Recent developments in uranium exploration

by P.M. Barretto*

Even in the most experienced and competent hands, mineral exploration is an expensive, risky, and time-consuming business. It has been described as a mixture of art and science: most exploration projects start from general ideas and geological concepts and involve a great variety of field and laboratory work, ranging from simple visual inspection of the ground to a detailed assessment of the economic feasibility of a prospect.

Uranium exploration is no different from the above, its sole advantage being that the uranium can be detected from afar because it emits gamma radiation. Therefore, radiometric techniques are the most useful exploration methods In developing countries that are interested in starting or that have started uranium exploration programmes there are other problems as well as those outlined above:

- Lack of, or difficulty in obtaining, the requisite number of qualified personnel for field and laboratory activities (lack of manpower);
- Lack of administrative and technological infrastructure needed to support an exploration effort (lack of technology); and
- Relatively small budget for a multi-year programme (lack of money).

In view of the above it is very important that the time and resources available to an exploration programme are utilized wisely. This means selecting optimum methods of obtaining the information needed and avoiding unnecessary duplication of effort by government organizations. Such duplication of effort in exploration is common in developing countries. In some cases three government organizations have been discovered doing geological mapping of the same area.

As the amount, quality and availability of geological information vary from place to place, and since the exploration programmes can have different sizes and objectives, following a standard procedure is difficult. The procedures or sequences outlined below (Figure 1) are suggested for areas that are being prospected for the first time. If carried out systematically, it will be possible to obtain both an inventory of the geology, and an assessment of the mineral potential of a given area with minimum investment and maximum efficiency.

Radiometrics surveys

The most useful techniques in uranium exploration are undoubtedly radiometric surveys. Indeed, the combination of aerial radiometric surveys, ground examination of the detected anomalies and the gamma logging of drilled holes has resulted in the discovery of a large proportion of known uranium resources. Radiometric surveys in which total or specific gamma-ray activity are measured have a variety of applications. Accordingly, there is a variety of field and laboratory instruments. The main techniques are described below.

Aerial radiometric surveys are conducted in the initial evaluations of large areas. Highly sensitive gamma-ray detectors are carried on board helicopters or a fixed-wing aircraft (Figure 2). Radioactive anomalies are detected, recorded, and plotted on maps for subsequent verification on the ground. The area is usually covered using a grid-type pattern.

In spite of the relatively high cost per line-kilometre, airborne gamma-spectromic surveys are very cost-effective. The total expenditure for flying, mapping, evaluating, and selecting sites for further exploration by this method compares favourably with other methods. Spectral data, when well evaluated, greatly reduce the amount of expensive ground checking required to assess the survey results (field checking is a necessary part of the survey and often costs more, per km^2 or per anomaly, than the aerial survey).

Surface radiometric survey· Ground follow-up of uranium anomalies involves the use of portable, hand-held scintillometers or spectrometers, borehole loggers, and emanometers (radon monitors).

Scintillation counters are used to measure gamma rays emitted by natural radioactive elements contained in rocks (U, Th, K). The main use of such instruments is in the search for radiometric anomalies that, eventually, might lead to the discovery of uranium deposits. The instruments are characterized by high gamma detection efficiency, giving high count rates and relatively low statistical fluctuations. This permits the recognition of small changes in the concentration of radioactive elements. Scintillometers are the most frequently used pieces of field equipment in uranium exploration; they are employed in all the various exploration phases and in conjunction with geochemical or geophysical surveys.

