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DETERMINATION OF BORON CONCENTRATION IN GLASS SAMPLES BY PGNAA METHOD

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Abstract

Boron is an element that can be effectively determined using the Prompt Gamma Neutron Activation Analysis (PGNAA) method. we applied the PGNAA method to quantify ^{10}B in glass through the reaction $^{10}B(n,\alpha\gamma)^{7}Li$. Measurements were conducted using an HPGe-BGO Compton suppression spectrometer system at the Dalat Nuclear Research Reactor. The construction of a linear calibration function for concentration calculations and the peak fitting technique to analyze the 478 keV peak, which overlaps with neighboring peaks and Doppler broadening effects were conducted.

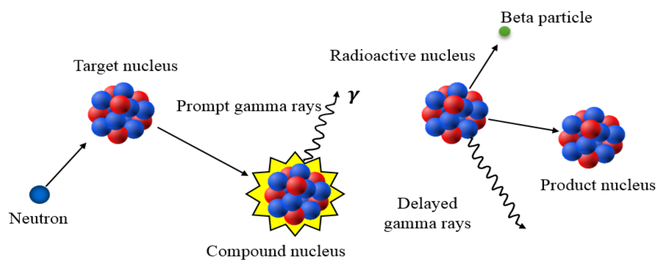
Introduction

● PGNAA

The PGNAA method allows for the simultaneous and non-destructive determination of trace elements such as hydrogen, boron, nitrogen, sulfur, phosphorus, silicon, and cadmium elements that are often difficult to analyze using conventional neutron activation analysis methods. This paper focuses on analyzing the boron content in glass samples, using a spectrometry system located at horizontal channel No. 2 of the Dalat Nuclear Reactor.

● Boron

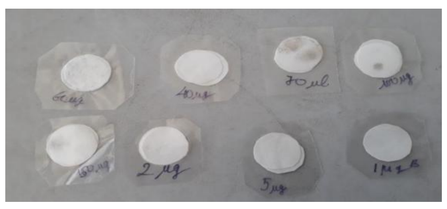
In particular, the reaction $^{10}B(n,\alpha\gamma)^{7}Li$ has a very high thermal neutron capture cross-section (3837 barns), making boron is one of the most sensitive elements in PGNAA. As a result, the concentration of boron can be accurately detected.



Research Subjects

Standard sample

Standard Boron solution from Sigma-Aldrich was sampled using a pipette into 18 mm diameter, 1 mm thick round discs, packaged in polyethylene bags.



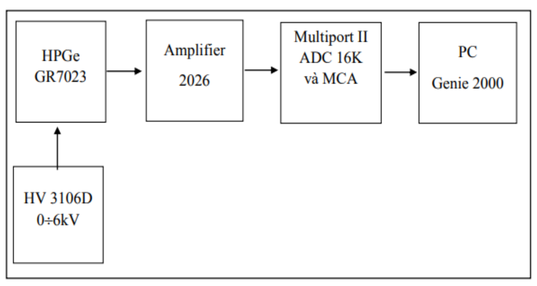
International Standard Reference Material

International standard reference materials ensure that laboratory analytical methods produce accurate and reliable results. These standards have well-defined chemical compositions recognized globally, enabling validation of analytical reliability. If measured values match certified values, results for other samples can be trusted. This project uses two solid reference materials, SRM 2709a and NIST 1570a, both internationally recognized and provided by NIST.

Analytical samples

The analytical samples are glass specimens for Boron content determination, prepared according to the IAEA CRP F11021 program. The glass pieces were broken into uniform-sized and weighted fragments, then sealed in polyethylene bags.

PGNAA System at the Dalat Nuclear Reactor



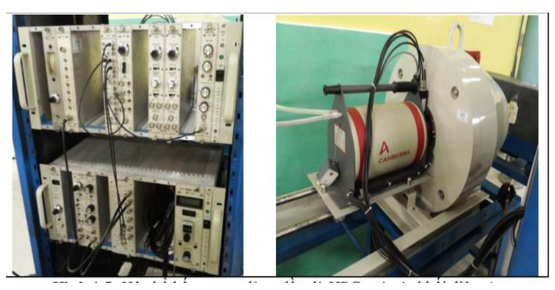
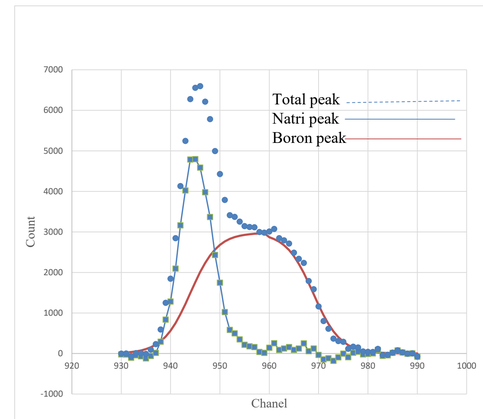


