

## PET TECHNICAL DATA:

### FDG:

The radioisotope used in most clinical facilities is FDF. FDF is an abbreviated name for the radiopharmaceutical Fluorodeoxyglucose (2-deoxy-2-[ $^{18}\text{F}$ ]fluoro-D-glucose), a radioactive glucose analog with a positron emitting fluorine isotope ( $^{18}\text{F}$ ) replacing a hydroxyl group (-OH). In the manufacturing of FDG,  $^{18}\text{F}$  is first produced in a cyclotron facility by bombarding  $^{18}\text{O}$  with high energy protons. The  $^{18}\text{F}$  is then placed in an automated synthesis unit where it undergoes a series of chemical processes to produce FDG.

$^{18}\text{F}$  is particularly useful because, in the spectrum of positron emitting radioisotopes, it has a relatively long half-life of 110 minutes [ $^{11}\text{C}$  has a half life of 20.4 minutes,  $^{13}\text{N}$ , 9.96 minutes; and  $^{15}\text{O}$ , 122 seconds].<sup>i</sup> Because we don't have a cyclotron unit here in Huntsville, our supplier in Nashville (P.E.T. Net Pharmaceuticals) must quickly get the FDG to our site where it can be used in our clinical facility [hence, patient scheduling is VERY IMPORTANT].

#### Physical Decay Chart For $^{18}\text{F}$ <sup>ii</sup>

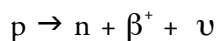
<i>Minutes</i>	<i>Fraction Remaining</i>
0*	1.000
15	0.909
30	0.826
60	0.683
110	0.500
220	0.250
440	0.060

*\*Calibration Time*

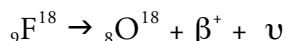
### POSITRON DECAY:

A positron is the anti-matter equivalent of the electron. It has an identical mass, rest energy, and charge magnitude, but with an opposite sign.

Positron Decay, or (more correctly) positive beta decay, is a radioactive decay process in which a proton decays into a daughter neutron, positron, and neutrino:



For a free proton, this process has a negative Q-value (relativistic energy value released in the process) and thus is not energetically feasible and never observed in nature. However this process does occur in many lightweight, neutron-poor nuclei in which there is a high degree of coulombic instability due to too much positive charge concentrated in the nucleus. Using  $^{18}\text{F}$  as an example nucleus, positive beta decay can be expressed as:



Using the Q-value for this reaction, one can get a good approximation for the maximum kinetic energy of a positron emitted in  $^{18}\text{F}$  decay.

$$\begin{aligned}
Q &= [m({}_9\text{F}^{18}) - m({}_8\text{O}^{18}) - 2m_e]c^2 && m_e: \text{electron (positron) mass} \\
&= [18.000938\text{u} - 17.999160\text{u}]c^2 - 2(.511\text{MeV}/c^2)c^2 \\
&= 1.656\text{ MeV} - 1.022\text{ MeV} && \text{keeping in mind: } 1\text{u} = 931.5\text{MeV}/c^2 \\
&= .634\text{ MeV}
\end{aligned}$$

Assuming, quite reasonably, that there is negligible recoil energy associated with the daughter  $^{18}\text{O}$  nucleus because of mass considerations:

$$Q \cong \text{Energy of Neutrino} + \text{Kinetic Energy of the Positron}$$

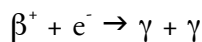
The positron has maximum kinetic energy when the neutrino energy is zero, so far a positron produced in  $^{18}\text{F}$  decay, its maximum kinetic energy is: 634 keV

Not all  $^{18}\text{F}$  positrons are this energetic. Petnet Pharmaceuticals literature lists the mean energy for  $^{18}\text{F}$  emitted positrons to be 249.8 keV.<sup>iii</sup> For imaging purposes, a low energy positron emitter is important for two main reasons: the positron travels a short distance before annihilation, and the resulting gamma rays will emerge in near opposite directions.

UCLA's Crump Institute gives, on their website, a maximum positron range for  $^{18}\text{F}$  of 2.6mm, while the University at Buffalo PET Center website lists an average range of .22mm before annihilation.

## ANNIHILATION:

Once emitted, the positron eventually comes into contact with an electron and an annihilation reaction occurs:



Total relativistic momentum must be conserved, so assuming both the positron and electron are at rest, the resultant gamma photons emerge with equal energy (511 keV, equal to the rest mass of an electron or positron) and travel in opposite directions.

PET imaging, as discussed below, is based on this assumption (it's a very good one), but what happened to the initial kinetic energy of the positron? Once emitted the positron, a positively charged particle, loses much of its kinetic energy through scattering. Many scientists have pointed to the formation of a positronium intermediate that forms when the KE of the "free winging" positron decreases and becomes "small" comparable to the KE of the electrons hanging around. Positronium forms, it quickly decays (lifetime of  $.125 \times 10^{-9}$  s) and produces the two gamma rays.<sup>iv</sup> The KE associated with the electron and positron is quite small (on the order of ten eV) and so is negligible compared with the rest energies (0.511 MeV each). The angular deviation from  $180^\circ$  is quite small, ranging from milliradians to a couple of degrees.<sup>v</sup> It is only  $180^\circ$  in the center of mass frame or in the unlikely event the annihilating particles are at rest. Given the acceptance angle of most detectors, these small deviations from  $180^\circ$  are of little significance in PET devices.

## DETECTION AND IMAGING:

In a PET study, a large ring of detectors, stacked in multiple rows, surrounds the patient. The detectors are made up of germanium crystals and the 511 keV photons produced from the annihilation event cause the crystals to become excited, releasing a lower energy light photon. These photons strike a photocathode and a photomultiplier effect is generated (using the photoelectric effect and accelerating electrons through a potential) until there are enough electrons to create a detectable current pulse. The pulse information is stored as a sinogram and, if two events are detected simultaneously (from the two photons going opposite directions), a

line of response is recorded from one detector to another. Single detections are discarded. The computer uses mathematical algorithms to reconstruct a visual image that gives information about the positron and concentration of FDG in the body.

## REFERENCES AND DISCLAIMER:

The information on this page was humbly put together by a guy with an undergraduate degree in physics.

UCLA's Crump Institute Website was a huge help in understanding things as was Brian Murphy's Teaching Series at The University at Buffalo Websites and The University of Southern California's PET Imaging Center Website.

Many thanks also to Dr. R.L. Reese and Washington and Lee University's Physics Department.

## OTHER LINKS:

For a more thorough discussion try:

UCLA Crump Institute site for "Let's Play PET":

<http://www.crump.ucla.edu/software/lpp.adp>

University of Southern California's PET Imaging Center Website:

[http://www.usc.edu/schools/medicine/academic\\_departments/radiology/uscpet/scientific.htm](http://www.usc.edu/schools/medicine/academic_departments/radiology/uscpet/scientific.htm)

University at Buffalo Website:

[http://www.nucmed.buffalo.edu/slides/525\\_photon\\_detection\\_II/index.htm](http://www.nucmed.buffalo.edu/slides/525_photon_detection_II/index.htm)

<sup>i</sup> Ronald Lane Reese, University Physics (extended version), (to be published by Brooks/Cole Publishing Company, Pacific Grove, California.

<sup>ii</sup> PET Net Pharmaceuticals Literature

<sup>iii</sup> PET Net Pharmaceuticals Literature

<sup>iv</sup> Northern Territory University Website:

<http://www.cs.ntu.edu.au/homepages/jmitroy/research/positronium.htm>

<sup>v</sup> D.M. Schrader and Y.C. Jean, Positron and Positronium Chemistry (Elsevier, Amsterdam, 1988) page 108