IAEA-TECDOC-1459

Technical data on nucleonic gauges

IAEA
International Atomic Energy Agency

July 2005

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The originating Section of this publication in the IAEA was:

Industrial Applications and Chemistry Section
International Atomic Energy Agency
Wagramer Strasse 5
P.O. Box 100
A-1400 Vienna, Austria

TECHNICAL DATA ON NUCLEONIC GAUGES
IAEA, VIENNA, 2005
IAEA-TECDOC-1459
ISBN 92–0–107805–6
ISSN 1011–4289

Printed by the IAEA in Austria
July 2005

FOREWORD

Nucleonic gauges or nucleonic control systems (NCS) have been widely used in industries to improve the quality of their products, optimize processes and save energy and materials. It is considered that NCS technology is by far one of the most requested among radioisotope technologies. Economic benefits have been demonstrated and recognized by industries. There are several hundred thousand nucleonic gauges installed in industries all over the world. Many of them are commercially available from several manufacturers. However, a significant number of NCS are not yet in the market as standard products and the development of a new generation of nucleonic devices is ongoing. The request for the NCS technology is steadily increasing; many developing Member States are interested in this technology.

Over the years, the IAEA has contributed substantially to the promotion of industrial applications of NCS, in particular throughout regional TC projects in East Asia (RCA) and Latin America (ARCAL). Significant progress has been made, enabling developing Member States to introduce this technology to well defined industrial processing fields.

Numerous meetings have been organized with the objectives of discussing the status and prospects of NCS technology and of preparing technical reports in this subject. A Consultants Meeting on NCS Directory was convened in November 2000; a Technical Meeting on R&D in Radiotracer and NCS Technologies was organized in June 2002, and a Consultants Meeting on Preparation of a Technical Document on Low Activity Nucleonic Gauges Design and Applications was conducted in May 2003. Experts from public institutions and private companies from developed and developing Member States participated in these meetings providing their experience and feedback reflected in this publication.

The purpose of this report is to provide basic information on nucleonic gauge methodology and technology as applied to major target areas of exploration and exploitation of natural resources and manufacturing industries. The basic principles of the most used techniques are reviewed and information sheets on major typical models of nucleonic gauges are included. The material contains practical information on NCS technology that could assist radioisotope specialists to promote the technology to end users and help them to select the most suitable alternative to solve a particular problem or to measure a certain parameter in a specific process. Managers of industry and decision makers will find useful information for making larger use of NCS technology.

The IAEA wishes to thank all the participants in the meetings for their valuable contributions. The IAEA officers responsible for this publication are J. Thereska and Joon-Ha Jin of the Division of Physical and Chemical Sciences.

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1. BACKGROUND

There are several hundred thousand nucleonic control systems (NCS) or nucleonic gauges installed in industry all over the world. They have been widely used by various industries to improve the quality of product, optimise processes, save energy and materials. The economic benefits have been amply demonstrated and recognised by industry. Looking at trends in the industrialisation process of developing countries, there is evidence that NCS technology will continue to play an important role in industry for many years to come.

Nucleonic control systems (NCS) are defined here as: "Control by instrumental measurement and analysis as based on the interaction between ionising radiation and matter". There are several ways of applying the NCS, among them:

- On-line (process),
- Off-line (process),
- In situ (well logging),
- Used in laboratory (on samples), and
- Portable, for site measurements.

Simple nucleonic gauges first began to be used in industry over forty years ago. Since then, there has been a continuous expansion in their usage. The competition from alternative methods shows that NCS have survived and prospered in the past because of their superiority in certain areas to conventional methods. The success of NCS is due primarily to the ability, conferred by their unique properties, to collect data, which cannot be obtained by other investigative techniques.

Many NCS are now commercially available from several manufacturers. Nevertheless, significant types of NCS are not in the realm of commercially available services. The development of supporting technologies such as compact electronics, fast computers, high-resolution detectors, small reliable neutron tubes, and dedicated computer modelling codes has resulted in increased technical viability and economic acceptability of NCS. The development of the next generation of nucleonic devices is still taking place.

Relevant target areas are defined in international priority industrial sectors, such as oil and gas production, mining and mineral ore processing, environmental monitoring, paper and plastics industries, cement and civil engineering industries, where the benefit is enormous and the technology competes well with conventional techniques.

Promotion of new applications and techniques in NCS design, calibration, quality control and operation is going on. There is need to stimulate, build and maintain consulting capability in interested developing Member States. Teams of skilled specialists need to be trained to look after the NCS used in their industries, to calibrate and to check the safety of the NCS used, and to advise their local industries in selecting the appropriate NCS from a techno-economic point of view.

One of the most significant changes in recent years has followed the introduction of on-line processing and display. Detector technology is rapidly changing and a number of solid state and other detectors are presently being developed that can be operated without cooling. However, there is still a need for an industrial detector that is capable of operating with very high counting rates, high total efficiency and at ambient temperature. Such a detector would have a counting rate high enough to follow fast process transients with good accuracy. In some cases alternative measurement principles are being investigated that allow significant source intensity reduction.

NCS systems employed in the exploration, exploitation and processing of natural resources are listed in Table I.

TABLE I. NCS APPLIED TO THE EXPLORATION, EXPLOITATION AND PROCESSING OF NATURAL RESOURCE

Techniques	FIELDS OF APPLICATION					
	OIL & GAS	LOGGING		MINERAL PROCESSING		
	Fluid flow	Delineation of deposit	In-situ assaying	On & Off belt analysis	Slurry analysis	Density, Weight, Level/Fill
Natural γ radiation		X	X	X	X	X
γ-ray transmission	X			X	X	X
γ-ray backscatter		X	X	X	X	X
PGNAA & DGNAA		X	X	X		
XRF analysis			X		X	

Where: PGNAA – Prompt gamma neutron activation analysis
DGNAA – Delayed gamma neutron activation analysis
XRF – X ray fluorescence

NCS systems used in manufacturing industries are listed in Table II

TABLE II. NCS USED IN MANUFACTURING INDUSTRIES

Applications	Techniques	FIELDS OF APPLICATION						
		Civil Engineering	Packaging	Plastic, Paper & Pulp	Metal Processing	Chemical & Petrochemical	Safety	Miscellaneous
Level / Fill	γ transmission		X	X	X	X		X
	n backscatter			X		X		
Thickness and Area Weight	γ transmission				X			
	β transmission			X	X		X	
	γ backscatter			X				
	β backscatter			X	X			X
	XRF				X			X
Density	γ transmission	X	X	X				X
	γ backscatter	X						X
Bulk Weight	γ transmission	X						
Fluid Flow	γ transmission single + multi-energy					X		X
Moisture	γ transmission	X						
	n transmission	X						X
	n moderation	X						X
Analysis	PGNAA	X						X
	γ transmission	X					x	X
	XRF				X	X	X	X
	Ionisation						X	

2. PRINCIPLES OF NUCLEONIC GAUGES

A nucleonic gauge consists of a suitable source (or a number of sources) of alpha, beta, gamma, neutron or X ray radiation arranged in a fixed geometrical relationship with one or more radiation detectors. Most of nucleonic gauges are based on a few most common nuclear techniques.

Natural gamma-ray technique

NCS based on natural gamma-ray technique utilize the correlation between natural gamma-ray intensity measured in one or more pre-selected energy windows and the concentration of particular elements (e.g. U, Th, K) or the value of a given parameter of interest (e.g. ash in coal).

Transmission

In the basic configuration of a transmission gauge the media to be measured is placed between the radioactive source and the detector so that the radiation beam can be transmitted through it (Fig.1). The media attenuates the emitted radiation (beta particles or photons) before reaching the sensible volume of the detector. Both source and detector can be collimated. The radiation intensity in the detector is a function of several parameter characteristics of the material.

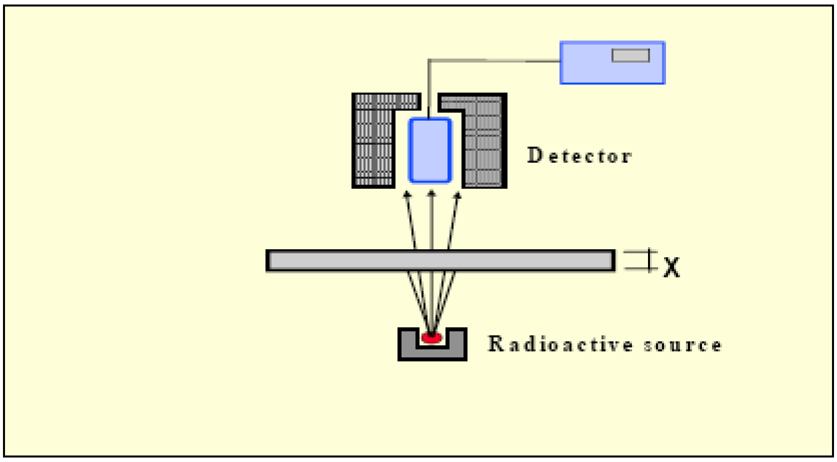

FIG. 1. Principle of transmission method.

Dual energy gamma-ray transmission (DUET)

This technique is probably the most common nucleonic method for on-the-belt determination of ash content in coal. Ash content is determined by measuring the transmission through coal of narrow beams of low and high-energy gamma rays (Fig. 2). The absorption of the lower energy gamma rays depends on ash content, due to its higher average atomic number than that of coal matter, and on the mass per unit area of coal. The absorption of the higher energy gamma rays depends almost entirely on the mass per unit area of coal in the beam. Ash content is determined by combining measurements of the two beams. The determination is independent of both the bed thickness and the mass of the coal. The technique is also applicable to the analysis of complex fluid flow where multiple energy beams are usefully applied.

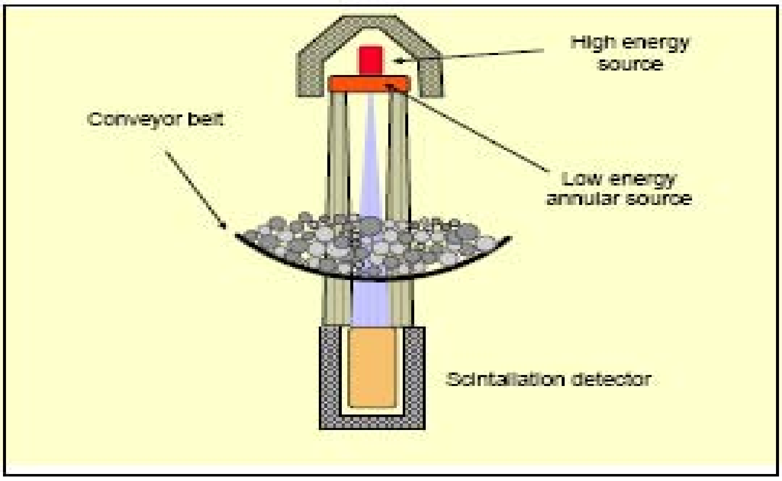

FIG. 2. Dual energy gamma ray transmission for on line measurement of coal ash concentration.

Backscattering

Whenever a radiation beam interacts with matter a fraction of it is transmitted, a fraction absorbed and a fraction is scattered from its original path (Fig. 3). If the scattering angle is greater than 90^{o} some photons or particles will come back towards the original emission point; the measurement of this radiation is the basis of the backscattering method.

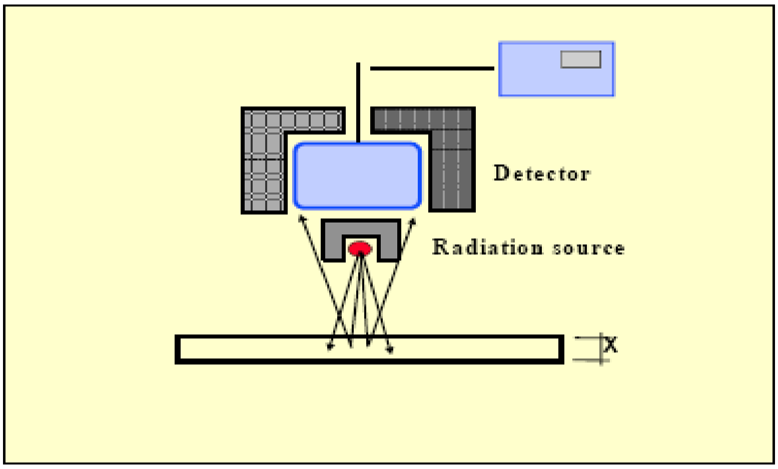

FIG. 3. Principle of backscatter method.

Gamma-ray backscatter

Measurement of radiation emitted by a stationary gamma-ray source placed in the nucleonic gauge and back-scattered from atoms of investigated matter enables some properties of this matter to be determined. The gamma-rays interact with atomic electrons resulting in scattering and absorption. Some of these gamma-rays emerge back from the investigated mater with degraded energy and intensity (count rate) characterizing the bulk density and the average chemical composition of the matter.

Neutron scattering (moderating)

Fast neutrons of high energies emitted from the neutron source collide with nuclei of investigated matter reducing their energy. In general, neutrons lose more energy on collision with light nuclei than with heavy nuclei. Due to its light nucleus hydrogen is most effective in moderating neutrons from the source. As hydrogen is major constituent of most liquids detection of the liquid through container walls is possible, as well as measurement of the moisture (hydrogen density) of soils, coke or other materials.

Prompt gamma neutron activation analysis (PGNAA) and Delayed gamma neutron activation analysis (DGNAA)

When a material is bombarded with neutrons, interactions with nuclei result in the emission of high-energy gamma - rays, at a variety of energy levels. The nuclear reactions excite gamma-rays of energies specific to the target nucleus and the type of nuclear reaction. If the intensity and energy of these are measured by means of a suitable spectrometric detector, the type and amount of an element present can be determined. The gamma-rays emitted may be classed as prompt, occurring within 10^{-12} seconds of the interaction, or delayed, arising from the decay of the induced radioactivity. (Fig. 4) The former gamma-rays are utilized in Prompt Gamma Neutron Activation Analysis (PGNAA) and the latter in Delayed Gamma Neutron Activation Analysis (DGNAA). The same probe can be used for both PGNAA and DGNAA elemental analysis (Fig. 5).

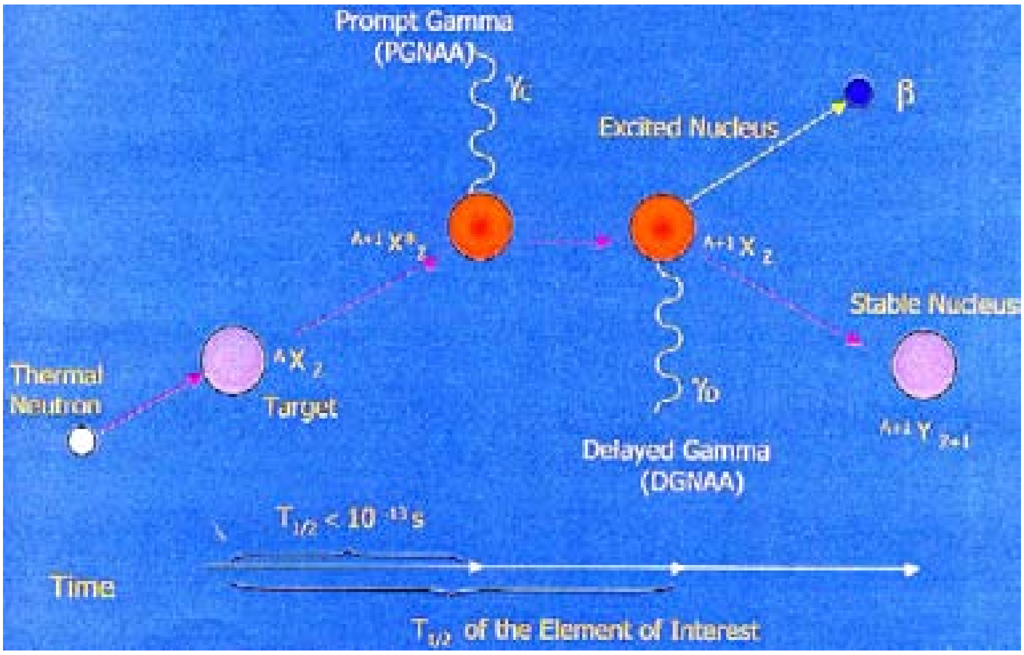

FIG. 4. Principle of PGNNA and DGNAA methods.

Cf-252 and ^{241}Am-Be neutron sources are used for PGNAA and DGNAA techniques. Most commercial PGNAA analysers use Cf-252 neutron source because they are mainly sensitive to thermal neutron capture (TNC). Typical activities are: 5-10 micrograms (100 –200 MBq – 1-2 .10^7 n/s) for borehole logging and 15—20 micrograms (300–400 MBq – 3-4. 10^7 n/s) for on-line bulk processing. ^{241}Am-Be source provides higher energy neutrons that can be used in addition for designing elemental analysers that employ neutron inelastic scattering reaction. Common activities are going from 20 GBq for borehole logging till 100 GBq for on-line bulk processing.

Scintillator detectors sodium iodide NaI (Tl) and bismuth germanate (BGO) are commonly used in PGNAA and DGNAA techniques. BGO detector, whilst having a lower resolution at room temperature than NaI, has higher photopeak efficiency, particularly for higher energy gamma rays generated during PGNAA reaction.

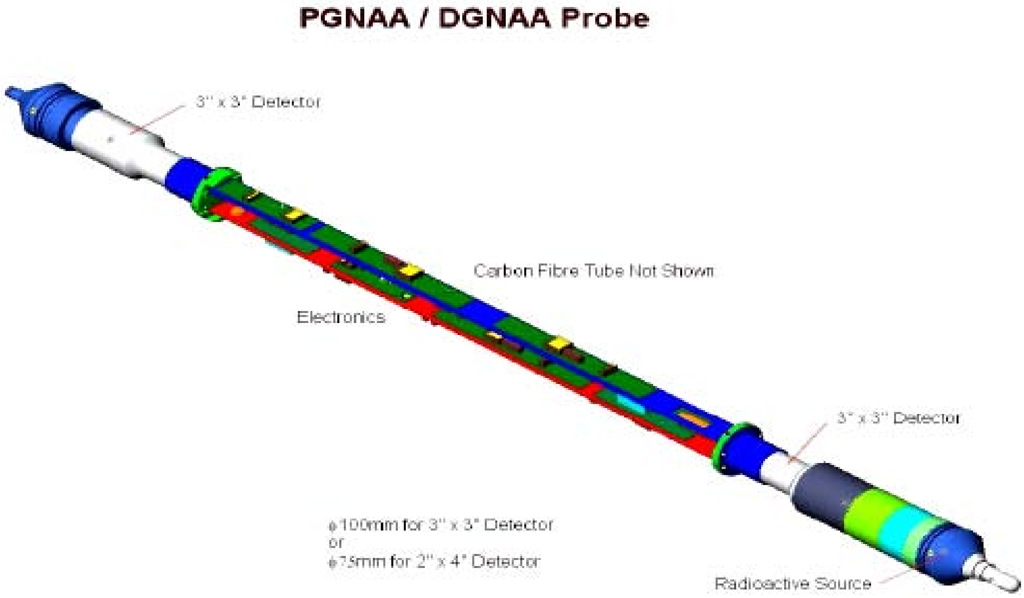

FIG. 5. PGNAA and DGNAA probe for borehole logging.

The PGNAA cross-belt analyzer is a precise on-line elemental analyzer for bulk materials. With accurate minute-by-minute analysis of their entire material flow, manufacturers can improve product consistency and increase throughput, while reducing fuel, grinding, and refractory costs. The PGNAA cross belt analyzer consists of two units, the shield block assembly, which is installed on the conveyor structure, and the electronics enclosure. Analysis period is once per minute and the parameters analyzed are silicon, aluminum, iron, calcium, magnesium, sodium, potassium, sulphur, chlorine, and moisture. Figures 6 presents a commercial PGNAA system installed on line in a cement plant for elemental analysis of clinker raw materials during their mixing in belt conveyor.

FIG. 6. PGNAA system in cement plant.

Figure 7 shows borehole logging process for copper ore analysis in Chuquicamata (Chile) open cut copper mine using PGNAA probe.

FIG. 7. PGNAA borehole logging for copper grade analysis in Chile.

Figure 8 presents the calibration curve for PGNAA logging probe tested in Chuquicammata copper mine, Chile. It shows good correlation.

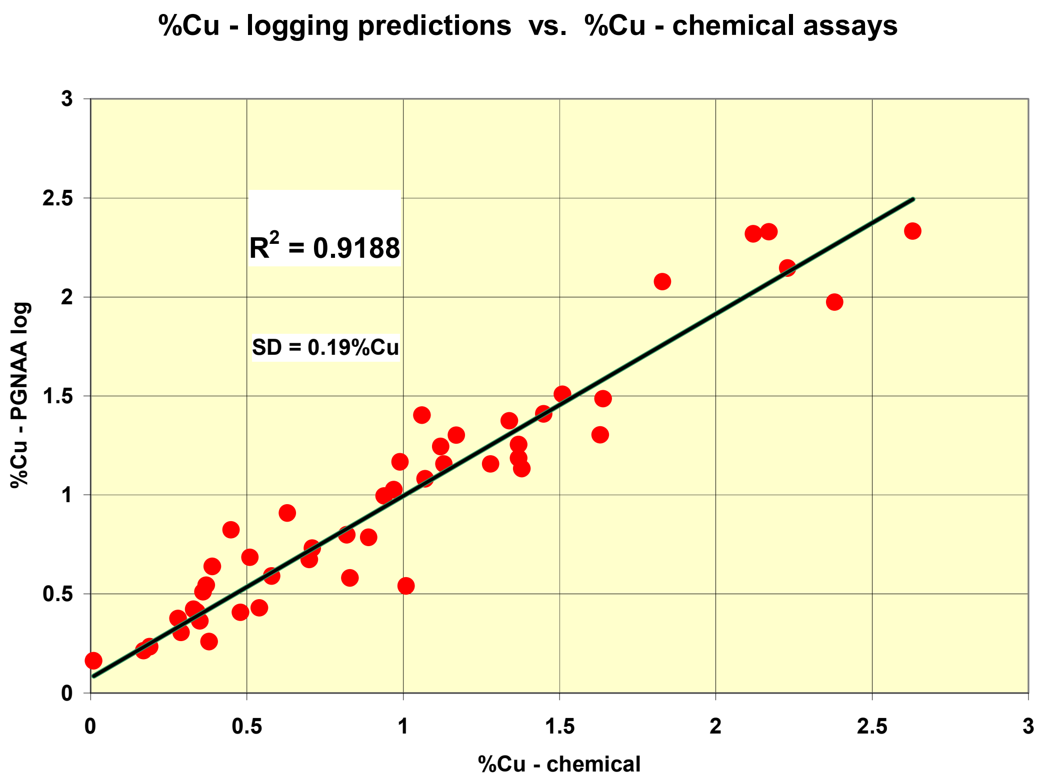

FIG. 8. Calibration of PGNAA logging probe for copper.

X Ray Fluorescence (XRF)

X ray technique is useful for measuring coating thickness (Fig. 9). One of the ways by which X rays are absorbed is by fluorescence. The yield of fluorescent X rays from the coating atoms can be used directly, or the attenuation of the X rays generated by fluorescence of substrate atoms as they pass back though the coating can be measured. The range through which this technique applies is up to 20 microns, useful for galvanized or paints.

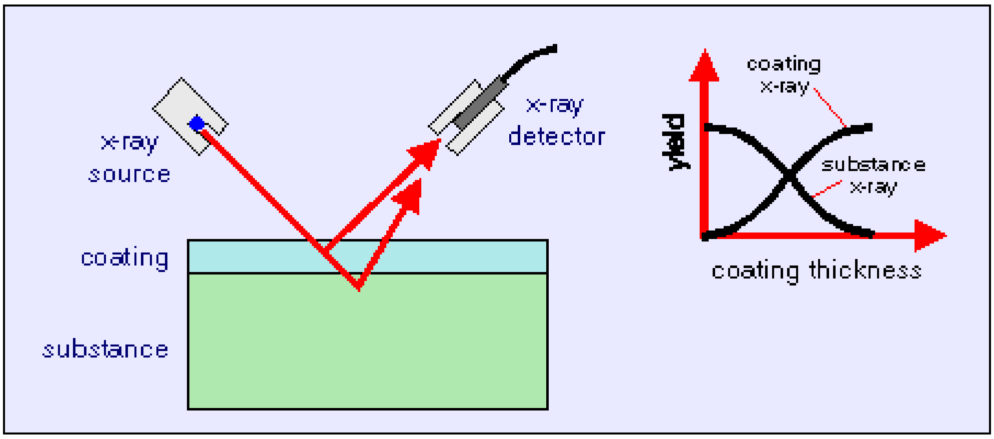

FIG. 9. Principle of XRF for measuring coating thickness.

Ore Analysis

The X ray fluorescence technique is often used to provide direct on-stream elemental analysis of mineral slurries. Compton effect and pair production, have differing sensitivities to Z, they can be used to analyze a binary mixture. The intensity of the annihilation radiation which results from pair production depends on both bulk density and average Z of the ore, whereas the Compton scattered radiation depends only on the bulk density. The ore grade can therefore be inferred by combining these two intensities. Compton backscatter alone is used to determine surface densities for sintering ores surfaces (Fig. 10).

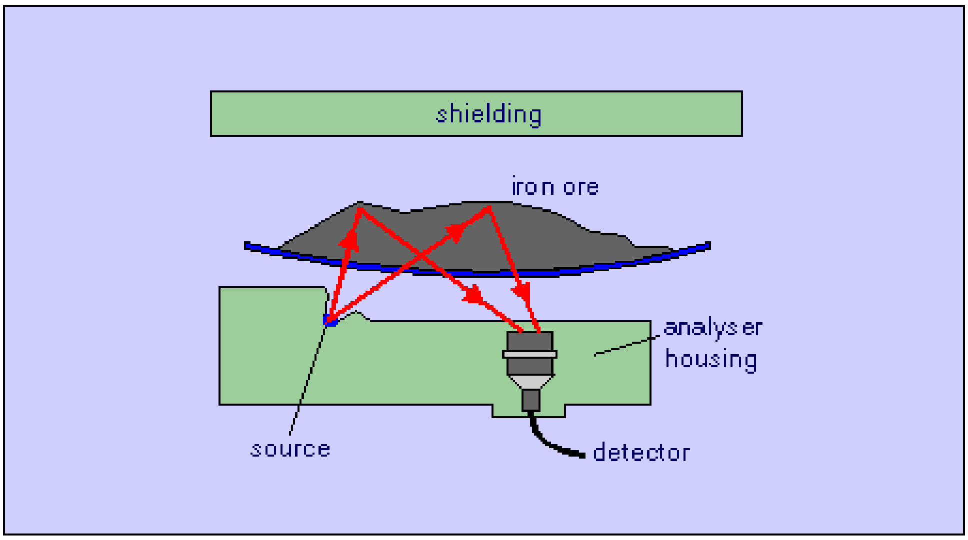

FIG. 10. Principle of XRF for ore analysis.

Nucleonic gauges for multiphase flow rate measurement

An increased number of applications with nucleonic gauges in the area of multi-phase flowrate measurement are reported, mostly by international companies investing in oil production. Here the oil, water and gas flowrates are measured continuous and in-line without separating the various phases. Measurement is important for reservoir modeling and production optimization and will result in huge costs savings and increased safety.

In multi-phase metering nucleonic techniques have very clear advantages compared to other techniques (e.g. dielectric constant, microwave, etc.). Several Dual Energy Gamma Ray Absorption (DEGRA) flowmeters for flow measurement of water, oil and gas phase fractions in a three phase mixture are already installed around the world, functioning with good reliability and accuracy. The gauges make use of Si solid state detectors with Peltier cooling and are designed to operate in remote areas and offshore platforms. Ultimately also sub sea applications are foreseen.

Multi-Energy Gamma Ray Absorption (MEGRA) devices for multi-phase flow measurements are now under investigation to improve the performance of DEGRA ones. In particular to correct for changing fluid parameters that might influence the calibration (e.g. salinity). The trend is to replace the radioactive sources with X ray tubes for higher X ray flux (increased accuracy) and safer use (e.g. during transportation and/or maintenance).

A class of multiphase flowmeters uses the principle of Dual Energy Gamma Ray Absorption (DEGRA) composition measurement to determine the individual water, oil and gas fractions employing Am-241 and Cs-137 sources (Fig.11). Venturi gauge is used to measure pressure drop in combination with gamma sources (Fig.12). Under homogenous flow conditions the ultimate uncertainty in phase fractions achievable with this technique depends strongly on the choice of component hardware. A typical DEGRA gauge uses unique components optimised for water, oil and gas fraction measurement, yielding theoretical uncertainties of 2% in the fractions over a 1 second measurement period.