Diagram of PGNAA Measurement System at Channel No. 2

Methodology

Experimental Spectrum Analysis

The measured spectrum contains many prompt gamma peaks; however, for Boron determination, the 478 keV peak is used in the analysis. This peak results from the neutron reaction with ^{10}B, producing ^{7}Li and an alpha particle. Due to the Doppler effect, the 478 keV peak is significantly broadened compared to typical prompt gamma peaks and may overlap with gamma peaks from other elements, such as Na or Ge. In samples containing a certain amount of sodium, overlap between the 478 keV peak of Boron and the 472 keV peak from the $^{23}Na(n,\gamma)^{24}Na$ reaction can occur.



Determination of Boron content using the relative method

Upon measuring the energy spectrum, the count of the 478 keV gamma peak is calculated using the following equation:

$$C = \frac{m}{M}\theta N_A \sigma_0 \Phi_\varepsilon(E) t$$

C is the 478 keV peak count; m is the mass of boron in sample (g) Φ is the neutron flux (n/cm²/s) t is the measurement time (s); σ_0 is the thermal neutron capture cross-section of Boron (cm²); ε(E) is the detector efficiency at 478 keV; θ is the isotopic abundance of B.

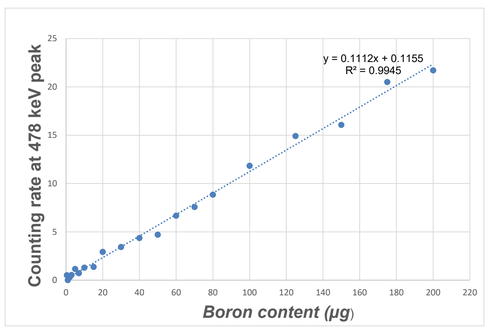
Let the reference sample be denoted as **"c"** and the sample to be analyzed as **"x"**. If both measurements are performed under the same conditions, the ratio of the two measurements can be established based on the expression above. After canceling out the common terms, the boron content in the sample **x** can be calculated as follows:

$$m_x = m_c \cdot \frac{C_x}{C_c}\frac{t_c}{t_x}$$

Determining the concentration using the above equation is simple, easy to perform, and helps minimize errors arising from the measurement system, including detection efficiency, neutron flux, reaction cross-section, and neutron self-absorption in the sample.

Results and Discussion

Results of standard samples and linear calibration curve



The PGNAA system used has a sensitivity of 0.1112 cps/μg for the element ^{10}B. The Boron content in the standard sample is shown in the figure, with coefficients C = 0.1112 and D = 0.1155.

$$m_x = \frac{CPS_x - 0.1155}{0.1112}$$

Boron concentration in the international standard reference material

Sample name	Mass (g)	CPS 478 keV	Boron concentration (ppm)	Error (%)	Published data in sample (ppm)
NIST 1570a	2.0016	8.073	***35.76***	2.42	37.7
SRM-2709a	4.0906	33.404	***72.53***	2.49	74

Boron concentration determination results in the sample

Serial number	Sample name	Mass of B in the sample (μg)	Boron concentration in the sample (ppm)	Concentration error (%)
1	Gl29	***29.198***	***34.469***	2.73
2	Gl30	***29.478***	***34.033***	2.66
3	Gl31	***8.583***	***10.558***	2.72
4	Gl32	***19.325***	***18.757***	2.75
5	Gl33	***12.216***	***11.698***	2.68
6	Gl34	***17.500***	***13.144***	2.78
7	Gl35	***10.497***	***10.188***	2.70
8	Gl36	***7.588***	***7.870***	2.73
9	Gl37	***3.038***	***3.353***	2.80
10	Gl38	***8.581***	***8.601***	2.67

Summary

- The analysis results show that Boron content in glass samples varies from 10 to several tens of thousands ppm, depending on the glass type (e.g., windshield, side window, rear window). This reflects the use of Boron mainly in the form of borosilicate compounds to improve heat resistance, reduce thermal expansion, and enhance mechanical strength. Some samples have higher Boron levels due to special applications, such as high-strength windshields or insulating glass.
- Boron quantification using the relative method and linear calibration curve yields low errors (below 3%), providing reliable results, especially for Boron, which is challenging to analyze by INAA. Measurement conditions were well controlled, including stable neutron flux, proper energy calibration, and sufficient counting time for good statistics.
- Comparisons of Boron content in two international standard samples with published values demonstrate high accuracy and reliability of the analytical method.