Uranium exploration and technology: Preserving the "know-how"

Market forces have opened up new opportunities for applying the data and expertise to environmental and other problems

by Arthur Y. Smith and Mohamad Tauchid

During the energy crisis of 1973 and thereafter, many countries around the world spent large sums of money on exploration activities for uranium, the source of fuel for nuclear electricity generating stations.

At the same time, research and development (R&D) of uranium exploration techniques was pursued with great vigour and major advances were made in both sensitivity and refinement. This situation began to decline after 1980, and by 1984 exploration expenditures in WOCA countries had decreased to the levels of 10 years earlier.* *(See accompanying figure.)*

The decline in uranium exploration had important repercussions: It brought with it the threat of the loss of knowledge and expertise — specifically, the exploration data accumulated over the "boom" years, and a decline in the use of the highly developed uranium exploration techniques. Specialists in uranium exploration left the industry as work opportunities dried up, and with them went the knowledge and skills in the use of these techniques. This situation applied to government organizations and commercial exploration groups alike.

Fortunately in a few cases, both the techniques and the data of past uranium exploration have been put to other important uses. They have demonstrated their application, for example, to general environmental problems as well as to earth sciences and multicommodity mineral exploration.

At the outset, a brief overview of uranium exploration and techniques may be helpful to understanding the range of applications.

Uranium exploration

Uranium exploration, like other types of mineral exploration, is an activity carried out in phases or steps. The phases are distinguished by the size of the area they cover. Thus the first, or reconnaissance, phase is designed to examine very large areas, in the order of tens of thousands of square kilometers, rapidly and at very low cost. It is obvious that such an operation is not intended to discover "deposits". Rather, the aim is to locate and define areas within the region covered where the potential to discover deposits is significantly greater. This is done by mapping at broad scale those environmental properties and features that are known or are suspected to be associated with uranium deposits — higher levels of radioactivity, increased concentrations of uranium and other radioactive and non-radioactive elements in the soil, stream sediments, rocks, and water.

Because the odds *against* finding an economic uranium deposit at the reconnaissance stage are infinitely great, techniques have been developed to provide maximum information at very low cost and with a high degree of reliability. The radioelements uranium, thorium, and potassium, along with total radioactivity, are mapped rapidly by highly sensitive gamma-ray spectrometer instruments mounted in aircraft and flown across the terrain. Areas of increased radioactivity or radioelement concentration may be sampled on the ground and the samples analysed for a selection of appropriate elements. The scale of the final map is closely related to the size of the area covered and the density of data points.

They are, thus, approximations to "ground truth". It is clear, however, that the areas outlined depict real large-scale features of the geological and surficial environment. Subsequent phases of the exploration programme re-examine these large scale features in greater detail to refine the approximation and "focus in" on the potential uranium deposit.

It is important to recognize that exploration data have spatial character — that is, they have aerial extent. The techniques used to gather them are designed to provide spatially distributed information. A single measurement in an exploration programme, no matter how precise and accurate, is of no value in depicting a spatially distributed feature. It is this aspect of both the techniques and the data of uranium exploration that make them of great value in fields other than uranium exploration.

Messrs Smith and Tauchid are staff members in the IAEA Division of Nuclear Fuel Cycle.

* WOCA = World Outside Centrally Planned Economies Area.

Uranium exploration techniques

Among the most widely used uranium exploration techniques, those based on airborne gamma-ray spectrometry have probably had the greatest development during the uranium boom period. The advent of large detector volume instruments, multichannel analysers capable of recording 256 and even 1024 channels of data, and digital recording and processing techniques provided survey facilities of great sensitivity and flexibility. These radiometric "geochemical analyses" are carried out from aircraft flying at altitudes of 50 to 150 metres and have attained a sensitivity to permit the detection of one or two parts per million of uranium and thorium in the ground below the aircraft.

To attain these levels of detection, careful calibration of the equipment is required, and in recent years, considerable effort has gone into the construction and use of such calibration facilities in many countries. Earlier total count as well as gamma-ray spectrometer surveys were not so carefully calibrated, or were not calibrated at all. Techniques are under development to permit back calibration of these earlier data to an acceptable standard.