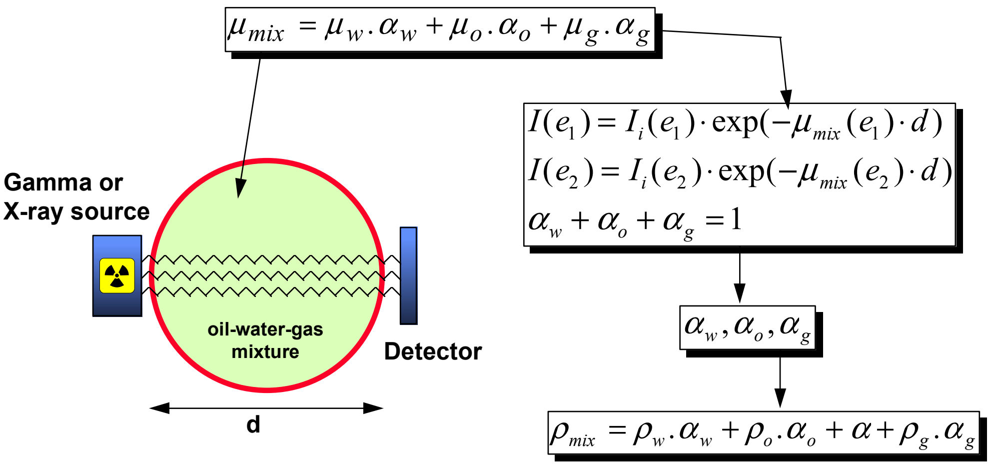

FIG. 11. Principle of the Dual Energy Gamma Ray Absorption (DEGRA) technique.

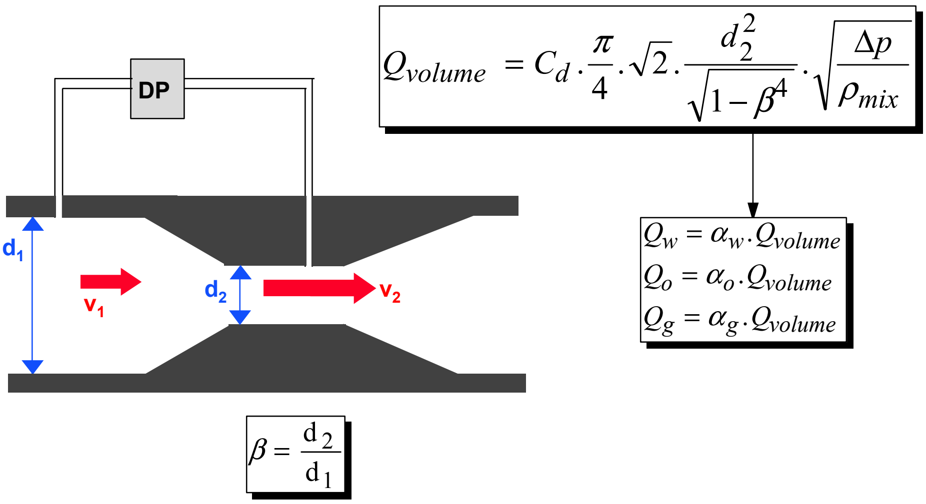

FIG. 12. Venturi application in multiphase flow measurement. Density ρ_{mix} and the fractions α_i are measured with the gamma ray absorption technique.

Generally DEGRA meters are sensitive to changes in production water salinity, causing significant systematic errors in the fraction and watercut measurements. A new measurement concept based on Multiple Energy Gamma Ray Absorption (MEGRA), which is insensitive to salinity variations is introduced. A multiphase flowmeter which employs the MEGRA concept does not require field calibration, a decisive advantage in sub sea or marginal field developments (Fig. 13).

FIG. 13. Multiphase flow meter (MEGRA) installed in oil platform

Oil-water-gas flow meter nucleonic gauge replaces expensive test separator saving several million of US$ in one oil field.

Table III summarizes the commonly used radioisotopes for nucleonic gauges.

TABLE III. MOST USED RADIOISOTOPES IN NUCLEONIC GAUGES

Parameter to measure	Source
Paper thickness	^{85}Kr, ^{90}Sr, ^{147}Pm and ^{204}Tl
Metallic layer thickness	^{141}Am, ^{137}Cs, ^{60}Co
Liquid density	^{137}Cs
Liquid level	^{137}Cs, ^{60}Co
Soil density	^{137}Cs
Soil moisture	^{241}Am – Be, ^{252}Cf
Suspended sediment concentration	^{109}Cd, ^{241}Am
Ash coal concentration	^{137}Cs + ^{241}Am
Multiphase flow meter	^{137}Cs + ^{241}Am

3. PORTABLE NUCLEAR ANALYSIS SYSTEMS (PNAS)

Nucleonic Control Systems (NCS) have been widely used by various industries to improve the quality of product, optimize processes, and save energy and materials. However, there has been significant evolution of both the capabilities of the instrumentation for more advanced quantitative analysis and a wider applicability of the information obtained from the instruments. In addition, these techniques are being applied to a wider variety of problems. Portability in the sense of miniature and compact nucleonic gauges for multipurpose services is a trend nowadays. This trend is particularly visible in new generation of nucleonic gauges designed and manufactured for elemental analysis in geological and environmental investigations. Therefore, it is much more appropriate to think of new class of nucleonic gauges and methodologies as Portable Nuclear Analysis Systems (PNAS).

The development of supporting technologies such as compact electronics, fast computers, high-resolution detectors, small reliable neutron tubes, and dedicated computer modeling codes has resulted in increased technical viability and economic acceptability of PNAS. Improvements in the capabilities of PNAS techniques can be achieved from developments of similar techniques from a variety of other fields, including medical physics, space exploration, and forensic science.

The promotion of new applications and techniques in PNAS and improvements in design, calibration, quality control and operation is continuing in many areas. These significant advances mean that there is an increasing need to stimulate, build and maintain consulting capability in interested developing member states. Teams of skilled specialists need to be trained to look after the PNAS used in their industries, to calibrate and to check the safety of the PNAS used, and to advise their local industries in selecting the appropriate PNAS from a techno-economic point of view.

International priority industrial sectors, such as mining and mineral ore processing, environmental monitoring, cement and civil engineering industries, and the oil and gas industries, have been identified. The application of PNAS in these sectors results in enormous economic benefits and the PNAS technology competes well with conventional techniques.

3.1. Current trends in development and applications of PNAS

The development of new PNAS technology needs enhancement in hardware and software. In recent years there have been many new system developments and novel new techniques developed in related fields. Often, costly research and development activities that could not be supported by a single application have been funded by multiple groups with application interests in different fields.

These costly projects have often resulted in inexpensive devices that can satisfy all, or most, of the needs for incorporation in PNAS. The observed trends and new developments include the following:

Nuclear techniques are being incorporated in and developed further in an ever broader range of interdisciplinary fields. Many of these fields are so far removed from the traditional areas of nuclear technique use that workers in the more traditional areas are likely to be unfamiliar with many new and innovative techniques and technology. A concerted effort needs to be made to make the most recent developments available for possible use in all applications.

A recent realization is that technology developments can be too expensive for a single group to justify on the basis of its own requirements. However, if multiple applications by different groups can identify common development needs, they can pool their resources to achieve the desired technology. This has been recently demonstrated by pooling funds from space exploration and forensic science to advance the development of more compact, reliable, pulsed X ray and neutron generators. A further advantage of technology and techniques developed for multiple groups is that they are more likely to be directly transferable to PNAS use under the conditions needed to operate for the interests of member states, as they had to meet combined needs of different applications.

Applications in planetary science require instruments that take little volume, have high reliability, and have low power requirements. Similar requirements apply to the development of analytical instruments for the forensic applications at crime scenes. However, the latter applications also require that the costs of instruments be reduced to reasonable levels to ensure that they can be used for the applications intended, which would require many instruments to be purchased and distributed. Therefore X ray and neutron generators are being developed for space exploration and forensic applications that are significantly smaller and more reliable than previously developed instruments.

Many new detectors have been developed for application in medical science, space exploration, forensic science, and other areas that can benefit PNAS systems. Many of these detectors are not currently commercially available, but could be if the appropriate application existed as their growth and fabrication technology has been established. Many new types of materials are available for use as X ray, gamma-ray, and neutron detectors. The efficiency and sensitivity of PNAS instruments can be improved by properly combining the optimum detector material and geometry for a particular application.

Replacement of radioactive sources with radiation generators goes one step further. The availability of relatively inexpensive neutron generators of significantly reduced size would permit the use of neutron-induced reaction analyzers in a range of applications where present neutron-source based instruments are not acceptable by local regulations and/or a negative perception to applicability of neutron sources, pose potential risk of radiation exposure to workers, or require shielding and other components that reduce the economic benefits.

In attempts to make nucleonic gauges more compact and portable for nuclear material monitoring, advanced electronics components have been integrated so that an entire processing chain from preamplifier to digitization and storage have been implemented on one or two chips. This has so far been used for X ray and gamma ray spectroscopy processing and can be incorporated in PNAS instruments to make them more portable and efficient.

Extending the use of the spectral data presently available from multi-channel spectrometric measurements provides information on some physical and/or chemical properties of the investigated ore/rock that is convoluted in the recorded spectrum. Enhancement of software programmes for data acquisition and processing, including multivariate analysis for calibration and 3-D visualization software packages permits a more universal application of energy-specific nuclear methods of analysis.

3.2. Portable nucleonic gauges: Radioisotope vs. X ray tube excitation

Portable nucleonic gauges for niche applications are in development. Miniaturization trend in electronics and X ray tubes has open new area in portable nucleonic gauge technology. Emerging new applications of nucleonic gauges in quality control of processes and products, in natural resource exploration and exploitation and environmental investigation are coming up. Fig. 14 shows a portable analytical nucleonic gauge, which can be either isotope-based or X ray tube-based. Both variants are handheld nucleonic gauges quite similar in their form and size.

FIG. 14. The isotope-based XLi™ Analyzer and the X ray tube-based XLt™ Analyzer.

The advent of the new generation of portable XRF analyzers utilizing x-ray tube excitation has enlarged the spectrum of applications and has facilitated the licensing process. X ray tubes are preferred in many applications towards radioisotope sealed sources. Although many XRF manufacturers are researching X ray tube technology for portable instrumentation, the radioisotope sealed sources are still in use in many nucleonic gauges.

Table IV and V provide advantages and disadvantages of X ray tube and sealed source techniques applied in nucleonic gauges, in particular in portable XRF gauges.

TABLE IV. X RAY TUBE STRENGTHS AND LIMITATIONS

Strengths	*Limitations*
Latest, most advanced technology	Less rugged than isotope
Potentially faster analysis	Less predictable
Wide element range	Slightly larger and heavier
Reduced regulatory requirements	Limited access in tight areas
Simplified licensing	Very little history as to the lifetime of X ray at this time
Easier to transport	
No slowing or loss of precision over time	Full X ray spectra not as clean as that of multiple-isotope instrument
Less “fear factor” over radiation issues	

TABLE V. ISOTOPE STRENGTHS AND LIMITATIONS

Strengths	*Limitations*
Rugged and durable Smaller / lighter weight Better access to tight areas Proven in field use Predictable characteristics No unexpected downtime Power requirements Widely accepted & trusted Higher-temp capabilities	Licensing requirements in many locations Source replacement Slowing of measurement over time May require multiple isotopes to cover desired element range

Table VI presents some common misconceptions about X ray tubes and radioisotopes.

TABLE VI. SOME COMMON MISCONCEPTIONS ABOUT X RAY TUBES AND ISOTOPES

Premise	*Fact*
X ray tube excitation eliminates the need for periodic source replacement.	*False*. Although the X ray tube does not experience the gradual decay inherent to a radioisotope source, the tube itself does have a limited lifespan. Since X ray tube sources are new to the world of portable instrumentation, there exists no clear data as to the useful life that can be assumed in this case. The average lifespan of an X ray tube in a traditional benchtop device is 3 to 4 years. Portable instrumentation is generally subjected to harsher working conditions. Therefore it is generally assumed among the developers of portable instrumentation that the useful life of an X ray tube in these systems will be at least 2 years.
A tube-excited instrument does not experience the loss of measurement speed over time that is common with radioisotope-based instruments.	*True*. However, it is important to note that although radioisotope-based instruments experience gradual slowing over time, they remain useable as the isotope decays. X ray tube-based systems do not experience the slowdown, but failure of the tube will occur suddenly – leaving the instrument unusable until the tube is replaced.
X ray tube-based instruments eliminate the regulatory hassles associated with radioisotopes.	*Partially true*. This is considerably less hassle associated with X ray tube devices in most locations, however there are still regulatory requirements that must be met. These vary by state and country, as with radioisotope licensing.
X ray tube-based instruments eliminate the need to measure with multiple sources.	*True*. The use of primary filters and variable voltage in X ray tube excitation allows the tube to provide excitation over almost the entire element range normally requiring three isotope sources.
X ray tube-based devices are safer to use than radioisotope-based instruments.	*False*. In fact, X ray tube devices typically produce a higher X ray flux – making it more critical that accidental exposure be avoided. The only safety advantage is that the tube devices do not produce X rays when not powered on, whereas radioisotopes produce rays constantly. A typical radioisotope-based system however, used constantly for 8 hours per day, 50 weeks per year, exposes the user to a total of less than 50 mR (or less than 1 percent the allowable annual exposure limit).

4. COMPUTER TOMOGRAPHY

Computerized Tomography (CT) is a fast developing technique focused on imaging and measuring multi-component and multi-phase processes realized in a wide range of industries. Computerized tomography is now a routinely applied technique in some universities and industrial laboratories in developed countries. It provides a vast amount of data needed for modeling and controlling industrial processes.

This can be illustrated by the latest applications of tomographic techniques in chemical, food, and pharmaceutical sectors, for example. Tomographic measurements can be obtained using different sensors such as x ray, or gamma ray, ultrasonic, acoustic, optical, microwaves, and electrical impedance electrodes.

Gamma tomography is based on radiation attenuation measurements (*I*) in several directions through an object (with thickness *x*), expressed by Beer's law:

$$I = I_0 B \exp(-mx)$$

This is a "hard-field" sensing principle provided that efficient detector collimation is applied to ensure that *B*, the buildup factor accounting for scattered radiation, is close to unity.

The linear attenuation coefficient (*m*) is proportional to

- r (density) at high energies (densitometry)
- Z^4 to Z^5 (atomic number) at low energies

Gamma transmission tomography allows measuring spatial distributions of material based on its attenuation properties. The attenuation properties take into account the nature of material (atomic number) and the density. It means that transmission CT can distinguish phases with significant different attenuation properties due to density (liquid-gas or solid-gas) and/or atomic number (iodide, tungsten).

For transmission tomography it is useful to start with the selection of radiation source and decide what is required with respect to:

- Energy
- Activity

Finally, detector collimation has to be considered to reduce the effect of scattered radiation:

- Electronic collimation (not possible for low energy systems)
- Mechanical collimation
- Combination of electronic and mechanical collimation.

The energy basically has to be selected according to the dimension and composition of the process vessel as indicated in the table above. The activity has to be selected to meet the demands of speed, spatial resolution and accuracy. The latter should be done according to the ALARA-principle.

Another important parameter in this context is the detector technology. The most realistic alternatives are presented in the Table VII.

TABLE VII. DETECTOR TECHNOLOGY USED IN CT

Detector technology		Radiation energy	Robustness Stability	Speed of response	Stopping efficiency	Cost
Scintillation-crystal with read-out:	PMT*	High	0	+	+	-
	PD*		+	-	+	0
	APD*	⇑	-	+	+	-
CdZnTe			+	+	+	0
Si		⇓	+	+	-	+
Gaseous (e.g. HP Xe)		Low	0	+	-	0

*PMT= Photomultiplier tube, PD= Photodiode, APD= Avalanche photodiode
+= good, 0= neutral, -= bad.

Software consists of three parts:

- Performances estimation of direct nucleonic gauge for CT (contrast, count rate, acquisition time etc.)
- Raw data processing before reconstruction (base line or noise correction, artifacts removal),
- Tomographic inversion process.

Figure 15 presents a laboratory scale gamma transmission tomograph constructed at the Bergen University, Norway.

The γ-ray tomograph has five 20 GBq ^{241}Am γ-ray sources (60 keV) and five detector arrays each with 17 CdZnTe detectors, that is a total number of 85 views.

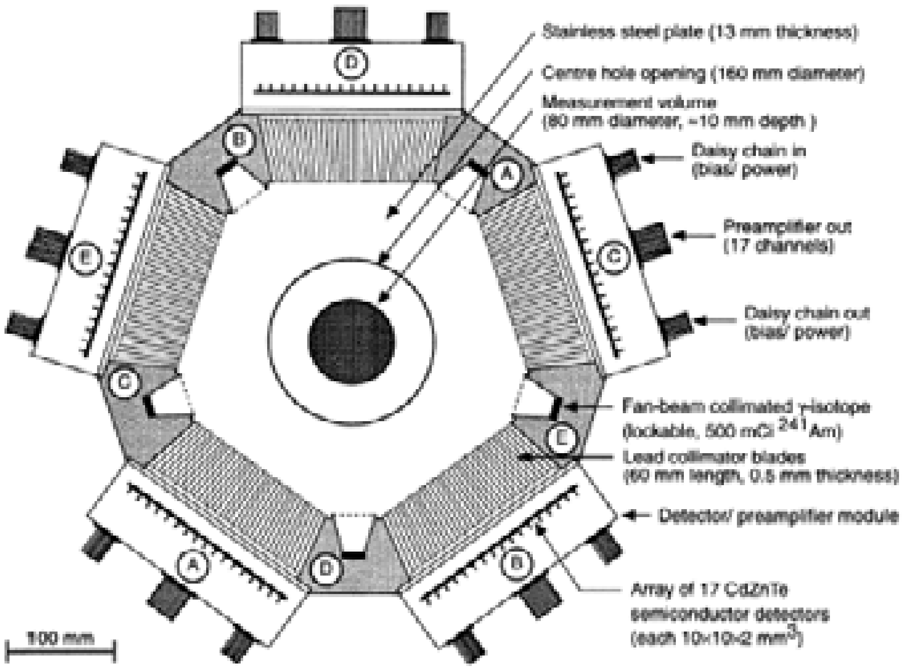

FIG. 15. Gamma transmission tomograph constructed at the Bergen University, Norway.

5. COST-BENEFIT ON NCS APPLICATIONS

The economic advantages to be gained from the use of nucleonic control systems vary greatly according to the application and the financial circumstances of different industries. For industry to invest in radioisotope applications there must be a clear incentive for it to do so. In today's economic climate costs are carefully controlled and to justify the purchase of a radioisotope applications service from an external supplier a well-argued case must, in general, be presented to senior management. Such a case must demonstrate either that:

- the proposed investment will generate rapid economic payback; or
- it will effect worthwhile safety improvements; or
- it will have an advantageous environmental impact.

The benefits to an industry which derive from accurate continuous measurement flow from:

- savings of raw materials,
- almost instantaneous monitoring of quality of manufactured product,
- reduced labour cost,
- reduction of waste and rejects.

Cost to benefit ratio for application of the nucleonic gauges is a very important parameter sometime playing decisive role in convincing the end user to the chosen measuring system. Methods of the cost to benefit calculations are relatively well known for the large gauging systems used mainly in the mineral processing industry. The cost to benefit ratio for some NCS can be different in various countries due to the different technologies and also to social and economic situation in the country where the system is being installed.

There is a group of nucleonic gauges for which it is not possible to determine the cost to benefit ratio (e.g. beta absorption monitors used for determination of the dust concentration in the ambient air). Also, the factual value of the cost to benefit ratio for many of the nucleonic gauges are reluctantly disclosed by the users and in some cases are even considered as classified information. Nevertheless, presentations to the end users some examples of the cost to benefit ratio can strongly influence their decision toward application of the chosen nucleonic gauging system.

Benefits derived from the use of on-line product monitors and analysers depend on each particular application. However, the main benefit is generally generated from delivering a product with mean value of some specified parameter closer to the specification and with a lower standard deviation. Apart from the economic benefits, which flow from operating closer to specifications, another benefit is the direct labour saving from a reduced requirement for laboratory staff.

5.1. Status of nucleonic gauges worldwide

NCS technology is by far one of the most requested among other industrial radioisotope techniques.

First IAEA complex survey on the NCS applications was carried out in 1962–63. It revealed that the total number of nucleonic gauges reported by 21 relatively high developed countries was around 20 000. The level, thickness and density gauges were typical simple gauges as majority at that time. The nucleonic gauge analysers and nucleonic control systems were just at the beginning. In Finland 72% of nucleonic gauges were used in paper industry, whereas in the U.K. the corresponding figure was 18%. The high number of nucleonic gauges in highly developed countries (USA, UK, USSR, Japan, Germany, Canada and France) was mainly reflection of industrial development in these countries in comparison to the others.

Nowadays, in many developed countries (Australia, France, Japan, etc), nucleonic gauge applications have reached a saturation (Fig. 16). The number of nucleonic gauges in France and Japan was reported around 6500 units in the period 1995–2000; this might be a typical number for many developed countries. On the other hand, manufacturing of NCS in China has steadily increased, reaching the number of 50 000 nucleonic gauges in 2000.

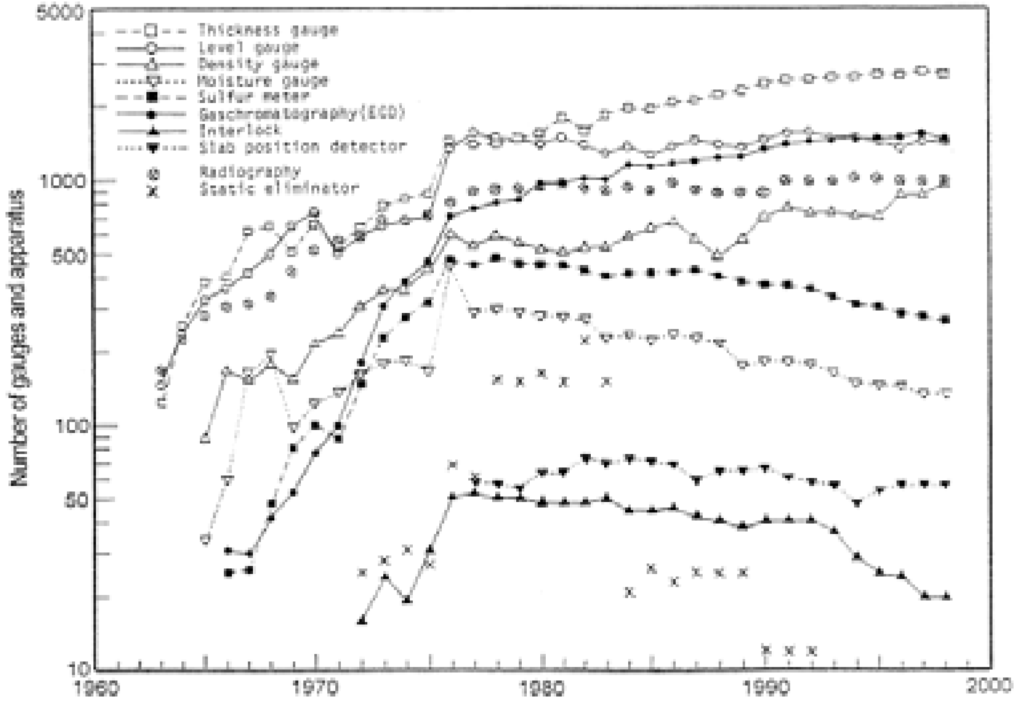

FIG. 16. Trend in number of nucleonic gauges in Japan.

There were conducted some partial surveys on the number of nucleonic gauges in East Asia and Pacific (RCA Region, 2000) and Latin America (ARCAL Region, 2000). It resulted that the RCA region accounts for nearly 71 000 nucleonic gauges, while in ARCAL Region there were around 3500 nucleonic gauges.

The United States of America is the biggest producer and user of nucleonic gauges worldwide. Statistics of 1975 showed the number of nucleonic gauges more than 100 000 units. The Russian Federation was a major producer and user of nucleonic gauges in sixties and seventies; at that time the number of nucleonic gauges was comparable with the United States of America. There are no available recent data about the nucleonic gauges in the Russian Federation, but for sure this technology is still operational and continuing to provide benefits to the Russian economy.

At present, the number of nucleonic gauges worldwide could be estimated around 250 000. A survey on nucleonic gauges worldwide in the mid seventies provided nearly the same figure. The number of nucleonic gauges very probably has been roughly constant since 1975, but R&D has been progressing, continuously designing and manufacturing very sophisticated NCS, so the value of nucleonic gauges has increased many times while the number of gauges remained more or less constant in most developed countries.

After 40 years of nucleonic gauge applications, the situation has changed for better; the structure of nucleonic gauges has been progressing towards online and portable elemental analysers. Another positive trend is the progressive use of nucleonic gauges in developing Member States. It is evident that the benefits of NCS applications in industry are steadily increasing during these decades and the NCS technology is playing a considerable role in economic development worldwide.

5.2. Case studies

1. Off-line nucleonic gauge for analyzing copper and zinc concentrations

The X ray fluorescence technique was used to measure copper and zinc concentration during the mineral ore processing line. The measurements were performed off line taking samples time after time. The benefit in copper and zinc concentrates coming from optimal monitoring of the concentrates was estimated for one year production time. The cost of an off-line XRF mineral ore concentration nucleonic gauge is from US$ 100.000 to 300.000. Table VIII gives the estimation of benefit for copper concentrate, which is calculated as difference in incomes with NCS and without NCS.

TABLE VIII. THE COPPER PRODUCTION IN ONE YEAR.

Copper analysis without NCS			
	Ton / year	*Copper (%)*	*Zinc (%)*
Mineral production	850.000	0,76	1,90
Copper concentrate	26.371	22,3	2,00
Residuals		0,06	0,16
Annual value of copper concentrate : US$ 10.550.000			

Copper analysis with NCS			
	Ton / year	*Copper (%)*	*Zinc (%)*
Mineral production	850.000	0,75	1,80
Copper concentrate	24.601	23,9	2,40
Residuals		0,06	0,13
Annual value of copper concentrate: US$ 10.800.000			

The benefit using NCS is of US$250 000 net incomes. The similar analysis for Zinc gives US$180 000 as additional benefit in this case. Annual benefit using NCS is: US$430 000

2. On-line NCS for iron analysis in mineral ore processing

NCS was applied for on-line measurement of iron ore concentration before entering a grinding mill. The NCS used ^{241}Am and ^{137}Cs sealed sources. The NCS costs around US$100 000. The magnetic separator used before the grinding mill has less capacity than the mill. Before installing the NCS the feed rate was kept constant using the best mineral available. The NCS monitors the average iron concentration in mineral ore entering the mill; based on this information the conveyor belt velocity changes according to a control equation feeding more mineral ore into grinding mill with lower iron concentration and vice-versa, increasing the iron production and bringing an annual benefit of US$ 400000, paying back the equipment cost in three months only.

3. Thickness nucleonic gauge (TC project in Bangladesh)

NCS was used for monitoring the basis weight and thickness of paper sheets. A medium size paper mill produced paper with thickness between 97 and 117 μm with the mean value of 107 (that means 20 μm tolerance). After installing the NCS the tolerance was reduced to 6 μm (very good homogeneity) and the mean value of thickness was shifted to 100 μm, which is the minimal thickness produced by the paper machine (Fig. 17). 7% of raw material was saved. The cost of NCS was approx. US$150 000 and the annual saving up to US$150 000, that means that the cost was paid back in one year.

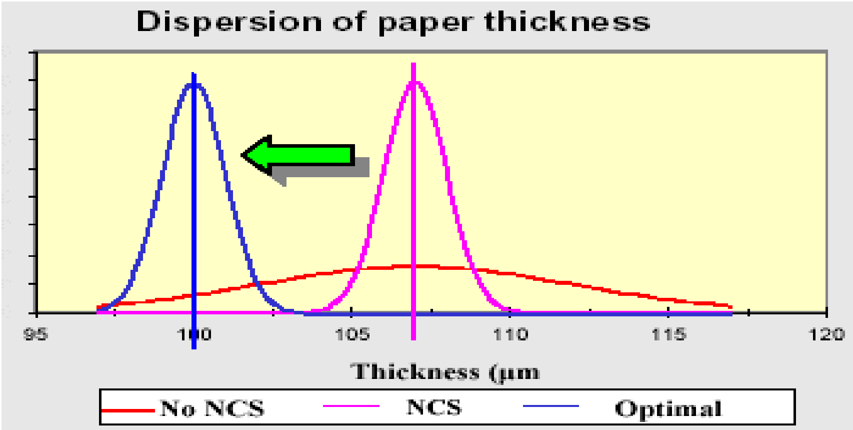

FIG. 17. Thickness gauge for process optimisation.

4. Spectrometric borehole logging gamma technique for coal analysis

An in situ spectrometric borehole logging technology for routine applications in mining deposits of coal and iron ore was developed in Australia. These so called SIROLOG gauges are commercial instruments largely used in mining of coal and other minerals. Because of the close correlation between the SIROLOG estimates and the laboratory-analysed ash and Fe, and the tight relationship between ash and calorific value, the need for cored hole drilling and laboratory sample analysis has been significantly reduced. Before 1993, up to 50% of all exploration holes drilled were cored holes. Following the advent of SIROLOG at Callide Coalfields in 1993, the number of cored holes drilled for coal quality has been reduced to 10% of the total number drilled. For approximately 150 exploration holes drilled each year 60 holes that were previously cored have been replaced by chipped rotary holes. An average depth of exploration hole is 120 metres. Costs of drilling a cored hole are around A$130 per metre. At A$25 per metre for a rotary chip and SIROLOG-logged hole, there is a substantial cost benefit.

Consequently, this allows the exploration geologist to either reduce the drilling budget for the same number of holes planned or drill more holes for the same cost budget.

