CNIC-00886

中国核科技报告

CHINA NUCLEAR SCIENCE & TECHNOLOGY REPORT

放射性同位素工业仪表在我国的发展与应用

DEVELOPMENT AND APPLICATION OF INDUSTRIAL RADIOISOTOPE INSTRUMENTS IN CHINA

原 子 能 出 版 社

中国核情报中心

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摘　要

放射性同位素仪表目前在我国被视为一种监测，控制和自动化手段。特别是以放射性同位素仪表为基础而形成的核控制系统(NCS)在工业过程现代化与最佳化中发挥着越来越重要的作用。在简要回顾我国近四十年来，放射性同位素仪表开发与应用的历史之后，着重叙述了放射性同位素仪表的发展现状及其应用实例。指出，放射性同位素仪表的工业应用取得了技术与经济效益，而仪表本身也已作为一类商品出现在市场。预计随着我国国民经济的高速增长，工业界对放射性同位素仪表将有更大的需求，以加速传统工业的技术改造和技术进步，并建立起生产技术密集型产品的高技术产业。今后有必要加强放射性同位素仪表的研究开发，以推进国产仪表的升级换代，同时满足我国现存较为普遍的中小型企业对低成本仪表的需求。

DEVELOPMENT AND APPLICATION OF INDUSTRIAL RADIOISOTOPE INSTRUMENTS IN CHINA

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ABSTRACT

Industrial radioisotope instruments are emerging as advanced monitoring, controlling and automation tools for industries in China. Especially the on-line analysis systems based on radioisotope instruments, referred to as nucleonic control systems (NCS), have more and more important role in the modernization and optimization of industrial processes.

Over nearly four decades significant progress has been made in the development and application of radioisotope instruments in China. After a brief review of the history of radioisotope instruments, the state of the art of this kind of instruments and recent examples of their applications are given. Technical and economic benefits have resulted from the industrial applications of radioisotope instruments and the sales of products of their own in marketing. It is expected that along with the high speed growth of national economy, there will be greater demand for radioisotope instruments and nucleonic control systems in Chinese industry to promote the technological transformation and progress of traditional industries and to establish high-tech industries with technology-intensive products. Sustained efforts for the research and development of radioisotope instrument should be made to upgrade domastic instruments and to satisfy the needs of the smaller scale industries more common in China for low cost systems.

INTRODUCTION

Through the efforts over nearly 40 years the distinguishing features of radioisotope instruments have gradually been recongnized by industries in China. Nowadays radioisotope instruments, in particular on-line analysis systems referred to as nucleonic control systems (NCS) are emerging as advanced monitoring, controlling and automation tools in various sectors of industry [1].

The degree to which any technique progresses depends on by how much it ad-

vantages outweigh its disadvantages in the face of competing techniques. The basic principles of industrial applications of radioisotope instruments are to acquire information from analysis, gauging and inspection through the interaction of radiation with matter. The unique attributes of nondestructive and non-invasive measurements and the operations of radioisotope instruments provide new opportunities for industrial applications in comparison with conventional methods. Radioisotope instruments possess a great deal of well known advantages including rapidity, relative simplicity of use and in some case, the possibility of application to severe environment where no other instruments or methods can be used. In addition, radioisotope instruments and NCS can be installed on site without disrupting the existing production line and without affecting the technological process for real time measurement and control in industry. These characteristics of radioisotope instruments make them to be suitable tools for promoting technological transformation of traditional industries and accelerating technical progress in industrial production with higher quality products, better utilization of energey, raw materials and plant, and minimization of wastage. Radioisotope instruments and NCS themselves are a category of technology-intensive products in high-tech industries.

1 DEVELOPMENT OF INDUSTRIAL RADIOISOTOPE INSTRUMENTS IN CHINA

Industrial radioisotope instruments have been developing as a part of nuclear program in China. The history of radioisotope instruments can be devided into three periods [2]:

(1) From the late 1950's to the early 1960's was the pioneer period. During that period intense research was concentrated on nuclear detectors and nuclear instruments including some instruments for uranium resouces exploration. There were some imported radioisotope instruments (e. g. gamma radiographic equipments) and simplest gamma relays at home for the early industrial applications;

(2) During the period from the middle 1960's to the middle 1970's on the basis of domestic supply of electronic components and radioisotope sources the ability in designing and manufacturing nuclear instruments was considerably improved with the accumulation of experience. The performance of nuclear instruments were also considerably improved by using transistor, digital display and scintillation detector instead of electronic tube, analogue display and G-M tube. In that period the radioisotope gauges started to be ready to come into wide use in industries;

(3) Since the middle 1970's the adaptability of radioisotope instruments has

been further improved by using microprocessors and computers with integrated circuits providing a large signal processing and data handling capacity. It is more important that up to the 1980's the strategic shift of China's nuclear program towards the service to the national construction and the improvement of people's life gave an impetus to the rapid progress of radioisotope instruments and opened up broad prospects for their industrial applications in China.

