NUCLEAR ANALYTICAL TECHNIQUES FOR COMMERCIAL APPLICATIONS IN CHINA

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1. NUCLEAR ANALYTICAL METHODS FOR COMMERCIAL APPLICATIONS IN CHINA

Since the establishment of the first Chinese nuclear reactor and accelerator in 1958, the nuclear analytical techniques (NATs) in China have dramatically developed in past half century. Nowadays 10 research nuclear reactors and over 100 small accelerators are available in China. Roughly, about 50 % of the machine time is applied for commercial purpose at the moment. The versatile nuclear analytical methods, mainly NAA, PIXE, XRF, etc., in China have been and are being applied widely and extensively in the following three fields: scientific, training, and commercial. This paper will briefly describe the past experience and present status about NATs for commercial applications. Some practical examples to demonstrate the role of NATs in this aspect will be given as well.

Basically, the NATs used for the commercial applications in China can be divided into two types, i.e. off-line and on-line. The former mainly includes instrumental neutron activation analysis (INAA) for compositional determination, particle induced X-ray emission (PIXE) also for compositional analysis, accelerator-based mass-spectrometry (AMS) for analysis of C-14, Be-7, Cl-36 and other long-lived radioactive nuclides, solid state nuclear track detector

2. SOLID STATE NUCLEAR TRACK DETECTOR FOR ANALYSIS OF FISSILE ELEMENTS

The on-line method refers to prompt gamma neutron activation analysis (PGNAA), X-ray fluorescence (XRF) and neutron inelastic scattering (NIS), all for compositional analysis; computerized tomography (XCT) for industrial image diagnostic; and positron emission tomography (PET) also for clinical image diagnostic. Of course, more NATs are available in China for commercial applications, e.g., Moessbauer spectrometry and isotopic tracing. The advantages of on-line analysis lie in:

— Rapid, accurate and continuous measurement;
— Reduction of sampling errors compared to conventional sampling and off-line analysis;
— Improvement of process control (higher efficiency, more consistent product quality); and
— Suitability for extreme conditions, e.g. high temperatures, high pressures and intensive radiation fields.

3. WHAT IS A COMMERCIAL APPLICATION?

In fact, NATs have been and will be continuously used in many industrial and economical fields to enhance the labor efficiency or to improve the product quality. The commercial applications of NATs discussed here, as far as we understand, cover two types:

— The so-called pure commercial application, i.e., analytical service with income, which could be used to increase pay of analytical workers or to improve laboratory infrastructure; and

— The hybrid commercial application, a combination of commercial service and scientific interest, such that this service is in accordance with the research direction of nuclear institutions.

In China both application types are widely and extensively implemented.

4. FIELDS OF COMMERCIAL APPLICATIONS OF NATs IN CHINA

The fields relying on commercial applications of in China NATs are varied, including geology, environment, biology, agriculture, industry, archaeology, forensics and materials. Because of the limited volume, here only some representative examples are briefly highlighted to demonstrate the position of NATs in commercial applications.

4.1. Off-line drug analysis

Drug trafficking is one of the most serious issues in the today's world. The epidemic of drug abuse and its associated problems have constituted a true threat to the social and economic structure and the stability of nations. In order to crack down on drug crimes, it is imperative to identify whether confiscated drug samples came from the same batch or region. In this way, it may be possible to find its trading routines. For this purpose, the data for elemental concentrations together with the data obtained by other techniques, such as gas chromatography and high-performance liquid chromatography, are expected to be useful for identifying drug samples.

The State Ministry of Public Security of China is the main stakeholder. Because of the small sample amount and low contents of chemical elements, INAA is an excellent technique characterized by its high sensitivity, good accuracy, capability for multi-elemental analyses, and no reagent blank compared with other analytical techniques, to provide multi-elemental abundances, by which a data bank of drugs for element fingerprint spectrum to identify the sources and transportation route of drugs is being established.

In this analytical service the contents of trace elements in about 1000 illicit heroin samples were analyzed by INAA. The aim of the present study was to characterize the contents of trace elements in these heroin samples, which may then finally be used to identify their sources and trade routes.