Quantified benefit generated by eliminating costly cored holes can be summarised as:

- Costs of drilling 60 cored holes of 120m depth at A$130 per metre: A$936 000
- Costs of drilling 60 chipped holes (the same depth) at $25 per metre: A$180 000
- Benefit generated from savings on drilling costs: ~A$750 000
- Costs of assaying 60 cored holes at ~A$1,800 per hole: A$108 000
- Costs of geophysical logging 60 chipped holes at ~A$110: A$7 260
- Benefit generated from savings on assaying costs: ~A$100 000

The total quantified benefit of ~A$850 000 per year is significant, particularly when compared with the cost of acquiring the SIROLOG logging system (total costs together with purchase of a dedicated logging vehicle) of A$170 000 (in 1993 Australian dollars).

5. On-line coal ash analysers

COALSCAN nucleonic gauge manufactured in Australia is used for on-line coal quality analysis. Coalscan ash monitors are used in a wide range of applications including mine grade control, raw coal monitoring, coal sorting, coal blending, stockpile management, power station feed monitoring and blending, and ash monitoring at coal shipping ports. It uses a dual-energy gamma ray transmission (Duet model).

A single scintillation detector measures intensities of collinear beams originated from Cs-137 and Am-241 sources. This system is most widely used for the on-line (on-belt) monitoring of the ash content of coal. The absorption of the lower energy gamma rays (Am-241) depends on ash content, while absorption of higher energy gamma rays (Cs-137) depends almost entirely on the mass per unit area of coal in the beam. Ash content is determined by combining measurements of the two beams. The determination is independent of both the bed thickness and the mass of the coal. The main advantages of the Duet gauges are simplicity, direct on-belt measurement and relatively low cost. The most important disadvantage of this technique is its relatively high dependence on variable composition of ash (high Fe and Ca content).

An economic evaluation, by an independent consulting company, of benefits to the Australian mining industry flowing from use of Coalscan nucleonic gauges was commissioned by CSIRO in 1988. The consultants assessed the costs and benefits over the period 1973 to 1993, allowing a maximum five-year benefit from any one installation. The total quantified benefit to Australia from productivity gains in the coal industry was estimated to be US$130 million (1988 dollars). The 39 Coalscan ash monitors (dual transmission gauges) installed by 1988 in Australia were saving the Australian coal industry about US$22 M per year, this estimate was based on an assumed 1.5% average improvement in productivity.

6. Natural radioactivity nucleonic gauges for ore processing

Iron ore analyser for alumina, potassium and manganese

Ironscan 1500 is a commercially available gauge for on-line monitoring of alumina, potassium and manganese of iron ore using spectrometric natural gamma method. Alumina (kaolin) is strongly correlated with thorium content in Australian iron ore. Manganese is also correlated with potassium radioactivity content. The on-stream analyser (Ironscan 1500) was developed for monitoring Al, K and Mn in iron ore. These impurities cause problems in some Australian and South African iron ore mines. The benefit from a single installation is estimated at A$3 million per year.

5.3. Conclusions

The beneficial role of nucleonic gauge technology for process control and optimization in industry is amply demonstrated and recognized by end users. The NCS technology derives a benefit to industry of billion US dollars a year worldwide.

The IAEA survey of early sixties and other partial surveys have shown that the NCS technology was well accepted and established since 40 years ago, and it was by far the most spread nuclear technique in industry. The saturation in the capacity of nucleonic gauge installations in developed countries (which account for more than 90% of total installations) happened in mid seventies. The new generation of more complex and sophisticated nucleonic gauges was designed and implemented in eighties, bringing additional benefits to industry. New development is expected in hardware and software to design and manufacture gauges using low activity radioisotopes or without radioisotopes (using radiation generators) which will be well accepted by end users.

6. TRENDS IN NCS TECHNOLOGY

The future for NCS in industrial applications depends upon many factors. Where their unique properties match the dominant requirement, then an extension in the intensity and range of applications can be expected. However, sustainable development of the supporting technologies and continuing economic viability of the areas in which they are presently used need to be demonstrated. In some areas of application, competing non-nuclear techniques will inevitably reduce the scope of applications.

There are certain NCS measurement techniques that are facing serious technical competition from non-nuclear methods. Microwave or capacitance techniques for moisture measurement, coriolis techniques for fluid mass flow, and electrical techniques for industrial tomography are pertinent examples. In some cases these techniques might completely eliminate the need for a nuclear technique, while in others, advantages and disadvantages must be weighed for a particular application. Also, in some cases a non-nuclear technique might be incorporated into a NCS to widen and improve its performance (e.g. multi-parameter measuring nuclear analysers). In any case it would be useful to have information on these emerging new competing technologies — possibly in the form of an inventory.

NCS have undergone impressive changes since the introduction to industry of early models of thickness, level and density gauges in the 1950s. The reasons and background for these changes have been described in the previous sections. In this section, some of the more typical and/or important new trends and emerging application techniques will be briefly discussed.

The development of new NCS technology needs enhancement in hardware and software. The observed trends and new developments include the:

- use of low activity sources;
- replacement of radioactive sources with radiation generators;
- integration of new detectors with higher efficiency and better resolution;
- development of high count rate nuclear electronics;
- enhancement of software programmes for data acquisition and processing, including multivariate analysis for calibration and 3-D visualisation software packages;
- use of Monte Carlo simulation for design optimisation, calibration and data processing;
- introduction of expert systems for the NCS field;
- extending the use of the spectral data that is available from multi-channel spectrometric measurements;
- implementation of imaging techniques;
- designing and manufacturing of portable nucleonic gauges.

One of the present trends is combining nucleonic gauges with non-nuclear techniques for obtaining more comprehensive information. For example the addition of a microwave beam to on-line coal analyser permits the determination of coal moisture with higher accuracy than that obtainable with a neutron moisture gauge. Nucleonic gauges, in many specific applications, can only benefit from introduction of complementary non-nuclear devices providing information otherwise not available from NCS only.

Another observed trend is the development of imaging techniques that apply gamma and X ray transmission tomography. These techniques are mostly applicable in process and chemical engineering.

Apart from the majority of NCS that apply substantial activity of radioisotopes there are a number of ingenious small nucleonic gauges using low radioactivity sources, under 3.7 MBq. This activity is defined in many countries as the minimum activity of a radioactive source requiring a License for Possession, Use and Transport of Radioactive Substances. These gauges are being recently implemented for several industrial applications in Australia and Japan.

7. TRANSFER OF NCS TECHNOLOGY

Experience has shown that on the NCS side of things is considerable scope for developing countries to produce simple, on-line (or off-line) analysers, utilising a wide range of nuclear phenomena. Of course, sophisticated NCS systems are widely available from many commercial suppliers, but generally at large expense. In reality, there are many analytical measurements on industrial plants that do not need this high level of sophistication. Using simple nuclear phenomena like beta-backscatter, neutron moderation, slow neutron absorption, differential gamma ray attenuation, isotope induced XRF, etc many useful measurements can be made with equipment that is little more than a source, a detector and a scaler-ratemeter. The development of such systems would considerably broaden, or at least reinforce, the knowledge of young scientists and technicians as well as giving them valuable appreciation of the needs of their local industries. Also, of course, these types of development can be done very cheaply.

Transfer of NCS technology to developing Member States is a continuous process. Many factors affect a successful transfer of technology, among them:

- existing infrastructure in the recipient country;
- identified end-user for the transferred technology;
- a good interaction between end-user, national NCS application groups and the technology provider, with well defined roles and responsibilities;
- clearly defined goals, objectives and milestones for the transfer;
- a continuing back-up after the transfer.

NCS technology transfer is carried out within the framework of the IAEA TC projects. Some examples of successful NCS technology transfers through the IAEA TC projects include:

- transfer of PGNAA technology for on-line and in-situ grade control of copper ore, to Chile from Australia and France;
- transfer of PGNAA technology for on-line and in-situ ash-in-coal analysis, to Colombia from Australia and France;
- transfer of low radioactivity portable nucleonic gauges for the Vietnamese coal mining industry to Vietnam from Australia, Japan and New Zealand.

In most cases the NCS market in developing countries is relatively small and, additionally, there are many particular situations that require specific solutions. For this reason, local large-scale manufacture of NCS is not feasible. Nucleonic gauges tend to be produced either on a case-by-case basis or in very small batches. Portable nucleonic gauges for niche applications are quite attractive for developing MS. These gauges could serve many end users for solving their specific problems time after time.

There are two kind of technology transfer, *"passive transfer" when the end user* is only a passive recipient of the technology (nucleonic gauges are installed as part of the purchased plant technology from abroad), and *"active transfer"* when nucleonic gauge specialists take active part either in assembling and in configurating the nucleonic gauge according to local conditions or adopting it for other applications.

Promotion of new applications and techniques in NCS design, calibration, quality control and operation is going on. There is need to stimulate, build and maintain consulting capability in interested developing Member States. Teams of skilled specialists need to be trained to look after the NCS used in their industries, to calibrate and to check the safety of the NCS used, and to advise their local industries in selecting the appropriate NCS from a techno-economic point of view.

8. RADIATION PROTECTION AND SAFETY

8.1. Background

Ionizing radiation can be very hazardous to humans and steps must be taken to minimize the risks. This Section provides only a brief summary of some of the principles of radiation protection associated with the use of sources of ionizing radiation used in nucleonic gauges. In order to concentrate on the important principles a certain fundamental level of knowledge of radiation physics has been assumed. An explanation of quantities and units is available in other IAEA publications [1-2].

The essential requirements for protection from ionizing radiation are specified in the International Basic Safety Standards (BSS) [3]. The Standards state that the prime responsibility for radiation protection and safety lies with the Licensee, Registrant or employer. Some of the fundamental requirements of the Standards relevant to nucleonic gauges are discussed in this section, but the Standards should be consulted in full for a comprehensive understanding of their requirements.

Principles of dose limitation

The principles of dose limitation are briefly summarized below:

- no application of radiation should be undertaken unless justified,
- all doses should be kept "as low as reasonably achievable" (ALARA), economic and social factors being taken into account,
- in any case, all individual doses must be kept below dose limits.

It should be emphasized that the most important aspect of dose limitation, assuming that the practice is justified, is to keep radiation doses As Low As Reasonably Achievable (ALARA).

Dose limits

The dose limits for workers and the public are given below, although doses to gauge operators are expected to be significantly below these levels during normal operations.

Occupational dose limits

Occupational dose limits are chosen to ensure that the risk to radiation workers is no greater than the occupational risk in other industries generally considered safe. Radiation doses must always be kept as low as reasonably practicable, but some industries may require employees to routinely work in high radiation areas and therefore dose limits are required. The BSS specifies that doses to individuals from occupational exposure should not exceed:

- an effective dose of 20 mSv per year averaged over 5 consecutive years
- an effective dose of 50 mSv in any single year
- an equivalent dose to the lens of the eye of 150 mSv
- an equivalent dose to the extremities (hands or feet) or the skin of 500 mSv in a year.

Public dose limits

If the use of nucleonic gauges may lead to the public being exposed, then the following dose limits must not be exceeded.

- an effective dose of 1 mSv in a year
- in special circumstances, an effective dose of up to 5 mSv in a single year provided that the average dose over five consecutive years does not exceed 1 mSv per year.
- an equivalent dose to the lens of the ye of 15 mSv in a year
- an equivalent dose to the skin of 50 mSv.

8.2. Administrative requirements

Authorization

In order to control the use of radiation sources and to ensure that the operating organization meets the requirements of the BSS, the legal person responsible for any radiation source will need to apply for an authorization from the national Regulatory Authority. This authorization is usually in the form of a license or registration. Prior to buying or acquiring a nucleonic gauging system, the operating organization will, therefore, need to apply for such an authorization from the regulatory authority. The regulatory authority will need details about the gauging equipment, such as: the purpose for which it will be used, the radionuclide(s) and activity, manufacturer and model, details of the storage facility and installation site, copies of approval certificates, end of life considerations (disposal or return to supplier) etc. The regulatory Authority will also need: information regarding the people who will be using the equipment, such as their qualifications and training in radiation safety etc. .Further details about the relevant legal and governmental infrastructure, the regulatory control of sources, and the notification and authorization for the possession and use of radiation sources are available from IAEA [4–7].

Inspection and enforcement

The Regulatory Authority may inspect the registrant/licensee to audit their provisions for radiation safety and to physically inspect the premises. Enforcement action may be taken against the operating organization if the level of radiation protection and safety are considered unacceptable [8].

8.3. Types of gauges

There are basically three main categories of nucleonic gauges used in industry:

Transmission gauges, used to measure density, thickness, etc. The source housing and the detector are on opposite sides of the material and the radiation is attenuated as it travels through the material. Typical beta source activity ranges from 40 MBq to 40 GBq, whilst gamma sources activities are between 0.4–40 GBq. X ray generators may also be used.

Backscatter gauges, used to measure thickness of coatings, well logging, etc. The detector and source housing are on the same side of the material and therefore the detector has to be shielded from the primary radiation. The radiation enters the material, interacts with it and scatters back out. Typical beta source activities usually range from 40–200 MBq whilst gamma sources are up to 100 GBq.

Reactive gauges (e.g. used for elemental analysis). Certain low energy gamma and X ray sources can cause fluorescent X ray emissions in the material being investigated. Typical source activities range from 200 MBq – 40 GBq. X ray and neutron generators may also be used.

IAEA have published a ‘Categorization of Radioactive Sources’ [9] — which provides a relative ranking of radioactive sources in terms of their potential to cause severe deterministic effects (i.e. how ‘dangerous’ they are). The Categorization is composed of 5 Categories — with Category 1 sources being the most ‘dangerous’ and Category 5 the least ‘dangerous’. Gauges generally fall into categories 3 and 4.

Table IX presents the major radioisotopes used in nucleonic gauges.

TABLE IX. RADIOACTIVE SOURCES TYPICALLY USED IN NUCLEONIC GAUGES

Radioisotope	Type of radiation
Promethium-147	Beta
Thallium-204	Beta
Krypton-85	Beta
Strontium/Yttrium-90	Beta
Americium-241	Gamma
Caesium-137	Gamma
Cobalt-60	Gamma
Americium-241/beryllium	Neutron
Cf-252	Neutron
Iron-55	X-ray
Cadmium-109	X-ray

8.4. Source construction and gauge housing

Sources need to be designed, manufactured and tested to meet the requirements of the appropriate ISO standard (currently ISO 2919) or equivalent national standard. Sources also should have been leak-tested in accordance with the appropriate ISO standard (currently ISO 9978) and have a valid leak-test certificate.

For the source housing, the specific standard is ISO – 7205 (1986). The standard specifies the built-in safety features to be incorporated in the design, construction and use of gauging devices, to ensure adequate safety of persons working with or in the vicinity of the gauges. Particular emphasis is placed on designing built-in safety so as to minimize leakage radiation on and around the gauging device, the reliability of the gauging device and its components to withstand special environmental conditions, and endurance with long term use.

The minimum test requirements include high and low temperature tests for normal use and an elevated temperature test for accident conditions. Levels of leakage radiation are measured on and around the gauge for both the beam ‘ON’ and ‘OFF’ condition to ensure safety of the persons working in the vicinity. A vibration test is also performed on a gauge that intended to be used in locations where there is likelihood of mechanical vibrations.

8.5. Management requirements

The operating organization has the ultimate responsibility for ensuring that gauges are used in compliance with the relevant national regulations. This responsibility cannot be delegated to employees, workers, the radiation protection officer (RPO), the Qualified Expert or anyone else. An effective management safety infrastructure is therefore necessary to ensure that a high standard of radiation protection and safety is maintained and that the national regulations/BSS requirements are met [10]. It is important that the organizational arrangements of the operating organization allow a free flow of safety related matters between the various levels. Written policies should demonstrate management’s commitment to safety and the duties of workers need to be identified. Some organizations may need to consult Qualified Experts for advice on specific areas of radiation protection (e.g. which radiation monitors to use). The scope and role of these experts should be clearly defined. Quality assurance programmes should ensure that radiation protection and safety measures within the organization continue to be effective.

Local rules and supervision

Employees should follow the procedures specified in Local Rules to ensure that an adequate level of protection and safety is maintained during normal daily work with the gauges and any maintenance on the gauges or other equipment in the proximity.

In order to provide adequate supervision of protection and safety and to ensure the Local Rules are obeyed, operating organizations will need to appoint a radiation protection officer (RPO). Management should ensure that the RPO is delegated the appropriate authority to ensure that operating procedures and local rules are followed. The RPO should also have the authority to stop any working practices they consider unsafe.

Quality assurance

Assurance that radiation protection and safety requirements are being satisfied should be achieved through formal quality control mechanisms and procedures for reviewing and assessing the overall effectiveness of protection and safety measures. Systematic audits and reviews should detect and result in correction of systems that do not function.

8.6. Practical protection for gauge users

The practical elements to radiation protection are: Time, distance, shielding and prevention of access. These are discussed in detail below.

Time

Radiation is normally emitted from a source at a constant rate and this is measured in microsieverts per hour (µSv/h) or millisieverts per hour (mSv/h). The shorter the time a person spends in the radiation field the lower the radiation dose will be to that individual. It is therefore advisable not to linger in areas where there may be high radiation levels and any work done close to a source should be done efficiently. This will help to ensure that the radiation risks are kept as low as reasonably achievable.

Distance

Radiation levels decrease rapidly with increasing distance and it is therefore important to never directly handle radiation sources. Specially designed tools with long handles must always be used if a source is to be replaced or manipulated.

Shielding

The main consideration for gauges is to prevent access to the high radiation levels close to the source. This can be achieved by providing an adequate thickness of suitable shielding material around the source. The amount of shielding required will be determined by the type and energy of the radiation and the activity of the source. For example several centimeters of lead may be required around a gamma source or a several millimeters of aluminium around a beta source. The environment in which the gauge will be used should also be considered when deciding on the material and design of the shielding (e.g. high temperature or corrosive chemicals could significantly reduce the effectiveness of the shielding).

Prevention of access

In many cases it is not possible to fully shield the source and the material to be examined. It will, therefore, be necessary to prevent access to any areas of high radiation by using shutters (manual or automatic), mechanical guarding or interlock systems. In some cases the designation of controlled areas may be additionally required in order to restrict access to authorized persons only.

8.7. Portable gauges

The use of portable gauges can present additional hazards if they are not used safely. It is not always possible to utilize interlocked shutters to shield the source and, therefore, care must be taken not to irradiate persons when the primary beam is exposed. Prevention of access may not always be possible by using physical barriers so other means must be used e.g. the establishment of a controlled area, use of portable barriers, suitable warning notices.

Additionally, the gauging device should also be capable of withstanding the rigors of shipping and transportation should be done in compliance with IAEA's Regulations for the Safe Transport of Radioactive Material [11] or the equivalent national transport regulations. Sources are normally shipped in specially designed containers called Type A or Type B.

8.8. Warning notices

All radiation sources should display the radiation trefoil to warn of the potential hazard. Details of the radionuclide, activity on a specified date and serial number should be included on a label permanently attached to the source housing. Any shutters should be clearly marked to indicate the status of the source to persons in the vicinity. X ray equipment should also display a clear indication when radiation is being generated. Notices should state whether any controlled areas are designated around the gauge.

8.9. Radiation monitoring

Operating organizations need to have in place an effective programme for monitoring occupational exposure to radiation. Guidance on establishing a monitoring programme for external exposure, the appropriate dosimetry to be used for workplace and individual monitoring and record keeping is given in an IAEA Safety Guide [12].

Workplace monitoring

Portable dose rate monitors can be used to measure radiation levels (normally in microsieverts or millisieverts per hour) around gauges. Monitoring may be carried out for several reasons, for example to;

- check the shielding around a gauge is intact
- check a shutter is closed before carrying out maintenance on or close to a gauge
- check the radiation levels around a shipping container to ensure it is safe to transport
- confirm the extent of a controlled area around a gauge
- check the shielding around a source storage facility is acceptable.

There are many different types of radiation monitor and it is important to ensure the correct one is used otherwise incorrect assumptions may be made which could lead to persons being inadvertently exposed, possibly to high levels of radiation. For example special monitors are needed to detect neutron radiation, monitors used to detect gamma radiation may not detect beta radiation. Persons carrying out monitoring should therefore be trained, follow approved procedures and keep appropriate records of the radiation levels measured.

All monitors should be routinely calibrated (normally annually) by a Qualified Expert.

Personal monitoring

The dose rate monitors discussed above can be used to indirectly estimate the radiation dose to a person who works in the area where the measurement was made. In some situation, however, workers may be required to wear personal dosimeters to assess their accumulated individual dose over a period of time, perhaps because they are carrying out maintenance on several gauges or perhaps are working with portable gauges.

There are several different types of personal dosimeter that gauge users may encounter, but they can be divided into categories: those that give a direct reading of accumulated dose and those that require processing by a laboratory (e.g. film badge or thermoluminescent dosimeter (TLD)). The type of dosimeter required and where/when it should be worn will normally be advised by the Radiation Protection Officer.

8.10. Storage and source accountancy

Storage

There will be occasions when sources need to be stored. For example, portable gauges not in use, gauges removed from a production line during maintenance, old gauges awaiting disposal, etc. To ensure the safety and security of the sources the storage facilities should:

- provide adequate shielding,
- be physically secure (e.g. locked when not in use) [13],
- not be used as a general storage area for other goods,
- be fire proof and not contain other hazardous materials (e.g. flammable liquids) be dry,
- appropriately labeled (e.g. radiation trefoil and warning notices in a local language).

Source accountancy

Records need to be kept which show the location of each source at all times. National regulations may specify how frequently the accountancy checks need to be carried out, but in general, the following can be applied:

- sources in permanently installed gauges should be accounted for at least once per month
- sources in portable gauges should be accounted for every day they are out of the store and once a week when they are in storage.

8.11. Maintenance and leak testing

Maintenance

Nucleonic gauges are often used in harsh environmental conditions which may result in the radiation safety and protection of the gauge be adversely affected, for example; shielding may be degraded, shutters may stick, warning notices may become illegible, etc. It is therefore important that gauges are included in a routine maintenance schedule. Persons carrying out the maintenance work need to be aware of the radiation hazards and be appropriately trained. When working close to a gauge a radiation monitor should always be used to confirm that any shutters are fully closed and that the source is fully shielded.

Leak testing

When a new radioactive source is purchased it should be supplied with a certificate confirming that it is free from contamination. Periodic re-checks need to be carried out by an appropriately trained and qualified person to ensure that the structure of the source remains intact. Gauges that are used under harsh environmental conditions (e.g. high temperature, corrosive chemicals, and high levels of vibration) may need to be checked more frequently. The intervals for leak testing should not normally exceed 2 years (and may be more frequent), but this will normally be specified by the regulatory authority.

8.12. Dealing with emergencies

Before first using any nucleonic gauge the operating organization should carry out an assessment to identify any abnormal situations that may occur and to estimate the magnitude of the hazard [14] [15]. Contingency plans should be prepared and rehearsed so that if an accident does occur the plan can be quickly implemented to regain control of the situation and therefore mitigate the consequences. Several accidents from the use of nucleonic gauges in industry have already occurred. These were mainly due to the sharp, unexpected rise of temperature in the process causing the melting of the gauge and source; and to the accidental loss during borehole logging. Special measures were taken in these cases, isolating the area and temporarily closing the process line or the hole.

Other examples of potential accidents to be considered are: lost or stolen source, other forms of physical damage to the gauge (e.g. crushing), jammed shutter, transport accident, suspected exposure of persons, leaking source etc.

8.13. End-of-life considerations

Many accidents have occurred with disused or abandoned sources. Before a source is purchased, consideration needs to be given to what will happen to the source when it is no longer of use or if the operating organization goes bankrupt etc. In many cases the preferred option is to return the source to the supplier, possibly for recycling. Other options include permanent disposal or long-term storage. All options have financial and logistical consequences that need to be considered before the gauge is purchased [4].

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9. NUCLEONIC GAUGES WITH LOW RADIOACTIVITY SOURCES

The number of nucleonic gauges installed in industry in developed countries had already reached maximum levels in a period of just after the middle of the 1970's. New generation of nucleonic gauges with improvement in hardware and software has been introducing last two decades. Ingenious nucleonic gauges with low activity sources present a trend. These gauges accommodate sealed sources with radioactivity not exceeding 3.7 MBq (100 μCi), as this upper limit is defined in some countries as the minimum activity of a radioactive source requiring a license for possession, use and transport of radioactive substances. For this reason in Japan and Australia, the nucleonic gauges with such low activity sources have been increasingly employed in recent years in mining, environmental monitoring and construction works in the civil engineering. But due to the exemption from legal regulation, there is not complete statistics of gauges and users worldwide.

There are several types of low activity gauges and their main applications are:

- Airborne dust monitors for environmental monitoring, utilizing β particles attenuation by deposited dust on a filter paper. ^{147}Pm or ^{14}C β sources of less than 3.7 MBq are applied.
- Soil compaction gauges for civil engineering utilizing both transmission and backscatter of neutrons and gamma-rays for measuring the degree of soil compaction. ^{252}Cf and ^{60}Co sources of less than 3.7 MBq are applied.
- Portable level gauges utilizing low activity gamma-ray sources of ^{137}Cs or ^{60}Co in transmission geometry are used for inspection of the content of fire extinguishers.
- Low radiation intensity spectrometric gamma-gamma tools utilising 1.1 MBq ^{137}Cs source are used for the mining industry in well logging applications.
- A coal face analyzer utilising 2.4 MBq gamma-ray activity for coal bulk samples and *in-situ* analysis on coal face is used in the coal mining industry.

Typical low activity nucleonic gauges are:

9.1. Low activity nucleonic gauges for coal mining

Low radiation intensity (1.1 MBq) gamma spectrometric borehole logging probe for coal delineation and coal raw ash content utilises single-scattered gamma ray to provide information about bulk density of the formation, and multi-scattered rays of lower energies to determine coal raw ash content (Fig. 18).

FIG. 18. Low radiation intensity (1.1 MBq) gamma spectrometric borehole logging probe for coal delineation and coal raw ash content.

Low activity portable coalface ash analyser for differentiating coal and look alike sediments permits selective mining and is applicable to the production phase in open-cut pits and underground mines. The analyser works as a backscatter gamma ray type gauge. The same gauge using another stockpile probe is used for coal ash monitoring in coal enrichment plants, or coal blending in thermo power stations (Fig. 19).

FIG. 19. Coal face and stockpile analyser for ash content.

9.2. Soil moisture and density gauges

In early days of the 1970's, ^{252}Cf was newly introduced to import to Japan as an attractive isotopic source of neutrons, capable of utilizing rather high flux neutrons with a weak radioactivity. In those days neutron moisture gauges with ^{241}Am-Be had been well known as a useful tool, being employed almost in research laboratories only. Big diffusion of neutron moisture gauges in open-air fields outside the laboratories was not realized until the gauges with ^{252}Cf less than 3.7 MBq were fabricated and accepted as a standard tool by the Japan Highway Public Corporation in 1985. The adopted gauges were composed of a ^{252}Cf neutron moisture gauge coupled with a ^{60}Co gamma density gauge, of which both sources were less than 3.7 MBq in radioactivity, for on-site quality control of soil compaction in road construction works, as can be seen later in data sheets. The adoption of the NCS freely usable in any place had a significant meaning, because it opened a door to the new field of low radioactivity applications. At present about 1000 sets of the compaction gauges are estimated in field use in the construction industry, though the gauges are mostly employed in a rental system nowadays.

The techniques described above resulted in furthermore developments and new products in the civil engineering and related fields. Examples are, as shown in data sheets as well,

- Density gauge for coal storage piles,
- High accuracy moisture/density gauge by surface scanning (Soil and Rock Engin. Co.),
- On-line moisture/density gauge for fresh concrete at construction sites,
- Moisture and density gauges in the cone penetrometer for the foundation engineering.

9.3. Density meters in pipelines

Under the influence of the above developments, small source utilization came to be flourishing in various types of nucleonic gauging in industry. One of the examples in industry are on-line gamma density meters using a gamma source of 3.7 MBq ^{60}Co, ^{137}Cs or ^{133}Ba for solutions and slurries in pipelines. These have been spreading over a wide range of industry including chemical plants and construction industry [5]. The total number is estimated more than several hundreds, probably close to 1000 sets.

9.4. Suspended particulate matter analyzer

Suspended particulate matter, corresponding smaller sized airborne dust with a diameter not exceeding 10 micrometers, is an object of regulation by the atmospheric environment standard. As the most practical instrument measuring its mass concentration in air per an hour automatically, equipment using beta-ray absorption has spread after the notice by the Environment Agency in 1981. Measurement is made by determining the degree of beta-ray attenuation through a sample consisting of particulate matter collected on a roll filter paper. Also in this case, a source of activity less than 3.7 MBq is adopted to avoid difficulties arisen from the legal regulation. Around 2000 sets of the nucleonic instruments are now working for continuous observation of air pollution at environment monitoring stations throughout the country in Japan.

10. TYPICAL MODELS OF NUCLEONIC GAUGES

There are different kinds of installed nucleonic gauges used in routine service to industry for process control and optimization. Figure 20 presents a typical distribution of nucleonic gauges worldwide.