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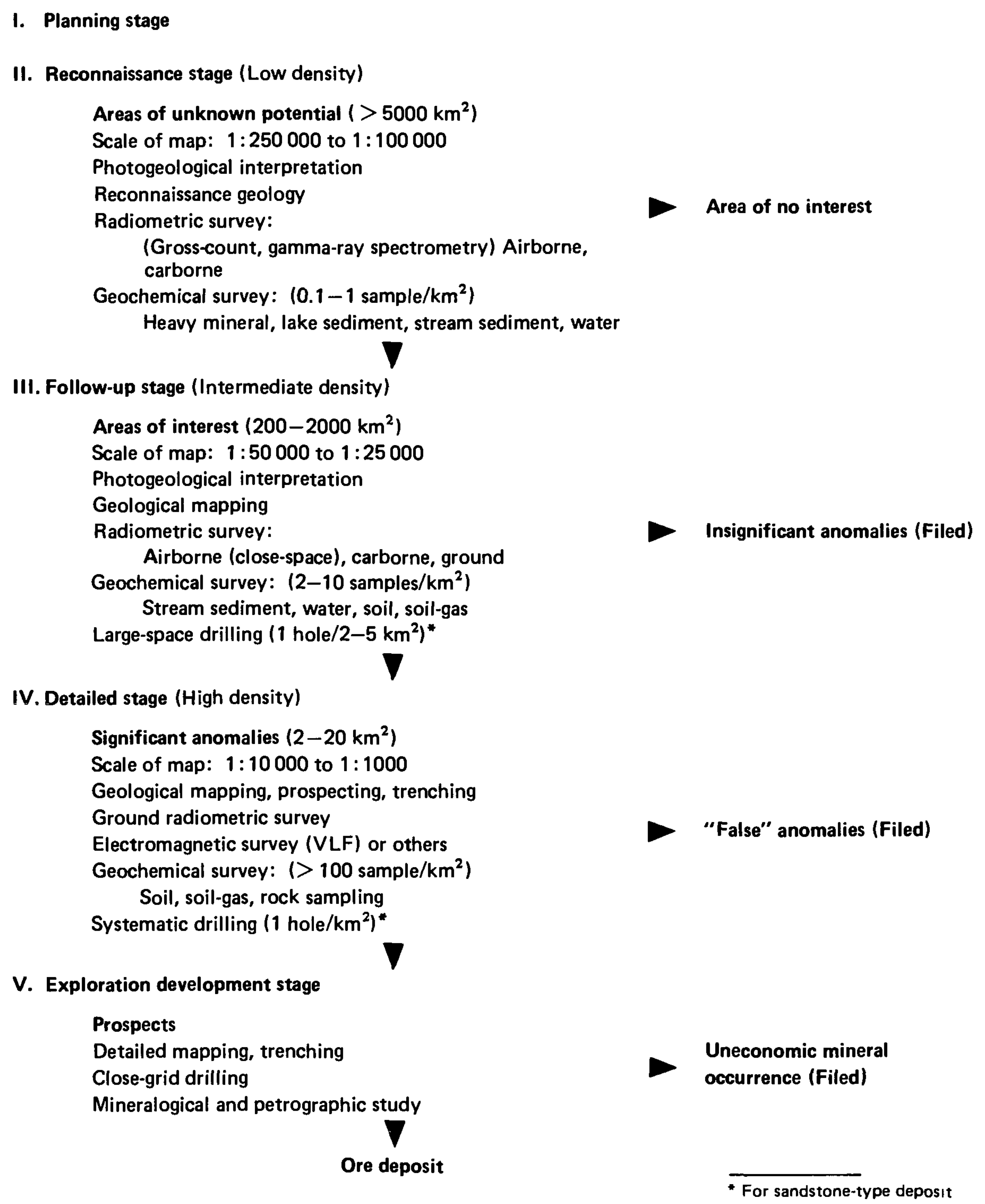

Figure 1. Uranium exploration sequence.

Scintillometers can be installed in vehicles for carborne radiometric surveys. Such surveys represent a very practical method of prospecting for uranium provided the network of roads and trails is good. Several deposits have been found by this technique.

The field spectrometer is an advanced piece of radiometric equipment that permits the determination of the particular energy of gamma radiation and, consequently, the radioactive nuclide responsible for the emission. The relative equivalent concentrations of U, Th and K can be determined in this manner. The capital outlay required for a field spectrometer is several times greater than for scintillometer. Amongst the disadvantages of field spectrometers, spectral measurements require more time than gross-count surveys, the equipment is difficult to maintain in remote areas, and frequent calibration is necessary. The value of the results generally depends on the extent to which the geology and geochemical parameters of a particular area are understood.

