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Nuclear Geophysics

Applications in Hydrology, Hydrogeology, Engineering Geology, Agriculture and Environmental Science

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Preface

Progress in geoengineering, hydrology and environmental sciences as a whole closely depends on the development of new methods of investigation, which are based on the latest achievements in adjacent branches of science such as physics, chemistry, electronics, geophysics and so on. This book provides the fundamentals and field applications of nuclear techniques in engineering geology, hydrogeology, civil engineering, agriculture and environmental study. The book is intended for scientists and researchers, teachers, students and postgraduates engaged in field studies for solving scientific and practical problems in applied geology and hydrology for civil, road, power, airfield, harbour engineering, drainage and irrigation.

Nuclear geophysics is a branch of applied geophysics, where the nuclear methods for study of physical-chemical and geoengineering properties of rocks and soils at their geological exploration are considered. Despite their relatively short history, nuclear methods have achieved worldwide popularity in science and technology. Because of their exceptionally advantageous features, they have found many practical applications whose range is continuously expanding.

The development of nuclear methods for solving geoengineering and hydrological problems depends first of all on the development of reliable and objective methods for estimating the physical parameters of grounds and rocks and of studying the dynamics and geochemistry of underground waters under natural conditions. It is not long since methods based only on the study of samples taken from excavations were used both in estimating physical properties (density, moisture content and porosity) of rocks in regional studies and in surveys for suitable building areas.

The development of field methods for determining the physical properties of grounds began with the use of gamma-rays and neutrons, which are now regarded as uniquely reliable tools for estimating the density and the moisture content of grounds under natural conditions. Italian physicist Bruno Pontecorvo was the founder of nuclear geophysics. In 1941 he was the first to propose neutron well logging for geological exploration of oil and gas fields. Since that time nuclear techniques have started to develop for the geological exploration of mineral resources, engineering geology and hydrogeology.

In 1950, Bernhard and Berdan of Rutgers University (USA) were the first to use gamma-ray absorption as a method of determining the density of grounds. The back-scattering of gamma-rays and of neutrons in 1950 was used by Belcher at Cornell University in the USA to investigate the density and the moisture content of grounds respectively. These methods were subsequently developed by many researchers in Germany, UK, France, former USSR, Poland and other countries.

The first gamma-ray density and neutron moisture gauges were used to estimate the suitability of various areas for civil engineering projects in the former USSR, e.g., at construction of the Volga and Nurek hydroelectric power stations for monitoring of density at the ground dam pouring out. They were also applied in geoengineering surveys in Western Siberia, in hydromelioration studies of irrigation schemes in Central Asia, in Southern Ukraine and many other areas in different countries.

The manufacture of neutron moisture and gamma-ray density gauges for the investigation of grounds and rocks was started in the USA, UK, France and the former USSR by firms such as Nuclear Chicago, Nuclear Enterprises, Russian Enterprise 'Isotope' and others. In 1966 the working group of the Coordinating Council of the International Hydrological Decade decided to recommend gamma-ray and neutron methods for determining the density and moisture content of soils and grounds as satisfactory and reliable for extensive practical use.

The successes in the development and application of neutron and gamma-ray methods in engineering geology and hydrogeology have not, however, led to the solution of a very important problem of cardinal improvement of the field methods of investigation in these applied sciences. When engineering geology surveys for suitable constructional areas are being carried out, it is essential to have data on the properties of the ground at depths down to 15–20 m.

So far, this can only be done by the nuclear well logging technique. This method is being widely used in industrial and prospecting geophysics. Many publications have appeared on this subject, including monographs by E.M. Filippov (1962), V.I. Ferronsky et al. (1968; 1969), C.G. Clayton (1983), IAEA (1968, 1971; 1981, 1983, 1999) and K. Froehlich (2010).

However, nuclear well logging, which was being used in prospecting geology and especially in prospecting for oil and gas fields, has not turned out to be suitable for engineering geological studies. The accuracy of the method was insufficient to determine the physical characteristics of grounds, owing to the interference by the very existence of the well casing.