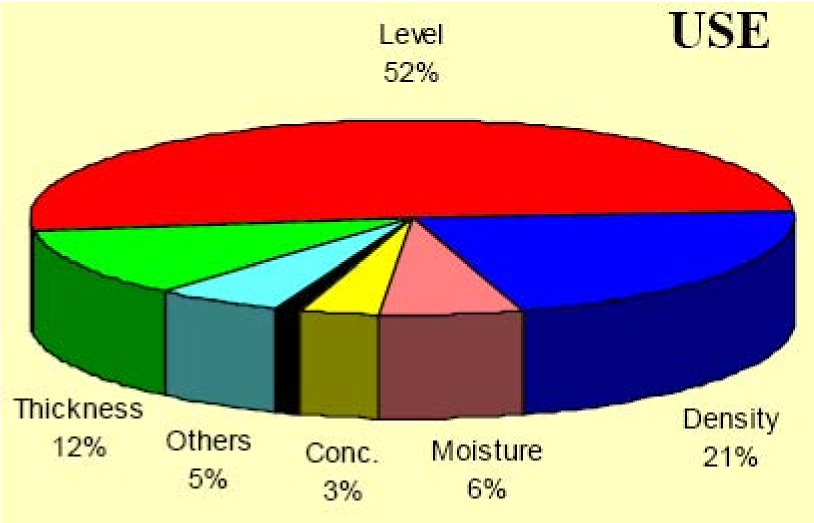


FIG. 20. Typical distribution of different kinds of nucleonic gauge installed in industry.

The detailed descriptions of major typical models of nucleonic gauges are presented in this chapter. For each model an information sheet is provided with basic parameters and applications. The models are classified according to the physical principles and applications:

- Level gauges
- Density, concentration and thickness measurement gauges
- Gamma nucleonic gauges for on-line coal ash analysis
- Prompt gamma neutron activation analysis (PGNAA) gauges for on-line bulk processing (coal, minerals and cement)
- X ray fluoresence (XRF) gauges for elemental analysis
- Gauges using natural radioactivity
- Combined nucleonic – conventional gauges
- Borehole logging gauges
- Low activity gauges
- Others: Niche applications.

10.1. LEVEL GAUGES

Portable gamma level indicator

1. General Information
1.1. Product Name / Model Number
Portable Gamma Level Indicator / DNG-P
1.2. Applications
Level/fill of bottles (liquids and liquefied gases) with an adjustable measuring arm.
1.3. Features
External installation. Measuring arm stretch: to 400 mm. Contactless measurement. High sensitivity. Fast response. High reliability and robustness.
1.4 Typical Price
Open price
2. Performance
2.1. Measuring Range
Bottle diameter: to 400 mm
2.2. Precision and/or Accuracy
± 1 cm
2.3. Radiation Source
^{60}Co, or ^{137}Cs: 7 - 20 MBq
2.4. Radiation Detector
Geiger Müller tube
3 Supplementary Explanation
(Measuring Principle / Block Diagram / Photo. etc.)

Portable Gamma Level Indicator - DNG-P.

Installed gamma level indicator

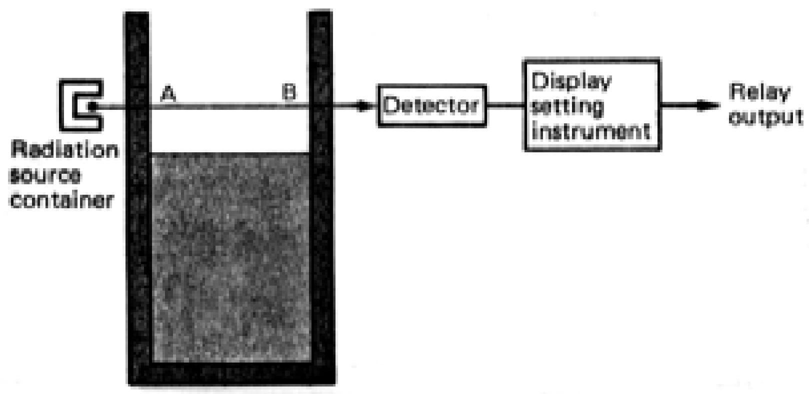
1. General Information
1.1. Product Name / Model Number
Gamma Level Indicator / DNG mod.2
1.2. Applications
Level / Fill control Industries: Cement, paper & pulp, chemical, petrochemical, glass, basic metal, construction, mining, food storage and processing, thermal power plants.
1.3. Features
External installation. Contactless measurement. High sensitivity. Fast response. High reliability and robustness.
1.4. Typical Price
Open price
2. Performance
2.1. Measuring Range
Adjustable for normal operation from 1.5 µGy/h to 15 µGy/h
2.2. Precision and/or Accuracy
Level determination with 5-10% accuracy
2.3. Radiation Source
^{60}Co or ^{137}Cs (source activity chosen according to the vessel parameters)
2.4. Radiation Detector
Geiger Müller tube
3 Supplementary Explanation
(Measuring Principle / Block Diagram / Photo. etc.)

Gamma Level Indicator DNG Mod. 2.

DNG installed at a cement factory.

Relay gamma level gauge

1. General Information
1.1 Product Name / Model Number
Relay gamma level gauge / NNL
1.2 Applications
Static level measurement of hot molten steel, glass, cement, etc.
1.3 Features
1) Non-contact and continuous measurement 2) Applicability in severe environments at high temperature etc. 3) Output signal provided for control of level.
1.4 Typical Price
On Request
2. Performance
2.1. Measuring Range
Continuous gauge: 100 – 200 mm
2.2 Precision and/or Accuracy
About 2.0 mm in 2 sigma and a response time of 1.0 s
2.3 Radiation Source
^{137}Cs or ^{60}Co, 1-2 GBq
2.4. Radiation Detector
Ionization chamber, G-M gas detector, Scintillation detector
3. Supplementary Explanation
(Measuring Principle / Block Diagram / Photo. etc.)



Gamma transmission level gauge

1. General Information

1.1. Product Name / Model Number

Continuous Level Gauge

1.2. Applications

The isotope level gauge is designed to measure contactlessly level of medium in tanks and containers. It is a continuous measurement of level for a large range of level fluctuations.

1.3. Features

Continuous measurement of level, display of measurement results on digital display panel, analogue output of measured level, transmission of measuring results to external computer or printer (optional). Head-controller distance max.1200m.

1.4. Typical Price

On request

2. Performance

2.1. Measuring Range

One segment: 0...1800mm max. number of segments per gauge:3

2.2. Precision and/or Accuracy

Precision. 1mm

2.3. Radiation Source

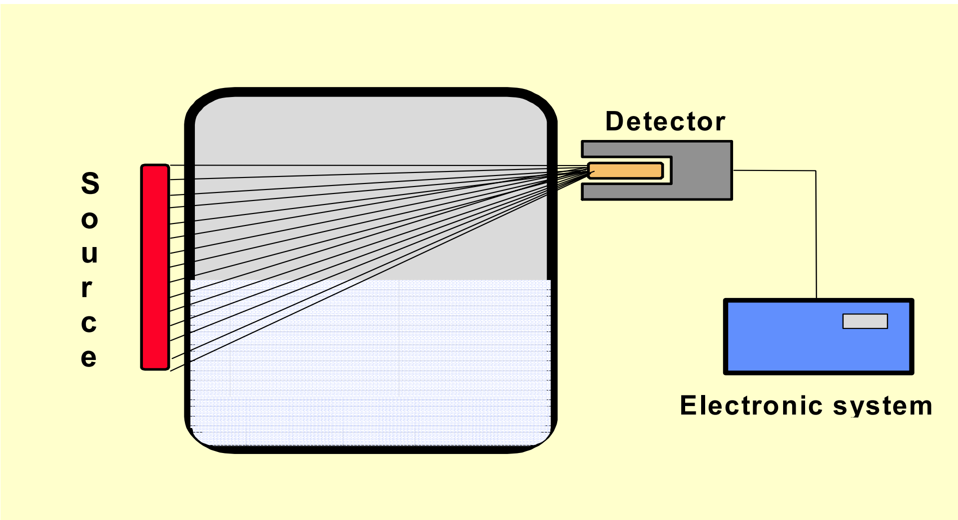
Long linear source; ^{137}Cs activity depending on tank diameter, from 1-2 GBq

2.4. Radiation Detector

Ionization chamber

3 Supplementary Explanation

(Measuring Principle / Block Diagram / Photo. etc.)

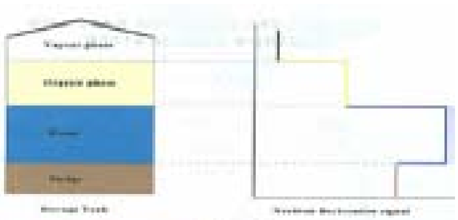


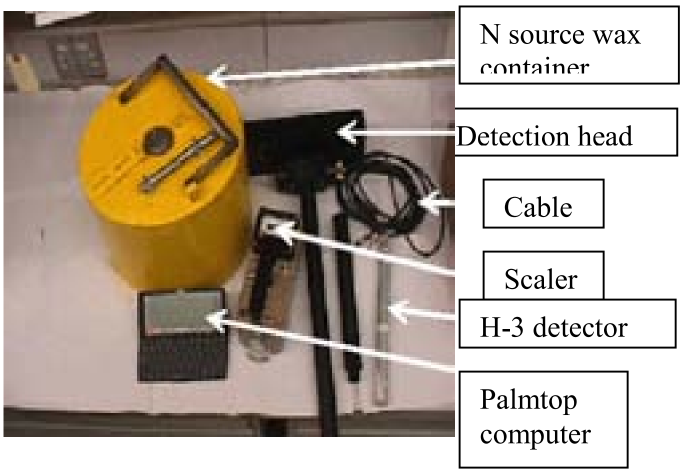
Neutron backscatter gauge for level and interface detection

1. General Information
1.1. Product Name / Model Number
Portable neutron backscatter gauge for level and interface measurement
1.2. Applications
Determination of levels of sludge, water, organic phases and vapour in storage oil tanks without installed level meters Calibration of conventional level gauges Monitoring of coke deposition during cracking process in fractionation column Detection of interface levels of liquid hydrocarbures in crude tar tank.
1.3. Features
High energy neutrons from a radioactive source are slowed down by hydrogen atoms of material inside a vessel. A part of thermal neutrons are backscattered towards the source where the neutron detector registers them. Neutron backscatter gauge clearly indicates solid/liquid, liquid/liquid and liquid/gas boundaries. For vessels and pipes with wall thickness less than 100 mm, this technique is quick and versatile, in particular if no access to both sides of vessel.
1.4. Typical Price
US$ 15 000 with Am-Be neutron source, and US$ 20 000 with Cf252 neutron source

2. Performance
2.1. Measuring Range
Multiphase systems where phase densities are different due to changes in hydrogen atom concentrations, and phase separation is at least few cm. Hydrocarbons transportation pipe where different fractions are pumped at least several seconds from each other.
2.2. Precision and/or Accuracy
Accuracy 1-2 cm
2.3. Radiation Source
^{241}Am/Be neutron source, Activity: 10-37 GBq, Flux 1-3 x 10^6 n/s; average energy 4. 5 MeV. Cf-252, Activity 0.5- 1 mg (10-20 GBq), Flux 1-2 x 10^6 n/s, ; average energy 2.1 MeV
2.4. Radiation Detector
He-3 or BF_3 neutron detector for thermal neutrons. He-3 detector has a higher efficiency. Source and detector are

3 Supplementary Explanation
(Measuring Principle / Block Diagram / Photo. etc.)





10.2. DENSITY, CONCENTRATION AND THICKNESS MEASUREMENT GAUGES

On-line liquid density gauge

1. General Information
1.1. Product Name / Model Number
Density measurement gauge, Type GM-06
1.2. Applications
Contactless measurement of density and concentration in liquid phase of acids, alkalis, sugar juice, etc. On-line continuous measurement with an option to regulate (keep constant) the density parameter
Features
1.3. Measurement of density as a function of temperature. Gamma ray transmission is applied in relatively small diameter and thickness pipes.
1.4. Typical Price
On request
2. Performance
2.1. Measuring Range
Density: 0,7- 2,0g/cm^3 ; temperature: -25...+200°C [248...473K]
2.2. Precision and/or Accuracy
Accuracy for fully filled pipe ≤0,3%
2.3. Radiation Source
^{241}Am max. 4,1GBq
2.4. Radiation Detector
Ionization Chamber
3 Supplementary Explanation
(Measuring Principle / Block Diagram / Photo. etc.)

Gamma high performance density gauge

1. General Information

1.1 Product Name / Model Number

High Performance Density Gauge (HPDG) System

1.2 Applications

Continuous on-line measurement of the density and/or % solids of slurry or solution streams in pipes (On-Pipe: f - Configuration) or in open tanks (Immersion Probe).
Typical applications are in the following industries:
- mineral processing, oil refining, processed foods, cement, paper, chemical engineering, alumina refining, iron ore, water treatment and mineral sands.

1.3 Features

- Choice of immersion or on-pipe configuration,
- Ease of installation and calibration,
- One point calibration using water for most applications,
- Automatic software source-decay compensation, with simple standardisation procedure.

1.4 Typical Price

On request

2. Technical Details & Performance

2.1 Measuring Range

0 – 10 g/ ml

2.2 Precision and/or Accuracy

Accuracy for fully filled pipe ≤0,5%

2.3 Radiation Source

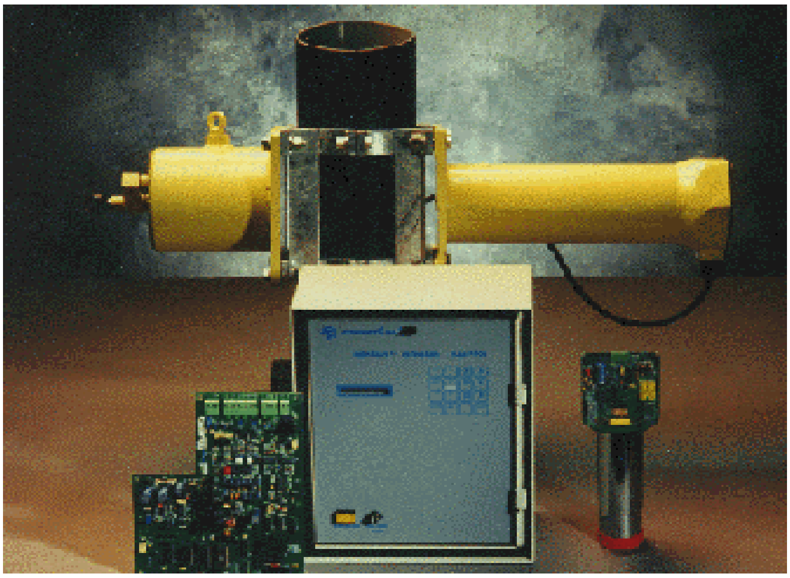
^{137}Cs or ^{60}Co gamma-ray sources , 750 MBq

2.4 Radiation Detector

Scintillation detector, NaI (Tl), 50x 50 mm

3 Supplementary Explanation

(Measuring Principle / Block Diagram / Photo. etc.)



Measurement: transmission of gamma-rays

Gamma absorption gauges for on-line coal sludge density

1. General Information
1.1 Product Name / Model Number
Density Gauges , models Lb 386-1c, Lb 444, Lb 367 & Lb 379
1.2 Applications
Monitoring of coal sludge in coal washing plants, determination of sludge content in pipelines in minerals processing, applications in chemical industry for alkalis and saline solutions (which result in density changes).
1.3 Features
- Continuous measurement of the density of liquids and bulk products, - Built-in temperature compensation, - A special backscatter set-up for density measurements in otherwise inaccessible containers, - Microprocessor-controlled operation, - Built-in automatic decay compensation.
1.4 Typical Price
On request

2. Technical Details & Performance
2.1 Measuring Range
For full filled pipe the density range is from 0.5 – 3.5 g/l
2.2 Precision and/or Accuracy
High long-term repeatability of + 0.1%.
2.3 Radiation Source
Mostly ^{137}Cs used, but also ^{60}Co and ^{241}Am, depending on application
2.4 Radiation Detector
Scintillation detector NaI (Tl), 50 x 50 mm

3 Supplementary Explanation
(Measuring Principle / Block Diagram / Photo. etc.)

Principle of measurement: Density measurement is based on the absorption of gamma radiation as it passes through the process material. Absorption is proportional to changes in material density, and as the measuring path is held constant, this indicates product density.

NCS for basis weight and thickness

1. General Information
1.1.Product Name / Model Number
Thickness Gauge, Model 03
1.2. Applications
Measuring the Area-Weight of Calendered PWC Films
1.3. Features
Transmission of beta rays.
1.4. Typical Price
US$ 100 000 – 150 000

2. Performance
2.1. Measuring Range
Basis weight of paper, plastics and films: 50-150 mg/m2
2.2. Precision and/or Accuracy
1-3%
2.3. Radiation Source
Kr-85 sealed source
2.4. Radiation Detector
Ionisation chamber

3 Supplementary Explanation

(Measuring Principle / Block Diagram / Photo. etc.)

Thickness gauge installed in factory for measuring the Area-Weight of calendered PWC films. Photos show the scanner (left) and PC display (right).

Combined gamma backscatter and microwave gauge for Basis Weight and Moisture

1. General Information

1.1. Product Name / Model Number

Basis Weight and Moisture Control System / SMS-BM-CRT

1.2. Applications

On-line Measurement and Control of the mass per unit area and moisture content in paper on paper making processes

1.3. Features

- Relatively low cost by the use of a single-sided measuring head coupled with a monorail scanning guide
- Gamma back-scattering basis weight gauge with an YAP scintillator, guaranteeing the high performance and long term stability in highly humid atmosphere
- Reliable microwave moisture sensor with a cavity resonator
- Reasonably simple system satisfying the requirements for automatic process control

1.4. Typical Price

US$160,000 (including a scanning frame, control box and display panel, controllers and valves for automatic operation)

2. Performance

2.1. Measuring Range

Basis weight: 30 - 130 g/m^2 typically (heavier or broader ranges available on request)
Moisture percent: 2 - 12 wt% typically (higher or broader ranges available on request)

2.2. Precision and/or Accuracy

Basis weight: 0.7 g/m^2 or 0.7% whichever greater, in 2 sigma, 3 s
Moisture percent: 0.2 wt%

2.3. Radiation Source

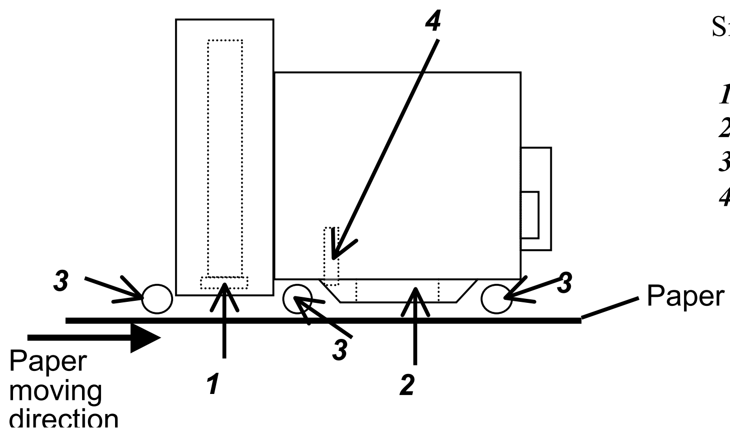
Gamma source: Am-241 3 GBq

2.4. Radiation Detector

Gamma detector: YAP (Yttrium Aluminate Perovskite) scintillator

3. Supplementary Explanation

(Measuring Principle / Block Diagram / Photo. etc.)



Side view of the sensor box

1: Gamma ray gauge probe
2: Microwave sensor head
3: Sensor protection roll
4: Laser displacement meter

Beta transmission airborne dust monitor

1. General Information
1.1. Product Name / Model Number
Automatic airborne dust monitor type AMIZ-2000
1.2. Applications
The instrument is intended for monitoring of the airborne dust concentration (emission) in the ambient air at stationary posts. The air volume at a constant flow rate through the filter is determined by the pumping time whereas the mass of the dust collected on the filter strip is measured using beta absorption principle. The results are displayed or printed and cab be transmitted to a PC.
1.3. Features
Liquid crystal display (LCD); Internal printer; Measurements of meteorological parameters (wind, temperature, pressure humidity)
1.4. Typical Price
Open price

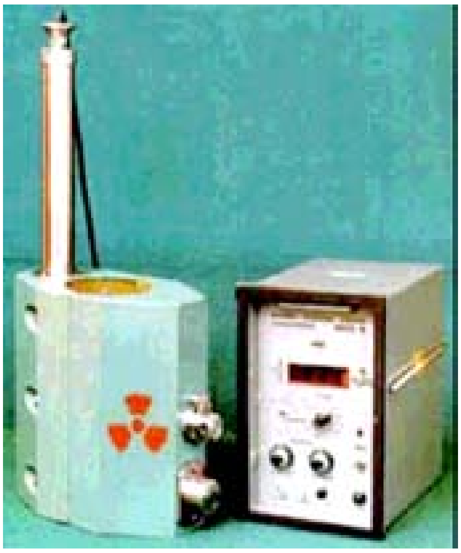
2. Performance
2.1. Measuring Range
5-5000 µg/m^3
2.2. Precision and/or Accuracy
2 µg/m^3
2.3. Radiation Source
^{147}Pm: 100 MBq
2.4. Radiation Detector
Geiger-Muller Counter

3 Supplementary Explanation
(Measuring Principle / Block Diagram / Photo. etc.)
View of the automatic airborne dust monitor type AMIZ-2000 with wind sensors.

Measuring range	5-5000 µg/m^3 in 7 subranges
Sensitivity of measurement	2 µg/m^3 for 24 h measuring cycle
Wind	0-60 m/s
Radiation source	Pm-147, 100 MBq
Air flow	1 m^3/h ± 2%
Dust deposit. time	30 min ÷ 24 h
Air filter	fiber glass band 40 m long
Digital port	CENTRONICS, RS232C

Neutron gauge for on-line sulphuric acid concentration measurement

1. General Information
1.1. Product Name / Model Number
Sulphuric acid concentration gauge MKS-6
1.2. Applications
MKS-6 gauge is designed for continuous, contactless measurements of sulphuric acid concentrations in industrial installations. The sulphuric acid concentration is determined by measuring the hydrogen content in the solution by moderation of fast neutrons and detection of thermal neutrons.
1.3. Features
H_2SO_4 digital display % H_2SO_4 digital display Outputs: – voltage 0÷10 V; – current 0÷5; 0÷10; 4÷20 mA
1.4 Typical Price
Open price
2. Performance
2.1. Measuring Range
90÷99% H_2SO_4
2.2. Precision and/or Accuracy
0,2 % H_2SO_4
2.3. Radiation Source
^{238}Pu-Be or ^{241}Am-Be neutron source: 24 GBq
2.4. Radiation Detector
Helium (He-3) proportional counter NEM – 525T15
3 Supplementary Explanation
(Measuring Principle / Block Diagram / Photo. etc.)



View of the sulphuric acid concentration gauge MSK-6, measuring head is installed on a bypass pipe

Combined gamma& neutron gauge for S and Pb analysis in oil

1. General Information
1.1 Product Name / Model Number
Sulphur and Lead Analyzer Lb 340b
1.2 Applications
Crude oil inspection, process monitoring in refineries, monitoring the emission values of SO_2 and SO_3 in fuel oil power plants, measurement of the lead content in gasoline.
1.3 Features
Microprocessor-controlled operations, Built-in automatic linearization and decay compensation, The measured result is independent of physical conditions such as product pressure, temperature, viscosity, flow rate and type of chemical bond.
1.4 Typical Price
On request

2. Technical Details & Performance
2.1 Measuring Range
0.05 – 1 %
2.2 Precision and/or Accuracy
Maximum repeatability +/- 30ppm Sulphur for concentrations below 500ppm, density measurement repeatability +/- 0.5g/l, Hydrogen content measurement repeatability +/- 0.05% H.
2.3 Radiation Source
^{244}Cm soft gamma and ^{137}Cs harder gamma, and ^{241}Am-Be source
2.4 Radiation Detector
Scintillation detectors for gamma rays ; He-3 detector for thermal neutrons

3 Supplementary Explanation

(Measuring Principle / Block Diagram / Photo. etc.)

From bottom to top, a sub-flow of the oil flows through the measurement configuration incorporating the systems for determining the sulphur content, density, hydrogen content and temperature.
The three radiometric measurement methods are based on:
Sulphur - The absorption of a ^{244}Cm soft gamma radiation is influenced substantially by the oil's sulphur content;
Density - The absorption of a ^{137}Cs harder gamma radiation depends mainly on the oil's density;
Hydrogen - The fast neutrons of a ^{241}Am-Be source are moderated to thermal neutrons by hydrogen atoms.

Lumbar gamma density gauge

1. General Information
1.1.Product Name / Model Number
Lumber Density Gauge / 1
1.2. Applications
Measurement of the green density of pieces of lumber for sorting prior to kiln drying. Uses a laser thickness gauge to calculate density from the radiation attenuation.
1.3. Features
Four-headed gauge capable of density measurements on pieces of lumber travelling at up to 1 metre/sec Operation is completely automated, with solenoid shutters to control tightly collimated sources. Feeds data via serial lines to plant PLC.
1.4. Typical Price
Starts at $US25,000, rising depending on number of heads and plant interfaces.

2. Performance
2.1. Measuring Range
Lumber thickness 25 to 100mm; 50 to200mm wide. Measures in intervals of 5 millisec.
2.2. Precision and/or Accuracy
Density range 450-1700 kg/m^3. Accuracy <3%.
2.3. Radiation Source
One 11.1 GBq Am-241per measurement head
2.4. Radiation Detector
50 mm NaI (Tl) gamma ray detectors in stainless steel jackets

3 Supplementary Explanation

(Measuring Principle / Block Diagram / Photo. etc.)

Photo shows installed gauge with pieces of lumber conveyed by chains beneath the four heads. The detectors can be water-cooled for stability. The cabinet on the right has the electronics, and is connected to plant PLC's by serial ports.

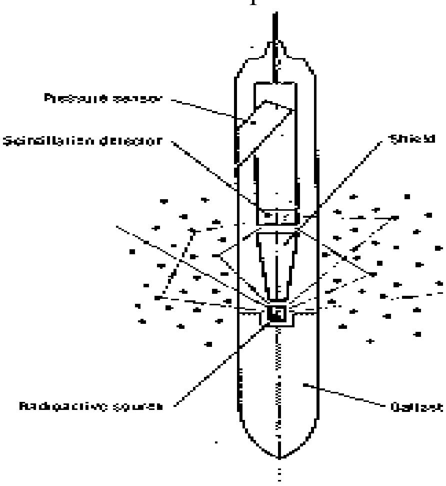
Gamma backscattering density gauge

1. General Information
1.1. Product Name / Model Number
Density meter / JTD3
1.2. Applications
Density measurement and control of sediments deposited in harbour basins, navigation fairways, dam reservoir, etc.
1.3. Features
1/ Very low radiation level with a weak radioactive source 2/ Easy installation and calibration 3/ Handled by computer controlled electrical winch 4/ Max depth use: 100 m
1.4. Typical Price
50 000 Euros (depending on options) including winch , data acquisition system and computer
2. Performance
2.1. Measuring Range
30 to 1000 g/l
2.2. Precision and/or Accuracy
Depending on counting time and concentration : for example ± 10 g/l in 2σ for T=10s and 300 g/l
2.3. Radiation Source
Cs-137 / 18.5 MBq
2.4. Radiation Detector
NaI(Tl) scintillation detector, 50 x 50 mm

3 Supplementary Explanation

(Measuring Principle / Block Diagram / Photo. etc.)

Cable to winch and computer



Principle of back-scattering density gauge JTD3

Gamma nucleonic gauge for sediment density measurement

1. General Information
1.1. Product Name / Model Number
Density meter / ECOTURB5
1.2. Applications
Density measurement and control of sediments deposited in harbour basins, navigation fairways, dam reservoir, etc
1.3. Features
1/ Very low radiation level with a weak radioactive source , distance between source and detector adjustable 2/ Easy installation and calibration 3/ Handled by computer controlled electrical winch, water depth measured by pressure sensor 4/ Max depth use : 100 m
1.4. Typical Price
30 000 Euros approx (depending on options) including winch and data acquisition system.

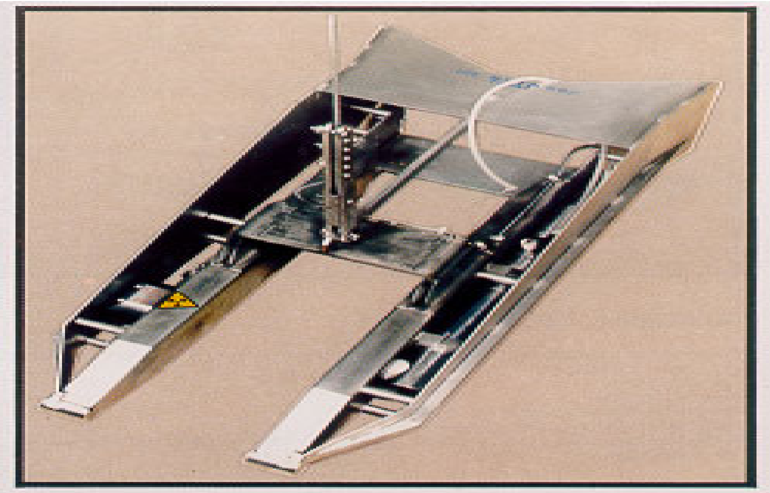
2. Performance
2.1. Measuring Range
Density 1.02 to 1.35 g/l
2.2. Precision and/or Accuracy
± 1% at 95 % confidence (2σ)
2.3. Radiation Source
Am-241 or Cs-137 / 222 MBq (typical)
2.4. Radiation Detector
NaI(Tl) scintillation detector, 50 x 50 mm

3 Supplementary Explanation

(Measuring Principle / Block Diagram / Photo. etc.)

