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URANIUM EXPLORATION METHODOLOGY IN COLD CLIMATES

by

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Introduction

Exploration activity for uranium has abated recently partly as a result of speculative attention and genuine exploration focus having been drawn towards precious metals but also as a real consequence of hesitancy and uncertainty within government concerning the future of uranium as a key energy base in the future. It is the firm conviction of most experts in the energy field that recent setbacks to the nuclear power program are transitory and that there are no viable alternatives to the role of nuclear technology in the provision of a vital long term segment of the nation's future energy needs.

The uranium prospecting boom of the past decade had, as a major consequence, the rapid development and proliferation of exploration methods for source materials. Numerous established methods were developed and refined whilst new techniques were introduced proving, in some instances, to be highly successful. To the explorationist the proliferation of instrumental hardware and detection systems was something of a headache with the result that in uranium exploration, more so than in other types of prospecting, the choice of exploration method at the appropriate stage of prospecting was frequently ill founded. The situation also spawned 'black box' purveyors who made extravagant claims for their equipment. Money was wasted through over kill applications of exploration method accompanied in many instances by deficiencies in the interpretation of results.

This project was originally conceived as a means of evaluating, reviewing and filtering from a burgeoning array of systems the most appropriate exploration techniques applicable to cold climate environments. This goal has been trimmed somewhat since it had been hoped to incorporate site investigation data assembled in the field by the writer as appropriate case history material. This was not possible and as a consequence this report is a 'state of the art review' of the applicability of currently available techniques in Arctic and SubArctic environments. Reference is made to published case history data, where appropriate, supportive of the techniques or methods reviewed.

Prospecting Methods in Relation to Arctic and Subarctic Environments

Arctic and Subarctic environments possess particular characteristics which must be fully considered when evaluating the effectiveness of exploration methods for uranium.

In mountainous areas glacial action and mechanical frost breakdown contribute to rapid erosion rates however chemical weathering processes are retarded with the result that oxidation and soil development is slow. Areas containing bedrock mineralization with relatively good exposure or poor cover can be expected to generate good radiometric signatures however the severe topographic expression typical of mountainous tracts in the Arctic and Subarctic possess severe monitoring problems for both airborne and ground tranversing.

Transported superficial cover comprising glacial drift, outwash sediments and loess will effectively mask gamma radiation from bedrock mineralization. Lakes and to a major extent muskeg, because of the saturated active zone, will nullify radiometric signals. Ice lenses provide an additional constraint on the passage of gamma rays however, permafrost conditions, provided good porosity is maintained, will diminish but not nullify gamma radiation from a buried source.

The characteristics described above typify very extensive tracts of Alaska and Northern Canada. The potential for the optimum use of radiometrics in these regions is limited to areas where bedrock exposure is good or where residual profiles permit the passage of gamma rays.

Vegetation cover especially when it induces high levels of moisture retention within the active layer, such as in muskeg and tundra, will greatly reduce the penetrative capability of gamma rays. Even in areas where moderate to good drainage occurs within thin superficial veneers radiometric monitoring should be restricted to periods when moisture is rising through the weathering profile--surveys conducted shortly after heavy rain or over saturated and poorly drained soils will yield depressed signals.

The conditions referred to are very common and collectively produce a pronounced fenestration effect rendering regional airborne radiometrics of dubious value for anything other than the crude definition of anomalous districts. The quite severe constraints imposed on the effective use of airborne radiometrics by transported materials, water and ice must be realized. Only in the coarsest sense will airborne surveys define anomalous uranium districts and such definition will, in Alaska, be restricted to upland areas.

Several geochemical methods are used in uranium exploration. Their effectiveness, to a greater or lesser extent, is influenced by some of the features found in cold climates which were mentioned in connection with radiometry. Water and soil gas geochemistry have more potential in all stages of exploration in cold regions than does soil geochemistry. The latter suffers from limitations imposed on its use by the extensive development of transported surficial material and spurious results generated by organically fixed uranium in typical soil profiles. Local restricted drainage patterns typical of low relief glaciated terranes further complicate the dispersal of uranium and its local fixing in organic humates. On a site specific basis, trace element pathfinder studies in residual profiles may have application especially in relation to genetic models.