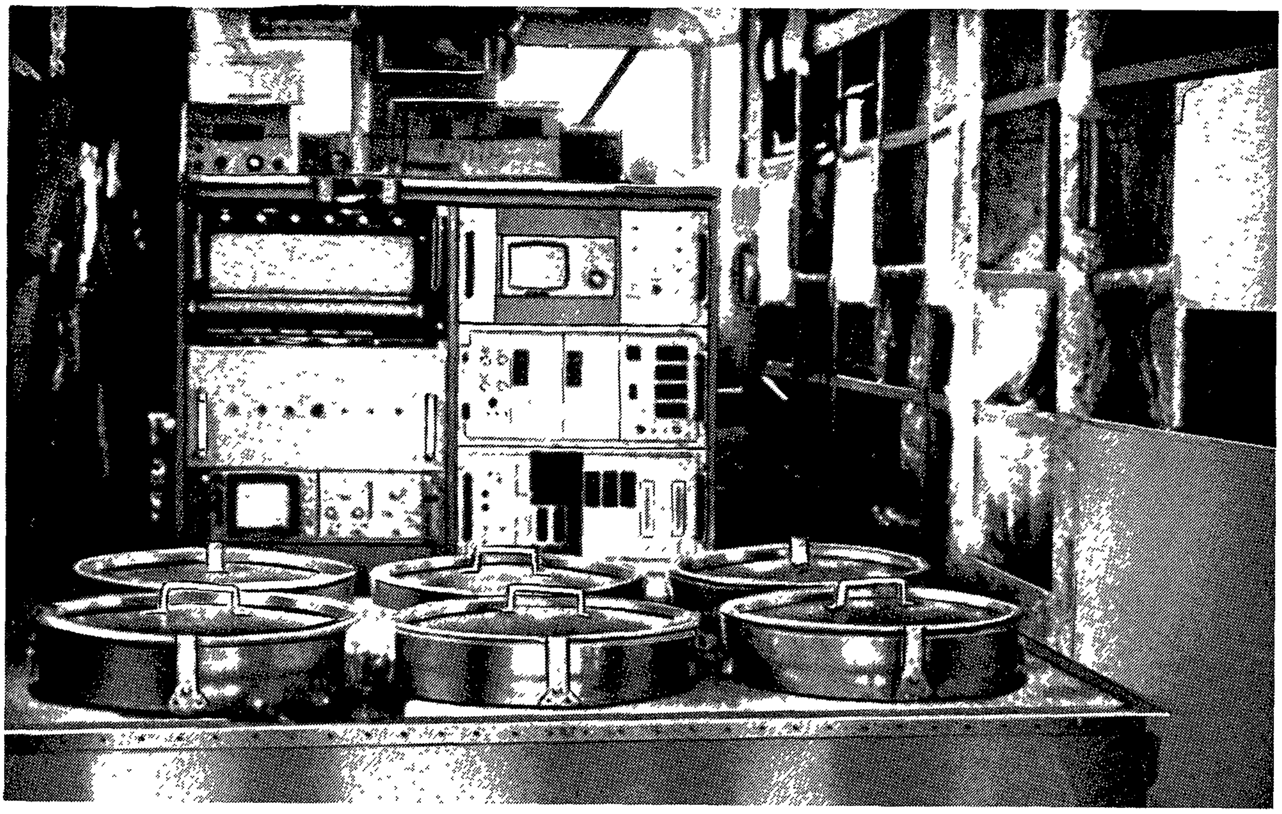

Figure 2. Airborne γ-ray spectrometric system consisting of six large sodium iodide - NaI(TL)-detectors shown here in the foreground of the picture installed inside a survey aircraft, with the associated electronics behind the detectors.

Figure 3. Borehole logging in Pakistan. The worker is standing behind the logger recording apparatus and the manual winch used to lower the probe into the hole, and is holding the probe itself in his hands.

Figure 4. Drill-core examination and sampling in Saskatchewan, Canada. In general, this is a more expensive procedure than borehole logging.

Considerable judgement is needed regarding the appropriateness of field spectrometry at any given exploration stage.

Borehole radiometric logging The inspection on the ground of the uranium anomalies may lead to the discarding of an area as having no potential for uranium mineralization or to a recommendation for detailed investigation. If a decision is taken in favour of further exploration, subsurface radiometric information will generally be needed. This is obtained by borehole logging and the examination of drill cuttings or cores.

Tens of millions of metres will be drilled as part of uranium exploration efforts by private industry and governments over the next few years. Drilling commonly represents 50 to 80% of the cost of an exploration programme, and efficient drilling is probably more important than any other single activity for effective uranium exploration.

