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Role of nuclear and radiation technologies in oil, gas and coal mining, distribution and power sector applications

Andrzej G. Chmielewski

Abstract. Nuclear and radiation technologies play an important role in power sector, starting from fossil fuels exploitation, their transport and distribution and finally power generation. Application of environmental isotopes, stable and radioactive, in ground water monitoring in the vicinity of open cast lignite mine, radon monitor applied for miner's safety in deep coal mines and nucleonic control systems for ash in coal control are discussed in the paper. Other applications of nuclear techniques reviewed, concern the oil industry, oil field recovery, transportation pipelines and refineries. Finally, the application of beta radiation-based gauges for air borne fly ash monitoring and radiation technology for flue gas treatment are the examples of using this technique in power sector equipped with coal and oil fired boilers.

Key words: nuclear techniques • radioisotopes • gamma scanning • nuclear gauges

A. G. Chmielewski
Institute of Nuclear Chemistry and Technology,
16 Dorodna Str., 03-195 Warsaw, Poland,
Tel.: +48 22 5041205, Fax: +48 22 8111532,
E-mail: a.chmielewski@ichtj.waw.pl

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Introduction

Nuclear and radiation technologies play an important role in power sector, starting from fossil fuels exploitation, their transport and distribution and finally power generation. This paper presents the work being carried out mostly in the Institute of Nuclear Chemistry and Technology (INCT) and other R&D institutions in Poland, and worldwide. Other applications are published elsewhere and a good review one can find in IAEA's technical reports and a book [3].

Coal mining

Coal is a main source for energy production (both heat and electricity) in Poland. Unfortunately, mining leads to degradation of the environment, especially affects ground and surface waters and may lead to degradation and contamination of water reservoirs. The volume quantities of water pumped from drainage systems at different opencast lignite mines in Poland (Fig. 1) are presented in Table 1. Analyses of stable isotopes composition (hydrogen, oxygen and sulfur) and the so-called environmental radioactive isotopes (^{222}Rn, T and ^{14}C), combined with analyses of inorganic salt concentration in the samples, give information regarding the drainage process planned and in operation. Tritium concentration measurements are used as the data for water infiltration study, ^{222}Rn is a measure of ascenazion, δ^{34}S and δ^{18}O are a measure of extraction of fly ash (deposited in the exploited mine) components and finally δ^{18}O and δ^{2}H in the water molecules allows to establish charging

Table 1. Volume water drainage ratios in Polish lignite opencast mines

Mine	Coal (mln Mg)	Soil cover (mln m^3)	Water pumped (mln m^3)	Ratio water/coal (m^3/Mg)
Adamów	159.4	1066.9	2595.2	16.28
Bełchatów	684.2	2928.1	599.2	8.76
Konin	493.6	2544.7	3963.7	8.03
Turów	792.8	1723.0	1016.3	1.28
Total	2129.8	8262.7	13,574.4	6.37

Fig. 1. Lignite mines in Poland.

water sources. Such work is being performed for the biggest Polish lignite mine at Bełchatów [11, 12]. The proper water system operation prevents salt deposit leaching (Fig. 2).

The mining radiometer (Fig. 3) is designed for rapid measurements of radon decay product concentration in pit mines, where the hazard of ^{222}Rn emanation and high concentration of radon daughters is particularly high. Measurement of radioactive radon ^{222}Rn decay products enables quick assessment of mine ventilation system, effectiveness and health hazard to the miners. The radiometer is adapted for operation in the harsh environment of coal, metal ores and chemical raw material mines which are classified as the first category of methane hazard. The radiometer has obtained a certificate of Higher Bureau of Mining of Poland. The radiometer measures alpha potential energy concentration of radon daughters and concentration of RaA (^{218}Po), RaB (^{214}Pb), and RaC + RaC' (^{214}Bi + ^{214}Po).

Fig. 3. Mining radiometer RGR-40. The radiometer measures alpha potential energy concentration of radon daughters and concentration of RaA (Po-218), RaB (Pb-214), and RaC+RaC' (Bi-214+Po-214).

The obtained results are displayed in μJ/m^3 for alpha potential energy concentration and in Bq/m^3 for decay product concentration, and are stored in operational memory of a microprocessor system. The results can also be transmitted to PC or a printer [8].

Quick measurements of fly ash content can be executed by the application of an ALFA-05/2E meter, based on absorption of low and medium energy gamma rays emitted by an isotope. The measurements are carried out on a conveyer belt for coal granules laying in the range 0–80 mm [5].