Stream and lake bottom sediments are a useful media for reconnaissance sampling and could outline mineralized districts. Lake sediment sampling is best undertaken in winter in conjunction perhaps with the deployment or retrieval of radon detectors placed on the bed of the lake.

Water geochemistry, in particular the determination of radon and and helium in groundwater, affords a means of detecting buried source rocks. A sound understanding of the local and regional hydrogeological cycles is essential to the correct extrapolation of groundwater geochemical data. The refinement of analytical procedures for water analysis has greatly enhanced the value of this type of survey. Containment and contamination problems may arise with hydrogeochemical sampling especially when samples have to be transported over long distances or are subject to a protracted time span between collection and analysis.

Cold climatic influences detract from the validity of stream water sampling as a means of identifying uraniferous districts. The run-off component in stream waters is usually very high due to direct snow melt and the retention of a high percentage of precipitation in the active surface zone due to constraints imposed on downward percolation by permafrost. This ensures that most precipitation water feeds directly into the surface drainage system. These are important constraints on the use of surface stream water sampling as an indication of buried mineralized bodies however in secondary and tertiary drainage basins hydrogeochemistry may be able to define anomalous districts.

Soil gas sampling for radon and increasingly for helium are methods which have documented success in cold climates. Soil gas sampling has a broad range of application from regional reconnaissance to detailed site specific and target definition. Radon gas sampling has gained wide acceptance since the development of 'Track Etch' which affords a ready inexpensive means of monitoring radon in soil over a protracted period of time thereby overcoming the effects of climatically induced perturbations relating to changes in barometric pressure. Radon has greater diffusion penetration through rock and overburden than gamma rays and several deposits lacking a radiometric signature have been found by radon monitoring. Track Etch has been developed for use beneath standing water in a setting in which radiometrics have no application.

The rapid diffusion characteristics of helium are being exploited increasingly in the search for deeply buried uranium deposits. Radon and helium contents of natural groundwaters should be investigated in conjunction with soil gas surveys wherever sampling sites are available.

The inventory of case history studies relating to applied geochemical prospecting for uranium in cold climates is limited but is growing at a rapid pace. A broad range of useful techniques are available to the explorationist however their successful use will depend markedly on a sound recognition of the constraints and influences imposed by the environment. Careful orientation work is necessary in applying techniques to cold environments.

Although vegetation cover in cold regions is frequently dense and relatively uniform, geobotanical studies are not regarded as a viable primary exploration method. There are so many variable factors relating to the plant physiology cycle which determine metal concentrations in plant tissues that meaningful results are difficult to obtain. Quite apart from botanical variations induced in the growth cycles the fact that much of Alaska is covered with transported soil components mitigates against plant tissue analysis as a means of identifying mineralization characteristics in bedrock.

Review of Direct Exploration Methods

In the following section exploration methods which appear to have the greatest application to uranium prospecting are discussed. Emphasis centres on relevance of the technique rather than upon step by step discussion of the methodology or descriptions of instrumentation. These facets are extensively documented in the literature and in manuals prepared by systems manufacturers.

The methods are evaluated in terms of their application in various stages of integrated exploration programs from reconnaissance to detailed site-specific target definition in the final section of the report.

Radiometric Methods

Radiometric methods measure the intensity of gamma rays, high energy electromagnetic waves, produced throughout a known energy spectrum by the process of radioactive decay. The energy of the electromagnetic wave or gamma ray is characteristic of the parent element.

Two types of instrument are used to measure gamma radiation; the scintillometer measures total gamma ray intensity whereas the spectrometer has the added capability of being able to descriminate contributions to the total energy spectrum from K, U and Th. The spectrometer can be used to determine relative concentrations of K, U and Th as well as total gamma ray intensity. To detect incoming radiation both the scintillometer and spectrometer utilise a sodium iodide (Nal) crystal which responds by emitting a light flash with a brilliance proportional to the energy level when impinged upon by a gamma ray. A photomultiplier tube converts the light flashes to voltage pulses preserving the original energy information which, in the case of spectrometers, allows the source elements to be identified. The scintillometer counts the scintillation events within windows or channels and is able in this way to determine the contributions made by K, U and Th. Actually the spectral peaks that are measured to determine uranium ^{238} and thoruim ^{232} are from the respective daughter products bismuth ^{214} and thalium ^{208}--this produces enhanced definition of the contributions from uranium and thoruim.