Gamma density meter gauge

1. General Information
1.1. Product Name / Model Number
Density meter / JTT4
1.2. Applications
Density measurement and control of sediments deposited in harbour basins, navigation fairways, dam reservoir, etc
1.3. Features
1/ Very low radiation level with a weak radioactive source 2/ Easy installation and calibration 3/ Handled by computer controlled electrical winch 4/ Max depth use : 100 m
1.4. Typical Price
50 000 Euros (depending on options) including winch, data acquisition system and accessories
2. Performance
2.1. Measuring Range
Density 1.02 to 1.35 g/l
2.2. Precision and/or Accuracy
± 1% at 95 % confidence (2σ)
2.3. Radiation Source
Cs-137 / 222 MBq (typical)
2.4. Radiation Detector
NaI(Tl) scintillation detector, 50 x 50 mm
3 Supplementary Explanation
(Measuring Principle / Block Diagram / Photo. etc.)



SAPRA JTT4 type detecting unit

Gamma transmission gauge for on-line fluid density measurement

1. General Information
1.1. Product Name / Model Number
Density meter / MICA
1.2. Applications
- Density measurement and control of solutions or slurries flowing inside pipes - On-line measurement of fluid density in chemical processes, etc… - Density and / or specific gravity monitoring in sludge, etc…
1.3. Features
1/ Very low radiation level with a weak radioactive source 2/ Easy installation and calibration 3/ Density or concentration measurement of fluid in pipe without influence of velocity, viscosity,etc… 4/ Automatic correction of long term drifts and maintenance free
1.4. Typical Price
20 000 Euros approx. (depending on options , source, etc..)

2. Performance
2.1. Measuring Range
0 to 2000 g/l
2.2. Precision and/or Accuracy
Depending on counting time and concentration : typically ±1 % at 95 % confidence (2σ)
2.3. Radiation Source
Am-241, Cs-137, Co-60 (depending on pipe diameter, material, measurement time,…)
2.4. Radiation Detector
NaI(Tl) scintillation detector

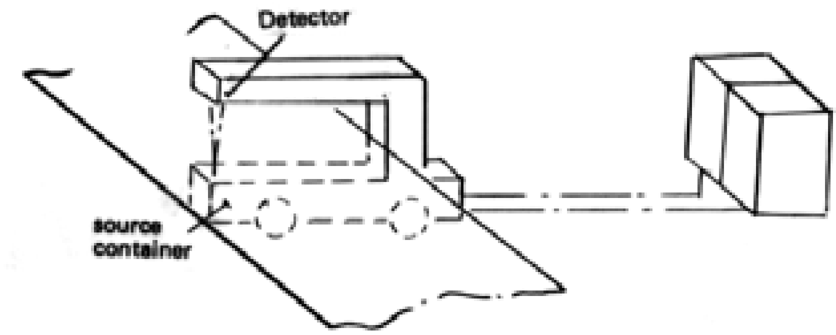
3 Supplementary Explanation
(Measuring Principle / Block Diagram / Photo. etc.)

Gamma transmission gauge for sediment concentration measurement in rivers

1. General Information	
1.1. Product Name / Model Number	**Density meter / SERES**
1.2. Applications	Concentration measurement of sediments in high speed flows (dam slushes, flooding wadis, etc…)
1.3. Features	1/ Very low radiation level with a weak radioactive source 2/ Easy installation and calibration 3/ Continuous sampling by peristaltic pump 4/ Automatic correction of long term drifts and maintenance free
1.4. Typical Price	50 000 Euros approx (depending on options , source, etc..)
2. Performance	
2.1. Measuring Range	0 to 2000 g/l
2.2. Precision and/or Accuracy	Depending on counting time and concentration : typically ± 1 % at 95 % confidence (2σ)
2.3. Radiation Source	Am-241, Cs-137 (depending on concentration range , measurement time,…), 10-30 MBq
2.4. Radiation Detector	NaI(Tl) scintillation detector
3 Supplementary Explanation	
(Measuring Principle / Block Diagram / Photo. etc.)	

Gamma thickness gauge

1. General Information
1.1 Product Name / Model Number
Gamma-ray thickness gauge (for plate mill) / NNE, NNF
1.2 Applications
1) Thickness measurement of iron plates in cooling lines (NNE) 2) Thickness measurement of iron plates in hot rolling mills (NNF)
1.3 Features
Non-contact and continuous measurement High speed response and high accuracy Easy maintenance by computer system
1.4 Typical Price
On request
2. Performance
2.1 Measuring Range
5 - 100 mm in steel plates
2.2 Precision and/or Accuracy
0.2% of measuring thickness or 20 micro m in 1.645 sigma at a sampling time of 0.4 s
2.3 Radiation Source
^{137}Cs 1.11 TBq (0.185 - 1.48 TBq)
2.4 Radiation Detector
High speed and fine stability scintillation detector
3. Supplementary Explanation
(Measuring Principle / Block Diagram / Photo. etc.)



Beta-ray thickness gauge

1. General Information

1.1 Product Name / Model Number

Beta-ray thickness gauge (for film) / NNA

1.2 Applications

Thickness measurement of plastic film, paper, gum sheet, clothe etc.

1.3 Features

1) Automatic calibration capability for different samples, preventing malfunctions caused by manual operation.
2) Wide applicability to twelve different materials with composition correction functions.
3) Optional profile measurement equipped with a variety of graphics.

1.4 Typical Price

Approximately US$ 150 000 – 250 000

2. Performance

2.1 Measuring Range

^{147}Pm: 2 - 160 g/m^2, ^{85}Kr : 10 - 1000 g/m^2, ^{90}Sr : 50 - 5500 g/m^2

2.2 Precision and/or Accuracy

0.2% or 0.3 g/m^2 in 2 sigma at a time constant of 0.8s, (typically in case of ^{85}Kr 0.74GBq)

2.3 Radiation Source

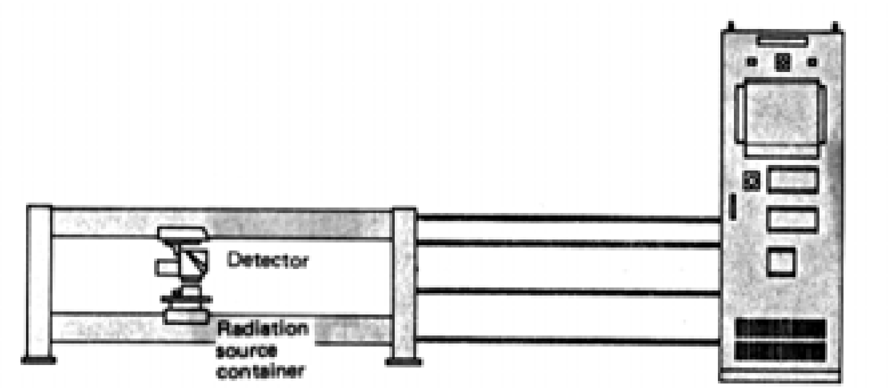
^{147}Pm, ^{85}Kr, ^{90}Sr

2.4 Radiation Detector

Ionization chamber

3. Supplementary Explanation

(Measuring Principle / Block Diagram / Photo. etc.)



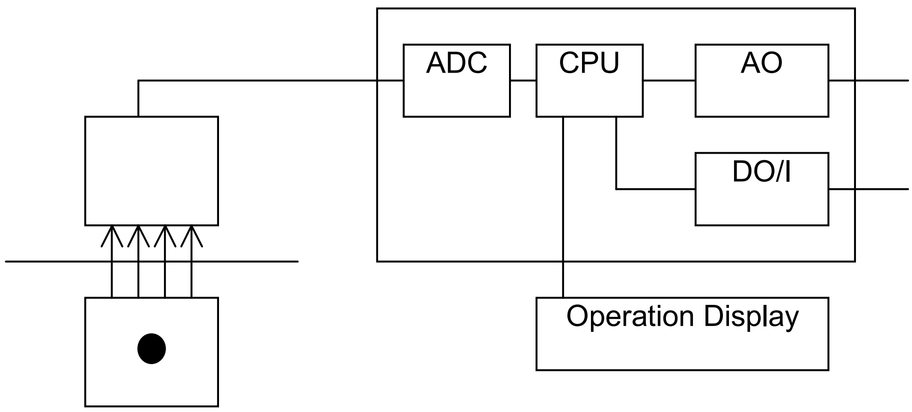
Beta-ray thickness gauge (for aluminum)

1. General Information
1.1 Product Name / Model Number
Beta-ray thickness gauge (for aluminium) / NNB
1.2 Applications
Thickness measurement in aluminium plate mills.
1.3 Features
1) Automatic calibration capability for samples preventing malfunctions caused by manual operation. 2) Applicability to different materials by composition correction functions with a table of twelve materials. 3) Automatic measurement and control of products with the aid of many optional functions in external outputs and settings.
1.4 Typical Price
Approximately US$ 180 000

2. Performance
2.1 Measuring Range
0 - 2.0 mm in aluminium plate
2.2 Precision and/or Accuracy
1 – 4 micro m in 2 sigma at a time constant of 0.4 s
2.3 Radiation Source
^{90}Sr 3.7 GBq
2.4 Radiation Detector
Ionization chamber

3. Supplementary Explanation

(Measuring Principle / Block Diagram / Photo. etc.)



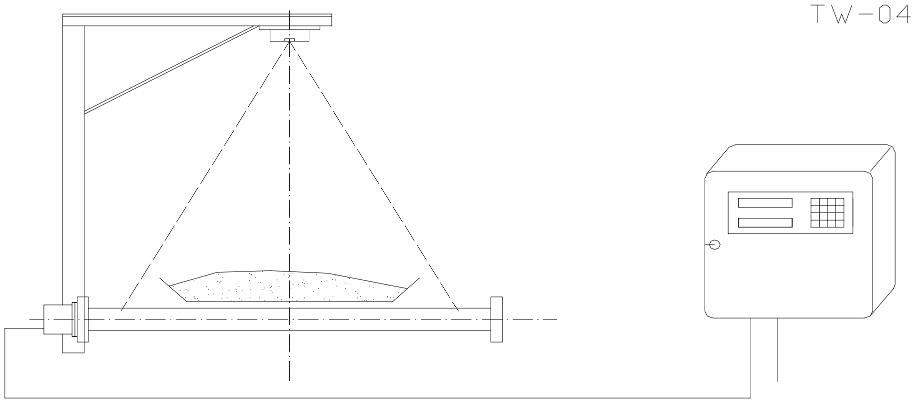
Radiation source, container

Gamma conveyor belt weighter

1. General Information
1.1. Product Name / Model Number
Isotope Conveyor Belt Weighter, Type TW-04
1.2. Applications
Contactless measurement of loose material mass transported by belt conveyor 800 mm wide.
1.3. Features
Measurement of material mass, registration every day, every month, every year, mass dosage, flow rate measurement, conveyor operation control, Hard copy of reports, external computer operation RS232C or RS422.
1.4. Typical Price
On request

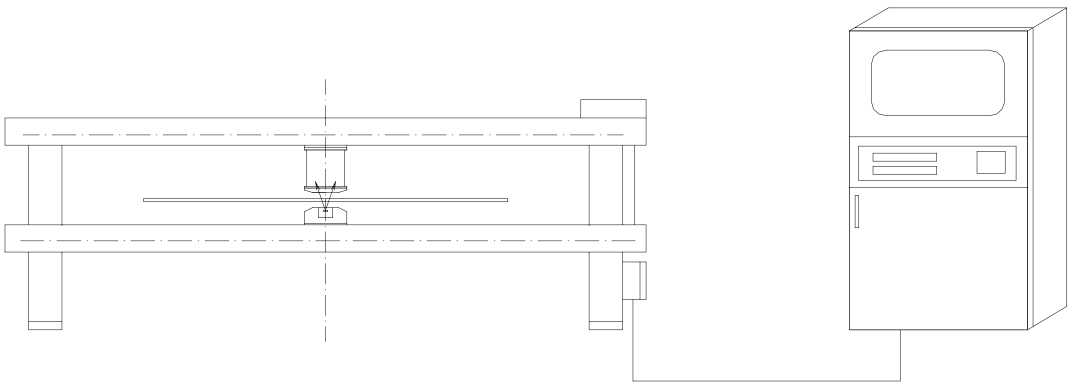
2. Performance
2.1. Measuring Range
Load: 20...80kg/m Flow rate: 120...1000Mg/h
2.2. Precision and/or Accuracy
Accuracy 1%
2.3. Radiation Source
^{241}Am max.3,7GBq or ^{137}Cs max. 1,2GBq
2.4. Radiation Detector
Ionization Chamber

3 Supplementary Explanation
(Measuring Principle / Block Diagram / Photo. etc.)



Basis weight gauge for paper processing (beta or X-rays)

1. General Information		
1.1. Product Name / Model Number		
Isotope Gauge of Plastic Foil Profile, Type MM-06		
1.2. Applications		
Contactless measurement of plastic foil, lining, rubber and similar materials employing scanning measuring head.		
1.3. Features		
Measurement of thickness, process control, operation with external computer (RS232C); reports of production process, graphic presentation of measured profile, archival storage of transverse profiles, archival storage of product certificates, hard copy of diagrams presenting measuring results.		
1.4. Typical Price		
On request		
2. Performance		
2.1. Measuring Range		
10...125µm	100...1000µm	400...1800µm
2.2. Precision and/or Accuracy		
Prec. 0,5-1µm	accuracy within 5sec. 0,5%+0,5µm	
2.3. Radiation Source		
90Sr	85Kr	X-ray source
2.4. Radiation Detector		
Ionization Chamber		
3 Supplementary Explanation		
(Measuring Principle / Block Diagram / Photo. etc.)		

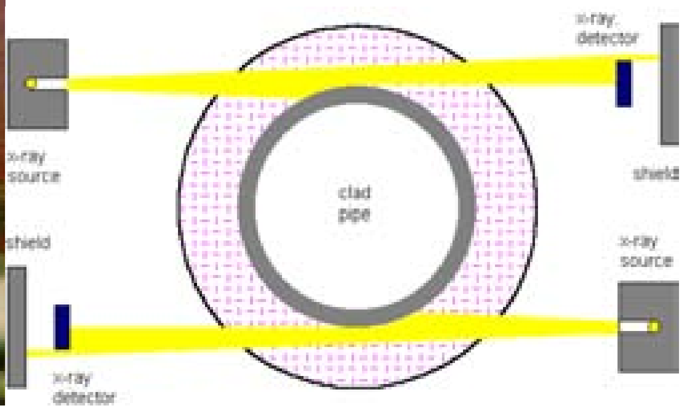


Portable XClad gauge for external corrosion of clad pipes

1. General Information
1.1. Product Name / Model Number
Portable XClad gauge
1.2. Applications
XClad is a new cost-effective nucleonic gauge for detection of external corrosion of clad pipes. Detection of this type of surface corrosion usually requires the laborious removal of the insulation material to visually inspect the pipe. XClad uses two tightly-collimated x-ray beams to penetrate the cladding, and measures the shadow caused by the pipe surfaces. Suitable for: aluminium or thin steel sheathing; fibreglass or calcium silicate insulation; insulation thicknesses 25, 40 and 50 mm; pipe ID's 50, 60, 75, 100 and 150 mm
1.3. Features
- measures diameter deviations to ±5 mm; - inspection rates to 6 metres per minute; - weights: carriage 5 kg, remote 0.6 kg; - alkaline 'AA' batteries, 100 hour life; - key-operated long-life sources; - negligible radiation hazard
1.4. Typical Price
US$ 15 000

2. Performance
2.1. Measuring Range
For pipes with external diameter from 10 to 50 cm.
2.2. Precision and/or Accuracy
Deviations from diameter down to ±0.1 millimetres are measured.
2.3. Radiation Source
Pairs of ^{241}Am radioisotopic sources. The sources are contained in key-operated enclosures; tight collimation ensures negligible stray radiation hazard.
2.4. Radiation Detector
X ray detectors are attached to each arm at positions selected according to the pipe diameter and insulation thickness. The x-ray detectors are CdZnTe solid state counters. The counting rates recorded by these are digitally transmitted to the remote computer.

3 Supplementary Explanation
(Measuring Principle / Block Diagram / Photo. etc.)



10.3. GAMMA NUCLEONIC GAUGES FOR ON-LINE COAL ASH ANALYSIS

Duet type gamma coal ash gauge

1. General Information
1.1 Product Name / Model Number
COALSCAN Model 2100
1.2 Applications
The applications in the areas of raw coal management, preparation plant, stockpile management, power utility and steel plant include: mine grade control, coal sorting, raw coal monitoring, preparation plant optimisation, raw coal by-pass control, consignment control, blending control, stockpile inventory reporting, coal supply contract monitoring, bunker feed monitoring, feed forward to boiler control and coke oven feed control.
1.3 Features
On-belt applications for belts up to 160mm, Single fully integrated unit , The rigid C-frame ensures precise alignment of source and detector (swings off belt for easy maintenance), Possibility or either off-belt or on-belt calibration, Fully on-line in real time monitoring , Single scintillation detector used for both co-linear beams, High speed processing of analyser signals, Automatic standardisation,
1.4 Typical Price
On request

2. Technical Details & Performance
2.1 Weight
Shipping weight: 250 kg
2.2 Precision and/or Accuracy
Typical analysis precision: +/- 0.5% ash in typical washed coals, +/- 1.0% ash in typical raw coals.
2.3 Radiation Source
140 μSv/hr maximum radiation dose at all points on the surface of the equipment from gamma-ray sources: ^{137}Cs and ^{241}Am.
2.4 Radiation Detector
Na I(Tl) – scintillation detector, 50 x 50 mm

3 Supplementary Explanation

(Measuring Principle / Block Diagram / Photo. etc.)

Measurement:
Dual Energy
Gamma-Ray
Transmission

Dual gamma rays transmission gauge for on-line coal ash monitoring

1. General Information

1.1 Product Name / Model Number

Coal Ash Monitor, model LB 420

1.2 Applications

Coal preparation plants for rapid determination of ash content and for monitoring control of coal blending, run-of-mine coal ash analysis, coal ash monitoring during train loading.

1.3 Features

Installation directly on the conveyor belt in the main flow,
Automatic decay compensation,
Two detectors-two sources configuration,
Simple dialogue-controlled operation,
Software-aided calibration.

1.4 Typical Price

On request

2. Technical Details & Performance

2.1 Measuring Range

0.5 – 5 % ash in low or uniform iron content coal

2.2 Precision and/or Accuracy

Typical analysis precision: +/- 0.5% ash in typical washed coals, +/- 1.0% ash in typical raw coals

2.3 Radiation Source

Activity of gamma ray sources: ^{137}Cs – typically 370-1110 MBq, ^{241}Am – 3700- 11100 MBq

2.4 Radiation Detector

Two NaI (Tl) scintillation detectors

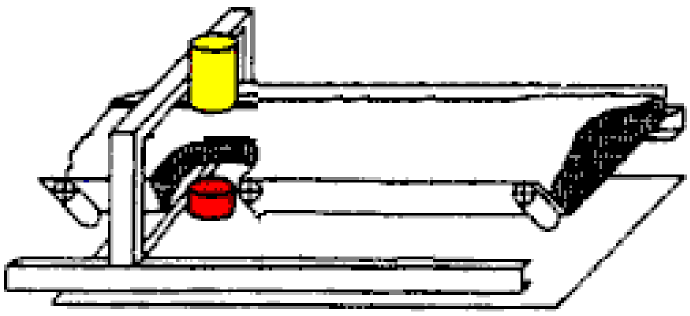
3 Supplementary Explanation

(Measuring Principle / Block Diagram / Photo. etc.)

Measuring Principle: Dual energy gamma-ray transmission method.

Double gamma rays transmission gauge for on-line monitoring of coal ash

1. General Information
1.1 Product Name / Model Number
On-Line Ash Monitor, model C 411a
1.2 Applications
On-line monitoring of ash content in black coal and lignite.
1.3 Features
Coal grain size: 0-80 mm, Thickness of coal layer: 50-250 mm, Suitable for conveyor belt's width of 800-2000 mm
1.4 Typical Price
On request
2. Technical Details & Performance
2.1 Measuring Range
0.5 – 5 % ash in coal (low or homogeneous iron content coal)
2.2 Precision and/or Accuracy
An average accuracy of +/- 0.5 – 1.5% ash.
2.3 Radiation Source
^{241}Am of 3.7GBq activity and ^{137}Cs of 3.7GBq activity
2.4 Radiation Detector
Scintillation detector
3 Supplementary Explanation
(Measuring Principle / Block Diagram / Photo. etc.)

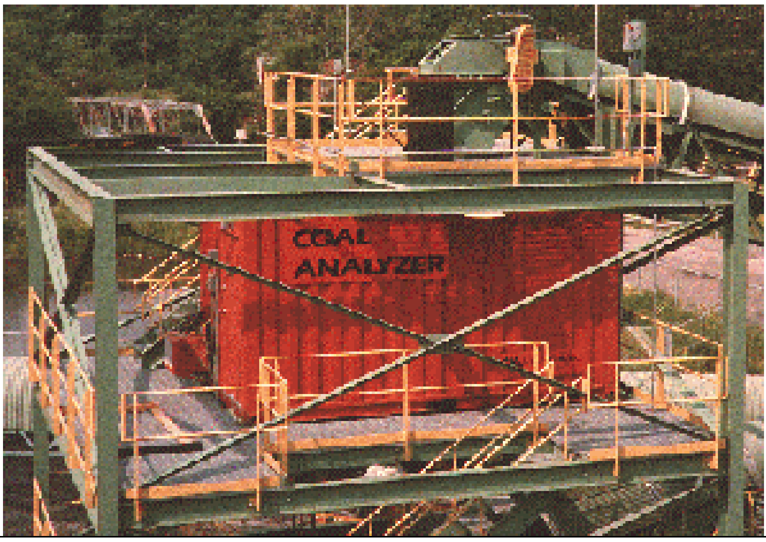


Measuring Principle: Dual energy gamma-ray transmission.

10.4. PGNAA FOR ON-LINE BULK PROCESSING (COAL, MINERALS AND CEMENT)

PGNAA on line coal analyser

1. General Information
1.1. Product Name / Model Number
On-line PGNAA Coal Analyzer 1812C
1.2. Applications
Coal blending, control of coal preparation plants (washeries), sorting, quality control of product shipped, and power plant emissions control.
1.3. Features
Fully automatic on-line operation, 5 – 100 tph capacity, Analyses of sulphur, ash, moisture, and calorific value are provided each minute.
1.4. Typical Price
On request (US$ few hundred thousand)
2. Technical Details & Performance
2.1. Measuring Range
Few percent content in S, ash and moisture
2.2. Precision and/or Accuracy
Ten Minute Precision: 0.04% S, 0.40% ash, 0.2% moisture, 75 Btu/lb calorific value.
2.3. Radiation Source
Cf-252, 20 microgram (400 MBq)
2.4. Radiation Detector
Scintillation detector NaI(Tl) 3” x 3”
3 Supplementary Explanation
(Measuring Principle / Block Diagram / Photo. etc.)



Measurement: PGNAA scintillation detector spectroscopy

PGNAA Cross-belt analyzer for cement analysis

1. General Information
1.1 Product Name / Model Number
On-line PGNAA *Cross-belt Analyzer*
1.2 Applications
On-line analysis of the elemental composition of bulk solid materials on a standard conveyer belt, stockpile management and raw mix proportioning in a cement plant applications.
1.3 Features
- Several models suiting various belt widths (from 600 to 1400mm) with no limitations on belt speed, - Dedicated software for stockpile management and raw mix proportioning applications in the cement industry, - Modular instrumentation, - Scintillation detectors assembly in transmission configuration.
1.4. Typical Price
On request

2. Technical Details & Performance
2.1 Dimensions & Weight
Shield Assembly: 2.3m x 2.7m x 2.5m 5,576 kg Electronics Enclosure: 1.7m x 1.7m x 2.1m 1,000 kg
2.2 Precision and/or Accuracy
Analysis Period: Once per minute.
2.3 Radiation Source
Cf-252 neutron source, 400 MBq
2.4 Radiation Detector
2 Scintillation detectors NaI (Tl) 3” x 3”

3 Supplementary Explanation

(Measuring Principle / Block Diagram / Photo. etc.)

Measurement: PGNAA scintillation detector spectroscopy
Application: cement manufacturing process
Parameters Analyzed: Silicon, Aluminium, Iron, Calcium, Magnesium, Sodium, Potassium, Sulphur, Chlorine, and Moisture

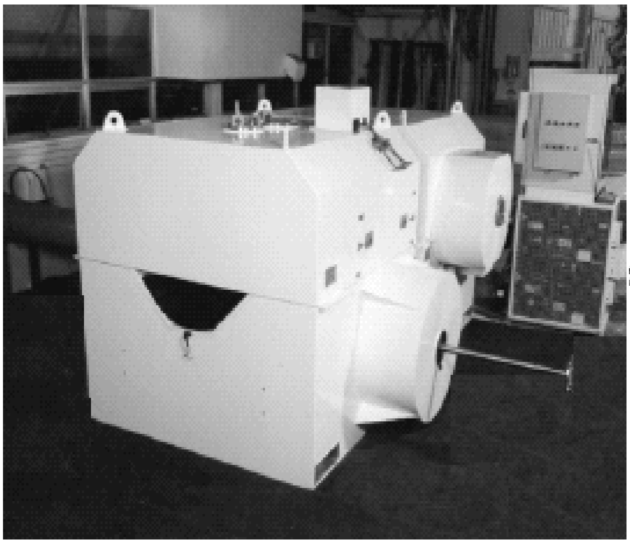
On-belt elemental neutron-gamma analyzer for cement raw mill feed

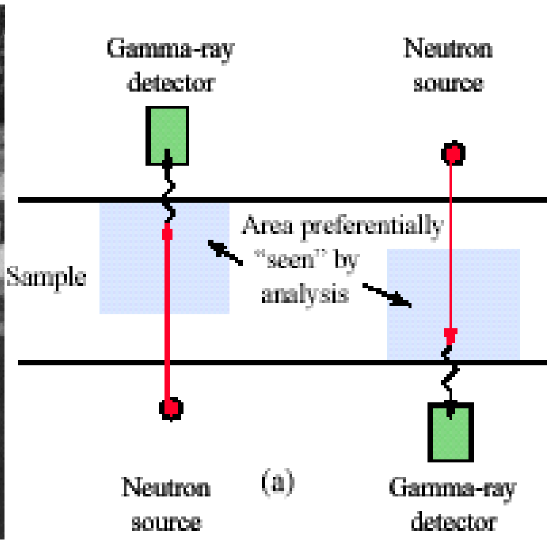
1. General Information
1.1. Product Name / Model Number
Neutron/gamma on-belt elemental analyser XENA
1.2. Applications
- Neutron/gamma on-belt elemental analyser XENA (X-belt elemental neutron analyser) is used for on-line cement raw mill feed; it is capable of accurately measuring key elements independently of both horizontal and vertical segregation and independently of changes in belt loading.
1.3. Features
XENA is a two halves system, each containing an Am-Be neutron source and two BGO detectors. It works in a transmission configuration. The use of multiple detectors and sources provides much reduced sensitivity to non-uniformity of composition both vertically and across the conveyor belt.
1.4. Typical Price
On request

2. Performance
2.1. Measuring Range
1-10 wt%
2.2. Precision and/or Accuracy
RMS (root mean square) error of 0.49; 0.52; 0.38 and 0.23 wt% for CaO, SiO2, Al2O3 and Fe2O3 respectively, when 10 min. counting period is used.
2.3. Radiation Source
2 neutron sources ^{241}Am-Be of 370 GBq (10 Ci)
2.4. Radiation Detector
2 Scintillation detectors (BGO) with size 76 mm diameter x 76 mm long.

3 Supplementary Explanation

(Measuring Principle / Block Diagram / Photo. etc.)





PGNAA gauge for coal ash monitoring

1. General Information

1.1 Product Name / Model Number

COALSCAN Model 9500

1.2 Applications

Complete on-line analysis of coal in two configurations: continuous and on a sample by-line. Applicable to the whole range of coal production cycle, from raw coal control up to coal load-out control.

1.3 Features

- Utilisation of a range of analysis techniques to monitor a wide range of coal parameters,
- The Harwell Spectrometer incorporated in the system,
- Up to 100 t/h flow rate,
- On-line maintenance and diagnostic facility,
- Supervisory control and data acquisition system (SCADA) runs on Microsoft Windows,
- Fully internal standardisation routine,
- Temperature stabilised operations.

1.4 Typical Price

On request

2. Technical Details & Performance

2.1 Measuring Range

The coal attributes measured by Coalscan 9500 include: ash, sulphur, moisture, carbon, hydrogen, nitrogen and chlorine.

2.2 Precision and/or Accuracy

0.1 – 0.5 %

2.3 Radiation Source

^{137}Cs and ^{252}Cf sources.

Radiation dose: 15μSv/hr at 300 mm from all upper surfaces accessible to plant personnel.

2.4 Radiation Detector

Scintillation detectors (Harwell Spectrometer)

3 Supplementary Explanation

(Measuring Principle / Block Diagram / Photo. etc.)

Measurement: Combines PGNAA, gamma-ray transmission and microwave absorption.

