Preliminary Study on ^{52}Fe Production for PET/MRI Contrast Agent

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1. Introduction

Since 2010, the integrated whole body PET/MRI systems have been installed at many institutes and hospitals. PET/MRI is a next-generation nuclear medical device, and it has an excellent sensitivity and specificity compared with PET/CT. In this situation, PET/MRI contrast agent is an important research topic. Moreover, in order to smoothly supply PET/MR instrument, the development of imaging contrast agents for PET/MR is necessary. Since iron oxide nanoparticles are one of the extensively studied agents, many researchers have tried to combine iron oxide nanoparticles with radioactive material such as ^{68}Ga, ^{111}In, ^{18}F, ^{64}Cu, and ^{89}Zr, by attaching to the chelator and conjugating linker [1].

On the other hands, ^{52}Fe in one of the iron isotopes and the half-life is 8.275 hours. This nuclide becomes ^{52m}Mn through β^+ decay, suggesting that ^{52}Fe can be used for PET diagnosis. The detailed physical properties of ^{52}Fe are summarized in Table I. Because ^{52}Fe has the same chemical properties as other iron stable isotope, iron oxide nanoparticles are a mixture of stable isotopes and ^{52}Fe. In addition, Fe_3O_4 is a ferromagnet at room temperature, and thus, $^{52}Fe_3O_4$ nanoparticles can work PET and MR image agents simultaneously. In this paper, we called $^{52}Fe_3O_4$ as BNP (Bimodal nano particle). Figure 1 compares the conventional and BNP methods to produce a contrast agent.

^{52}Fe can be produced by a proton accelerator through ^{55}Mn(p,4n) or ^{nat}Ni(p,xn) nuclear reactions at proton energies above 50 MeV. In this study, we accomplished preliminary results on ^{52}Fe production using a 100 MeV proton beam irradiation.

Table I: Physical properties of ^{52}Fe

Half-life	8.275 h
Decay mode	β +
Major gamma energy and intensity	168.7 keV / 99.2%
Daughter isotope	^{52m}Mn
Nuclear spin and parity	0+

2. Methods and Results

2.1 Sample preparation and proton beam irradiation

We used Ni foils and $MnCl_2$ pellets to measure ^{55}Mn(p,4n)^{52}Fe and ^{nat}Ni(p,xn)^{52}Fe nuclear cross-section and used aluminum sheets to measure the beam current and aluminums energy degrader to adjust the energy (Fig. 2). Details of each sample are shown in Table II.

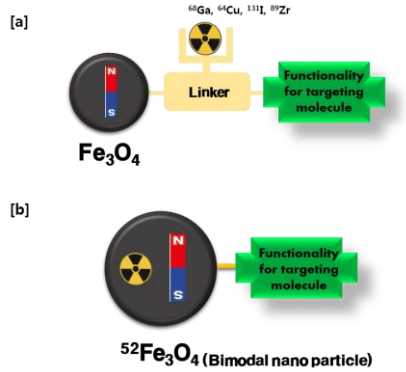

Fig. 1. Conceptual illustration of contrast agent for PET/MRI. [a] Conventional, [b] BNP.

The proton beam was bombarded using a collimator as shown in Fig. 3. The energy of the proton beam was 99.7 MeV±0.1 MeV which was measured by the first aluminum sheet. Each sheet was stacked to irradiate a proton beam. The proton beam energy was measured in the same manner as the method reported by H.S. Kim [2]. The irradiated energy for each sheet was calculated by SRIM simulation [3].

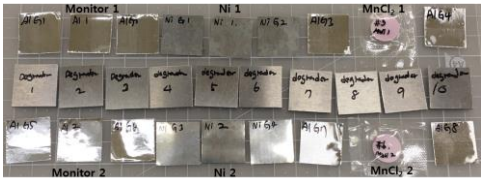

Fig. 2. Photograph of sample stack array.

