ON THE POSSIBLE MEDICAL APPLICATION OF μe DECAY AND μSR MEASUREMENTS

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Negative muon (μ^-), when it stops inside the materials, forms hydrogen-like atomic states around nuclei called muonic atoms. The atomic formation probability in complex element materials $(Z(i)_i Z(j)_j \ldots)$ is roughly proportional to $i \times Z(i)$. During its atomic cascade transition, characteristic X-ray is emitted. While, during stay at the ground 1s state the high energy (up to 50 MeV) electron is emitted with a characteristic life time (τ_μ) due to competing process of nuclear capture. The typical numbers of X-ray energies (2p-1s transition) and τ_μ, both relevant to medical applications are listed in Table 1. By measuring either X-ray or decay electron, it is, in principle, possible to obtain the "in vivo" 3-dimensional chemical maps with special reference to O, N, C and F, which can not be measured by other methods. The stopping region of μ^- can be adjusted, for the first step, by beam collimation in x-y plane and range absorber in z direction. There are advantages and disadvantages in the "μe" method compared to the "X-ray" method as it is described in the followings.

Practically, the μe method is sensitive to density in the major elements like μ^-O in H_2O in human body. (in most molecules containing H, μ^-H is quickly transferred to the higher Z element). The resolving capability of each element among light elements C, N, O is limited due to a small difference in τ_μ. However, pulsed muon which is now available at UT-MSL BOOM facility[1)] is quite helpful for this purpose, since it is possible to measure μe decay in a longer time range ($>10\tau_\mu$) than ever achieved. Typical μe decay time spectrum observed for μ^- in human liver is shown in Fig.1: separation between μ^-O and μ^-C is clear.

In the μe method, spacial resolution of μ^- stopping region can be further improved by a solid angle determined by a sophisticated electron-telescope (Fig.2). The arrays of MWPC are needed, each wire of which is linked to the non-stop TDC, like those developped at UT-MSL[1)]. Without such a help, spacial resolution is strictly limited by either multiple scattering in x-y plane or range straggling in z direction.

There is another important potentiality in the μe method. In some materials, like μ^- in water, the μ^- is partially polarized at the ground state of muonic atom. Utilizing asymmetric e^- emission along the polarized μ^- spin, the μ^- can probe strength and fluctuation of the magnetic fields in the local environments (μSR method). Recently, μ^-SR was observed in pure water at UT-MSL facility. The result is shown in Fig.3, where existence of the long-lived μ^- polarization is clearly seen. Let us suppose that the polarized μ^- is implanted in the specific part of human body. When there is a mechanism producing μ^- spin relaxation and, at the same time, when this mechanism is correlated with the status of the part probed, the μSR method might sense the status of the human body. Similar effect is widely used in recently developped NMR-CT method.

In conclusion, the spin relaxation phenomena, with a capability of good special resolution as well as a capability of element analysis, the μe/μSR method could be taken as candidate for the promising medical applications. Certainly, present μ^- intensity at UT-MSL facility is not enough for this purpose. With this respect, ultra-intense pulsed proton generator such as GEMINI project proposed by KEK-BSF is waited for in the nearest future.

We acknowledge collabarations of the members of UT-MSL, particularly Mr. K. Ishida for μ2 port experiments.

1) UT-MSL NEWSLETTER No.1(May, 1981) and (May, 1982) ed, K. Nagamine and T. Yamazaki.

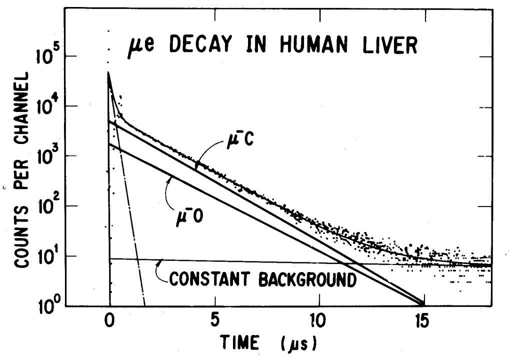

Fig. 1

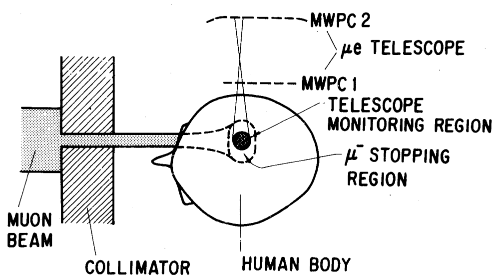

Fig. 2

Table 1. Properties of light muonic atoms

muonic atom	E(2P-1s) (keV)	τ_μ (μs)
μ^- ^{12}C	75	2.026(2)
μ^- ^{14}N	83	1.907(3)
μ^- ^{16}O	132	1.795(2)

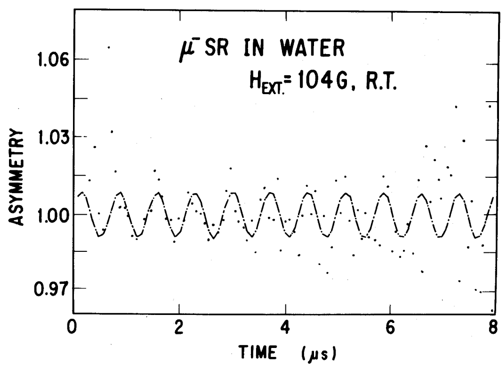

Fig. 3