Determining correction factors due to threshold reaction interference in Neutron Activation Analysis

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Motivation

Neutron Activation Analysis (NAA) is a non-destructive and highly sensitive technique for determining the elemental composition of a material. It involves irradiating a sample with neutrons, causing certain nuclei to emit gamma radiation. In a reactor fission spectrum, however, fast neutron-induced **threshold reactions** can produce the same radionuclides as thermal neutron capture, introducing spectral **interference**. If uncorrected, this can lead to significant **overestimation of certain elements**. This study focuses **correcting** these interferences by determining these **apparent concentrations** and corresponding **correction** factors, next to calculating the effective **cross-sections** of selected threshold reactions

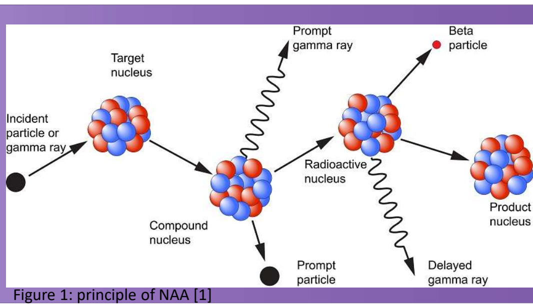

Figure 1: principle of NAA [1]

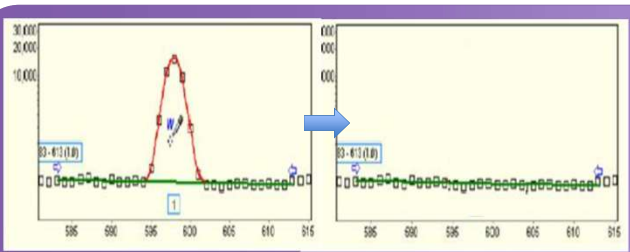

Figure 2: removal of interfering peak

Objectives

The main goal is to quantify the impact of threshold reactions in BR1's irradiation channels and correct for their contribution to gamma spectra in NAA. Specifically, we aim to:

- **determine** the fast neutron spectrum averaged **cross-sections** (σ) for key threshold reactions,
- **calculate correction factors** per reaction and per irradiation location,
- **compare experimental results** to Monte Carlo simulations and literature values,
- support future standardization efforts for threshold correction in reactor-based NAA.

Approach

Samples of elements are **irradiated** in two distinct locations in the BR1 reactor, each with different neutron spectrum characteristics. After irradiation, the induced gamma spectra are **measured** using high-resolution HPGe detectors. The **spectra** are analyzed in HyperLab and exported as CSV files for processing.

Each measured sample is linked to a predefined list of relevant nuclides. A custom **Python** script fills **Excel** templates automatically with measurement data, retrieves nuclear constants from the KAYZERO database, and performs all necessary **calculations**. For each sample, a complete Excel summary is generated, containing both raw and processed outputs. The final dataset is used **to compute reaction cross-sections**, **estimate correction factors**, and generate visual overviews.

Figure 3: BR1 reactor [2]

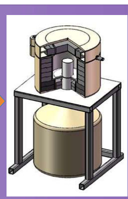

Figure 4: HPGe detector [3]

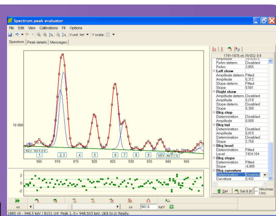

Figure 5: Hyperlab spectrum

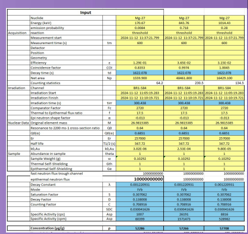

Figure 6:Excel calculation template

Table 1: Comparison of some experimental results to literature data

Channel	Reaction	Apparent Concentration ($\mu g\,g^{-1}$)	Counting statistics	Cross Section (mb)	MCNP (mb)	Literature (mb)	Note
S84	$^{27}Al(n,p)^{27}Mg$	5.67×10^4	0.65 %	3.98	4.01	4.28	
S84	$^{28}Si(n,p)^{28}Al$	1.36×10^3	1.4 %	5.37	6.38	6.13	
S84	$^{66}Zn(n,p)^{66}Cu$	3.09×10^1	4.8 %	1.20	9.90×10^{-1}	6.20×10^{-1}	
S84	$^{64}Zn(n,p)^{64}Cu$	3.73×10^2	2.6 %	3.35×10^1	3.18×10^1	3.10×10^1	
S84	$^{52}Cr(n,p)^{52}V$	$<5.43 \times 10^{-1}$	—	$<5.39 \times 10^{-1}$	—	8.57×10^2	Preliminary
S84	$^{65}Cu(n,p)^{65}Ni$	1.12×10^2	34 %	8.55×10^{-1}	4.27×10^{-1}	4.80×10^{-1}	Preliminary
S84	$^{56}Fe(n,p)^{56}Mn$	5.86	1.6 %	1.29	9.65×10^{-1}	1.07	
Y4	$^{24}Mg(n,p)^{24}Na$	3.94×10^1	2.1 %	1.82	1.27	1.53	

Results

Experimental irradiations in two BR1 reactor channels allowed determination of **spectrum-averaged cross sections** and correction factors for key threshold reactions. **Correction factors** were derived that express the **apparent concentration bias** per gram of interfering element. These values were validated against MCNP simulations and aligned well with literature data, confirming their **reliability for use** in routine NAA at BR1.

Conclusion

This study provides experimentally validated **correction factors** for **threshold reaction interferences** in **NAA** at **BR1**. By quantifying spectrum-averaged cross sections and comparing them with MCNP simulations, the accuracy of analyses in mixed neutron spectra is significantly improved. These results enhance **reliability** in routine NAA and lay the groundwork for broader application of **fast-neutron corrections**.

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[1] M. D. Glascock, "NAA Technical Overview," Archaeometry Laboratory, University of Missouri Research Reactor. [Online]. Available: https://archaeometry.missouri.edu/naa_technical.html
[2] SCK CEN, "BR1 – Belgian Reactor 1," SCK CEN, Mol, Belgium. [Online]. Available: https://www.sckcen.be/nl/infrastructuur/br1-belgian-reactor-1
[3] K. Putk, *Veeproovide ettevalmistamismetoodika valideerimine raadiumi isotoopide aktiivsuse kontsentratsioonide gammaspektromeetriliseks määramiseks*. M.Sc. thesis, Institute of Physics, University of Tartu, Tartu, Estonia, 2016. [Online]. Available: https://dspace.ut.ee/handle/10062/51834