The optimal solution of the problem of the nuclear logging method in engineering geology for studies of loose deposits down to a depth of 20–25 m was put forward by V.I. Ferronsky (1969). The idea of his approach was as follows. To avoid the influence of interference due to construction of the well, the penetration logging method (including gamma, gamma-gamma and neutron-neutron logging) is used. In this case the logging probe, which is mounted on the tip of the drill rod, is forced into unconsolidated deposits by an axial load, which is applied by a vehicle-mounted hydraulic-mechanical system. The method is most readily applicable in solving engineering geological problems and for hydrogeological investigations of aquifers in both saturated and unsaturated zones.

Practical applications of advanced original nuclear logging techniques and methods are presented in the book. These techniques are the penetration logging methodology and facilities, where the logging sonde is sunk into the friable deposits under investigation by a vehicle-mounted hydraulic device. The logging sonde is penetrated to depths about 40 m in loose formations at rates of up to 2 m/min on land and near shore marine areas. Besides having obvious operational advantages such as fast penetration, this method also avoids some of the well construction problems. The sonde is in direct contact with the medium and thus gives increased accuracy and reliability for interpretation.

Radioactive and stable isotopes, which are the constituents of water molecules, or migrate with them, have been used widely in recent years in a number of countries to investigate the motion of water on a regional scale. These isotopes include above all tritium (half-life of decay $T_{1/2}=12.32$ year), carbon-14 ($T_{1/2}=5730$ year), deuterium and oxygen-18. Natural tritium as a constituent of water molecules, chemical properties of which are practically indistinguishable from hydrogen, is particularly widely employed in investigations. Tritium and carbon-14 are used to solve many hydrogeological problems related to water movement in saturated and unsaturated zones.

Hydrogeological processes occurring over longer periods of time are being investigated with the aid of natural radioactive carbon-14. Because its half-life of decay is equal to 5730 year, it can be used to cover very long periods of time during the motion of water in nature, including the glacial period.

Some information related to other natural radioactive isotopes in groundwaters like ^{7}Be, ^{10}Be, ^{22}Na, ^{26}Al, ^{32}Si, ^{32}P, ^{33}P, ^{36}Cl, ^{37}Ar, ^{39}Ar and radioactive isotopes of the uranium-thorium series is presented in the book. But investigation of the regularities on the distribution of these isotopes in natural waters is limited by technical difficulties of sampling, concentration and measurement of the corresponding samples.

The use of stable isotopes of deuterium and oxygen-18 enables us to establish the interrelations between water-bearing horizons, the supply sources for groundwaters and the connections between open reservoirs and other sources of effluents and the origin of individual water-bearing horizons and also to investigate the conditions under which glaciers are formed and moved.

Systematic measurements of precipitation and of the abundance of natural isotopes in precipitation are essential for the success of regional hydrogeological and hydrological studies using naturally occurring isotopes. The first condition is satisfied by using the data supplied by the hydrometeorologic service supported by an appropriate national network of stations. To satisfy the second condition, the International Atomic Energy Agency (IAEA), since 1953, is collecting and publishing the data obtained from the WMO/IAEA Isotopes-in-Precipitation Network.

It must be stressed the role of the International Atomic Energy Agency in providing the Secretariat for the Working Group on Nuclear Techniques in Hydrology of the UNESCO International Hydrological Decade (1965–1974), regular scientific symposia and systematic research coordinated programs on this subject. All these

IAEA actions create an efficient basis for fruitful scientific cooperation of the specialists in nuclear techniques from different countries.

The use of artificial and natural radioactivity as a tracer in groundwater as well as mathematical modelling for interpretation of experimental data are also discussed.

In this book we systematically review and generalise the results obtained by the author and his colleagues from many countries during the field and laboratory studies concerned with the development and application of radioactive sources and tracer techniques in geoengineering and hydrology.

Particular attention is paid to the range of validity of these methods and to the solution of practical problems. The basic physics of radioisotopes and emitted radiation, as well as the interaction of radiation with matter, methods of radiation detection, radiation hazard problems and many others are briefly discussed in the book.

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