The growth in the total number of radioisotope instruments installed in industries in China is clear proof of technical and economic benefits derived form their application during the period over nearly 20 years (Fig. 1). It is estimated that at present there are more than 10 000 sets of radioisotope instruments or NCS systems, including level gauges, thickness gauges, density gauges, nuclear weigh scales, moisture content gauges, coal ash monitors, nuclear well logging devices, X-ray fluorescence analyzers, gamma radiographic equipment, static eliminators and so on, to be used in various industrial sectors throughout the country [3]. Some of them are domestic products, which include micro-computers with Chinese language software system in many cases.

According to rough statistics there are more than 50 establishments including companies, forctories, institutes, universities, industrial enterprises, etc. which have been developing and manufactaring 40 different kinds of nuclear instruments and several series of industrial radioisotope sealed sources. Among them the largest one is the China National Nuclear Corporation (CNNC) (the former Ministry of Nuclear Industry). CNNC provides varieties of nuclear detectors, nuclear instruments, and radioisotope sealed sources for industrial users. The products of CNNC in these fields are worth about US 10 millions annually with a yearly growth rate of 15 percent [4]. At present time more attention is given to the development of current domestic instruments to improve the stability and reliability of their performance in severe condition of industrial actual field and to become an industry-scale products for commercialization.

Up to the present, most of imported complete sets of industrial equipment have been attached by radioisotope instruments. For instance, the earlier introduction of NCS attached to 1700mm rolling mill Wuhan Iron & Steel Works imported from Germany can go back to the 1970's. Nowadays more and more foreign companies are interested in setting joint ventures in China to upgrade and develop the radioisotope instruments and NCS systems for industrial applications.

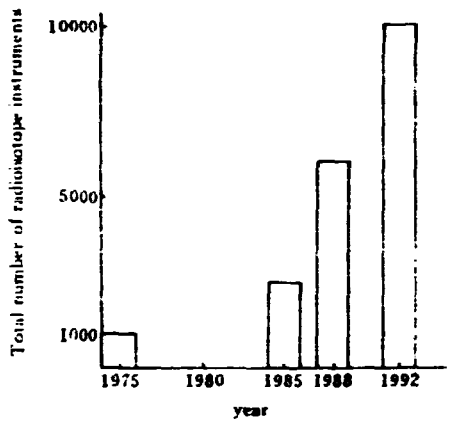

Fig 1 Growth in the total number of radioisotope instruments during the period over the past two decades

2 CURRENT EXPAMLES OF RADIOISOTOPE INSTRUMENTS FOR INDUSTRIAL APPLICATIONS

In recent years rapid growth of economy in China has demanded for increasing applications of industrial radioisotope instruments. In fact, all varieties of radioisotope instruments have almost been applied to various industrial sectors. Some of them have been on an industrial scale used in many main plants throughout the country (Tabie 1). More and more Chinese entrepreneurs have recognized that the appropriatness of radioisotope instruments in industries can get significant technical and economic benifits compared with other non-nuclear methods.

2.1 Gamma relay and radioisotope level switch

Gamma relays (or level switch) are the simplest radioisotope instruments, which act as on-off switches in response to the intensity of γ-rays. These gauges are often used to monitor the level and position of materials in a tank or a vessel with the convenience of installation and maintenance. Several gauges can also be combined to form an interlock equipment for coke oven. To this day, gamma relays remain by far the widespread applications in industries. It is estimated that there are more than 3000 sets of this kind of gauges to be used across the country for material seal controlling of shaft kiln in cement industry to get rid of dangers

due to the empty materal and wind leakage for safety in production. According to the statistics in 36 cement mills, the benifits obtained by using level gauges are to increase output of cement on the average by 30%. In chemical plants and iron & steel works the alignment of several gamma relays are being used to realize a pusher inter-lock for coke oven. In Kunming Sodium Polytriphosphate Plant (KMSTPP), Yunnan Province, there are 180 sets of level gauges for montoring and controlling the raw material production of detergent [5].