10.5. XRF FOR ELEMENTAL ANALYSES

XRF in –stream analyser

1. General Information

1.1 Product Name / Model Number

In-Stream Analysis (ISA) System

1.2 Applications

Continuous and intermittent on-line analyses of process streams in a variety of applications including mineral concentrators, coal washeries and mineral sands concentrators.

1.3 Features

- 1 minute assay update time,
- User friendly, menu driven software,
- Easy operation and calibration,
- High degree of flexibility of the ISA system.

1.4 Typical Price

On request

2. Technical Details & Performance

2.1 Measuring Range

Element range: Calcium to Uranium (atomic numbers 20 to 92)
Choice of the Single-Element Probe and the Multi-Element Probe. The Density Probe is also available

2.2 Precision and/or Accuracy

Typical Relative Accuracies (% metal) 4-6% for 0.05-0.2% assay range, 2-5% for 0.2-10% range and 1-2% for 10-80% assay range. Relative accuracy for density (%solids): +/- 0.3-1.5%

2.3 Radiation Source

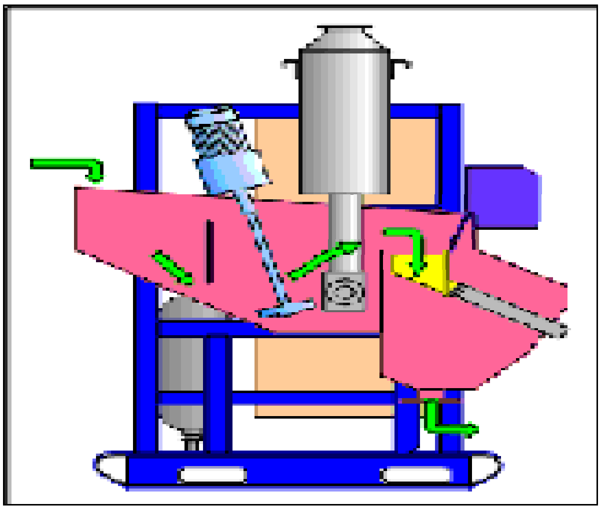
Low intensity X-rays from radioisotopes

2.4 Radiation Detector

NaI(Tl) – for Single-Element and Density Probes;
Solid-state Si(Li) detector for Multi-Element Probe

3 Supplementary Explanation

(Measuring Principle / Block Diagram / Photo. etc.)



The Single-Element Probe measures one element per probe and contains a scintillation detector for X-ray measurement. The Multi-Element Probe contains a solid-state detector, Si (Li), and is capable of measuring up to 8 elements plus pulp density simultaneously.

Measurement: X-ray Fluorescence Analysis

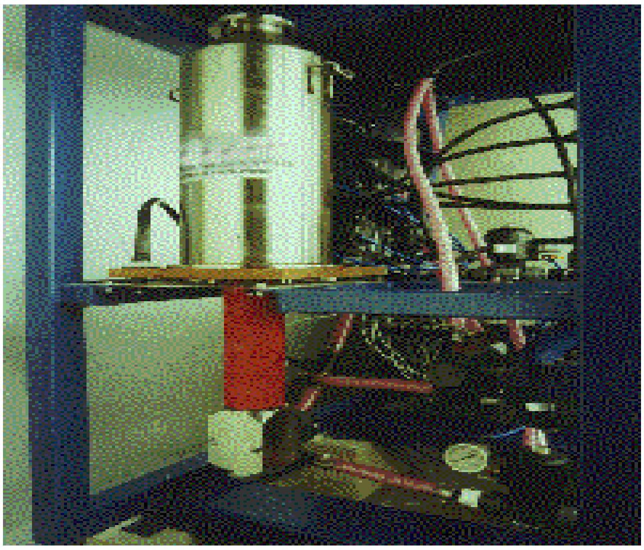
XRF on line elemental analyser

1. General Information
1.1 Product Name / Model Number
Multi-Stream Solution Analyser (MSSA)
1.2 Applications
Continuous on-line analysis of elements above S in the periodic table in solution streams in SX/EW plants, refineries and hydrometallurgy.
1.3 Features
- Up to 8 elements analysed, - 1 to 12 streams per analyzer, - Comprehensive DCS interfacing & graphic software, - Analysis time – typically 60-100 seconds.
1.4 Typical Price
On request

2. Technical Details & Performance
2.1 Measuring Range
Elements from sulphur to uranium
2.2 Precision and/or Accuracy
Typical Accuracy (relative): 1-2% above 10g/l, 2-4% in the range 1-10g/l, 2-8% in the range 1mg-1g/l
2.3 Radiation Source
Minimal activity radio-isotope to suit application
2.4 Radiation Detector
Energy dispersive solid-state Si(Li) X-ray detector

3 Supplementary Explanation

(Measuring Principle / Block Diagram / Photo. etc.)



Measurement:
X-ray Fluorescence Analysis

XRF on site and laboratory analyser

1. General Information

1.1. Product Name / Model Number

X-ray fluorescence analyser AF-20 for on-site and laboratory sample analysis

1.2.Applications

The gauge finds application in analysis of galvanic bath, of minerals, cement, determination of ash content in coal and thickness measurements of metallic and non-metallic coatings in the range up to a few tens micrometers

1.3. Features

The X-ray fluorescence analyzer AF-20 is an instrument designed for fast, non-destructive analysis of the elements with atomic number higher than of sulphur in solid and liquid samples

1.4. Typical Price

US $ 10 000

2. Performance

2.1. Measuring Range

0.5 – 5 %

2.2. Precision and/or Accuracy

0, 5-1% in laboratory conditions

1–3 % on site conditions

2.3. Radiation Source

Cd-109, Am-241 (1- 3 GBq)

2.4. Radiation Detector

Proportional counter

3 Supplementary Explanation

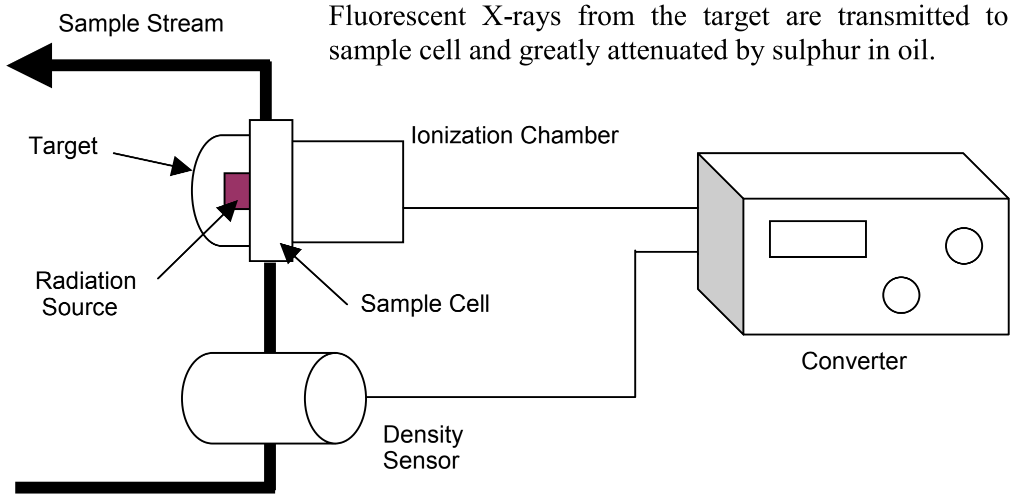
(Measuring Principle / Block Diagram / Photo. etc.)

Analyzed elements	all elements with atomic number not lower than 16
Analyzed samples	solid, liquids, granular, deposited on a filter
Measuring time	0.1 – 15 min programmed from keyboard
Radiation source	Cd-109, Pu-238, Am-241, exchangeable
Radiation detector	proportional counter

Low energy gamma gauge

1. General Information
1.1. Product Name / Model Number
Sulphur in oil Analyser / PS6
1.2. Applications
Sulphur concentration measurement in oil at process stream lines.
1.3. Features
- Continuous process stream analysis. - Insensitive to C/H ratio change. - Stable performance for longer term.
1.4. Typical Price
US$ 100 000 (including sampling cabinet)
2. Performance
2.1. Measuring Range
Min: 0 - 0.5 % Max: 0 - 5 %
2.2. Precision and/or Accuracy
0.005 %S
2.3. Radiation Source
^{241}Am : 20.4 GBq
2.4. Radiation Detector
Dedicated Ionisation Chamber
3. Supplementary Explanation
(Measuring Principle / Block Diagram / Photo. etc.)

Fluorescent X-rays from the target are transmitted to the sample cell and greatly attenuated by sulphur in oil.



Portable XRF elemental analyser

1. General Information

1.1. Product Name / Model Number

PortX portable elemental analyser

1.2. Applications

Non-destructive analysis of the major elements in samples by X ray fluorescence

1.3. Features

Lightweight, battery powered. Peltier-cooled silicon detector for high resolution X ray spectroscopy. Uses handheld computer running Windows CE for spectrum analysis. 512 channel display. Key-operated shutter for safety.

1.4. Typical Price

$US22,000 +, depending on particular applications

2. Performance

2.1. Measuring Range

Depends on source. With Cm-244, lowest practical element is potassium (Z=19). Concentrations should be >1000 ppm.

2.2. Precision and/or Accuracy

Depends on matrix corrections. Typically 3%

2.3. Radiation Source

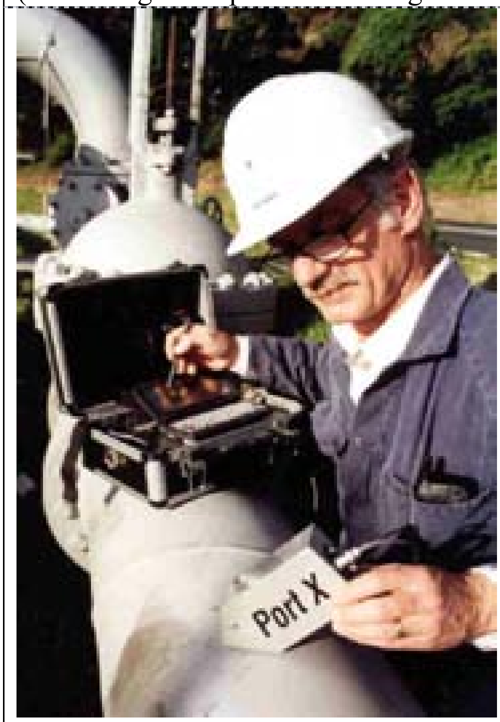
Standard is 1.11 GBq Cm-244, but others such as Fe-55 or Cd-109 can be ordered

2.4. Radiation Detector

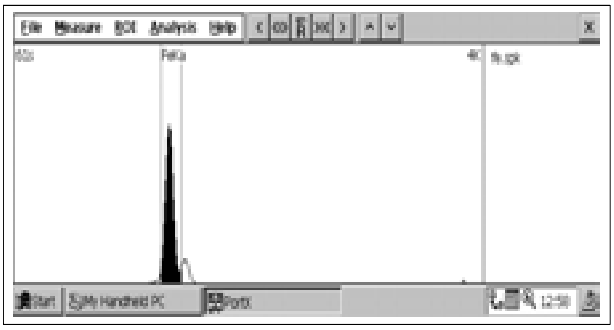
Amptek XR-100CR

3 Supplementary Explanation

(Measuring Principle / Block Diagram / Photo. etc.)



PortX being used on a metal pipe. The XRF head is connected by cables to its electronics and power supply. The multichannel analysis (MCA) is based on a field programmable gate array to provide a 6 microsecond data acquisition time and 512 channel ADC. The stored spectrum is transferred by a serial connection at one second intervals to a handheld PC for display and processing.



10.6. GAUGES USING NATURAL RADIOACTIVITY

Natural radioactivity gauge for on line analysis of U, Th and K

1. General Information
1.1 Product Name / Model Number
Radiometric Analyser (RA)
1.2 Applications
Continuous on-line analysis of uranium, thorium and potassium in mineral sands streams and uranium and potassium processing plants.
1.3 Features
- Slurry and dry stream versions of the instrument, - Truck discriminator version for the uranium mining, - Ultimate safety of radiometric measurement.
1.4 Typical Price
On request
2. Technical Details & Performance
2.1 Measuring Range
0.01 – 1 %
2.2 Precision and/or Accuracy
5- 10%
2.3 Radiation Source
Natural gamma-ray radiation
2.4 Radiation Detector
Scintillation detector, NaI (Tl), 4” x 4”
3 Supplementary Explanation
(Measuring Principle / Block Diagram / Photo. etc.)

Three channel measurement of naturally occurring gamma radiation (U, Th, K)

On-belt ash monitoring gauge utilizing natural gamma rays of coal

1. General Information
1.1 Product Name / Model Number
COALSCAN Model 1500
1.2 Applications
On-line measurement of ash in mine grade control, preparation plant feed monitoring, preparation plant feedback control and train loadout control.
1.3 Features
- Ultimate safety of radiometric measurement, under-belt configuration, - Fully automatic operation, - Drift free performance – gain stabilised, - No upper limit for tonnage rate and coal bed depth, - Analog and serial outputs available, - Low maintenance costs,
1.4 Typical Price
On request
2. Technical Details & Performance
2.1 Measuring Range
1-10 % ash content in coal
2.2 Precision and/or Accuracy
Precision: typically +/- 1% ash for low ash coals, +/- 2% ash for high ash raw coals.
2.3 Radiation Source
No radiation sources.
2.4 Radiation Detector
Large volume scintillation detector NaI (Tl) (10 x 10 x 40 cm). To minimise the effects of cosmic radiation, and hence improve the sensitivity of the system, a thick (10 cm) lead shield surrounds the detector and also is mounted above the conveyor.
3 Supplementary Explanation
(Measuring Principle / Block Diagram / Photo. etc.)

Measurement: Gamma total and Spectrometric measurement of naturally occurring gamma radiation

Natural gamma gauge for on-line coal ash measurement

1. General Information

1.1 Product Name / Model Number

System RODOS - for on-line coal quality - quantity monitoring

1.2 Applications

On-line measurement of ash content, mass and calorific value - in raw coal - feed on preparation plant, run of mine monitoring(underground of mine)

1.3 Features

- Continuous process stream analysis.
- Running information about coal quality and mass. Transmission and visualisation current measuring to chosen places; storage of measuring result and control results in data base; making reports about coal quality and mass in the form of tables and graphs.

1.5 Typical Price

US$ ~50 000

2. Performance

2.1. Measuring Range

5-80 % Ash

2.2. Precision and/or Accuracy

σ = 1.5 % - 2.5 % Ash ,

2.3. Radiation Source

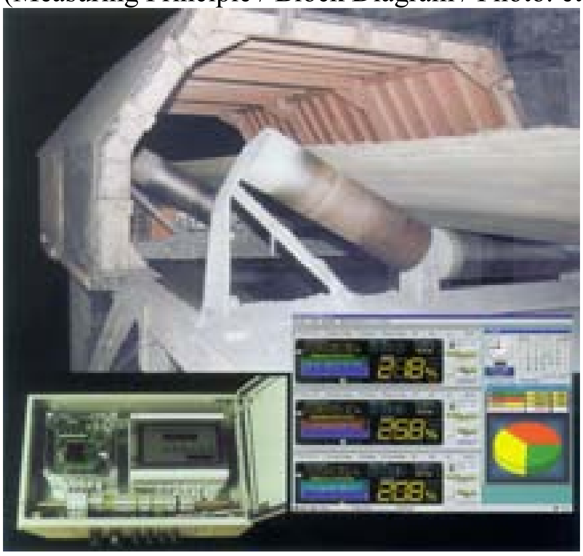
Natural radioactivity of coal

2.4. Radiation Detector

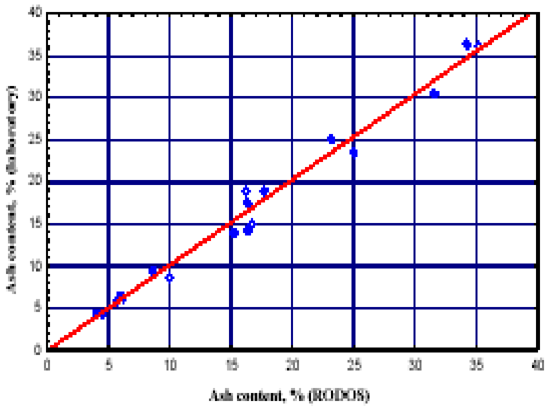
Scintillation detectors NaI (Tl) 3”x3”

3 Supplementary Explanation

(Measuring Principle / Block Diagram / Photo. etc.)



Calibration curve



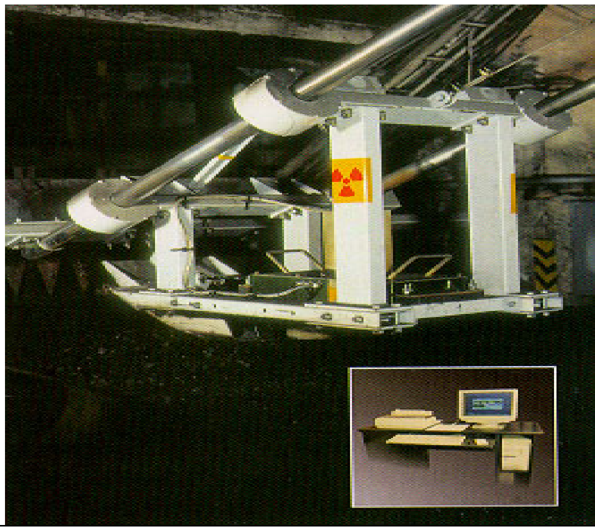
10.7. COMBINED NUCLEONIC-CONVENTIONAL GAUGES

Combined backscatter gamma gauge with microwave sensor for on-line coal monitoring

1. General Information
1.1 Product Name / Model Number
Coal Quality Monitoring System C 132
1.3 Applications
On-line measurements of ash content and moisture of black coal.
1.4 Features
Measurement of ash combined with microwave based moisture monitor, Calorific value calculated from ash and moisture values, Minimum coal bed of 100mm, Narrow range of coal grain size (0 – 30 mm).
1.5 Typical Price
On request
2. Technical Details & Performance
2.1 Measuring Range
Ash: 1-10 %, Moisture: 20-50%
2.2 Precision and/or Accuracy
Accuracy of ash determinations: the same as for C112A, accuracy of moisture content determination: +/- 1% (weight), accuracy of calorific value determination: +/- 200kJ/kg.
2.3 Radiation Source
3.7 GBq of ^{241}Am.
2.4 Radiation Detector
Scintillation detector
3 Supplementary Explanation
(Measuring Principle / Block Diagram / Photo. etc.)

Measuring principle: Measurement of ash content based on backscatter gamma-ray combined with microwave based moisture measurement.

Combined gauge: gamma backscattering for ash and microwave for moisture

1. General Information
1.1 Product Name / Model Number
ALFA-05 system - for on-line coal quality monitoring ;
1.2 Applications
On-line measurement of ash content, moisture content and calorific value in small coal - in loading points, in control system of beneficiation processes (on the conveyor belt) -coal preparation plants, power plants, coking plants, coal handling installation.
1.3 Features
Continuous process stream analysis. Running information about coal quality parameters. Transmission and visualisation current measuring to chosen places; storage of measuring result and control results in data base; making reports about coal quality in the form of tables and graphs.
1.4 Typical Price
US$ ~45 000
2. Performance
2.1 Measuring Range
3-50 % Ash; 3-20 % Moisture
2.2 Precision and/or Accuracy
3-20 % Ash σ = 0.7 %A , > 20 % Ash - σ = 1,5 %A for moisture σ = 1 % M.
2.3 Radiation Source
Am-241 , 3,7 GBq
2.4 Radiation Detector
Scintillation detector NaI (Tl), 50 x 50 mm
3 Supplementary Explanation
(Measuring Principle / Block Diagram / Photo. etc.) Measuring principle- gamma -ray backscattering (ash meter) , microwave backscattering (moisture meter) 

10.8. BOREHOLE LOGGING GAUGES

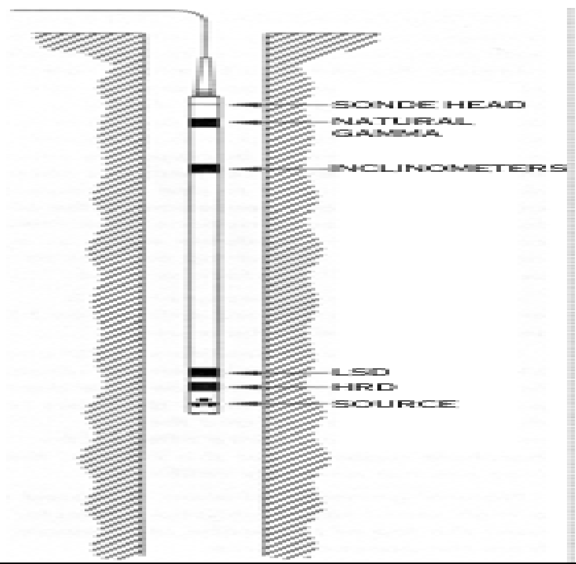
Borehole logging probe for density measurement

1. General Information
1.1. Product Name / Model Number
Density gamma probe (Trisonde)
1.2. Applications
- Bulk density variations - Lithology identification (coal logging) - Bed thickness and boundaries - Location of missing cement behind casing - Borehole inclination and true vertical depth
1.3. Features
The probe provides continuous measurements of rock formation density using two source-to-detector spacing. The shorter spacing provides good resolution of bed thickness and boundary positions while the longer spacing offers deeper formation penetration and greater immunity from borehole influences.
1.4. Typical Price
On request

2. Technical Details & Performance
2.1. Operating Conditions
Maximum depth: 2000 m, Borehole diameter: 45mm to 300mm, Borehole type: open / cased: water / air-filled
2.2. Specifications
Diameter: 38mm, Length: 2.31m, Weight: 7.6kg, Maximum temperature/pressure: 70ºC/2MPa
2.3. Radiation Source
^{137}Cs – 370 MBq
2.4. Radiation Detector
Natural Gamma detector: NaI (TL) scintillation detector, size: 50mm x 25mm (+ larger options)

3 Supplementary Explanation

(Measuring Principle / Block Diagram / Photo. etc.)



The principle of measurement: Measurements of natural radioactivity and back-scatter gamma radiation. The probe provides continuous measurements of rock formation density using two source-to-detector spacings. The detector located 24cm from the source (HRD) provides good resolution of bed thickness and boundary positions, while the further detector (LSD – located 48 cm from the source) is used for qualitative indication of formation bulk density changes. A larger size scintillation crystal, located near the top of the probe, measures natural radiation of logged formation.

Low activity borehole logging probe for density measurement

1. General Information

1.1 Product Name / Model Number

Small source density probe

1.2 Applications

Measurements of density (and porosity), bed-boundary definition, lithology identification (in conjunction with other formation logs), ash content in coal, detection of weathered and fractured zones, location of aquifer, location of cement cavities behind casing.

1.3 Features

Provision of : Borehole-compensated formation density (g/cc), High-resolution density (cps), Bed-resolution density (cps), Caliper (mm or in), Natural gamma (API)

1.4 Typical Price

On request

2. Technical Details & Performance

2.1 Operating Conditions

Hole diameter: 60 - 250mm, Borehole type: open hole, water-filled/air-filled, Logging speed: 2.5m/min.

2.2 Probe Specifications

Diameter:51mm, Length: 2.85m, Weight: 25kg, Maximum temperature/pressure: 70 ºC/10MPa

2.3 Radiation Source

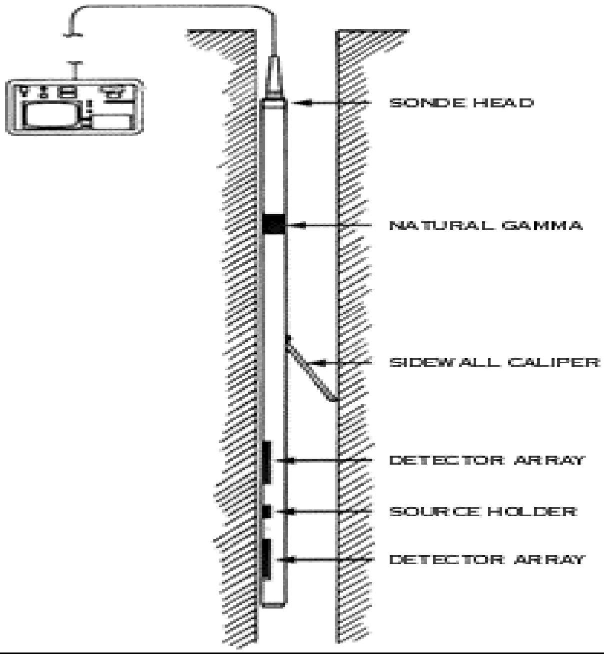
[1] ^{60}Co – 3.7 MBq

2.4 Radiation Detector

Na(Tl) 50 x 50 mm

3 Supplementary Explanation

(Measuring Principle / Block Diagram / Photo. etc.)



The principle of measurement: Measurement of back-scatter gamma radiation by an array of collimated detectors arranged symmetrically above and below the nuclear source of low activity (3.7 MBq). The outputs of individual detectors are integrated to improve the signal-to-noise ratio of the measured count rate. The SSDS provides calibrated density logs. Background natural gamma radiation is measured by the far end scintillation detector and stripped from the density signal.

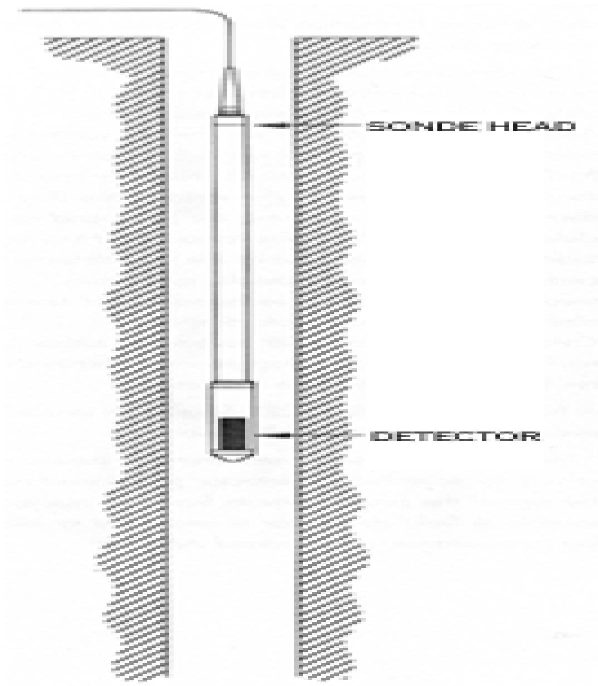
Spectrometric gamma natural logging probe

1. General Information
1.1 Product Name / Model Number
Natural gamma spectroscopy sonde
1.2 Applications
Downhole *in-situ* determination of lithology, mineral detection, sedimentology and improved shale content computation.
1.3 Features
Automatic temperature compensation and gain stabilization, Data acquisition in five pre-set energy windows (K, U and Th determinations) or in 256 channels.
1.4 Typical Price
On request

2. Technical Details & Performance
2.1 Operating Conditions
Hole depth: 2000m, Hole diameter: 75mm to 300mm, Borehole type: open / cased; water / air-filled.
2.2 Probe Specifications
Diameter: 60mm, Length 1.68m, Weight 10.5kg, Temperature 70ºC, Pressure 20Mpa.
2.3 Radiation Source
None
2.4 Radiation Detector
NaI(Tl) scintillator (option BGO), Detector size: 38mm x 150mm.

3 Supplementary Explanation

(Measuring Principle / Block Diagram / Photo. etc.)



The principle of measurement:
Measurement of natural radioactivity. The probe operates either in ‘full spectral’ mode utilizing 256 energy channels (static measurements only), or in ‘fixed window’ mode, using five preset energy windows to determine concentrations of Potassium, Uranium and Thorium in continuous measurements. Measurements are performed using a large-volume scintillation detector.

Neutron borehole logging probe for well porosity measurement

1. General Information

1.1 Product Name / Model Number

Neutron probe (single spacing)

1.2 Applications

Downhole *in-situ* determination of porosity, lithology identification (in conjunction with other formation logs), strata correlation between wells.

1.3 Features

Possibility of combination with Natural Gamma log, Single Point Resistance log and Spontaneous Potential log,
Optional natural gamma log and Casing Collar Locator (CCL) log,

1.4 Typical Price

On request

2. Technical Details & Performance

2.1 Operating Conditions

Hole depth: 2000m, Hole diameter: 45mm to 300mm, Logging speed: 4 to 6m/min,

2.2 Probe Specifications

Diameter: 38mm, Length 2.08m, Weight 8kg, Temperature 70ºC, Pressure 20Mpa.

2.3 Radiation Source

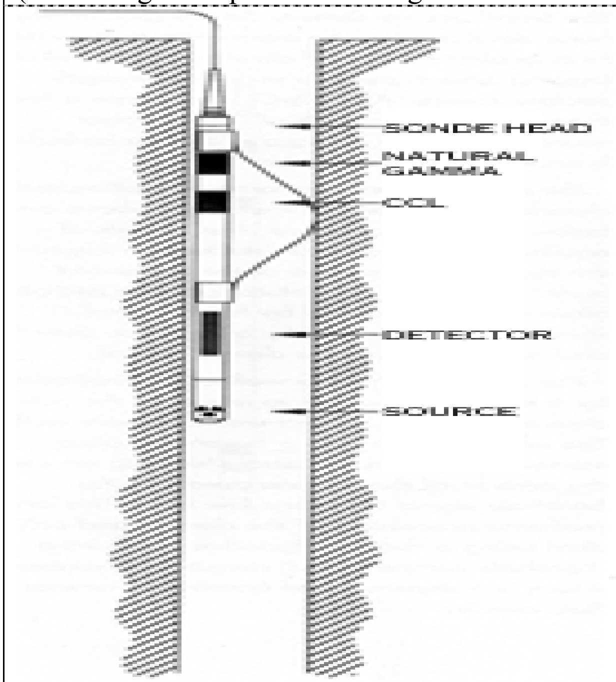
^{241}Am-Be fast neutrons source of 37 GBq (1 Ci) activity.