Table II: Detailed sample information

	Ni 1	Ni 2	$MnCl_2$ 1	$MnCl_2$ 2
Energy [MeV]	99.2	56.3	95.7	55.5
Size [mm^2]	400.0	400.0	132.7	132.7
Thickness [μm]	49.5	49.6	447.7	422.4
Weight [mg]	176.4	176.7	177.0	167.0

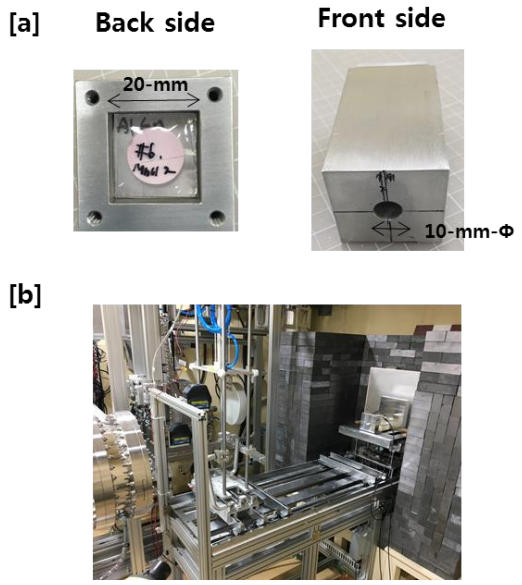

Fig. 3. Photographs of collimator[a] and beam irradiation [b].

2.2 Gamma-ray spectrum measurement and analysis

The gamma ray emission from the sample after the proton beam bombardment was measured using a HPGe detector. All measurements were repeated 3 times and the measured values were averaged. The monitoring reaction $^{27}Al(p,x)^{24}Na$ was measured to calculate the nuclear reaction cross-section, resulting in a fluence of approximately $8.5x10^{11}$ particles/cm^2·sec. The measured ^{55}Mn $(p,4n)^{52}Fe$ and $^{nat}Ni(p,xn)^{52}Fe$ nuclear reaction cross-section data is shown in Fig. 4.

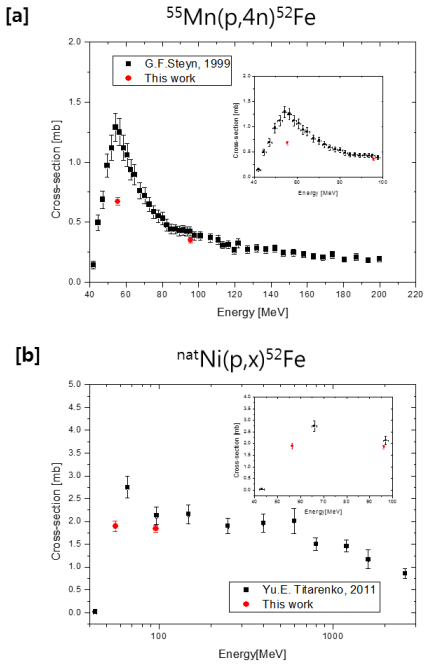

Fig. 4. Calculated nuclear cross-section. [a] $^{55}Mn(p,4n)^{52}Fe$, [b] $^{nat}Ni(p,x)^{52}Fe$

The cross-section data from Ni foil were well matched with the published data [4]. However, the data from $MnCl_2$ target are different from the previous data [5]. G.F. Steyn et. al. used nickel/Manganese (Mn-88%, Ni-12%) alloy as a target and they used $^{27}Al(p,x)^{22}Na$ monitoring reaction, which may cause the difference

3. Conclusions

We carried out a proton beam irradiation experiment to measure the proton beam-induced ^{52}Fe cross section. The measured $^{nat}Ni(p,x)^{52}Fe$ data was similar to the previous data. According to the figure 4, a proton beam irradiated on Nickel, the cross-section was higher than using Manganese. In the future, we are going to make ^{52}Fe using nickel target. And we will chemically separate and purify ^{52}Fe. And, finally, we will establish hot model of BNP synthesis for PET/MRI contrast agent.

4. Acknowledgments

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