Oil pipe transport and rafineries

During oil exploitation, the mixture of oil and water is pumped and then separated. The nucleonic system facilitates the process of separation control (Fig. 4). Oil is transported via pipes and their tightnen conditions control is very important to prevent leaks which can be a disaster for the environment and may lead to economical losses. The isotope methods using ^{82}Br (in the form of methyl bromide) are applied for localization of leakages in pipelines. In this method gaseous methyl bromide labeled with bromine-82 is

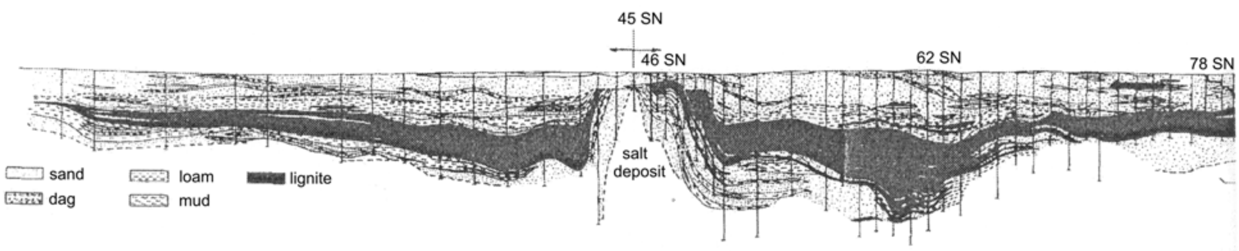

Fig. 2. Lignite opencast mine fields Bełchatów and Szczerców. Salt deposit located in the middle. Environment isotopes analyses help to protect underground water systems.

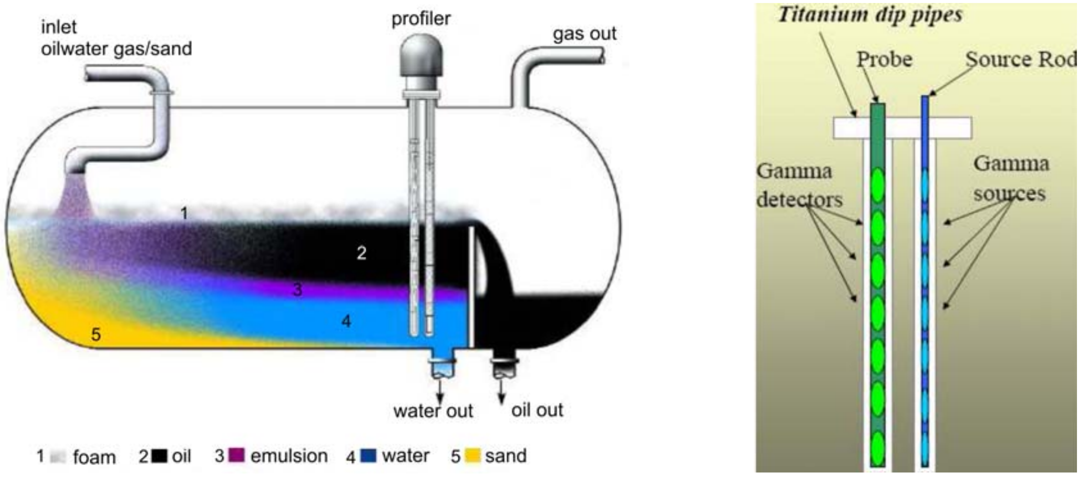

Fig. 4. Nucleonic control system (NCS) applied for oil separator [9].

introduced into the medium flowing in the pipeline directly from the generator or from special containers with the aid of compressed air or nitrogen. The leak (if present) is detected by means of a special gamma-ray detector (placed in a pressure casing) moving together with the medium (Fig. 5). The detector is introduced into the pipeline immediately after the radioactive tracer has passed. It continuously records the natural background in the pipeline as well as the peaks of ^{82}Br in the leak (if present). The activity of ^{82}Br in the leak necessary for distinct registration amounts to 1–10 μCi (37–370 KBq). The obtained record called "general localization of the leak" provides information as to the location of the leak with an accuracy of several to several tens meters depending on the distribution frequency of distance markers (^{60}Co sources) placed on the outer walls of the pipeline. Accurate location of the leak is obtained by carrying out radiometric measurements of the ground below or the space above the pipeline in the zone selected on the basis of the "general localization". The minimum detectable leak is 500 cm^3/h. Using follow-up detectors, it is possible to control pipelines with diameters of 200 to 600 mm.