The concentration ranges of the elements are shown in Figure 1. The element of the highest concentration in the illicit heroin samples was calcium. The lowest and highest values of calcium were 89 and 694 μg/g, respectively. The second highest element found in the region A heroin samples was zinc, while in the region B samples it was sodium. Gold and samarium concentrations were very low in all samples. The median concentrations of barium, bromine, sodium, thorium, and zinc were similar in the samples from the two regions. The median concentrations of cobalt, chromium, and antimony in the region A samples were higher than those in the region B samples. The median concentrations of the other elements, gold, calcium, cerium, iron, lanthanum, scandium, and samarium, were higher in the region B samples [1].

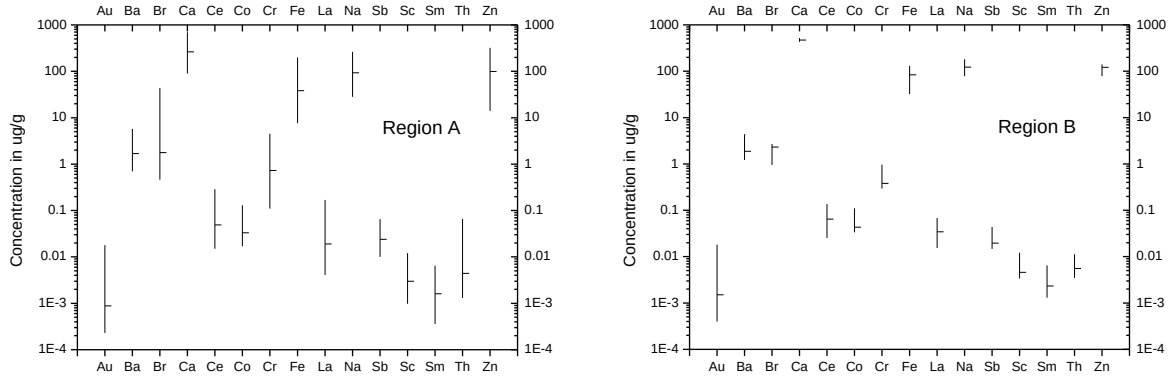

Fig. 1. Concentration ranges and median values of 15 trace elements in μg per gram of original heroin powder (850 samples from Region A and 150 from Region B).

To improve the group classification of a large amount of concentration data, the hierarchical cluster analysis was a good approach. For this statistical analysis, all 15 elements presented in Figure 1 were used as variables. Figure 2 shows the dendrogram deduced by this method. As it can be seen, the samples from Region A and Region B are clearly separated into two main groups. The region A samples are located at the upper part of the dendrogram, and the Region B samples at the lower part. The samples from the two main groups can be further separated into subgroups according to the similarities and differences among the samples. This application of NATs has important social impact to maintain national security, along with the substantial payment for nuclear laboratory. The future work will be focused on the isotopic identification and online analysis of drugs, which will produce more socio-economic values.