The advantages of spectrometry over total-count instrumentation are readily apparent however there are limitations or constraints which have to be weighed by the explorationist. The cost factor is an obvious consideration since spectral instrumentation is several times more expensive than gross-count equipment. Added to this consideration are the higher cost of maintainance and the propensity for spectral equipment to develop calibration problems. Spectral surveys are more time consuming which is another factor contributing to make spectrometer surveys perhaps ten times more expensive than total count coverage. The explorationist has to resolve the question of whether the additional information obtained through expensive spectral coverage is worth it in the first instance. Spectral surveys appear to be most appropriate in the realms of highly sophisticated regional airborne coverage and mapping and secondly in follow up or detailed site specific exploration on the ground. For initial ground regional surveys it appears to be more appropriate to use total-count surveys in the first instance to identify anomalous areas for investigation using spectral techniques. Radiometric methods are used in surveys ranging in scope from regional airborne coverage to quantitative site sampling of uranium deposits. There are many limiting factors relating to both natural gamma radiation characteristics and instrumentation which should temper any temptation to view radiometric prospecting methods as a panacea for the uranium prospector. A discussion of some of these factors is appropriate.

Gamma radiation even from a highly responsive bedrock can be severely depressed, even completely subdued, by the soil profile. Detailed studies have shown that profiles of as little as 12" (30 cms) can achieve this. Alaska is blanketed to a large extent by transported veneers of glacial debris, outwash gravel, alluvial sand and gravel, loess and migrating solifluction debris which not only chokes off bedrock sources of gamma radiation but itself can produce spurious signals from the allochthanous materials or from the reactivity of the surficial soils with mineralized run-off waters.

Standing or running water in lakes and rivers prevents the passage of gamma rays. Pervasive surficial saturation of tundra and muskeg depresses radiometric signals as does permafrost, buried ice lenses, aufeis and snow cover. Variations in the moisture content of soils over even a relatively short time span greatly affect radiation characteristics. Where possible, radiometric surveys should be timed to coincide with periods when soil moisture is tending to rise through the soil profile. For this reason surveys should not be undertaken shortly after a significant rainfall.

Vegetation can contribute to the suppressing of gamma radiation. This applies to cold as well as warm and temperate climatic regions. It could be a significant factor affecting radiation emission from the land surface in Alaska.

Airborne Spectrometry

An important consideration in airborne coverage is the decline in radiation level, attributable to surface emission, with height. For this reason minimal ground clearance and constant height monitoring are desirable qualities in airborne mapping. The area being sampled at any one time is a function of height. It is easy to appreciate how land surface geometry can and does introduce a significant and complex error factor into airborne surveying. In Alaska where extensive exposure coincides with rugged mountainous terrane the problem is obvious. Where the terrane is less severe in broad valleys and rolling uplands the constraints are imposed by factors such as soil or debris cover.

There are many aspects related to normal environmental characteristics as well as inherent limitations on radiometric methods which create problems of credibility in so far as the sound interpretation of airborne radiometrics is concerned.

Large regional surveys using sophisticated spectral techniques in conjunction with other airborne geophysical and geochemical systems have, in recent years, been mounted by governmental agencies. The objective is not to identify specific anomalies but rather to characterise terranes on the basis of a range of parameters. The instrumentation is this type of survey is expensive and highly sophisticated. The Geological Survey of Canada (GSC) which is engaged in a programme of regional mapping, uses a spectrometer which embodies a NaI crystal configuration of several thousand cubic inches which is partially lead shielded and is connected to a modern on board high speed computer. Systems such as this produce spectral coverage simultaneously in up to 400 windows (channels) generating an immense inventory of data. Meaningful interpretation of the data hinges upon many intangibles and poorly understood factors. Some of the problems are common to all rapid-pass airborne methods and relate to poor count statistics (function of gamma radiation as random process) weak geologic responses, excessive background levels coupled with an inadequacy in terms of an understanding of and adoption of effective means of reducing background effects whilst enhancing the integrity of the core information.