2.4 Radiation Detector

^{3}He proportional counter

3 Supplementary Explanation

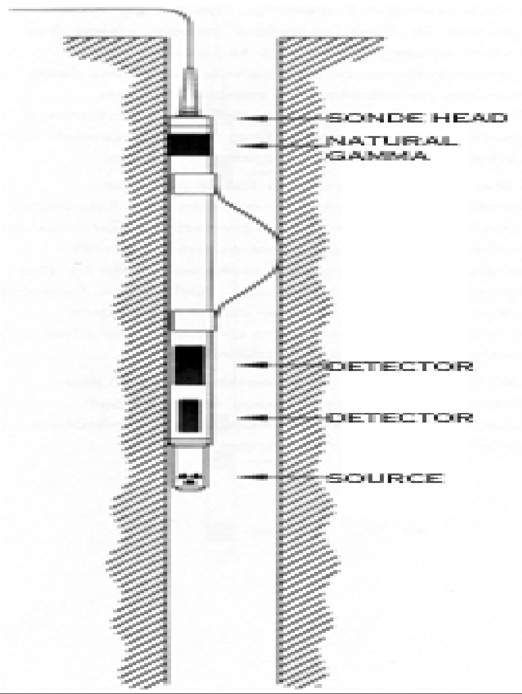
(Measuring Principle / Block Diagram / Photo. etc.)



The principle of measurement: Fast neutrons emitted by the source are scattered and slowed down (principally by hydrogen in the formation) until they reach thermal energy levels are absorbed. The thermal neutrons flux reaching the detector is a measure of the formation hydrogen content and indirectly its porosity.

Neutron downhole logging probe

1. General Information
1.1 Product Name / Model Number
Neutron probe (dual spacing)
1.2. Applications
Downhole *in-situ* determination of porosity and Hydrogen Index, lithology identification, shale content, fracture analysis in coal.
1.3 Features
- Combination with Natural Gamma log, - Provision of borehole-size compensated porosity log, - Measurement range: -15% to =45% apparent limestone porosity.
1.4 Typical Price
On request
2. Technical Details & Performance
2.1 Operating Conditions
Hole depth: 2000m, Hole diameter: 75mm to 300mm, Borehole type: open / cased; water-filled (natural gamma and qualitative neutron also in air-filled boreholes), Logging speed: 4m to 6m/min.
2.2 Probe Specifications
Diameter: 60mm, Length 1.94m, Weight 18.8kg, Temperature: 70ºC (option 125ºC), Pressure: 2MPa
2.3 Radiation Source
^{241}Am-Be fast neutrons source of 120 GBq activity.
2.4 Radiation Detector
Two ^{3}He proportional counters
3 Supplementary Explanation
(Measuring Principle / Block Diagram / Photo. etc.)



The principle of measurement: The compensated neutron measurement uses two ^{3}He proportional detectors for measuring the ratio of the flux of thermal neutrons reaching the near and far detectors. This ratio depends on the formation's Hydrogen Index and porosity. This probe permits borehole-compensated porosity measurement which is independent of borehole size over a range of borehole diameters.

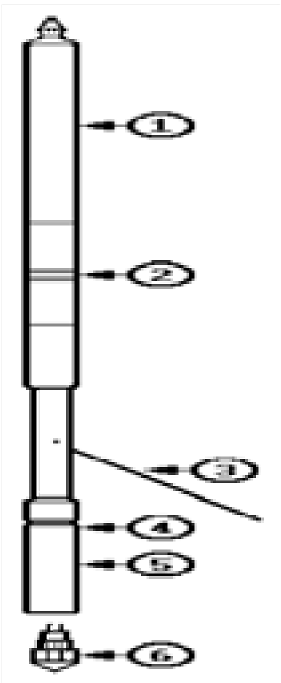
Natural gamma logging probe for bulk density and lithology

1. General Information
1.1. Product Name / Model Number
Compensated density tool, 9039 Series
1.2. Applications
Downhole *in-situ* determination of borehole compensated bulk density and lithology. Additionally the tool also records natural gamma, calliper, medium guard resistivity and borehole temperature logs.
1.3. Features
The Series 9039, Compensated Density logging tool uses the two focused density detectors to compute borehole compensated density real time while logging. No post processing required producing CDL bulk density. The tool also records natural gamma, calliper, medium guard resistivity, and borehole temperature.
1.4. Typical Price
Tool with NG, CAL, ND, FD, MG, TEMP: US$ 20 000

2. Technical Details & Performance
2.1 Operating Conditions
Max. Temperature: 85ºC, Max Pressure: 175 kg/cm2, Logging Speed: 9 m/min.
2.2 Probe Specifications
Length:280.3 cm, Diameter: 56 mm, Weight:29.5 kg
2.3 Radiation Source
Activity of ^{137}Cs source: 7400 MBq
2.4 Radiation Detector
Large size FD detector: 2.2 x 10.2cm, ND detector: 2.2 x 3.2cm, NG detector: 2.2 x 10.2cm

3 Supplementary Explanation

(Measuring Principle / Block Diagram / Photo. etc.)



1. Natural Gamma (NG),
2. Element Guard Resistivity, Borehole Temperature,
3. Caliper,
4. Far Density (FD),
5. Near Density(ND),
6. Radioactive Source

The principle of measurement: Measurement of natural radiation by a NaI(Tl) scintillation detector located near the top of the probe combined with measurement of back-scatter gamma radiation by two collimated NaI(Tl) detectors. Far Density (FD) detector is placed 30.9cm from the source, and Near Density detector (of a smaller size) is located 14.9cm from the source. The probe permits measurements of borehole compensated bulk density. CD log is produced in real time while logging.

Combined natural gamma and neutron logging probe for lithology, density and porosity

1. General Information

1.1 Product Name / Model Number

Natural gamma and neutron tool, model 9058

1.2 Applications

The Natural Gamma, Neutron logging tool is designed for open and cased hole use. In open holes the neutron log may be converted to porosity units based on a limestone, sandstone or dolomite matrix.

1.3 Features

The tools small diameter makes it useful for logging Natural Gamma and Neutron through drill rods in cases where the hole is to unstable to be logged open hole. Natural Gamma, X-Y Inclinometers and Azimuth are optional.

1.4 Typical Price

Tool with NG, TEMP, NN: US$ 10 000

2. Technical Details & Performance

2.1 Operating Conditions

Temperature: 80ºC, Pressure: 292 kg/cm2, Logging Speed: 9 m/min.

2.2 Probe Specifications

Length: 243 cm, Diameter: 42 mm, Weight: 12.0 kg.

2.3 Radiation Source

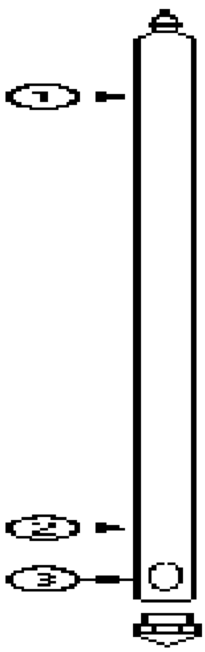
^{241}Am-Be fast neutrons source.

2.4 Radiation Detector

Natural Gamma: NaI(Tl) 2.2 x 102 mm, Neutron-Neutron: ^{3}He Detector 25.4 mm x 152 mm

3 Supplementary Explanation

(Measuring Principle / Block Diagram / Photo. etc.)

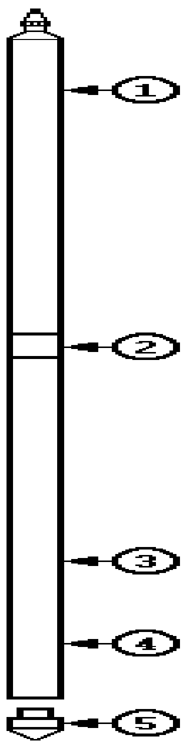


1. Natural Gamma,
2. Neutron-Neutron,
3. Temperature

The principle of measurement:
Measurement of thermal neutron flux by a single ^{3}He detector combined with measurements of natural radioactivity by a NaI(Tl) detector.

Compensated neutron logging probe

1. General Information
1.1 Product Name / Model Number
Compensated Neutron Logging Tool, Model 9073
1.2 Applications
Measurements of neutron porosity of the formation.
1.3 Features
The tool also records short and long neutron counts, natural gamma and a deep guard resistivity.
1.4 Typical Price
Tool with NG, CNL, Guard Log: US$ 15 000
2. Technical Details & Performance
2.1 Operating Conditions
Temperature: 85ºC, Pressure: 232 kg/cm2, Logging Speed: 9 m/min.
2.2 Probe Specifications
Length: 283.5 cm, Diameter: 50.8 mm, Weight: 25.0 kg.
2.3 Radiation Source
^{241}Am-Be fast neutrons source of 150 GBq activity.
2.4 Radiation Detector
Natural Gamma: 2.2 x 10.1 cm NaI (Tl), Neutron Detectors, Far Spacing: ^{3}He 3.8 x 24.4 cm, Near Spacing: ^{3}He 3.8 x 10.1 cm
3 Supplementary Explanation
(Measuring Principle / Block Diagram / Photo. etc.)



1. Natural Gamma,
2. Deep Guard Resistivity,
3. Neutron Detector, Far Spacing,
4. Neutron Detector, Near Spacing,
5. Radioactive Source.

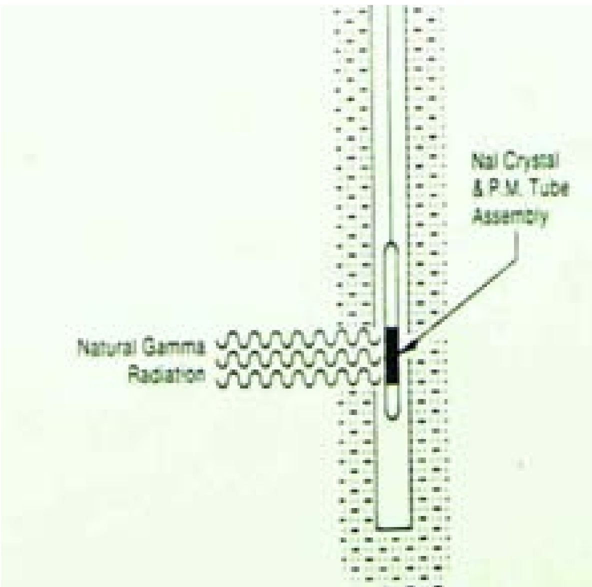
Natural gamma probe

1. General Information
1.1 Product Name / Model Number
Natural gamma tools, models A75 & A31
1.2 Applications
Specific applications in Groundwater: indication of clay content; Uranium Exploration: grade determination, and Coal Exploration: delineation of coal seams.
1.3 Features
The natural gamma tool is available in combination with almost any other Scintrex/Auslog tool. The tool can be used in all holes conditions: dry, water-filled, steel cased or PVC cased.
1.4 Typical Price
On request

2. Technical Details & Performance
2.1 Operating Conditions
Max. Temperature: 60ºC, Max. Pressure: 21 MPa
2.2 Probe Specifications
Length: 113cm, Diameter: 33mm (A75), 42mm (A31), Weight: 3.4kg (A75), 4.4kg (A31).
2.3 Radiation Source
None
2.4 Radiation Detector
NaI(Tl) 12.7mm x 44.5mm (model A75), 25mm x 76mm (model A31)

3 Supplementary Explanation

(Measuring Principle / Block Diagram / Photo. etc.)



The principle of measurement: These tools detect natural Gamma radiation emanating from the subsurface rocks. Gamma rays are very high frequency electromagnetic radiation and are derived from the radioactive decay of various elements.

Gamma-gamma logging probe for density measurement

1. General Information
1.1. Product Name / Model Number
Slim Density Tool, model A101
1.2. Applications
- Groundwater: relation between strata density and porosity, Engineering: indication of rock strength. - Factors such as weathering, fracturing and porosity can be evaluated, Iron ore & coal exploration, where ore or coal density differs significantly from barren rock density.
1.3 Features
Provides high quality repeatable results. Three different borehole configurations are available. Field calibration is maintained using an optional low value radioactive source calibrator. Mallory metal shields are used to reduce back-scatter effects and to provide high accuracy in focusing of the source and shielding of the detector.
1.4 Typical Price
On request

2. Technical Details & Performance
2.1 Operating Conditions
Max. Temperature: 60ºC, Max. Pressure: 34.5 MPa.
2.2 Probe Specifications
Length: 130cm, Diameter: 34mm, Weight: 4.5kg.
2.3 Radiation Source
^{137}Cs of 1.85 GBq activity
2.4 Radiation Detector
NaI(Tl) 12.7mm x 44.5mm

3 Supplementary Explanation

(Measuring Principle / Block Diagram / Photo. etc.)

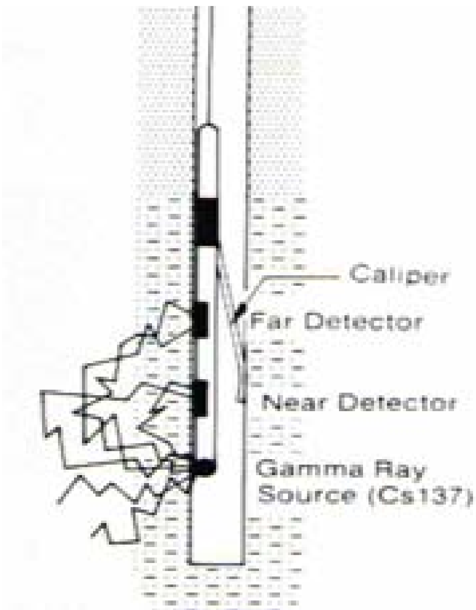
The principle of measurement: The density tool or gamma-gamma log contains both a source of gamma radiation, usually in the form of Cs-137, and a gamma detector. The proportion of the gamma rays emitted by the source and back-scattered to the source is a measure of the density of the formation within the vicinity of the source/detector combination. Different source detector spacings may be used, for example to maximise thin bed resolution or to improve the accuracy of the density calibration. The density tools are often run decentralised in conjunction with a single arm calliper. The source and the detector are both collimated.

Gamma density logging probe

1. General Information
1.1 Product Name / Model Number
Gamma-Gamma Density Tool, model A59 & ***Dual Gamma-Gamma Density/Calliper/Gamma Tool, model A5***
1.2 Applications
- Groundwater: relation between strata density and porosity, Engineering: indication of rock strength. - Factors such as weathering, fracturing and porosity can be evaluated, Iron ore & coal exploration, where ore or coal density differs significantly from barren rock density
1.3 Features
A59: Standard spacings are provided to allow short and long spaced density measurements. Spacings are 200, 300, 350 and 400 mm. The surface controlled motor driven calliper arm provides decentralisation of the tool and provides continuous borehole diameter measurements. A5: One short spaced density log, one long spaced density log, calliper log and natural gamma log are obtained from a single run. Standard source detector spacings are 200 and 450 mm. Optional spacings are available.
1.4 Typical Price
On request

2. Technical Details & Performance
2.1 Operating Conditions
Max. Temperature: 60ºC, Max. Pressure: 21 MPa.
2.2 Probe Specifications
Length: 143cm (A59), 226cm (A5), Diameter: 51mm, Weight: 8.8kg (A59).
2.3 Radiation Source
^{137}Cs of 1.85 GBq activity
2.4 Radiation Detector
NaI(Tl) 12.7mm x 44.5mm

3 Supplementary Explanation
(Measuring Principle / Block Diagram / Photo. etc.)



Neutron logging probe

1. General Information

1.1 Product Name / Model Number

Neutron logging tool, model A 009

1.2. Applications

Groundwater Evaluation – Hydrogen content can be equated with porosity.
Engineering – Water content is often an indirect indicator of rock strength.
Oil Shale – Neutron log response is a direct indicator of oil content.
Coal Exploration – Often the neutron log is a good indication of ash type.

1.3. Features

Provides high quality repeatable results, provided with a 1 Curie (37 GBq) Americium 241 Beryllium source. Option source strengths of 3 Curies can be provided. Standard source detector spacing is 320mm. Other spacings can be provided. Bow-spring assemblies provided for decentralisation.

1.4 Typical Price

On request

2. Technical Details & Performance

2.1 Operating Conditions

Max. Temperature: 60ºC, Max. Pressure: 21 MPa.

2.2 Probe Specifications

Length: 121cm, Diameter: 33mm, Weight: 3.8kg.

2.3 Radiation Source

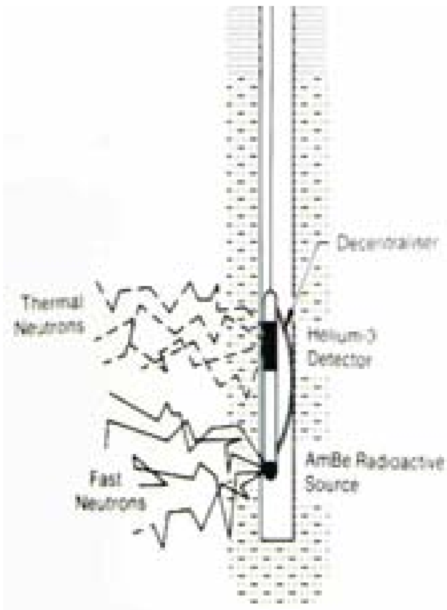
^{241}Am-Be fast neutrons source of 1 Ci (37 GBq) activity, optionally: 111 GBq.

2.4 Radiation Detector

^{3}He detector 25mm x 152mm

3 Supplementary Explanation

(Measuring Principle / Block Diagram / Photo. etc.)



A neutron tool consists of a source of neutrons and a neutron detector. The ^{241}Am-Be source emits fast neutrons. The neutrons occasionally collide with the nuclei of atoms comprising the rock minerals. When a collision occurs with the nucleus of a hydrogen atom the nucleus loses a portion of its energy. When several such collisions have occurred the neutron will reach the thermal energy level and be capable of detection by the thermal neutron detector (^{3}He). Since hydrogen plays such a large role in the process of energy loss, the neutron log is basically an indicator of water content. The tool is run decentralised to minimise the effects of drilling mud and caving.

Gamma natural radioactivity logging probe

1. General Information
1.1 Product Name / Model Number
SIROLOG Natural Gamma Probe
1.2 Applications
In-situ delineation of coal seams and ore-bodies, determination of alumina content in iron ore, seam correlation.
1.3. Features
Large volume BGO, or alternatively CsI detectors, Spectrometric data recording in 480/960 channels, WINVIEW data visualisation & interpretation software, Three probe diameters: 60mm (37mm x 75mm detector), 70mm (50mm x 100mm detector), and 100mm (75mm x 75mm detector).
1.4 Typical Price
On request

2. Technical Details & Performance
2.1 Operating Conditions
Centralised log, Hole diameter: 90 – 420mm.
2.2 Probe Specifications
Various probe lengths, diameters and weights – depending on application.
2.3 Radiation Source
None
2.4 Radiation Detector
BGO, alternatively CsI(Tl), see Features.

3 Supplementary Explanation

(Measuring Principle / Block Diagram / Photo. etc.)

The principle of measurement: Spectrometric measurement of natural gamma-radiation in 480/960 energy channels.

Gamma-gamma (backscatter gamma) logging probe

1. General Information

1.1 Product Name / Model Number

SIROLOG Gamma-Gamma Probe

1.3 Applications

In-situ delineation of coal seams and ore-bodies, determination of raw ash content in coal and ore-grade in monometallic ores (e.g. iron ore).

1.4 Features

Data recording in 480 channels,
Gain-stabilised logging operation,
WINVIEW data visualisation & interpretation software.

1.5 Typical Price

On request

2. Technical Details & Performance

2.1 Operating Conditions

Centralised operation, Spectrometric data acquisition in 480 channels.

2.2 Probe Specifications

Length: 120cm – 185cm, Diameter: 60mm

2.3 Radiation Source

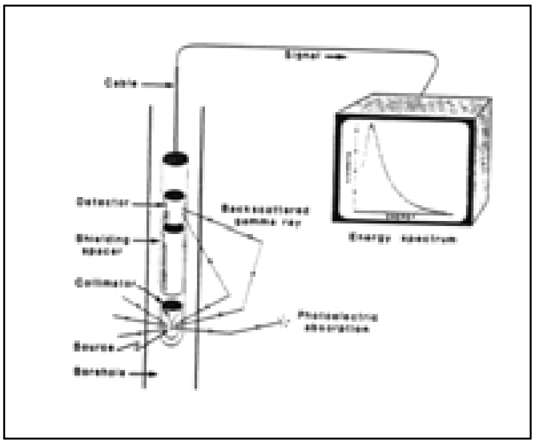
Moderated gamma-ray source activity (37-74 MBq ^{137}Cs or ^{60}Co, depending on the application).

2.4 Radiation Detector

NaI(Tl) 37.5mm x 76mm.

3 Supplementary Explanation

(Measuring Principle / Block Diagram / Photo. etc.)



The principle of measurement: Spectrometric measurement of back-scatter gamma-rays

PGNAA logging probe

1. General Information

1.1 Product Name / Model Number

SIROLOG Neutron-Gamma (PGNAA) Probe

1.2 Applications

In-situ delineation of coal seams and ore-bodies, determination of raw ash content and coal slagging components in coal, and assaying of metalliferous ores for ore-grade and impurities content.

1.3 Features

Data recording in 480/960 channels,
Gain-stabilised logging operation,
WINVIEW data visualisation & interpretation software,
Three probe diameters:
60mm (37mm x 75mm detector),
70mm (50mm x 100mm detector), and
100mm (75mm x 75mm detector).

1.4 Typical Price

On request

2. Technical Details & Performance

2.1 Operating Conditions

Centralised operation, Spectrometric data acquisition in 480/960 channels.

2.2 Probe Specifications

Length: 185cm, Diameter: 60,70 & 100mm (depending on application).

2.3 Radiation Source

Moderate neutron source activity (100MBq of ^{252}Cf).

2.4 Radiation Detector

BGO in three sizes

3 Supplementary Explanation

(Measuring Principle / Block Diagram / Photo. etc.)

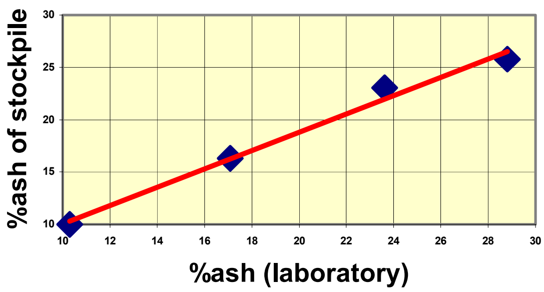
The principle of measurement: Spectrometric measurement of energy and count rate of gamma-rays originated from Prompt Gamma Neutron Activation.

10.9. LOW ACTIVITY GAUGES

Portable face and stockpile coal ash analyzer

1. General Information
1.1. Product Name / Model Number
Portable face and stockpile coal ash analyser
1.2. Applications
The Coal Face and Stockpile Probe are portable nucleonic gauges for the determination of ash content on the coal face and in coal stockpiles...
1.3. Features
The analyser works as a backscatter gamma ray type gauge (from Ba-133). There are two different probes connected to the same data logger (laptop computer). The Cs-137 source is used for gain stabilisation only.
1.4. Typical Price
US$ 20 000
2. Performance
2. Measuring Range
2.1. The time per measurement is 15-20 seconds, and by taking a large number of measurements the accuracy for the average is improved
2.2. Precision and/or Accuracy
The accuracy is 5-10% for ash content in coal in the range of 1-5 %.
2.3. Radiation Source
The instruments employ the backscattered gamma-gamma technique. There are two gamma-ray micro-sources used in each instrument: a 1.1 MBq ^{133}Ba source and a 37 kBq ^{137}Cs; and a 1.1 MBq ^{133}Ba source and a 370 kBq ^{137}Cs, respectively.
2.4. Radiation Detector
Scintillation detector NaI (Tl) 50 x 50 mm
3 Supplementary Explanation
(Measuring Principle / Block Diagram / Photo. etc.)

Low activity portable coal face ash analyser for differentiating coal and look alike sediments. It permits selective mining and is applicable to the production phase in open-cut pits and underground mines. The analyser works as a backscatter gamma ray type gauge.



Low gamma activity logging probe

1. General Information

1.2 Product Name / Model Number

SIROLOG Low Radiation Intensity Gamma-Gamma Probe

1.3 Applications

In-situ delineation of coal seams and ore-bodies, determination of raw ash content in coal and ore-grade in monometallic ores (e.g. iron ore).

1.4 Features

Two probe configurations:
Zero Probe – applying 1.1MBq of ^{137}Cs and 0 cm source-to-detector distance, and
Low Activity Tool – applying 1.85MBq ^{133}Ba with 0.37 MBq ^{137}Cs and 35mm s-t-d distance,
Ultimate bed resolution for coal seam delineation,
Fully spectrometric, gain stabilised logging operations,
Ultimate safety of operations due to ultra-low radiation intensity of applied gamma-ray sources.

1.5 Typical Price

US$ 25000

2. Technical Details & Performance

2.1 Operating Conditions

Centralised operation, Spectrometric data acquisition in 480 channels.

2.2 Probe Specifications

Length: 185cm, Diameter: 60mm.

2.3 Radiation Source

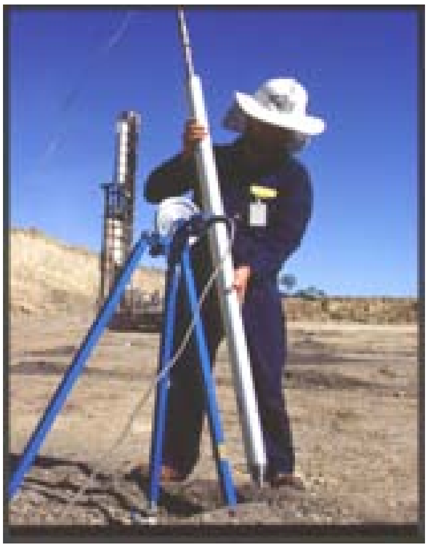
Zero Probe –1.1MBq of ^{137}Cs, Low Activity Tool –1.85MBq ^{133}Ba + 0.37 MBq ^{137}Cs.

2.4 Radiation Detector

Scintillation detector, NaI(Tl), 50 x 50 mm

3 Supplementary Explanation

(Measuring Principle / Block Diagram / Photo. etc.)



The principle of measurement:
Spectrometric measurement of back-scatter gamma-rays.
Low radiation intensity (1.1 MBq) gamma spectrometric borehole logging probe for coal delineation and coal raw ash content. It utilises single-scattered gamma ray to provide information about bulk density of the formation, and multi-scattered rays of lower energies to determine coal raw ash content.

Combined neutron and gamma gauge for soil surface moisture and density

1. General Information

1.1. Product Name / Model Number

Surface Type Moisture-Density Gauge / FT-102 (Low activity)

1.2. Applications

On-site quality control of soil compaction in embankments in road construction works

1.3. Features

1. Transmission techniques employed both for gamma radiation and neutron
2. Design: standard manual of the Japan Highway Public Corporation (FT-102K2)
3. Easy operation and rapid measurement (1min) in a range of 20 cm depth
4. The Gauge displays and prints out the value of wet density, dry density, moisture percent, degree of compaction and air void percent, measured in a 1-minute in situ
5. Low radioactivity sources not exceeding 3.7 MBq in total

1.4. Typical Price

US$ 32 000 (standard)

2. Performance

2.1. Measuring Range

Wet Density : 1.00 - 2.50 g/cm^3
Moisture Content : 0.05 - 0.90 g/cm^3

2.2. Precision and/or Accuracy

Wet Density : 0.015 g/cm^3 (in 1 sigma, 1 minute)
Moisture Content : 0.005 g/cm^3 (in 1 sigma, 1 minute)

2.3. Radiation Source

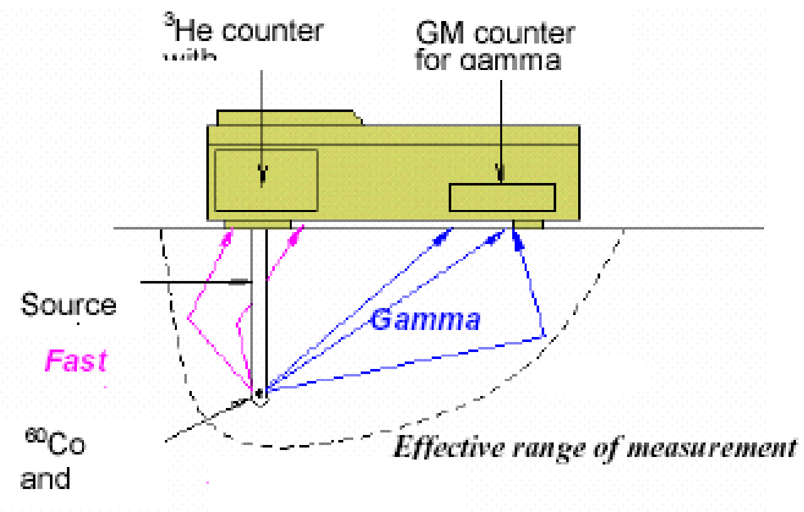
Gamma source : 2.6 MBq Cobalt-60
Neutron source : 1.1 MBq Californium-252

2.4. Radiation Detector

Gamma rays: Geiger-Mueller counter (5 tubes)
Fast neutrons : Helium-3 proportional counter (2 tubes) with moderator

3 Supplementary Explanation

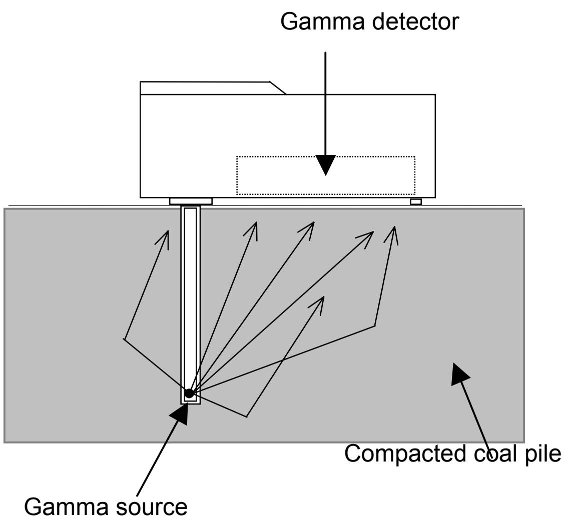
(Measuring Principle / Block Diagram / Photo. etc.)



