# Optimization of Positron Source Used in Positron Annihilation Lifetime Spectroscopy (PALS)

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## 1. Introduction

Positron annihilation lifetime spectroscopy (PALS) is a powerful tool for analyzing material defects and the free volume of polymers. The unsealed positron source is considered for surrounding contamination and handling convenience because the positron source ($^{22}$NaCl) is liquid. Therefore, the opening source is often used after enclosing for easy operation. The positron lifetime commonly appears in two or three parameters. The first component comprises the probability of positron annihilation in the bulk state and at the lattice where positrons are trapped. The first component is commonly called the short lifetime ($\tau_1$). The second component, which is frequently called the long lifetime ($\tau_2$), is the probability that annihilates after a long time compared to the bulk state because the positron lifetime increases within the defect of a material. If the material has a free volume, a lifetime ($\tau$) of ortho-positronium ($o$-Ps) will be longer than the $\tau_2$. The third component is commonly called an ortho-positronium ($o$-Ps) or $\tau_3$. The intensity of each positron lifetime is written as $I_1$, $I_2$, and $I_3$.

In the metallic material, the positron lifetime often appears in two parameters. However, the third component of positron lifetime is usually observed in metallic materials. We expect the third component to be detected from positron sources of PALS. We manufactured some positron sources to analyze the change in the third component. This study will identify which type of source is the optimized method when manufacturing positron sources.

## 2. Materials and Methods

### *2.1 Positron Source*

A 30-μCi $^{22}$NaCl was dried on both sides of the supporting foil (nickel thickness: 2.5 μm). We covered the support foil with the plates (nickel thickness: 50 μm) because the adhesive should not be contaminated with $^{22}$NaCl (Fig 1). The nickel plate was punched to reduce the fraction at which positron annihilated from the nickel plates. The positron source of 2.5-μm Ni foil was located between the nickel plates. The enclosed positron source appears in Fig 2 ($S_1$). The thickness of the positron source using contaminated $^{22}$NaCl with the adhesive was the same as the support foil of the non-contaminated positron source, and the size was $10 \times 10$ mm$^2$ ($S_3$). We prepared a sealed positron source that the activity (50-μCi) is placed between two layers of 5.1-μm titanium foil, supported by two 0.25-mm titanium disks ($S_2$). This positron source is assembled by electron beam welding (POSN-22, Eckert & Ziegler) before being sealed as the disks. We collected the PAL spectrum using different positron sources in the same nickel sample. A positron lifetime spectra were obtained by measuring more than $3 \times 10^6$ counts.

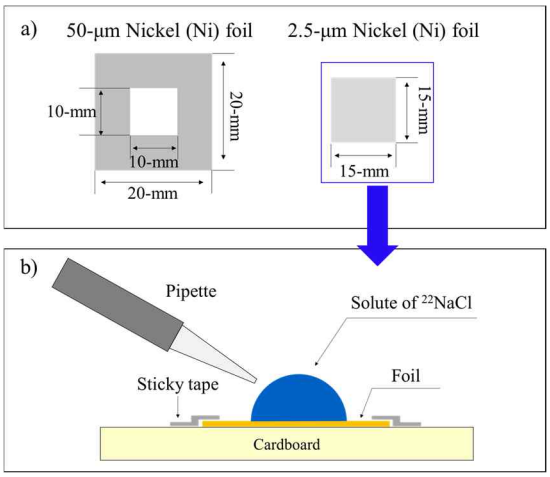


Fig 1. (a) The size of a support foil is $15 \times 15$ mm$^2$ (thickness: 2.5- μm Ni), and the size of a disk is $20 \times 20$ mm$^2$ (thickness: 50- μm Ni). (b) Production of positron source.

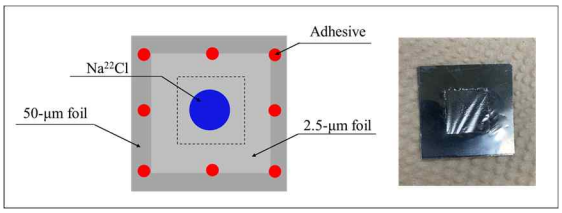


Fig 2. The positron source of 2.5- μm Ni foil is located between the plate. We used adhesive on the side of the nickel plate.