The aims of industrial financed exploration are different and the focus is usually on local site specific programs within permissive terrane. The search usually involves identification of discrete anomalies and to further this limited objective gross-count and minimal spectral instrumentation in fixed wing and helicopter mounts is used. The spectral capability gives an immediate means through direct channel observation and ratio plots of assessing the nature of anomalous gamma levels. (A uranium source as opposed to a thorium of potassium host environment can be identified.)

Helicopters have significant advantages over fixed wing aircraft for airborne radiometric work. The advantages are offset to some extent by much higher cost and a slower rate of progress. The major advantages of helicopter surveys are:

1) Easier to maintain constant ground clearance.
2) Lower air speed greatly improves the counting statistics of the data.
3) Site checking capability by immediate follow up.

In both helicopter and fixed wing surveys background characteristics are commonly determined by flying at constant height over standing water.

Factors such as air speed, ground clearance and orientation and spacing between lines will depend upon the type of survey and aircraft being used. In a regional highly sensitive spectral survey such as the program being undertaken over several years on the Canadian Shield the surveys are being flown at a height of 400' (120m) at air speeds of 120 m.p.h. (200 km/h) on a line spacing of 3 miles (5kms).

Flight trends will depend upon various influences. Where no identifiable 'grain' is apparent from stratigraphic knowledge parallel evenly spaced flight line coverage is best. In areas of strong physical relief there would be operational advantages in flying along and parallel to ridge features. Where a favorable formation is known to occur the survey configuration could follow the elongation trend or alternatively closely spaced line coverage perpendicular to the anticipated mineral trend could be followed.

As with other exploration methods phasing may be applied to airborne surveys. Initial coarse coverage may identify anomalies which are followed up by closer spaced more detailed spectral coverage before ground checking procedures are started.

Since anomalous radiometric districts tend to be extensive the regional approach despite process and sensitivity limitations will find them. Thereafter it becomes a question of identifying real from false or misleading anomalies which may result from:

1) Factors influencing statistical processing.
2) Meteorological effects which may locally produce inbalances of radon gas.
3) Terrane effects--such as soil, water and vegetation cover.
4) Poor characterisation of the geological environment.
5) Disequilibrium effects associated with down slope migration of gamma emitters from the parent deposit.

Clearly radiometric mapping has an important role in general regional investigations however some important limitations which may severely impair the quality of the data and hence scientific inferences which may be drawn from it must be recognized.

Car borne and Hand Held Instrumentation

In certain terranes car borne systems have been used to achieve rapid regional coverage. Their applicability is partly a function of road density and reasonable access across open country. In Alaska where the road system is embryonic and off road accessibility is poor, the use of car borne systems has little or no application.

Hand held instruments are used extensively to examine and map the distribution of radio elements at or near the surface. Total count scintillometers are relatively inexpensive and lightweight instruments constructed to withstand robust handling. They have become identifiable as just about a basic element of an exploration geologists' field equipment. Spectral instruments are more vulnerable to develop problems with routine protracted field use, are of necessity more cumbersome besides being very much more expensive. The ideal operational method which is extensively practiced is to identify radio element anomalies using simple effective total count instrumentation and systematically follow-up and evaluate such anomalies with spectral methods using an appropriate window-spectrometer to characterise the gamma source.

The scintillometer can be used in several ways:

1) to systematically determine gamma ray intensity at points on a regular grid or traverse line.
2) to identify anomalous responses in the course of random traversing.
3) as a sample screening device to determine whether samples collected for assay (perhaps involving other metals) should also be run for source metals.

Most portable compact scintillometers have the following in common:

1) A range switch with sufficient positions to keep the reading on scale.
2) A function switch for on/off, battery test and various sensitivity ranges.
3) An audible alarm which can be pre-set to sound-off when certain levels of gamma radiation are surpassed.

An operator should be thoroughly familiar with the controls of the instrument which basically is easy to use.

Systematic surveys should follow a standard procedure to reduce possible sources of error. Readings should always be made at a constant height above the surface at points on a regular spaced grid or at a constant spacing along a traverse line. Geometry of the surface at and proximal to the sample point influences the gamma ray intensity. Simple corrective calculations can be made to compensate for errors of measurements due to surface geometry thereby improving the quality of the data. The operator should during the course of a survey note rock lithologies and surficial soil characteristics--the presence of feldspars and micas could suggest and explain high potassic gamma sources. The probable characterisation of an anomaly as due to potassium could be deduced with reference to spectrometry.