Measuring Principle:
Density and moisture measurement by gamma-ray and neutron transmission

Low activity gamma transmission gauge

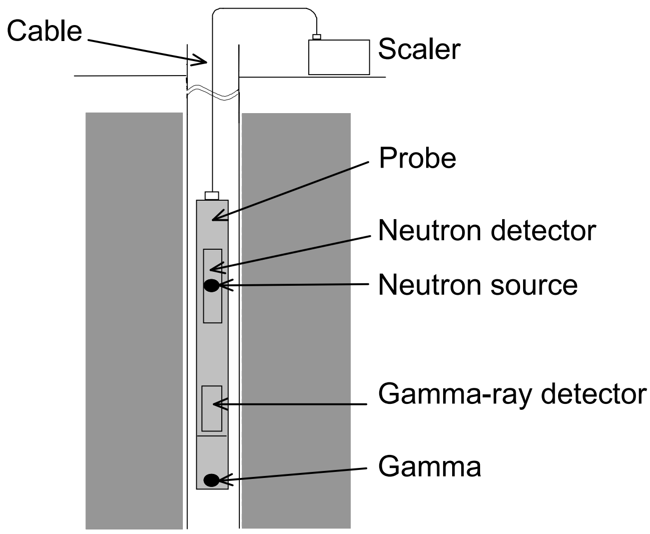
1. General Information
1.1. Product Name / Model Number
Surface type Gauge for Coal Storage Pile / FT-105 (Low activity)
1.2. Applications
Bulk density measurement in compacted coal storage piles in thermal power stations.
1.3. Features
- Suitability to compacted-coal by using a thin boring rod. - Rapid measurement in one minute in situ. - Measurement results obtained in a LCD display and a printer. - Weak radiation source with an activity not exceeding 3.7 MBq.
1.4. Typical Price
US$ 30 000
2. Performance
2.1. Measuring Range
Wet Density : 0.8 - 1.5 g/cm^3
2.2. Precision and/or Accuracy
Wet Density : 0.015 g/cm^3 (1 sigma, 1 minute)
2.3. Radiation Source
Gamma source : 3.7 MBq Cobalt-60
2.4. Radiation Detector
Gamma rays : Geiger-Mueller tube
3 Supplementary Explanation
(Measuring Principle / Block Diagram / Photo. Etc.)



Measuring Principle: Density measurement by gamma-ray transmission

Combined gamma neutron gauge for moisture and density

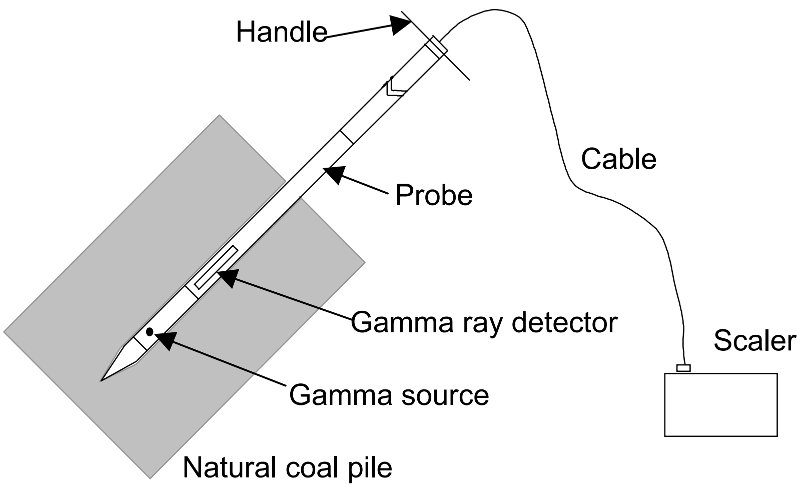
1. General Information
1.1. Product Name / Model Number
Sub-surface Type Moisture-Density Gauge / PB-205 (Low activity)
1.2. Applications
Simultaneous measurement of wet density and moisture content in sub-surface soil underground
1.3. Features
- Lifting a probe inserted in an access tube performs the measurement of density and moisture non-destructively, hence this offers a good tool for observing the changes with time in strata. - Weak radiation sources with an activity not exceeding 3.7 MBq in total.
1.4. Typical Price
US$ 35 000
2. Performance
2.1. Measuring Range
Wet Density :1.00 - 2.50 g/cm^3 Moisture Content : 0 - 0.8 g/cm^3
2.2. Precision and/or Accuracy
Wet Density : 0.02 g/cm^3 (1 sigma, 1 minute) Moisture Content : 0.003 g/cm^3(1 sigma, 1 minute)
2.3. Radiation Source
Gamma source : 2.6 MBq Cobalt-60 Neutron source : 1.1 MBq Californium-252
2.4. Radiation Detector
Gamma rays : Scintillation counter Thermal Neutrons : Helium-3 proportional counter
3 Supplementary Explanation
(Measuring Principle / Block Diagram / Photo. Etc.)



Measuring Principle:
- Moisture measurement by neutron moderation
- Density measurement by gamma backscattering

Subsurface gamma backscatter gauge for bulk density

1. General Information
1.1. Product Name / Model Number
Sub-Surface Type Gauge for Coal Storage Pile / FT-201 (Low activity)
1.2. Applications
Bulk density measurement in natural coal storage piles in thermal power stations.
1.3. Features
- Rapid measurement in one minute in situ. - Measurement results obtained in a LCD display and a printer. - Weak radiation source with an activity not exceeding 3.7 MBq.
1.4. Typical Price
US$ 40 000
2. Performance
2.1. Measuring Range
Wet Density : 0.8 - 1.5 g/cm^3
2.2. Precision and/or Accuracy
Wet Density : 0.015 g/cm^3 (1 sigma, 1 min)
2.3. Radiation Source
Gamma source : 3.7 MBq Cobalt-60
2.4. Radiation Detector
Gamma rays : Scintillation counter
3 Supplementary Explanation
(Measuring Principle / Block Diagram / Photo. Etc.)



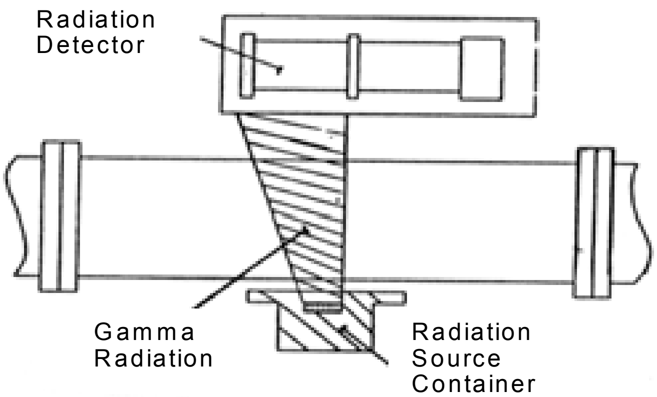
Measuring Principle: Density measurement by gamma-ray backscattering

Gamma density gauge for soil

1. General Information
1.1 Product Name / Model Number
Gamma-ray soil density gauge / NNU (Low activity)
1.2 Applications
Measurement of cutting soil mass in tunnel construction with the shield driving method.
1.3 Features
1) Non-contact and continuous density measurement of mud-water mixture flowing in a tube of 25 - 400 mm in diameter.. 2) Easy mounting on an existing tube from outside. 3) Low radioactivity source employed that is exempted from legal regulation in some countries (Australia and Japan).
1.4 Typical Price
Approximately US$ 30000

2. Performance
Measuring Range
Density: 1.0 - 2.9 g/cm^3
Precision and/or Accuracy
0.005 - 0.006 g/ cm^3 in 2 sigma, at a response time of 120 s and a density of 1.0 g/cm^3 in a tube of 100 – 400 mm diameter.
Radiation Source
^{137}Cs 3.3 MBq or ^{60}Co 3.3 MBq
Radiation Detector
Scintillation detector

3. Supplementary Explanation
(Measuring Principle / Block Diagram / Photo. etc.)



Ionization Smoke Detector

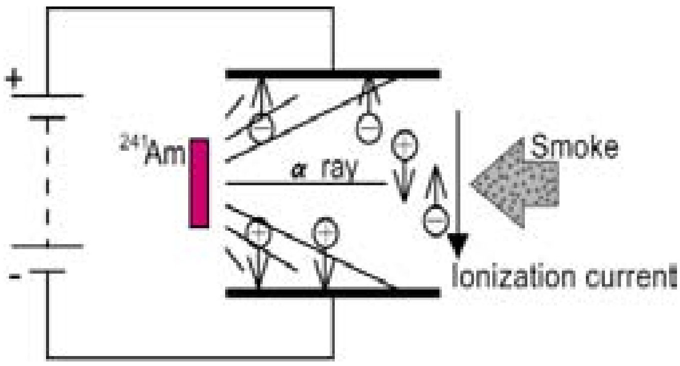
1. General Information
1.1. Product Name / Model Number
Ionisation Smoke Detector / FDS 01U (Low activity)
1.2. Applications
Fire detection for ordinary buildings
1.3 Features
1) Wide range input voltage 10.2 to 36.8 VDC 2) Improved fine mesh insect screen 3) Remote functional test capability 4) Low radioactivity source
1.4. Typical Price
US$ 220 (including circuits producing a fire alarm signal)

2. Performance
2.1. Measuring Range
Nominal smoke detection limit: 1.3 % per foot (Reduction of light intensity per foot)
2.2. Precision and/or Accuracy
Variation range of detection limit: 0.75 to 1.75 % per foot
2.3. Radiation Source
Alpha source: 26 kBq ^{241}Am
2.4. Radiation Detector
Ionisation chamber

3. Supplementary Explanation

(Measuring Principle / Block Diagram / Photo. etc.)

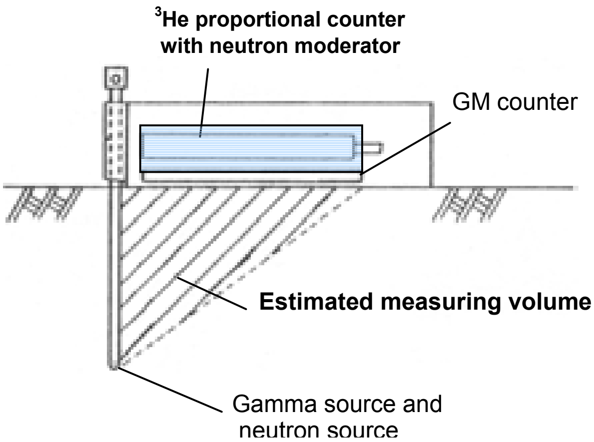
Operating principle:
The ionisation smoke detector is equipped with an ionisation chamber for detection of smoke. It operates on the change in Ionisation current caused by smoke entry in the chamber to send a fire signal to the fire control panel.



Combined gamma –neutron gauge for density and moisture

1. General Information
1.1 Product Name / Model Number
Density and Moisture Gauge / SRDM-2SV (ANDES) (Low activity)
1.2 Applications
On-site quality control of soil compaction in embankments in road construction works
1.3 Features
- Transmission techniques employed both of gamma radiation and neutron - Design based on the standard manual of the Japan Highway Public Corporation and some others as well available - Easy operation and rapid measurement (1 min) in a range of 20 cm depth - Low radioactivity sources not exceeding 3.7 MBq in total - Output (LCD and printer): Wet density, dry density, water ratio, water content, saturation ratio, air void ratio and degree of compaction
1.4 Typical Price
US$ 32 000
2. Performance
2.1 Measuring Range
Wet Density : 1.0 - 2.5 t/m^3 Moisture Content : 0 - 1.0 t/m^3
2.2 Precision and/or Accuracy
Wet density : 0.012 t/m^3 in 1 sigma, 1 min, approximately Moisture content : 0.003 t/m^3 in 1 sigma, 1 min, approximately
2.3 Radiation Source
Gamma source in density gauge : Co-60 2.6 MBq Neutron source in moisture gauge : Cf-252 1.1 MBq
2.4 Radiation Detector
Density gauge : GM counter Moisture gauge : ^{3}He proportional counter
3. Supplementary Explanation
(Measuring Principle / Block Diagram / Photo. etc.)

Measuring Principle:
- Density and moisture measurement by
- Gamma-ray and neutron transmission



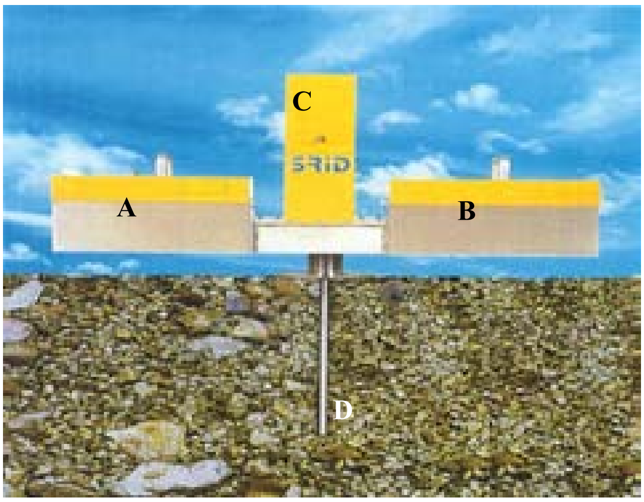
Gamma-neutron gauge for density and moisture (low activity)

1. General Information
1.1 Product Name / Model Number
Automated Scanning RadioIsotopic Densimeter "SRID" / SRDM-PWS30C
1.2 Applications
Field compaction control of soil in embankments in road construction works etc.
1.3 Features
- Rotary surface scanning - Averaged measurement in a larger range of 30 cm depth and scanned surface area - Applicability to coarse soil - Rapid measurement (2 min.) and easy operation - Low radioactivity sources not exceeding 3.7 MBq in total - Output (LCD and printer): Wet density, dry density, water ratio, water content, saturation ratio, air void ratio and degree of compaction
1.4 Typical Price
US$ 45 000

2. Performance
2.1 Measuring Range
Wet Density : 1.0 - 2.5 t/m^3 Moisture Content : 0 - 1.0 t/m^3
2.2 Precision and/or Accuracy
Wet Density : 0.007 t/m^3 in 1 sigma, 2 min, approximately Moisture Content : 0.007 t/m^3 in 1 sigma, 2 min, approximately
2.3 Radiation Source
Gamma source in density gauge : Co-60 2.6 MBq Neutron source in moisture gauge : Cf-252 1.1 MBq
2.4 Radiation Detector
Density Gauge : Scintillation counter Moisture Gauge : ^{3}He proportional counter

3. Supplementary Explanation

(Measuring Principle / Block Diagram / Photo. etc.)



Measuring Principle:
Density and moisture measurement by gamma ray and fast neutron transmission

A: Density sensing unit
B: Moisture sensing unit
C: Rotary scanning driver
D: Radiation sources (Located at 30 cm below the ground level)

Gamma-neutron gauge for on-line flow concrete density and moisture (Low activity)

1. General Information
1.1 Product Name / Model Number
On-Line Moisture Gauge for Flow Concrete / SRD-2PC125G /SRM-2PC125H (COARA)
1.2 Applications
Moisture measurement in fresh concrete for the quality control at construction sites
1.3 Features
- Continuous monitoring of fresh concrete without sampling - Low radioactivity sources not exceeding 3.7 MBq in total
1.4 Typical Price
US$ 36 000
2. Performance
2.1 Measuring Range
Wet Density : 1,500 - 2500 kg/m^3 Water Content : 100 - 250 kg/m^3
2.2 Precision and/or Accuracy
Wet Density : 15 kg/m^3, in 1 sigma, 1 min in 5” pipe, approximately Water Content : 4 kg/m^3, in 1 sigma, 1 min in 5” pipe, approximately
2.3 Radiation Source
Density Gauge : Co-60 1.85 MBq Moisture Gauge : Cf-252 1.85 MBq
2.4 Radiation Detector
Density Gauge : GM counter Moisture Gauge : ^3He proportional counter
3. Supplementary Explanation
(Measuring Principle / Block Diagram / Photo. etc.)

Measurement is made in transmission geometry both for the density and moisture gauges.

The density and moisture gauges are mounted on a red colored pipe.

Combined gamma&neutron gauge for density and moisture in boreholes (Low activity)

1. General Information

1.1 Product Name / Model Number

Insertion Type Density Probe / SRD-1D
Insertion Type Moisture Probe / SRM-1D Scaler / SRC-004M

1.2 Applications

Measurement of the density and/or moisture distribution under the ground

1.3 Features

1) The probes are used by putting into vertical or horizontal bore-holes previously arranged
2) Motorized winder operation controlled by a computer with memorized data
3) Low radioactivity sources employed

1.4 Typical Price

Density Probe (SRD-1D) US$ 21 000
Moisture Probe (SRM-1D) US$ 15 000
Scaler (SRC-004M) US$ 5 000
Cable Winder US$ 3 000 (operation program available in option)
Accessories US$ 4 500

2. Performance

2.1 Measuring Range

Wet Density : 1.0 - 2.5 t/m^3
Water Content : 0 - 1.0 t/m^3

2.2 Precision and/or Accuracy

Wet Density : 0.006 t/m^3, in 1 sigma, 1 min, approximately
Water Content : 0.002 t/m^3, in 1 sigma, 1 min, approximately

2.3 Radiation Source

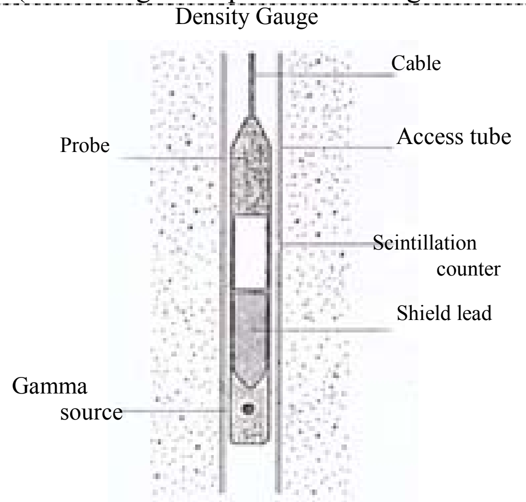
Density Probe : Cs-137 3.7 MBq
Moisture Probe : Cf-252 1.11 MBq

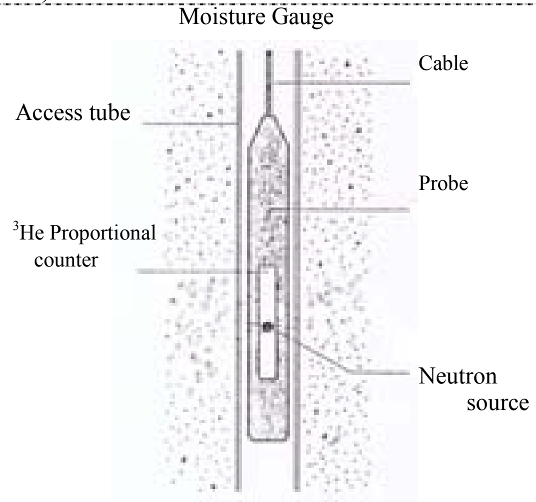
2.4 Radiation Detector

Density Probe : Scintillation counter
Moisture Probe : ^3He proportional counter

3. Supplementary Explanation

(Measuring Principle / Block Diagram / Photo. etc.)





Combined gamma&neutron gauge for density and moisture in underground (Low activity)

1. General Information

1.1 Product Name / Model Number

Penetration Type Density Probe ”Density Cone” / SRD-1DP
Penetration Type Moisture Probe ”Moisture Cone” / SRM-1DP, Scaler / SRC-004M

1.2 Applications

Measurement of the density and/or moisture distribution in the ground

1.3 Features

1) Common use in the cone penetration test, in which a probe is pushed into underground by the hydraulically driving unit.
2) Low radioactivity sources employed

1.4 Typical Price

Density Probe (SRD-1DP) US$ 21 000
Moisture Probe (SRM-1DP) US$ 15 000
Scaler (SRC-004M) US$ 5 000
Accessories US$ 4 500

2. Performance

2.1 Measuring Range

Wet Density : 1.0 - 2.3 t/m^3
Water Content : 0 - 1.0 t/m^3

2.2 Precision and/or Accuracy

Wet Density : 0.006 t/m^3, in 1 sigma, 1 min, approximately
Water Content : 0.002 t/m^3, in 1 sigma, 1 min, approximately

2.3 Radiation Source

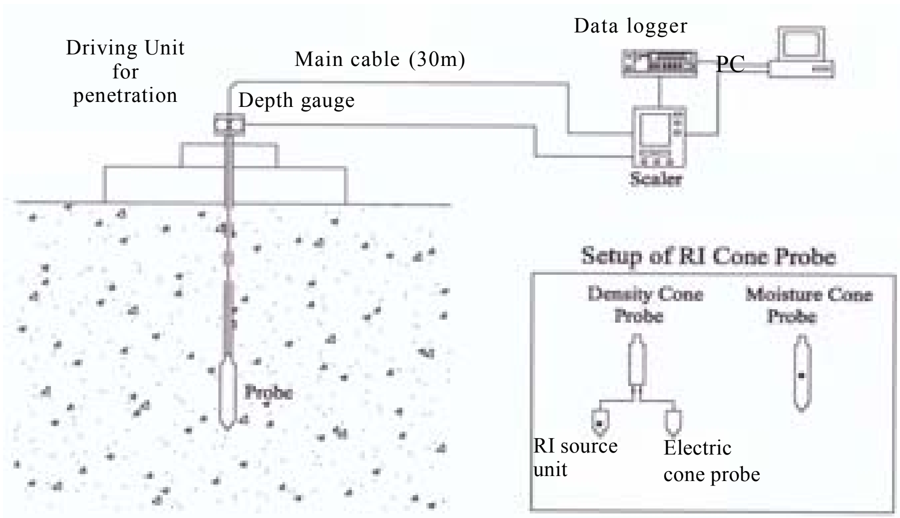
Density Probe : Cs-137 3.7 MBq
Moisture Probe : Cf-252 1.11 MBq

2.4 Radiation Detector

Density Probe : Scintillation counter
Moisture Probe : ^{3}He proportional counter

3. Supplementary Explanation

(Measuring Principle / Block Diagram / Photo. etc.)



Any one of probes can be fixed at the bottom end of equipment. In the density cone probe, the RI source unit and the electric cone probe are exchangeable

Gamma level gauge

1. General Information
1.1. Product Name / Model Number
Level Meter / LM-900 (Low activity)
1.2. Applications
Measurement of the liquid levels in extinguisher cylinders containing liquefied carbon dioxide, for instance, installed in ships, buildings, garages etc. (Inspection of the amount of extinguishing material)
1.3. Features
- Small sized, light weight portable probe for manual scanning outside cylinders - Simple and rapid operation - Mini-computer incorporated for calculating the weight of extinguishing material - Low radioactivity in gamma sealed source
1.4. Typical Price
US$ 7 000 (including mini-computers)
2. Performance
2.1. Measuring Range
Max. 300 mm in diameter of cylinder (applicable to larger diameter by using attachments)
2.2. Precision and/or Accuracy
Level: 3 mm
2.3. Radiation Source
Co-60 3.7 MBq
2.4. Radiation Detector
Scintillation counter
3 Supplementary Explanation
(Measuring Principle / Block Diagram / Photo. etc.)
Operation principle: Moving the probe with a source from the top to the bottom on outer surface of an extinguisher cylinder makes measurement complete. The indicator of the meter points the liquid level, at which the gamma counting rate decreases suddenly.

Gamma transmission density meter for on-line liquid density monitoring

1. General Information
1.1. Product Name / Model Number
Density Meter type C or type B (Low activity)
1.2. Applications
- Density measurements and control of solutions or slurries flowing inside pipes. - On -line measurement of liquid density in coal preparation processes: heavy media density , density and concentration of thickened sludges from radial setting pond outflow, density of dust -air mixtures e.g. cement, coal , diatomaceous earth etc.
1.3. Features
- Continuous process stream analysis. - Very low radiation level with a weak radioactivity source. - Density or concentration measurement of liquid or suspended solids together with measurement of velocity of flow. - Easy installation and calibration. - Automatic correction for long term drifts and maintenance free. - Outputs of electronic system adapted for use of densimeter in control and visualisation systems.
1.4. Typical Price
Open price
2. Performance
2.1 Measuring Range
0 - 2500 kg / m^3
2.2 Precision and/or Accuracy
± 5 kg/m^3
2.3 Radiation Source
Cs -137 or Ba-133 gamma source (3,7 MBq)
2.4 Radiation Detector
Scintillation detector NaJ/TI
3 Supplementary Explanation
(Measuring Principle / Block Diagram / Photo. Etc.

10.10. OTHERS: NICHE APPLICATIONS

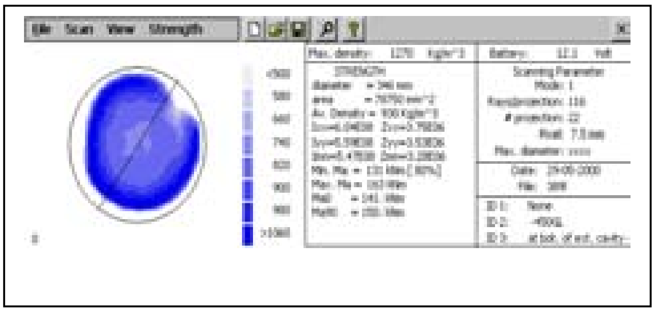
Portable gamma tomograph for pole inspection

1. General Information
1.1. Product Name / Model Number
PortaCAT CT scanner
1.2. Applications
Imaging of wooden utility poles for interior defects. Safe to use on streets without usual industrial radiography exclusion. Enables on-the-spot full engineering analysis of pole strength based on cross sectional image.
1.3. Features
Battery powered and lightweight. One man operation. Self-centring scanner; very quick to attach to pole. Uses rf digital transmission between detector and electronics. Handheld PC for analysis.
1.4. Typical Price
US$30,000, depending on size

2. Performance
2.1. Measuring Range
Images up to 450mm diameter poles. Pixel size variable from 10-15mm side. Gives density image.
2.2. Precision and/or Accuracy
Density accurate to about 100 kg/m^3. Scanning time typically about 12 minutes per image
2.3. Radiation Source
11.1 GBq Am-241
2.4. Radiation Detector
20x10x2 mm CdZnTe

3 Supplementary Explanation

(Measuring Principle / Block Diagram / Photo. etc.)



(above) Screen dump of HPC showing PortaCAT image and engineering calculations from the image.

(left) Scanner being attached to a pole.

Portable datalogger for nucleonic gauges

1. General Information

1.1. Product Name / Model Number

GNS Series 3 Portable Data Acquisition System (Datalogger)

1.2.Applications

Radioisotope experiments, or any measurement where event pulses from multiple sources are to be repetitively counted over fixed dwell time intervals

1.3.Features

Lightweight, battery operated and designed for intrinsic safety. Uses a handheld PC operating under Windows CE to record data. Up to 6MB can be recorded All parameters are software definable.

1.4.Typical Price

US$ 2 800, including HPC

2. Performance

2.1. Measuring Range

From 1 msec to 600 second dwell time intervals. Maximum 65536 events can be stored for each input in each interval. 16 BNC inputs, 5 to 12 volt logic (TTL to NIM) pulses, minimum width 100 nsec.

2.2. Precision and/or Accuracy

Either software or pulsed trigger to initiate logging. Less than 2 microsecond dead time between time intervals.

2.3. Radiation Source

None

2.4. Radiation Detector

None

3 Supplementary Explanation

(Measuring Principle / Block Diagram / Photo. etc.)

The datalogger is shown with the HP360 handheld computer used to control and store the data acquired from the 16 front panel BNC inputs. Data accumulated in the HP360 is compatible with spreadsheets, and easily downloaded via a serial port. The logger is powered by two alkaline ‘D’ cells, giving in excess of 50 hours of operation.

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