2.2 NUCLEAR WEIGH SCALE

Nuclear weigh scale is a continuous conveyor belt weigher based on the non-contact principle of γ-ray absorption to monitor and control mass flowrate for bulk material on line. Domestic products of nuclear weigh scale with specially designed large Volume gas-filled ionization chamber include such features as simple structure, easy installation, stable performance and minimum maintenance, and become an important component of NCS. During the early stage, nuclear weigh scales were mainly for monitoring individual material transported by the conveyer. Later these gauges started to be realized continueous on-line measurement of coal, coke, ore, salt, sintered material for blast furnace, clinker at high temperature in cement plant respectively on various conveyors including belt, spiral, chain plate, chain bucket, scraper and double tube reamer. The accuracy was within $\pm 1\%$ in all cases. Recently, a new type of nuclear weigh scale with automatically burdening sys-

Table 1 Main applications of radioisotope instruments in various industries in China

Radioisotope instrument	Industry
Thickness gauge	iron & steel, paper-making, textile, chemical, non-ferrous metal, civil engineering
Level gauge	iron & steel, chemical, cement
Density gauge	mining, iron & steel, chemical, cigarette
Moisture content gauge	iron & steel, civil engineering
Weigh scale	cement, coal, chemical, iron & steel, power
Composition analyzer gauge	cement, petroleum, mining, non-ferrous metal
Well-logging device	petroleum, coal, mineral
Radiographic equipment	power, chemical, petroleum, machinery
Smoke detector	factories, shops, high-buildings, offices, stores for various industries
Static eliminator	printing, rubber, textile, plastic, paper

tem has been succesefully developed for real time measurement and control of the mass flowrate of various materials to make the materials burdened according to specific proportion. The domestic systems of nuclear weigh seale have been widely accepted and operated in many sectors of industry [5]. It is estimated that there are about 3000 sets of nuclear weigh scale in use throughout the country.

2.3 Nuclear well-logging device

Among the borehole geophysics, nuclear well logging has become a routine tool for locating and evaluating deposits of oil, gas, coal, uranium and other nonferrous metal minerals. The use of nuclear well-logging methods such as natural gamma, gamma-gamma, neutron-gamma, radiotracer, etc. in the oil fields is well known. Recently progress in spectral measurements of gamma rays induced by neutron has been able to provide better information in oil well to solve complex problems. There are several hundreds of well-logging teams in the oil-fields across China providing nuclear well-logging service with testing about 10 000 well-times per year for the exploration and exploitation of oil to determine the lithology surrounding a borehole, its porosity and the presence of hydrocarbons.

2.4 Coal ash monitor

The ash (mineral) content of coal is a very important parameter for coal production and consumption. It can be most simply determined by gamma ray techniques based on the fact that the effective atomic number of ash is greater than that of coal matter. Early work placed emphasis on the development of coal ash gauge with ^{238}Pu as gamma ray source to determine ash composition for the coal with high Fe content. There are on-line ash gauges based on the back scattering of 60 KeV ^{241}Am gamma rays to determine coal ash content in advanced coal preparation plants in China. Recently, the new generation of domestic ash gauges with dual energy gamma ray transmission (DET) is being developed on the basis of combining measurements of the intensities of narrow beams of low and high energy gamma rays transmitted through the coal for industrial practice. Introduction of radioisotope ash gauge is of great importance since the annual output of coal in China is now about 1.2 billion tonnes ranking first all over the world.

2.5 Gamma radiography

Indnstrial gamma radiography using radioisotopes (e. g. ^{60}Co, ^{192}Ir, ^{169}Yb, ^{170}Tm, etc) is one of the most important nondestructive testing (NDT) methods to detect defects of nontransparent material or apparatus or to discover their internal structure. The development of NDT systems for industrial gamma radiography has

lead to the domestic radiographic set-up with S-shaped channel containers of depleted uranium shielding ^{192}Ir source from outside. The systems are gammagraphic equipments which could be held in one hand and need no supply of electricity and water for producing radiograph. It is estimated that there are about 500 units of gamma radiographic equipment with ^{192}Ir for intensive use in various industries throughout the country. Economic benifits are considerabie from practical performance of gamma radiography, especially from the panoramic exposition to pressure vessels and pipelines for checking all types of welds. The similar effect can be for inspection of not easily accessible position in a complex construction with small dimentional radioactive source.

2.6 X-ray fluorescence (XRF) analyzer

The radioisotope XRF systems are suitable for on-site assay of mineral samples and for on-line analysis and control of production process due to such features of the systems as compactness, simplicity, reliability and so on. In resent years there have been several sorts of XRF analyzer and other element composition gauges to be developed in succession for exploration of gold and copper ores, for determing Ca, Fe, Si and Al in cement and rare earth elements in mineral, and for analysis of an economically important mineral deposit-FeMn nodule in the sea bed.