If the instrument is to be used non-systematically (i.e. to identify anomalous areas in the course of routine mapping traversing) the operator should first determine a reasonable background reading. This can be done by observing the instrument during the course of a brief loop traverse with the system activated. The audible alarm could then be pre-set to sound-off at say 1 1/2 times the 'background' value. An operator can stow the scintillometer in his pack and, providing it is switched on, go about his other duties mindful of the fact that an anomalous level of radiation would activate the alarm mechanism.

A radiation test source supplied with the instrument should be used to check the performance of the instrument periodically.

Having identified an anomaly demanding follow up investigation a gamma-ray spectrometer can be used to distinguish the constituent sources of gamma radiation.

Various systems are on the market each basically having a similar range of capabilities. The gamma ray spectrometer measures all sources of radiation and reports the contribution from the three common geological sources of radioactivity, the elements potassium uranium and thorium. A total count reading is also recorded which enables percentage contributions and ratios to be determined.

Whilst it may be counter productive and unnecessary to use spectral methods in early phases of reconnaissance nevertheless the current generation of spectral field instruments can fulfil a function in all phases of exploration from initial reconnaissance through to detailed mapping and site specific in-situ and core sampling.

Most instruments are equipped with digital analog ratemeters (l.e.d. display) which sequentially display the four channels. Sample times from 1 second up to 30 minutes can be chosen and set by the operator.

With spectral surveys sites should be sampled using a time constant which will reduce the effects of random statistical counting. As with total count instrumentation measurements should be taken at a standardised height clearance. Stripping coefficients which are predetermined for the operator are applied to spectral data to determine corrected values attributable to potassium and uranium. This manipulation overcomes the effects of Compton Scattering.

Using a portable spectral instrument to follow up initial total count anomalies can itself be a two stage process. The anomalous site should first be checked to determine which radio elements are producing the anomaly and to decide upon the layout of further survey lines.

If a detailed survey is warranted the digital mode is used and systematic grid point sampling at fixed interval is carried out for all channels. This information can then be presented as radioelement contour, percentage or ratio plots.

Using the scintillometer for field assays is a valuable asset. There are several potential sources of error in the measurement which may be attributable to:

1) Geometry of geological source.
2) Surface moisture.
3) Inprecise window settings.
4) Errors in determination of sensitivity values and stripping constants.
5) Incomplete background removal (significant only in low sensitivity ranges).
6) Disequilibrium conditions between the key radio elements and their daughter products.

Geochemical Methods

Soil Gas Surveys.

Radon and helium gas monitoring systems constitute the most reliable direct methods of prospecting for uranium under conditions where radiometric responses are suppressed.

$Radon^{222}$ determination has formed the basis of various detection systems and has been effective in locating buried mineralized bodies. $Radon^{222}$ is the sixth member of the U^{238} decay series and with $Radium^{226}$ forms an isotope couple specific for uranium. Radon is an inert gas possessing several properties which identify it as a useful pathfinder for uranium. Radon has a half life of 3.8 days but because it is dense it has limited diffusion capabilities. As a consequence radon persists as a restricted halo around uraniferous bodies. Data assembled from various case histories and orientation surveys give the following diffusion characteristics:

Dry permeable soils	20' (6m) Dyck, 1975 33' (10m) Childers, 1978
Wet saturated soils	8" (0.2m) Childers, 1978
In flowing stream waters	650' (200m) Dyck, 1975
Leakage through fracture systems and porous rocks	400' (120m) claimed in site specific instances

Radon diffusion is severely arrested by high moisture content in surface profiles and bedrock aquifers. Variations in moisture content can account for a high percentage of the variance experienced in gas monitoring. Atmospheric pressure changes also play a significant role in radon diffusion into and through soil profiles.

Radon diffusion is not apparently severely affected (arrested) by frost or snow cover however ice does constitute an effective barrier. Diffusion rates are considerably accelerated by increases in soil moisture temperature.

