HIGH YIELD 0-18 WATER TARGET FOR F-18 PRODUCTION ON MC-17 CYCLOTRONS

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The MC-17 cyclotron (Scanditronix AB) was installed in university and hospital PET centers worldwide until the sale of the company in about 1993. The majority of those machines were supplied with a water target for F-18 production that was made of silver in a double-foil keyhole design. (1,2)

The targets were designed to meet the needs of PET facilities of the late 1980's which engaged primarily in research with only a small, if any, clinical component. Conservation of 0-18 water while permitting the production of a few GBq, or a few hundred mCi, of F-18 fluoride was the primary goal. The target was therefore designed to be small. It accepted enough beam current to produce the necessary amount of fluoride, but used only half the beam that was produced by the cyclotron. That target met the design goals and has produced daily batches on the order of 20 GBq for routine synthetic use over the past ten years. However, the earlier slow and steady increase in clinical use of PET worldwide resulted in reasonable reimbursement for clinical studies which in turn has made hospitals much more willing to provide clinical PET. Combined with the appearance of positron-capable gamma and SPECT cameras, this has dramatically increased the demand for fluorine-IS from many of the MC-17 installations. Although the original silver target was sufficient for the demand of the time, it does not make full use of the ability of the cyclotron, and its production leaves something to be desired in a high-demand environment. It also requires maintenance at intervals of three to eight weeks mainly because of build-up in the target of silver oxidation products. In order to increase production capability and reduce the need for maintenance, a new target was designed and tested.

This target has a different set of design criteria. Enriched water is no longer the severely limiting factor that it was through the late 1980's. Effective recovery and recycling techniques combined with strong increases in supply capacity have removed it as a limiting factor in the operation of a PET facility. Water conservation is therefore no longer a stringent design goal. Production requirements have strongly increased. The demand for F-18 from a single PET seamer has increased five fold since the design of the earlier MC-17 targets. In addition, there is a strong possibility that each cyclotron will be supplying multiple PET and coincidence gamma cameras, multiple institutions, and transporting product some distance from the radiochemistry laboratory. Therefore this design was intended to maximize the production capacity of the target, and make the beam capacity of the cyclotron the limiting factor in production.

The beam of the MC-17, most of which were installed without external beam lines or focusing optics, is about 3mm in height and 3 cm wide. It is not uniform intensity across the entire width, but tends to have ‘hot spots’ at the outside edge. The foil entrance must therefore be at least this large. The resulting foil area and beam density variations create a tendency for target foils to fail under high operating pressure. In the past (2), we have shown that a sufficient gas space above the target water allows the water to cavitate and reflux within the target under low pressure without ejecting water from the target and without loss of target yield. The previous silver design gave the produced fluoride good chemical reactivity, but required maintenance at intervals of a few weeks. Titanium foils had been very successful with that design, and others have reported successful titanium target designs, so this target was designed to be built from titanium. The double foil design of the previous target mainly acted to reduce the effects of wear on the target interior and make maintenance easier. We anticipated that titanium would not wear or oxidize like silver and so would not need the same consideration. The new design was therefore a single foil type with a solid target back. Cooling fins were added to the water cooling chamber because of the low heat conductivity of titanium. A large gas space was incorporated over the target water to provide a reflux space, and cooling jets
were included in the helium cooling chamber to direct fresh helium evenly across the short axis of the target foil. The water chamber was 2.8 cm high, with a slightly sloping base to aid water removal.

A prototype was constructed of aluminum and tested by irradiation of natural-abundance water to produce N-13. It was assumed that a total target N-13 production consistent with theory (saturation yield per microamp, S. calculations) for a particular irradiation would indicate that F-18 production would also be consistent with theory and that a target failure to produce N-13 would also extend to F-18. The prototype was originally constructed with a target chamber 1cm thick and 4cm wide. A series of irradiations was performed to evaluate the performance under maximum F-18 production conditions. The chamber size was then reduced in stages by inserting aluminum spacers in the sides to reduce width and by machining the face to reduce the thickness. It was determined that a width of 3.2 cm would accept over 90% of the cyclotron beam, and that a thickness of 6mm would allow beam up to 50 microamperes for a two hour irradiation without significant loss of target yield of N-13. Smaller dimensions led to a decrease in saturation yield per microamp at lower beam current or irradiation time.