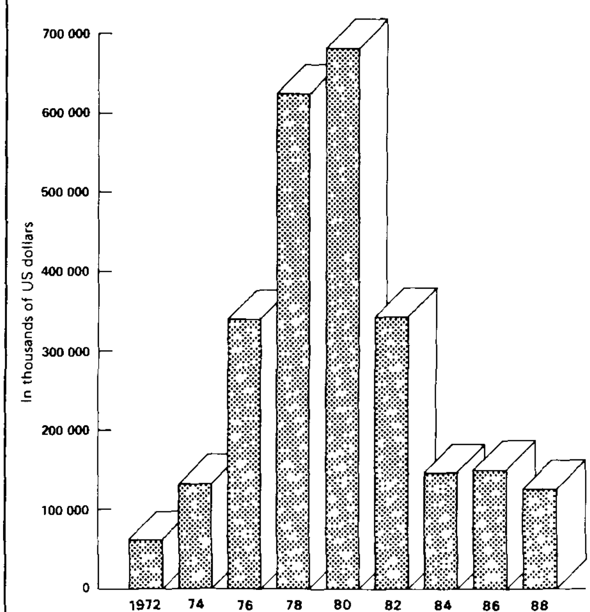
Geochemical techniques have also played an important part in uranium exploration. Samples of water, stream, or lake sediment or soil are collected at widely spaced intervals — in the order of one sample per 10 or 15 square kilometers, and analysed by rapid and inexpensive techniques capable of dealing with several hundreds of samples per day. Uranium and elements known to be associated with uranium in its deposits — such as molybdenum, gold, arsenic, mercury, and vanadium, to name a few — may be determined as well, along with copper, lead, zinc, and other elements for which the region may have potential. These data are not looked at individually but are integrated and plotted using sophisticated computer-based techniques, and presented as element distribution maps covering large areas of terrain.

Radon techniques have undergone considerable development for use in uranium exploration programmes. In such programmes, radon is measured because of its close association with its parent uranium. This association is important because of the discovery of abnormal concentrations of radon in houses built in uranium-enriched areas. In many countries, the most commonly used technique for detecting and measuring indoor radon in houses is the alpha-track detector (Track-Etch) method. It was developed primarily for uranium exploration use, but has been extensively used as well, particularly in the USA, in earthquake prediction studies.

Uranium exploration data

Uranium exploration surveys have been carried out over wide areas in WOCA countries. These have commonly been airborne radiometric surveys, either for total radioactivity, or gamma-ray spectrometer surveys that discriminate between radioactivity due to uranium and thorium and their daughters, and potassium. Recent surveys generally have been well-calibrated spectrometer surveys, but in earlier years calibration was less carefully carried out or not done at all. Total count surveys were common as well. While the quality of these earlier surveys is variable, they nevertheless provide a general view of the regional radiation background. When recalibrated, and converted to units of exposure rate, radiometric surveys, both airborne and ground, depict the general distribution of background radioactivity in the area surveyed.