### *2.2 PALS system*

PALS system consists of a high voltage power supply (HVPS) (556 model, ORTEC), plastic scintillators (BC-422Q, SAINT-GOBAIN), a photomultiplier tube (PMT) (R329-02, HAMAMATSU), PMT base (265A model, ORTEC) , constant fraction differential discriminator (CFDD) (583B model, ORTEC), nanosecond delay

(425A model, ORTEC), time to amplitude converter (TAC) (556 model, ORTEC), and multichannel analyzer (MCA) ($A^{spec}$-927, ORTEC). Fig 3 shows the PALS system in KAERI. Two HVPSs were connected to the PMT base, and a high voltage of -2100 V was applied to both PMTs for the gamma energy of the start signal (1.27-MeV) and the stop signal (0.511-MeV). The output signal of the PMT base (start and stop) has received two CFDDs. The stop signal was transmitted in the nanosecond delay (425A, ORTEC) to optimize the time interval of each output signal. The output signals of CFDD were recorded in ADC/MCA after the time difference between start and stop signals was amplified in the TAC. The MCA was integrated with the analog to digital converter (ADC) and sent into 4,096 channels.

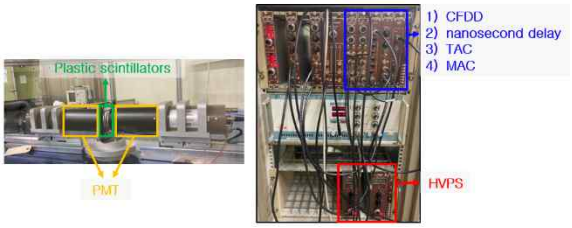


Fig 3. The NIM nodules for positron annihilation lifetime spectroscopy. PMT: photomultiplier tube HVPS: high voltage power supply, CFDD: constant fraction differential discriminator, nanosecond delay, TAC: time to amplitude converter, MCA: multi-channel analyzer.

## 3. Results and Discussion

For pure nickel samples, the $\tau_1$-value, the bulk lifetime, was about 110 ps [1, 2]. The $\tau_1$ would be the component of positrons that have been annihilated at the bulk state of the support foils, disks, and samples. The $\tau_2$ was the component that had been annihilated at the defects of the material. We measured pure nickel samples with contaminated and non-contaminated $^{22}$NaCl with adhesives. The analysis results of the positron spectrum appear in Table 1.

The contaminated $^{22}$NaCl with the adhesive was observed to be high in $\tau_3$-value ($S_3$). On the other hand, The $\tau_3$-value of the non-contaminated $^{22}$NaCl with adhesive was low measured ($S_1$ and $S_2$). We could expect that the adhesives in $^{22}$NaCl can lead to unnecessary signals in the *PALSfit3* software [3] when manufacturing positron sources. The large $\tau_3$-value was expected due to the influence of the adhesive [4].

Table 1. The type of source is non-contamination $^{22}$NaCl source ($S_1$), sealed source of Eckert & Ziegler ($S_2$), contamination $^{22}$NaCl source ($S_3$). The positron lifetime ($\tau_i$) and positron relative intensity ($I_i$) of sample (Ni).

| | $S_1$ | $S_2$ | $S_3$ |
|---|---|---|---|
| $\tau_1$ (ps) | 114.5 | 115.6 | 132.5 |
| $\sigma_{\tau_1}$ (ps) | 4.2 | 4.5 | 0.8 |
| $\tau_2$ (ps) | 182.9 | 186.1 | 325.7 |
| $\sigma_{\tau_2}$ (ps) | 6.0 | 6.1 | 6.8 |
| $\tau_3$ (ps) | 772.8 | 794.8 | 1754.5 |
| $\sigma_{\tau_3}$ (ps) | 37.8 | 41.3 | 63.5 |
| $I_1$ (%) | 52.0 | 51.3 | 85.4 |
| $\sigma_{I_1}$ (%) | 6.71 | 6.71 | 0.67 |
| $I_2$ (%) | 46.7 | 47.6 | 13.7 |
| $\sigma_{I_2}$ (%) | 6.62 | 6.63 | 0.65 |
| $I_3$ (%) | 1.2 | 1.2 | 0.9 |
| $\sigma_{I_3}$ (%) | 0.11 | 0.11 | 0.04 |
| $\tau_m$ (ps) | 154.5 | 157.0 | 173.4 |
| $\sigma_m$ (ps) | 0.3 | 0.3 | 0.4 |

## 4. Conclusions

We experimented with manufacturing of positron sources ($^{22}$NaCl) to analyze the PALS spectrum accurately. As a result, we recommend a method of reducing the amount of adhesive used in the positron source or combining the support foil by electron beam irradiation for an accurate PALS experiment.

## Acknowledgment

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