Systems which rely upon short duration sampling periods were affected by excessive noise signals due to rapid climatic variation. Modifications to sampling technique involving the drilling of deeper holes and allowing equilibrium conditions to develop in the hole to be sampled before recording actual concentrations did little to alleviate the situation. Inconsistent and erratic results obtained using radon-probe detectors on a site specific basis lead to a downgrading of acceptance of short duration in-situ radon counting devices in favor of methods which effectively sample radon over a time period of several weeks.

Portable on-site analysing systems have, it is claimed, analysed radon leaking from bodies up to 120m (400') below surface. Two types of measuring instrument are used for on-site radon measurement:

1) Alpha probe (radon probe)
2) Pump monitors

The modus-operandi for both systems is to measure soil gas concentrations of radon from at least 2' (75cms) below the surface within the soil profile. It is customary to drill auger holes to this depth or to drive a hollow sampling rod through the soil cover to the appropriate depth. Soil conditions must be permitted to stabilise before determinations are made.

The alpha probe (radon probe) is inserted into the hole, a process which itself can cause disequilibrium. A stabilisation period of a few minutes is allowed. The counting device employs a zinc sulfide phosphor contained within a perspex rod. Alpha scintillations are internally reflected up the rod to a photo-multiplier optically coupled to the above ground end of the instrument. It is usual to take two measurements separated by at least ten minutes. By doing this a correction is made for the presence of $radon^{222}$ a thorium derived isotope with a short half life. During the time interval between recordings virtually all the Rn^{220} will decay leaving the signal attributable to uranium specific Rn^{222}. The procedure is time consuming and, depending upon site spacing, only about two grid points can be tested per hour. The operation is two stage since the holes have to be drilled a matter of days before actual sampling.

Many of the same constraints apply to pump evacuation methods in which soil gas is evacuated from the hole via a flexible tube into a measuring chamber. Alpha scintillations generated in the zinc-sulfide lined chamber are amplified by a photomultiplier and digitised. An alternative method used in one system passes soil gases into a mean current ionization chamber which measures the ionization current produced by alpha activity in the sample. A simple adjustment to the instrument can be made to compensate for contamination of the detector.

All scintillation monitors are liable to alpha contamination which is overcome by periodic replacement of the phosphor assembly.

Alpha probes contain no moving parts and hence can be both operationally simple and robust. Pump monitors have greater sensitivity than probes and have been adapted to the measurements of radon in waters.

The counting of individual alpha particles which is the basis of all radon detection methods is highly sensitive and accurate however the major problem encountered concerns the substantial variation in soil gas components induced by fluctuations in moisture content of the soil, atmospheric pressure, wind and even tidal pumping amongst lesser causes of perturbation.

Radon signatures will be most pronounced over profiles in which the moisture content is well below saturation--this is an important consideration in cold climates.

The effectiveness and reliability of radon gas sampling was greatly improved with the development of alpha-track dielectric film methods. The great advantages of this technique are:

1) Problems associated with short term variability of soil gases are overcome.
2) The system is versatile and extremely simple to run in the field.

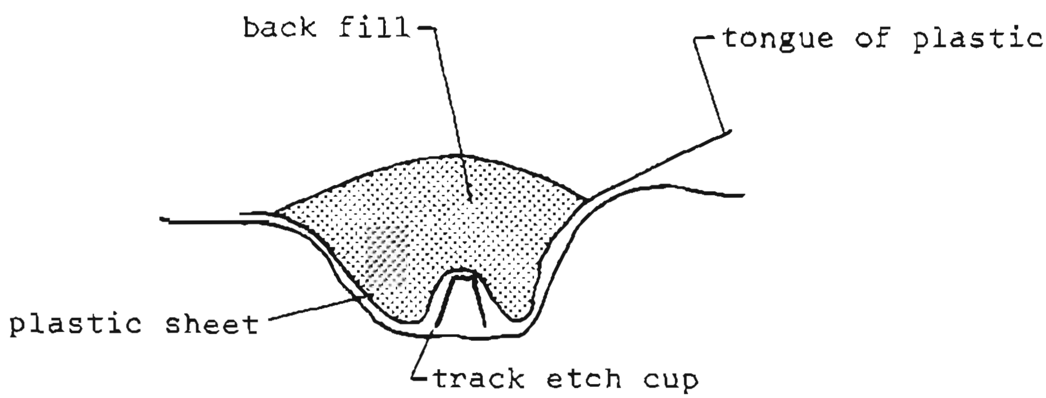
The method makes use of the phenomenon of degradation of the energy of nuclear particles. As such particles traverse solids they experience atomic collision and leave evidence of their passage along the particle trajectory as a track. Tracks can be made visible photographically or by a material known as C.N. (cellulose nitrate) developed by the General Electric Company. C.N. film is sensitive to alpha particles but not to light and is stable under a wide range of atmospheric conditions. The use of this material as a radon sensing method is embodied in the "Track Etch" system developed and marketed by the Terradex Corporation.