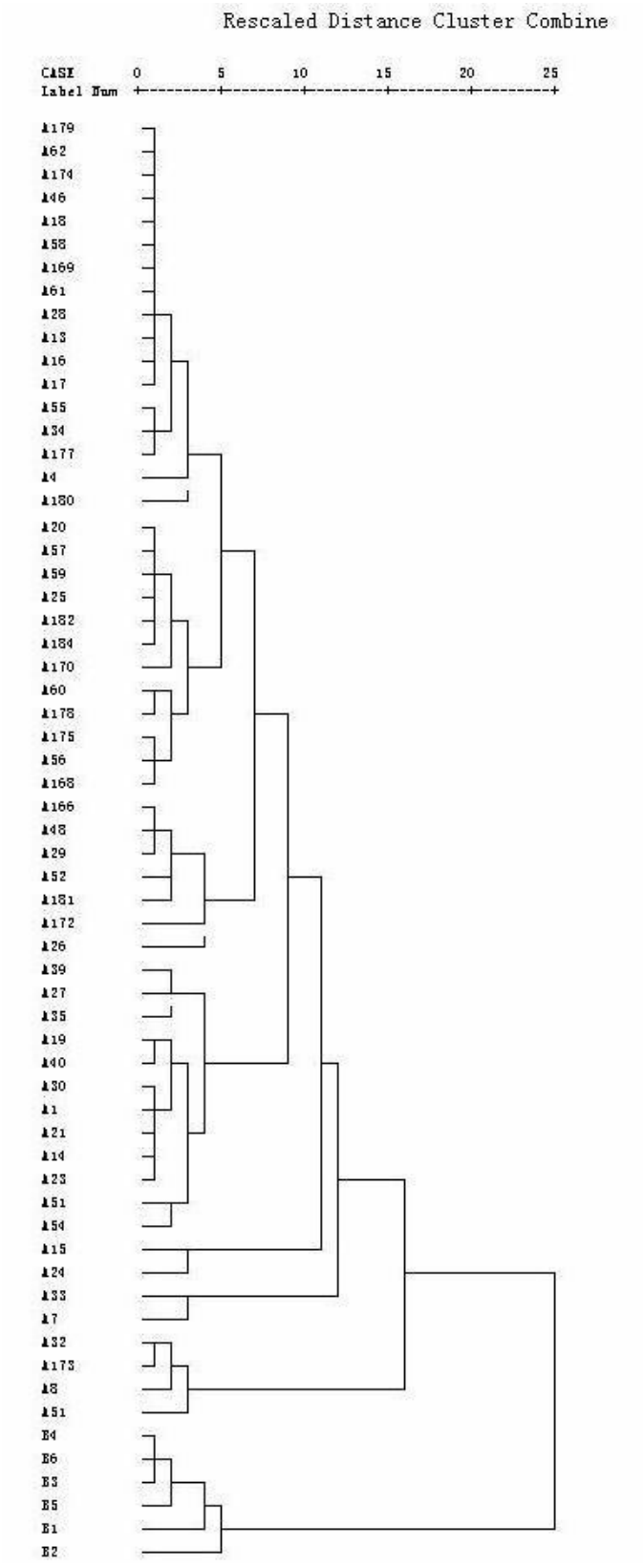

Fig. 2. Cluster diagram for 62 heroin samples using 15 elements.

4.2. Off-line archaeological identification: A case application

INAA and SRXRF were used to provide the multi-elemental abundances in Chinese ancient pottery, porcelain and Tang-San-Cai specimens. Some big figures were identified by NATs for their true and false with very high pay.

Tang Sancai is a general name for the colour-glazed pottery produced in the Tang Dynasty, especially in the Prospering and Middle Tang periods. “Sancai” in Chinese means “three colors”. Yellow, green and white are the three dominant colours in Tang Sancai’s glaze. This technique somehow symbolizes the cosmopolitan and colourful life of Tang Chinese. Tang Sancai was famous for its distinctive and multiple colors along the “Silk Road”. Some favorite Tang Sancai of camels, guardian figures and a woman on horseback are the “Silk Road” highlight. Many Tang Sancai specimens have been unearthed mainly near the two capitals of the Tang Dynasty, Chang’an in Shaanxi Province and Luoyang in Henan Province. Even with its paramount importance to archaeological, historical and ceramic research, the provenance of many kinds of Tang Sancai, especially the large figures, has not been well identified until now.

Our laboratory was requested in a payment basis to involve in identification of Tang-Sancai specimens recently unearthed by NATs. In order to clearly distinguish the chemical differences among specimens from different kilns, the contents of Ce, Nd, Eu, Yb, Lu, Ta, Th, Sc, Cs, La, Sm, U and Tb of body samples from the four kilns (Huangye, Huangbu, Xi’an and Xing Kiln) were all processed by factor analysis using the SPSS program. In Figure 3, factors 1 and 2 account for 77% of the total variation, indicating that the two factors contain the majority of total variation. In rotated component matrix, factor 1 is mainly related to the variations of Hf, Ta, Th, Sc, Cs, U, Yb and Lu, while factor 2 denotes strong and high contribution of the variations of Eu, Tb, Yb, Cs, Nd, Eu, Tb, Yb, Lu and Sm. Most of the data points for the Tang Sancai samples from the Huangye, Huangbu, Xing and Xi’an Kilns are located inside circle A, B, C and D, respectively [2]. Further analytical service for identification of big figures will be continued with good income.