Borehole logging entails lowering a gamma-ray detector (probe) into a hole and recording the radioactivity therein (Figure 3). The method provides most of the subsurface information required by the exploration geologist rapidly and economically. This includes *in-situ* sampling and assaying, lithological identification, stratigraphic correlation, and, with more sophisticated logging programmes, petrophysical parameters such as density, and moisture, and various types of geochemical information. Often logging can greatly reduce drilling costs by making it possible to obtain the data needed from less costly non-cored holes or from holes previously drilled for other purposes. Generally, logging provides more representative and objective data in less time and at lower cost than does descriptive logging, sampling and assaying of cores or cuttings. The cost of multi-parameter geophysical borehole logging should only rarely exceed 10% of the drilling cost (Figure 4).

Drilling and logging techniques are also very important in the evaluation, mine development, and grade control phases of uranium production.

In view of the great demand for information on logging techniques the IAEA is preparing a manual on borehole logging in uranium exploration for the benefit of its Member States. This will be a comprehensive, up-to-date "how to do" manual, and is expected to be available for distribution by the end of 1981.

Radon surveys: This technique involves the monitoring of radon, a radioactive gas, in soil, rocks and water. Radon measurement is specific for uranium whereas gamma radiation in the natural environment results from other elements in the uranium series. Radon measurement may be used to indicate uranium to depths of 5 to 50 metres, while gamma-ray emission can be masked by 0.5 metres of overburden.

The field instruments used are emanometers, also called radon monitors (Figure 5), which detect anomalous concentrations of radon (Rn-222), and thoron (Rn-220), and their immediate decay products. It is possible with the technique to distinguish between radon and thoron and then to obtain measurements that are independent of background gamma radiation. Several types of device are available for measuring radon concentration, and all of them based on the monitoring of alpha particles emitted as radon (Rn-222) gas decays to the solid polonium (Po-216).

There have been recent developments of this type of detection. One technique utilizes alpha radiation damage (tracks) to solid-state plastic detectors (track-etch). Another uses a silicon surface barrier detector (alpha nuclear) and still another (collector method) utilizes the "active deposit" resulting from the decay of radon products accumulated over a small and thin aluminized mylar disc (alpha card).

Last year yet another technique became commercially available. It was developed in South Africa and was dubbed *roac,* an acronym for "radon on activated charcoal". It is based on the absorption of radon on activated charcoal; the radon present is then measured by any commercially available scintillation detector mounted inside a lead castle. The field procedures for placing the roac cups are identical to the alpha track systems.

The alpha track and alpha counting methods have an advantage over the emanometer method in that the signal variation in time encountered in many environments are eliminated. Furthermore, it is not necessary to bring complicated electronic equipment into the field.

The ultimate objective is to guide selection of the most favourable locations for follow-up exploration activities such as drilling or trenching.

Geochemical surveys

Geochemical techniques can be applied in surveys to areas of various sizes. These surveys may be classified as: low density (reconnaissance) 0.1–2 samples/km^2, intermediate density (follow-up) 10–20 samples/km^2; and high density (detailed survey) 200 samples/km^2. Preliminary investigations should indicate whether or not geochemical methods can be used at all. They should also yield the information needed to plan and carry out a routine survey. Before any systematic exploration programme can be started, an orientation survey or preliminary investigation is needed to select the method to be used.

Preliminary investigations should, whenever possible, be carried out in areas where the mineralization is similar in type to that which will be sought, and located as close to the survey area as possible. Where this is not possible, guidance can be obtained from studies on other regions with similar geological and climatic conditions.

Low-density sampling surveys (scale 1:250 000–1:25 000) are conducted to permit the selection of the most favourable areas within a larger region without an attempt at precise delineation. Experience has shown that the waters and stream sediments (Figure 6) of a hydrographic network that is widely dispersed are perfectly suited to this kind of prospecting. The sampling interval is determined during the orientation survey such that the haloes of dispersion in the hydrographic network surrounding an occurrence of average significance will be indicated by at least three anomalous samples.

Intermediate-density sampling surveys (scale 1:20 000–1:50 000): The objective of the intermediate phase is to locate and determine the origin of surface anomalies within the areas of interest delineated in the course of low-density sampling. This is accomplished by increasing the sampling density to 10–20 samples/km^2. At the same time an attempt is made to relate the anomaly to the local geology, stratigraphy, and tectonics. Water and stream sediment samples are taken from all streams in the anomalous zone. Where possible, seepage and spring waters are sampled in addition to well-water. If the geology of the anomalous area is not well known, more geological information on the anomalous zones should be obtained. If such intermediate prospecting only rarely locates uranium-bearing ores, it nevertheless permits substantial reduction of the area of interest, assessment of its potential, and a better understanding of the origin of the geochemical anomaly. It is then possible to select the method best suited for further studies – such as geochemistry, radiometry or a geophysical technique.