Exploration expenditure in WOCA countries, 1972–88



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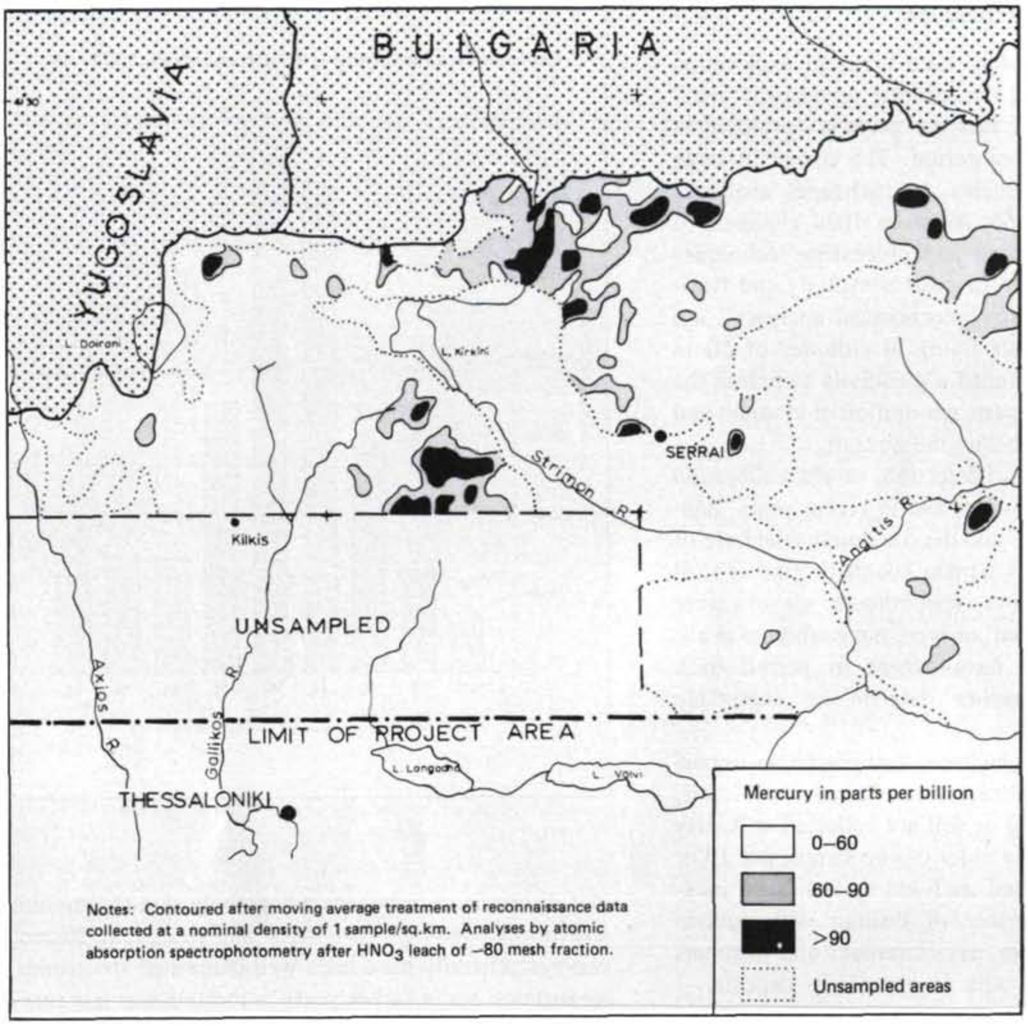
Exposure rate maps of background radioactivity have been prepared in Canada, Sweden, USA, Federal Republic of Germany, and elsewhere. They have been used extensively to provide a baseline against which man-made radioactive contamination may be judged. They also have been found to be of great use in the recognition of areas where the possibility of natural radon contamination in houses should be examined.

Recent IAEA technical co-operation projects in uranium exploration involving airborne gamma spectrometer surveying, for example in Syria, have included the recalculation and presentation of the results in the form of background radiation maps.

The airborne mapping of subtle variations in ground potassium concentrations made possible the recognition of areas of alteration often associated with gold and copper mineralization. The general geological information contained in a gamma-ray spectrometer survey has ensured that these methods have become an important ad-



In northern Greece, large areas of anomalous mercury content in stream sediments were mapped during an IAEA-assisted uranium exploration project. Mercury's environmental significance made the results valuable in areas of public health, agriculture, and fisheries.

junct to geological mapping in many countries. Uranium-enriched areas, readily mapped from the air, were found to be related to increased radon concentrations in houses, often at levels hazardous to human health.

Airborne gamma-ray spectrometer techniques have demonstrated their importance in cases of nuclear emergency as well. In 1978, the fall of the Soviet satellite Cosmos-954 spread radioactive debris from its nuclear reactor over a wide area in the Northwest Territories of Canada. The large gamma-ray spectrometer system of the Geological Survey of Canada was called into action, along with its experienced operators, and succeeded in finding and mapping the distribution of the debris in short order.*

After the Chernobyl accident in the Soviet Union in 1986, first warnings were sounded in the West by Sweden. The airborne gamma-ray spectrometer facilities of the Swedish Geological Company were called upon by the National Institute of Radiation Protection, which had knowledge of the facilities and competence of the group. Within a day, the aircraft was refitted and had begun the first of two complete mappings of the distribution of the radioactive fallout. Not only their skills in airborne surveying, but also their expertise in the preparation and presentation of geophysical data were of great value and permitted the supply of a complete map of the contamination to every household in Sweden. In addition to mapping the contamination, which indicated where precise ground measurements and remedial action had to be taken, the Swedish Geological specialists were able to map the fallout of individual isotopes associated with the accident.*