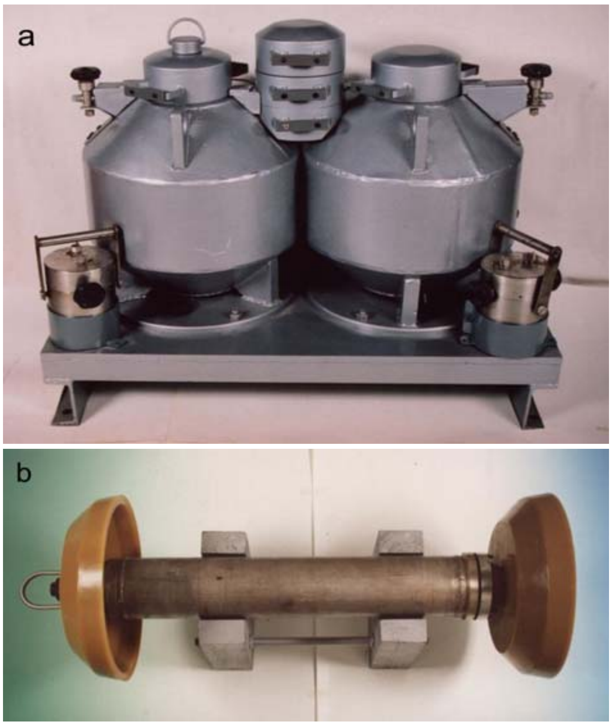

Fig. 5. Leakages testing at oil pipelines. a – methyl bromide generator (Br-82); b – "Pig" with gamma radioactivity measuring probe and recording system inside [7].

Similar method is used for testing of oil refinery installation. The general principle of the radioisotope method consists of introducing to the controlled object a radioisotope tracer, which after having mixed with the control or working medium travels towards the leak, where it is adsorbed on natural (soil, thermal insulation) or synthetic sorbents (special materials applied before the control). In the case of organic medium methyl bromide is used, and potassium bromide is applied for water tanks and installations. Radiometric measurement of the adsorbent permits to precisely locate the leak or to exclude its presence [6, 10].

Gamma scanning has become a popular distillation column diagnostic tool [7]. It allows inspection of the column internals without interrupting operation (Fig. 6). A collimated beam of gamma rays passes through the column wall, is affected by the column internals and hydraulic conditions, and passes through

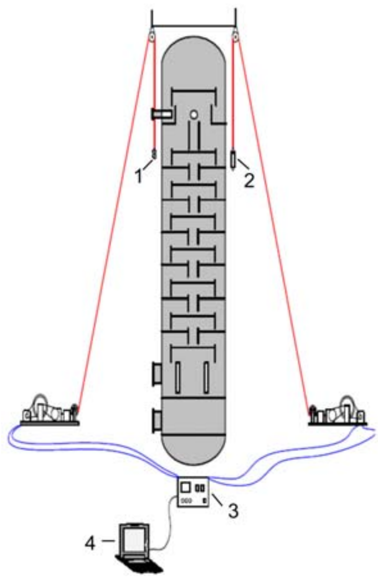

Fig. 6. Scheme of distillation column gamma scanning system [9]. 1 – gamma source with collimator; 2 – detector; 3 – radiometer; 4 – PC.

the other side. By measuring the intensity of the radiation registered on the other side of the column, one is able to determine the density of the material through which the radiation passed. The higher the density of the material, the higher absorption of radiation. The radiation absorption is a function of the amount of liquid, froth, and metal present between the column walls in the area being scanned. A gamma-ray source and radiation detector are lowered simultaneously along opposite sides of a distillation column. The intensity is recorded at predetermined length intervals or positions along the side of the column. A radiation absorption profile is then produced. Tray structures and deck liquid provide the highest radiation absorption. Vapor spaces provide the lowest absorption. Froths and foams appear between these two boundary conditions, depending on their densities and heights. When scanning conventional cross-flow trays, the gamma scan is conducted in a straight line across either the tray deck or the downcomer in order to gain a tray deck or downcomer profile, respectively. Ideally, these scans are only affected by the density of the tray ring and process conditions on the tray or in the downcomer. Gamma scanning can be utilized to:

- locate tray positions, tray damage, tray orientations, downcomers, weirs; antipenetration pans, castellated disengagement plates, distributors, and horizontal and vertical feeds under wet or dry conditions, preferably under dry conditions;
- identify the presence of froths on trays and of liquid in distributors and down comers;
- detect flooding and the onset thereof.

Coal fired power plants

Coal is the most dirty fossil fuel regarding air pollution. Vast quantities of acidic pollutants like SO_2 and NO_x, mercury and fly ash (especially PM2.5) are emitted. Sulfur isotope ratio is a good marker regarding anthropogenic SO_2 emissions. The desulfurization technologies may change normally observed sulfur isotopes ratio in emitted gaseous sulfur dioxide. Sulfur isotope compositions were determined in two different Polish coals (hard coal and lignite) and by-products originating from their combustion. The desulfurization process was also investigated. It was demonstrated that desulfurization changes the isotopic composition of sulfur emitted in the form of SO_2 to the atmosphere even if the process is conducted in a different way: wet lime technology (FGD) and electron beam method (EBFGT). This fact has to be considered in the studies regarding anthropogenic sulfur genesis and its fate in the environment [4].