By the way, an on-line prompt gamma neutron activation analysis (PGNAA) system with ^{252}Cf source was successfully developed and used in two aluminium plants in China. This was a positive effect in terms of both technical and economic benefits.

It is worth mentioning that smoke defectors with ^{241}Am are extremely sensitive to very small amounts of smoke for fire-alarm and contribute to increasing assurance of public safety. Such detectors being in wide use in factories, stores and high buildings are produced with the yield of over 200 000 sets every year in China. Other radioisotope appliance, the static eliminators with ^{210}Po or ^{238}Pu have been used for ten years in such industries as printing, paper, film, plastic, rubber, camera, light guide fiber, textile, package, etc.

3 TYPICAL APPLICATIONS OF NCS IN INDUSTRIAL PROCESSES

NCS is the refined embodiments of extension and expantion of radioisotope instruments in industrial processes. It involves highly sophisticated development of peripheral techniques such as nuclear, microprocessing and automatic techniques.

In general terms, the principal functions of a NCS system are

—to measure instantaneously and accurately the key parameters in a manufacturing process with radioisotope instruments for operators to monitor it;

—to feed back immediately the information for continuous real time control of the process by means of on-line analysis bassd on converting the measurements to electrial signals which are used to readjust the parameters to predetermined optimum values;

—to provide the data useful for the management of operation, production and quality control. In practical terms NCS results in enhanced quality through closer tolerance control and improved economics of operation through reduced product wastage and more efficient energy use.

3.1 Iron & steel industry

NCS for cold - and hot-making process in iron and steel plants is successful at controlling and monitoring product thickness of steel plate on the mills such as hot strip mill. Economic benefits have been obtained owing to the reduction in thickness variation, decrease in maintenance costs and increase in production through NCS. In blast furnaces and sinter plants, the burdening systems of NCS can guide material charging, distributing and discharging to achieve automatic burdening and hance continuous production, and further, the efficiency of blast furnaces can be greatly enhanced under controlling the moisture content of the coke fed into the furnace by NCS. Another example is the dramatical reduction of surplus material in continuous casting through computer control. The application of NCS to the steel industry in China has been increasing. According to recent statistics, there are about 400 sets of NCS including level gauge, moisture gauge, nuclear weigh scale, density gauge, thickness gauge, content analyzer, aligning gauge, slob position detector, continuous level gauge, coating weight mass gauge (Table 2).

Baoshan Iron & Steel Complex (" BS" in Table 2), Shanghai, is the largest and the most modernized complex in China, whose equipment was imported from abroad. The varieties of NCS attached to the equipment are playing a very important and, in some cases, an indispensable role in on-line measurement and real time control for a continuous production process. Recently the domestic products have become a part of NCS in the Complex's plants.

3.2 Paper-making industry

The basic effect of NCS in paper-making mills is the optimazing raw material and energy consumption through the measurement of the thickness and moisture

Table 2 The applications of NCS in main iron & steel plants in China (number of set)

Contents of NCS	Name of iron & steel plant *							
	BS	BT	SG	PZH	AS	WH	TS	CQ
Level gauge	22	10	8	4	5		70	2
Moisture gauge	9	4	2	4	2	4		4
Nuclear weigh scale	2	2	4				6	2
Density gauge	2							
Thickness gauge	21	17	14		8	42		
Content analyzer		7				13		
Aligning gauge	6	8		2	4			
Slob position detector	15					18		
Continuous level gauge	1		16		12			1
Coating mass gauge	1							
Total	77	45	44	10	31	77	76	9

* BS (in Shanghai)
BT (in Baotou, the Inner Mongolia Autonomous Region)
SG (in Beijing)
PZH (in Pang Zhihua, Sichuan Prov.)
AS (in Anshan, Liaoning Prov.)
WH (in Wuhan, Hubei Prov.)
TS (in Tangshan, Hebei Prov.)
CQ (in Chongqing, Sichuan Prov.)

content of paper to control average weight of paper and steam usage. Recently the application of NCS to paper-making industry has been popularized. It is estimated that there are about 200 sets of NCS used in large paper mills throughout the country, and half of them are domestic products. The benefits from NCS in paper-making are truly considerable with the result of increasing yield by 10～15%. Detail economic calculations have shown that the investiment for NCS can be recovered in less than one year. With the installation of NCS a paper mill of daily output 150 tons would produce qualified products with extra yied of 4520 tons each year. It is worth noticing that the annual output of paper is more than 17 million tons in nearly 600 paper mills in China, of which most are the smaller scale industries. Therefore, It is imperative to develope low cost NCS to satisfy the needs of regional smaller paper mills.