The Swedish Geological Company and the Geological Survey of Sweden have been in the forefront of development of radon measurement techniques for uranium exploration purposes. Their knowledge and ex-

* See "Estimating the Fallout on Great Slave Lake from Cosmos-954", by Grasty, R.L., Trans. Am. Nucl. Soc., Fall Meeting, Washington (12–16 Nov. 1978); and "The Search for Cosmos-954", by Grasty, R.L., in *Search Theory and Applications*, edited by Heley, K. Brian, and Stone, Lawrence D., Plenum Publishing Corp. (1980).

* See *Airborne Gamma Spectrometer Measurements of Fallout over Sweden after the Nuclear Reactor Accident in Chernobyl, USSR*, by Mellender, H., Swedish Geological Company, Report TFRAP 8803 (1988).

pertise in radon measurement has been called upon to assist when awareness began to grow that the natural distributions of radon in houses could constitute a hazard in some areas of the country.

Ground geochemical data for uranium and other elements, representing the sampling of large areas, is full of information of significance to other fields. They include agricultural land use, animal husbandry, and human health, in addition to geological mapping and mineral exploration for other commodities. In northern Greece, large areas of anomalous mercury content were mapped during an IAEA-assisted uranium exploration project that required examination from the agricultural, fisheries, and human heath points of view. *(See accompanying figure.)*. Anomalous gold contents of heavy mineral concentrates in stream sediment deposits, taken during a similar IAEA-assisted project in the Philippines, pointed the way to possible gold deposits in the region.

Examples of such "fallout" from uranium exploration programmes are legion. In many cases, these benefits have never been realized because of a lack of awareness of their existence and significance on the part of national authorities. Even those authorities concerned with atomic energy matters frequently do not understand or appreciate the nature of the data their raw nuclear materials groups have accumulated in the course of their uranium exploration programmes.

Cigar Lake in Canada, site of a large uranium deposit discovered in 1983. (Credit: CEA, France)

The IAEA's role

The IAEA has played a significant role over the years in the improvement and use of uranium exploration techniques. Meetings have been held on R&D in uranium exploration techniques, and documents published on standards of instrumentation and recommended practice in their use. In the field of gamma-ray spectrometry the Agency, in addition, has developed specifications for the construction and use of calibration facilities for field instruments. It has further prepared a set of reference materials of very high quality for the calibration of laboratory instruments for analysis of geological materials.

In its technical co-operation programme, the IAEA has assisted in the supply of sensitive radiation detection instruments and in the training of local workers in the various uranium exploration techniques through projects and training courses. These techniques have included those based on radioactivity as well as on exploration geochemistry.

In many countries, uranium exploration workers constitute the most competent and experienced group available in a nuclear emergency. After the Chernobyl accident, this was well demonstrated in a number of countries. They are also frequently the only group equipped and experienced to make environmental radon measurements. Requests for technical assistance in these areas continue at a high level from national geological surveys and university geology departments, as well as from nuclear raw materials groups in atomic energy commissions.

In recent years, the IAEA has shifted emphasis from strictly uranium exploration to the more extensive use of the techniques and data of past exploration programmes. Thus it has recently joined the United Nations Educational, Scientific, and Cultural Organization (UNESCO) through its International Geological Correlation Programme (IGCP) to support a new project in international geochemical mapping. The project aims to encourage and co-ordinate collection and compilation of geochemical data for the production of regional geochemical maps with the eventual goal of producing a geochemical world atlas. The IAEA is taking a leading role in dealing with the radioelements uranium, thorium, and potassium. Work already has begun on preparation of manuals on the use of older gamma-ray data and methods of back calibrating these survey data. In addition, a document is in preparation setting state-of-the-art specifications and methodologies for airborne gamma-ray spectrometer surveys for all purposes, including response to nuclear emergencies.

Future directions

As concern for new uranium resources appears to decline, the IAEA's role in uranium exploration and development has come more and more into question. It is frequently remarked that sufficient uranium resources