The radioisotope air borne dust monitoring system is applied in the vicinity of power plants to control air pollution. The gauges can operate as individual dust pollution monitor or in monitoring network. A microprocessor system used to control the measuring cycle and to process measuring head signals, permits also of presentation of measured dust concentration and the speed and wind direction on a LED display. A hardcopy of measuring results can be made (if the gauge is equipped with a printer). The measuring results can also be transmitted to a computer by a serial port for archival purposes or for further processing. The principle of operation of the gauge is based on the measurement of dust mass deposited on a filter from known volume of air. The air volume is determined by dust deposition time while the air flow is constant. The dust mass deposited is determined by attenuation of beta radiation from a ^{147}Pm source. Contemporary wireless transmission of data makes it possible the creation of an information channel for transmission of data from measuring devices to other places where the data are collected and processed. The measuring devices can

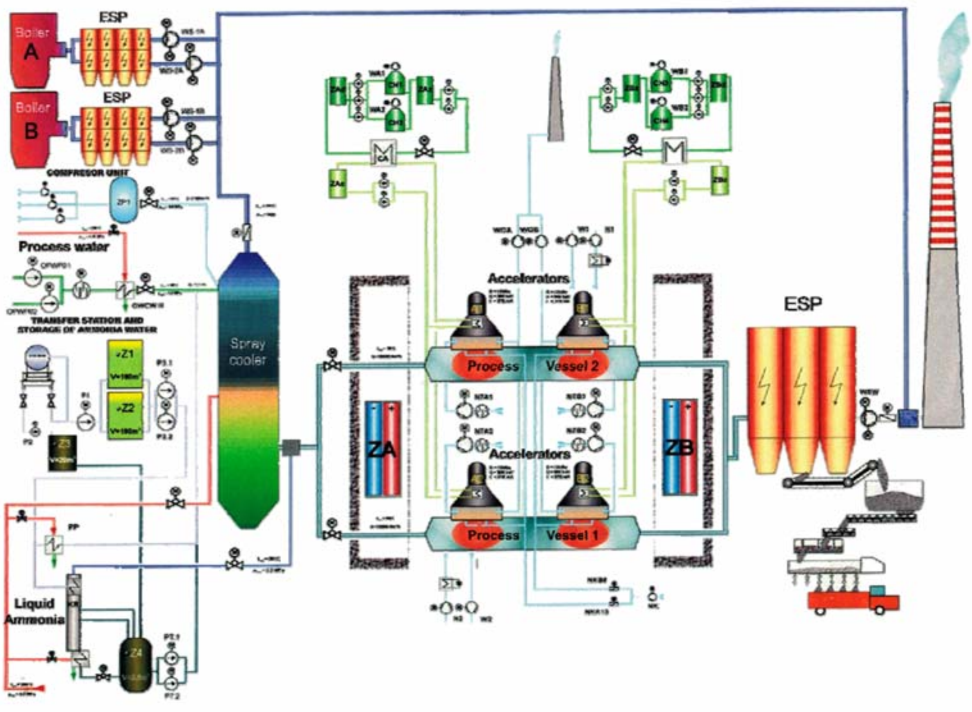

Fig. 7. Electron beam flue gas treatment installation consist of four subsystems; gas cooling system, ammonia injection system, reaction vessels with accelerators, electrostatic precipitator for by-product collection.

also be controlled and programed with the help of such information channel from a central computer. Present typical solution of wireless transmission system employs existing infrastructure of mobile phone networks and mobile phone operators. The measuring data between the monitoring devices and the central computer are transmitted with a GSM modem [9]. Neutron activation analysis (NAA) is used to establish dust heavy metal concentration.

Beside monitoring, the radiation technology can be applied to clean off gases from coal and oil combustion. Electron beam flue gas treatment technology is the technology for simultaneous SO_2 and NO_x removal applied on an industrial scale (Fig. 7). Both pollutants can be removed with a high efficiency and a by-product is used as an fertilizer [1, 2].

Conclusions

Nuclear and radiation methods, including radioisotopes analysis and applications, stable isotopes analysis, are applied for safety and process control, including environment impact assessment in coal mining and oil exploitation. Radiotracers and sealed sources methods are applied to control oil pipes and equipment of refineries. Stable isotope methods and nucleonic control gauges are applied for air pollution monitoring in the vicinity of oil and coal fired stations. Finally, radiation technology has been applied for air emission control at coal fired power stations. These methods and technologies have proved their feasibility and importance from economical, safety and environment protection points of view.

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