Figure 5. Measurement of radon gas in soil.

High-density sampling survey (scale 1:5 000–1:500): The objectives of high-density surveys are to locate suspected sources of anomalies and/or extensions of known or associated ore bodies and to evaluate the radiometric survey. Generally speaking, the aim in this phase is to distinguish between anomalies resulting from possible economic mineralization and those due to uneconomic mineralization or other causes. Geochemical prospecting in this phase is preferred, particularly where weathering is important or where barren overburden (which renders radiométric methods ineffective) is present. Experience has shown that soil sampling is best suited in this phase. A square sampling grid is usually adopted, with intervals varying from 10 to 50 m. Attention must be paid to possible contamination resulting from mining operations, the use of certain phosphate fertilizers and other human activities.

Other techniques

There are other techniques which, though not specifically applicable to uranium prospecting, are used for the purpose of obtaining a better understanding of the emplacement or structure of the mineralization, some of them are:

Surface resistivity and induced polarization: These techniques are based on the transmission (conductivity) and distribution of electric currents in the ground. The

Figure 6. Sampling water from a domestic well in Turkey to analyse its uranium and radon content.

choice of a suitable array of electrodes is dependent on many factors – particularly the target geometry and the conductivity and thickness of the overburden. The so-called Wenner-Schlumberger and dipole-dipole arrays are the most widely used. In general, the interpretation techniques for induced polarization are nowhere as advanced as for resistivity. These electrical techniques are used only at the detailed exploration phase, where a target has already been defined, on any other conducting zones, and to determine the thickness of the sedimentary strata over known structure or deposits. Resistivity and induced polarization surveys can provide guidance in planning drilling programmes.

Remote sensing: Multispectral reflectance data obtained from satellite or aircraft images (photos) can aid in mapping discoloured, possibly altered, ground very rapidly over broad areas. Image enhancement by computer markedly improves the ability to distinguish such target areas as compared with black-and-white, or often even colour, photographs. Some studies show that the spectral bands on *Landsat* images are not optimum for some of the subtle discriminations needed in uranium exploration. Nevertheless, Landsat data have been enhanced by computer to show distinctly the reddish altered ground used in the past to guide exploration in uranium prospecting areas in the USA. Lineaments seen on these images may mark structures which, locally, could have affected the deposition of the uranium-bearing formation.

Additionally, under certain conditions, thermal-infrared images are an excellent aid in detecting and mapping potential targets for uranium exploration (for example, conglomerate-filled channels within formations). Remote sensing techniques are only an indirect method for uranium exploration, used only to obtain geological and tectonic information on a regional scale. As such, their application is in the preliminary investigation and area-selection stage.

New techniques: There are a few potentially interesting techniques being studied, although they have not yet been used on an appreciable scale and some have not yet been tested under experimental conditions. They include radiogenic heat, remanent magnetism, helium measurements and radiogenic lead.

Research and development

The methods and equipment described above are the result of much research and development. The Agency is interested in such research and development with the objective of improving techniques and equipment to increase the rate of discovery. For this reason, in 1976 a group was established jointly by IAEA and Nuclear Energy Agency (NEA) of OECD to review the status of research and development in connection with uranium exploration. This group, the NEA/IAEA joint group of experts on research and development in uranium exploration techniques, identified several areas for which existing techniques could, with international collaborative effort, be significantly refined and new techniques developed. Since this time, countries have co-operated in setting up international projects covering eight areas of interest.

Dissemination of the information which results from the studies undertaken during the projects is a vital part of the effort. Therefore a Newsletter is prepared and circulated to the uranium industry and others concerned with uranium exploration. The main aim of this Newsletter is to publicise, about twice a year, the progress made in the various r. & d. projects that are being co-ordinated by the group of experts by publishing progress reports, reviewing specific studies undertaken by the various working groups, outlining future activities, and by giving details of relevant meetings and symposia. However, it is also expected that the Newsletter could, in future, contain short informal notes on related r. & d. activities other than those being undertaken by the co-ordinated project, in addition to any comments on current, or suggestions for future r. & d. activities. Those countries or organizations interested in receiving the Newsletter could write to the Agency in this regard. A symposium to present and discuss the results of the r. & d. work is planned for 31 May–3 June 1982 in Paris.

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