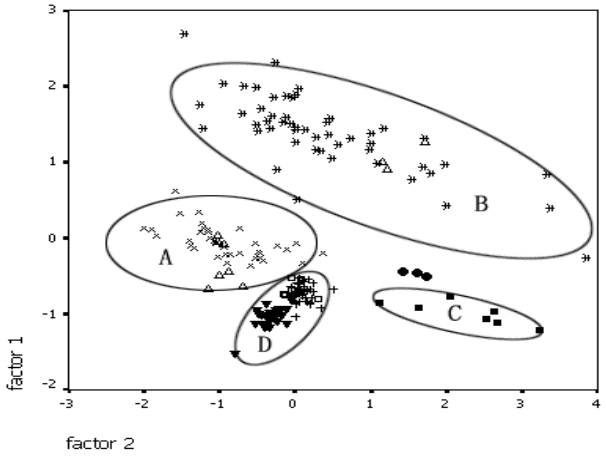

Fig. 3. Factor analysis for Tang Sancai from Xi’an, Huangbu, Huangye and Xing Kiln.
A: Huangye Kiln, B: Huangbu Kiln, C: Xing Kiln, D: Xi’an Kiln
Body color: + Red ▼Offwhite ● Pink □ Gray ? White

4.3. Online coal analysis

In the 1980s, over ten thousands of coal samples from the main 19 Chinese coal fields were analyzed by INAA. The former Ministry of Coal and Charcoal Industry was the primary customer. But nowadays on-line coal analysis is preferred for process control, whose purpose is aimed at:

— Raw coal quality monitoring;
— Coal sorting;
— Stockpile management;
— Monitoring at shipping ports;
— Power station – feed monitoring;
— Meeting ISO requirement;
— Alleviating environmental pollution;
— Economic analysis; and
— Enhancing coal burning efficiency at boiler.

Commercial on-line element analysis of coal based on PGNAA using a D-T neutron generator, combined with fast neutron inelastic scattering technique for analysis of C, H, O, N, S, Al, Si, Fe, Ca and Ti in coal used for power plant (See Figure 4) [3].

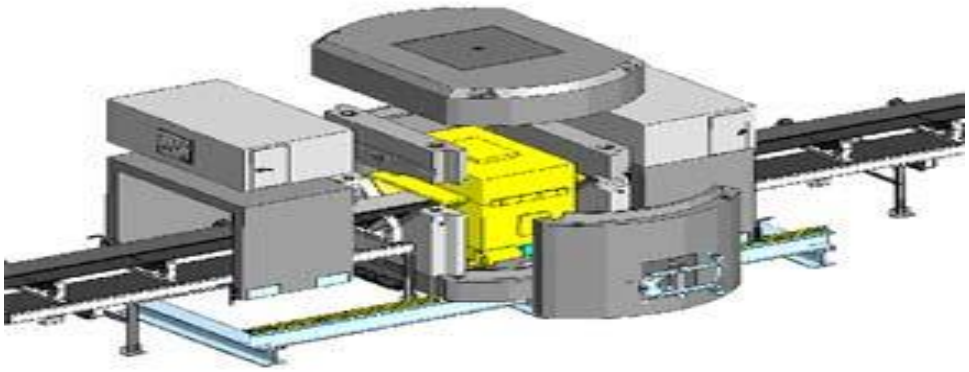

Fig. 4. Layout of PGNAA on-line analytical facility for coal analysis.

4.4. Container inspection system

The density detection based on gamma ray attenuation produced by linear accelerator has been used for container inspection system. Over 30 sets of the Chinese product for the container inspection have been well equipped at the Chinese customs and also exported to over 20 countries that are playing important role to inspect the smuggling cases. The detailed description of this nuclear analytical device can refer to [4]

5. MARKET ORIENTED PHILOSOPHY

A very important issue in the commercial applications of NATs is to develop a market-oriented strategy system. The Chinese experience lies in the following 5 items:

(i) **Customer is god**: This motto is also suitable for nuclear analytical workers in the commercial service.

(ii) **Price is key**: The price for each sample should be competitive against the challenge from non-nuclear methods, e.g., ICP-MS, AAS and others.

(iii) **Time is money**: A fast response to customer needs is imperative. Otherwise, customers will leave for other laboratories.

(iv) **Quality is life**: Wrong data is worse than no data. The life of NATs lies in its good accuracy. Thus, the accreditation system is highly needed.

(v) **Knowledge is capital**: The know-how of nuclear analysts is a precious asset to win a certain quotient in severe market competition. It is impossible to attract customers without any basic interdisciplinary knowledge.

6. REFERENCES

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