3.3 Cement industry

Varieties of cement-NCS, including gamma relay, continuous level gauge, nuclear weigh scale, XRF analyzer and neutron activation analysis system have been used to improve the process of cement production, the quality of end product and the safety of production.

As mentioned above, the domestic systems with gamma relay, early developed for smaller scale cement mills, have become popular in material seal control of shaft kiln to get rid of danger with material empty and wind leakage. Up to now nuclear weigh scales with automatically burdening system are extansively used to burden limestone, clay, coal and iron powder to be fed to the grinding machine in cement mills. With the qualified rate of raw material increased from less than 30% to more than 70% by the cement-NCS, kiln operating condition would be improved and the clinker yield would increase. More and more cement-NCS with XPF analyzers and neutron activation analysis systems are put into the production practice for monitoring and controlling the content of raw materials to ensure the quality of end products in cement mills Though the application of NCS in cement industry is in progress, the next challenge is how to satisfy the great need of about 10 000 cement mills all over the country.

3.4 Civil engineering

In the field of civil engineering, nucleonic gauging systems are used to measure in situ density moisture content of such materials as soil, cement and asphalt, for instance, to monitor the impact of engineering works on soil moisture level and soil density over an extented period of time. There are domestic varieties of radioisotope instraments, such as portable and moving earth density moisture gauges, surface density gauges, neutron moisture gauges, etc, developed for the construction of highways, dam and large buildings in China. An important advantage of nucleonic gauging systems is rapid and economical for measurement with reliability and repetitiveness in comparison to traditional techniques. It is particularly useful in regularly monitoring the impact of engineering processes.

4 CONCLUSIONS

(1) The progress of radioisotope instruments and NCS, and their applications in industries depend greatly on the principle of national nuclear program and the development of social economy. Since the 1980's the strategical shift of China's nuclear program has provided broad prospects for the applications of nuclear technology, including radioisotope instruments in industry. Along with the high

speed growth of national economy there are continuous demands for radioisotope instruments and NCS to promote technological transformation of traditional industries and technical progress in industrial production and to realize the modernization and optimization of technological process. Therefore, the potential for market and application of such products is great in China.

(2) Radioisotope instruments have gained widespread acceptance through the evidence of technical and economic benefits and their adaptability is now recognized. It is necessary for actual instruments to become routine products available on industrial scale in domestic market. Establishment of technical standards of the current domestic products is under consideration in order to improve the stability and reliability of instrument performance. More streamlined and stringent licensing regulations have been introduced to carry out fully validated applications and to ensure radiation safety in industry.

(3) Sustained efforts for the development of more sophisticated products in accordance with the features of Chinese industries are required to upgrade current products. Increasing emphasis is now being placed on the development of low cost NCS suitable for smaller scale industries which are more common in China. There is a trend towards the combination of nuclear and ralated non-nuclear techniques to advance measurement performance of radioisotope instruments with multiplication and intellectualization by electronics and computers for widening the scope of application in industry.

(4) Apart from the import of industrial complete set and technology, extensive international technical and economical cooperation is being strengthened in view of learning advanced achievement and exprience from abroad. This is opening up further oppotunities for current domestic products, more sophisticated innovations and the scope of their applications to bridge the gap between China and economically developed countries in the world.

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（京）新登字 077 号

图书在版编目（CIP）数据

放射性同位素工业仪表在我国的发展与应用＝DEVELOPMENT AND APPLICATION OF INDUSTRIAL RADIOISOTOPE INSTRUMENTS IN CHINA/吕延晓著. —北京：原子能出版社，1994. 9

ISBN 7-5022-1247-7

Ⅰ. 放… Ⅱ. 吕… Ⅲ. 放射性同位素-工业仪表-技术现状 Ⅳ. TL8

中国版本图书馆 CIP 数据核字（94）第 08152 号

原子能出版社出版发行

责任编辑：张铣清

社址：北京市海淀区阜成路 43 号 邮政编码：100037

中国核科技报告编辑部排版

核科学技术情报研究所印刷

开本 787×1092 1/16 · 印张 1/2 · 字数 12 千字

1994 年 9 月北京第一版 · 1994 年 9 月北京第一次印刷

CHINA NUCLEAR SCIENCE & TECHNOLOGY REPORT

ISBN 7-5022-1247-7

9 787502 212476 >

P.O.Box 2103

Beijing, China

China Nuclear Information Centre