 and 18 MeV in water has been determined using the Stopping and Range of Ions in Matter program (SRIM), presented in fig. 1. A 5 mm depth of the target chamber was chosen to provide full functionality with 65/35 % water/vapour mixture (at 8 bar).

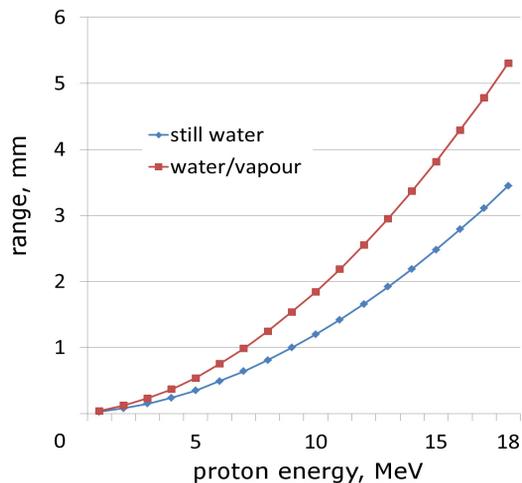


Fig.1. Proton range in water (SRIM).

Niobium has been chosen as a material for the target body, since it is a proper and well-known interface material due to its excellent chemical compatibility. Unfortunately, niobium suffers from a relatively low thermal conductivity. To overcome this problem, heat exchange mechanisms other than simple water-metal-cooling water conduction have to be considered. The new target has been designed to allow boiling in the target chamber to take advantage of the high rate of heat transfer. Heat deposition in the water causes boiling and results in formation of voids or bubbles. The buoyancy

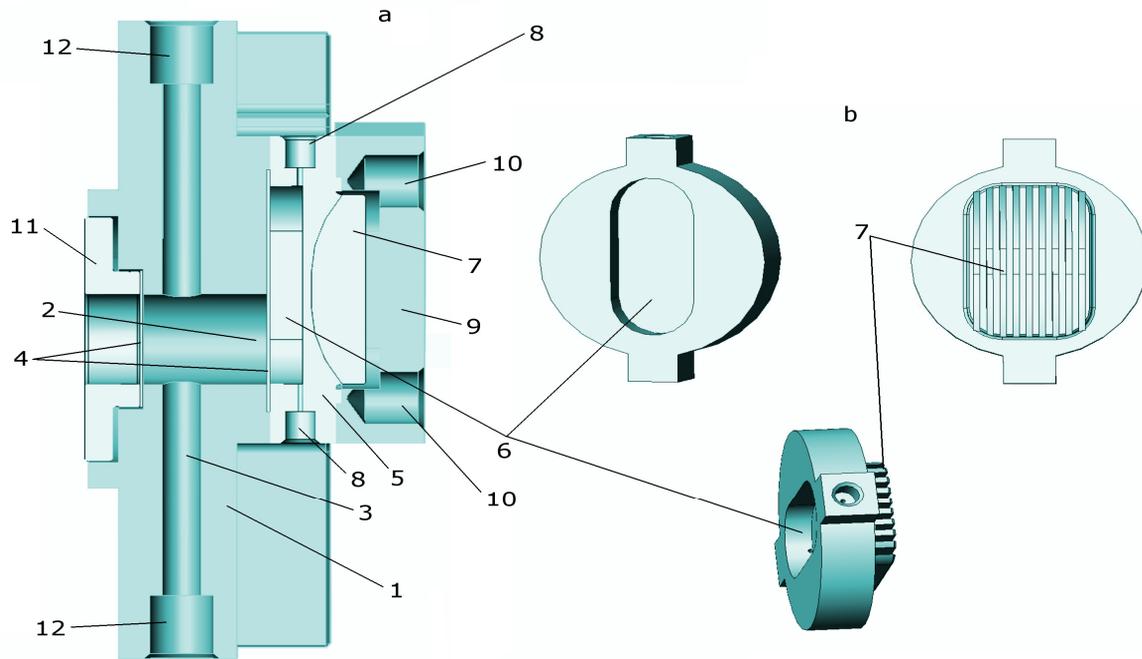


Fig.2. Target system scheme.

forces cause these bubbles to rise and condensate on the walls of the target. The condensation region mode of operation implies that bubbles, which rise to the top of the target, enter a distinct condensation region. Steam condenses on the chamber walls and flows back down the walls into the boiling pool. Aluminum has been used for the target housing due to its low cost and ease of machining. Since the target cooling system is located completely within the tantalum internals, good thermal contact between the internals and the housing is not necessary.

Target system scheme is presented in fig. 2a, target body is presented in fig. 2b, where 1 – main flange, 2 – proton window, 3 – helium cooling chamber, 4 – foils, 5 – target body, 6 – irradiated volume/condensation surface, 7 – fins (grill), 8 – 1/4"-28 UNF threads for Supelco fittings, 9 – cooling water flange, 10 – cooling water inlet/outlet, 11 – vacuum-helium foil holder, 12 – G1/4 pipe threads.