The prototype design was then used to construct a target of titanium for F-18 production. The prototype had used flat gaskets for sealing the chambers, but these proved prone to extrusion into the target chamber. For the production target, we returned to an 0-ring design using helicoflex 0-rings. The change forced a reduction in the height of the target chamber to 24 mm and a rounding of the edges (Drawings). The production target has been used for four months for daily routine production. It has not required cleaning or other maintenance during this time, a fact that represents a strong improvement over the silver target. The yield of products made with fluoride produced by the target have been consistently high (example: FDG 50% radiochemical yield at 50 mm LOB, 65% chemical yield). The target yield capability has not equaled that of the prototype target, however. While a production over 190 GBq (5 Ci) would be expected from the prototype performance, to date the target has suffered from reduced S yield with beam currents exceeding 30 microamperes and one hour. Therefore, further design modifications are still being considered. However, the target has consistently been able to produce yields of fluoride exceeding 90 GBq (2.4 Ci) from which greater than 45 GBq (1.2 Ci) FDG has been produced, usually after removal of some fluoride for other purposes. This performance greatly exceeds that of the standard MC-17 target.

References
Discussion

John Clark: What was the problem getting the water through the fins?

Marc Berridge: I think what is going on with these fins is they are too thick and too close together and they act more as insulators than conductors. This is because I’m not really capable of doing the calculations so I borrowed some dimensions from two targetry workshops ago but that was from a different application and not for the heat conductivity of titanium. But the other idea of it is they are thick enough to reach the back of the cooling water chamber and get some mechanical support. The idea to thin the back down to a couple tenths of a millimeter and just have enough fins to support the pressure.

John Clark: Has anyone experience with fins on the inside of the target?

Lou Carroll: Not directly, but for those who are inclined to try their hand at some of these heat transfer codes, there is a particularly nice one available as shareware from a company called Tera Analysis, the code is called “Quick Field” and it has the virtue of being “user friendly”, if you pardon the expression. But it is true, a novice can actually sit down and within a few hours be running rather sophisticated heat transfer calculations. You know you plug in the conductivity’s and the film coefficients and so on and out come answers in color coded graphs and so on. It is very nice.

John Clark: Could you scribble all of that down as a website and put it on one of the poster boards so we can all copy that. Thank you very much.

Editor note: http://www.teraanalysis.com/qfield.html
Unidentified Attendee: Is that a 2D or 3D?
Marc Berridge: A 2D heat transfer.

Karl Erdman: Back in the days when people were doing initial tests on reactors where you needed water cooling, fins worked best when they were across the water flow rather than the direction of the water flow and most people don't realize that. The reason is because you set up turbulent channels that circulate inside the fin and you get a lot more cooling if the water is flowing across the fins rather than parallel to the fins.

John Clark: That wouldn't work inside because there is no water flow. Well, possibly no flow.
Lou Carroll: There is a concept called the “Hyper Vaportron” and it’s the heat transfer method of choice in the fusion world. They have to cool these beam dumps and they use the “Hyper Vaportron” which is precisely the transfer fin concept and it’s very effective. It exploits the boiling regime and you get rid of a lot of heat with a relatively small water flow.

Marc Berridge: There is another problem that we ought to consider and that’s the cooling on the front foil. The evidence that we are seeing so far is that the targets are starting to see a decrease in the saturation yield before you reach the heat flow through the back that should be limiting. It looks as if there is cavitation boiling at the front foil before the heat transfer is limited through the back so it sounds like it is really the conductivity of heat through the water that is limiting the cooling on the backside and that the front foil cooling is actually very important.

Jean-Luc Morelle: About fins. For easy machining reasons one often makes square fins but actually the optimal fins do not have that shape they are suppose to be like little waves. You can find the description of the way the optimal shape of the fins is derived in the textbooks on reactor design. Usually its something like an elliptical shape where the ratio of the depths to the width will depend upon the heat conductivity of the cooling medium and of the metal being cooled.

Bill Alvord: A word of support, I didn't want to rain on the fin parade too early but a word of support to what Marc said. Two things have led me to believe that the foils are far more important. One detailed 3D analysis of our water targets showing that the highest heat stresses and the best place to try and remove heat is in fact right at the front top of the foil where it domes out. You have flow patterns inside your target where you are bringing your boiling or nearly boiling water up against the top of the dome and cooling there is through that thin membrane is by far the best place to do it. The other comment is that because of the geometry of our RDS-111 target changer, these targets have to be modular and so the cooling on the outside of the targets is like you would do for a gas target as well. That means I don't have any jets near the back, or anywhere near the back of the target and we can still reach 40 microamps at 11 MeV and seem to remove the heat just fine and I think it is through the helium window cooling that is doing most of the work in that case.

John Clark: So you have evaporative cooling right at the top layer of the water that is dumping heat into the foil and the front part of the target?
Bill Alvord: Yes, when done right.