COMSOL HEAT EXCHANGE MODEL

To improve heat exchange between cooling water and the target body, fins are used. The fins significantly increase the target surface area for heat transfer without significant increase of the effective conduction distance. For certain geometries, addition of fins can greatly improve heat removal capability. Effectiveness of adding fins has been investigated to gain additional heat removal margin. Additional heat transfer gained by adding fins has been calculated using a COMSOL Multiphysics heat transfer model (fig. 3). Fins of different rectangular

configurations have been investigated (1, 1.5 and 2 mm thick). In all cases, calculations were carried out at the wall thickness of 1.5 mm. Boiling and cooling heat transfer coefficients have been acquired experimentally for model niobium target body with 1.5 mm fins. Mode that ensured yield at least 80% of the theoretical saturation yield for the model target has been chosen as a reference point (37 μA , 629 W). Calculated effect of fin height on total dissipated heat is represented in fig. 4. One can see that under described conditions (8 bar pressure inside target chamber and existing cooling system with known heat transfer coefficients) dissipated power as high as 860 W (50 μA) is achievable. It should be noted that operation of the target is still possible above the defined thermal limit, though 18F yields will suffer.

Since it is difficult to evaluate the exact contribution of different heat transfer mechanisms that affect chamber inner wall, simulated heat input is considered to be uniform throughout the chamber wall surface. That simplification still leaves a possibility to evaluate optimal fin configuration and improve productivity of the target system.

Target system has proven its efficiency and reliability in over 110 production runs with average productivity of 90 GBq at 40 μA (1 hour irradiation). No noticeable yield reduction is observed during routine production, which indicates that target body and seals (Tefzel) do not degrade.

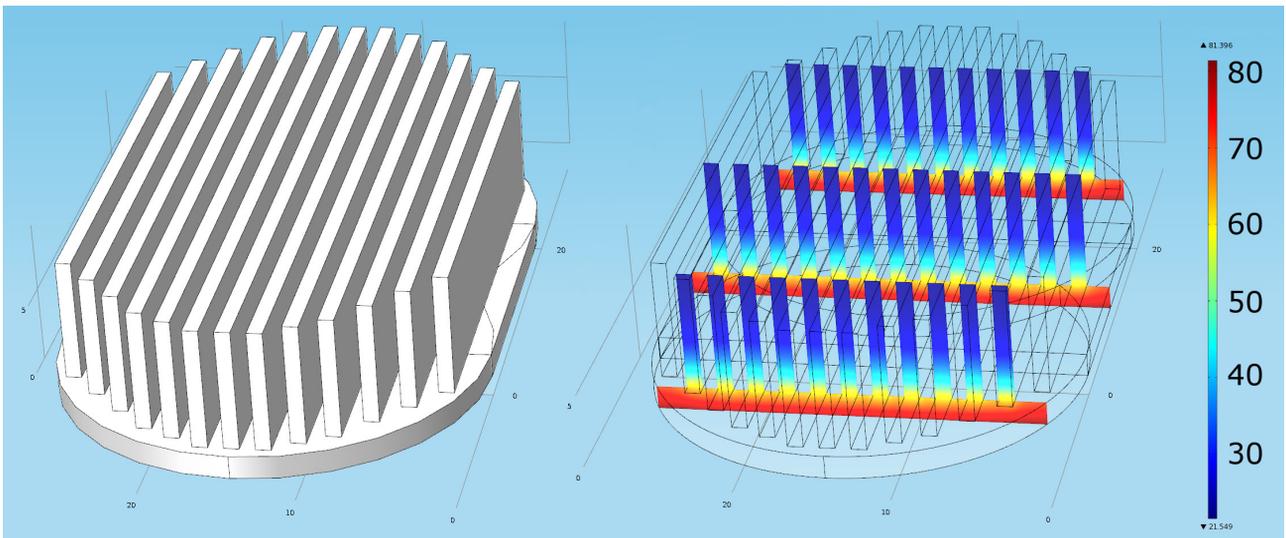


Fig. 3. COMSOL Multiphysics heat transfer model.

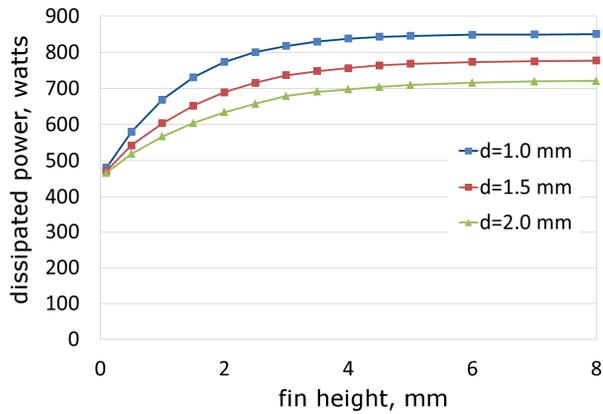


Fig. 4. Effect of fin height on total dissipated heat.

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