Since the introduction of "Track etch" filters have been developed which permit discrimination of the effects of $Radon^{222}$ a derivative of thorium. This was not possible previously and this advance clearly enhances the usefulness of the system.

The "Track etch" system has, through numerous case history studies, been shown to be effective under a wide range of climatic conditions extending from tropical to arctic and in a variety of terranes. It has definite applications in areas where radiometric methods are ineffective due to thick veneers of residual or transported soils. To a lesser extent it also suffers from similar constraints relating to overburden characterization.

Deployment of the system is simple and in cold climates its use extends the prospecting season to a year round basis. In fact winter deployment from a logistical view can be more effective. A regular grid can be sampled covering swamp and muskeg, lakes and less restrictive terrane.

The special dielectric film segments are housed in an inexpensive clear plastic cup. Emplacement of the cups is a simple process which can be varied to accomodate different superficial conditions. Holes to accomodate the inserted cup should be dug to a depth of +15". One method of ensuring rapid recovery or retrieval at the end of the monitoring period is to cover the track etch cup at each station with a sheet of plastic over which the excavated dirt is back filled. A tongue of plastic should be visible after back filling and this can easily be flipped back in order to extract the cup during retrieval operations.



All stations should be clearly marked by flagging or some other appropriate method.

In swampy conditions such as muskeg cups can be positioned by hand pressure and restrained by using stones or branches of vegetation to wedge them firmly in place.

For lake sampling, under water or ice, large cups of more durable and robust construction are used to house the film. Cups are weighted with a lead collar and are lowered usually through auger holes drilled in the ice onto the lake floor. The trapped air bubble in the inverted plastic cup prevents water coming into contact with the film. Deployed cups are attached to a recovery line which itself is attached to a stake or buoy on the lake surface. Recovery procedures are simple and straightforward and are undertaken at the end of the deployment period.

Track Etch is a method which lends itself to reconnaissance, semi-detailed and detailed site specific prospecting stages. Grid configuration and site density will vary with the primary objective of the program. Anomalies identified as a result of a coarse regional grid employing a 1000 meter spacing can be followed up by a closer spaced program of say 100 m centres in much the same was as refinements of geochemical or geophysical surveys are made.

A simple computation will determine the number of stations necessary to cover a given area at an acceptable spacing. In laying out surveys regular equidimensional grids should be employed unless there is a very compelling reason inherent in bedrock trends which mitigates otherwise.

The radon measured in surface soils is composed of two components. One of these is a normal background level whilst the other is a migratory component emanating from buried source rocks. It is essential to be able to differentiate between the effects of these components, therefore the statistical variability of the background must be adequately defined. This can be achieved with a sufficiently large population which under ideal conditions may be as low as 100 stations. Contracted surveys by Terradex stipulate a minimum of 250 cups which is claimed as a minimum requirement to adequately identify background statistics.

Since the "Track etch" method is marketed as a commercial system deployment and retrieval is the responsibility of the user however Terradex performs the interpretation and analysis of the results through maps etc. Surveys are subject to a minimum tariff based on a 250 station survey. Economies per sample are achieved by surveys which involve the deployment of larger numbers of cups.

Prior mention was made of Track Etch as a winter prospecting method in cold climates. Surveys can be undertaken which involve positioning the cups in the Fall and collecting them just prior to Spring break-up. Surveys of this type have given sound results in northern Canada. With winter run surveys the cups do not have to be buried quite so deep within the soil profile. Winter surveys have been undertaken in which the detecter cups were placed in shallow 6" holes in the soil and then covered with soil and snow. Longer periods of exposure are recommended for snow cups because radon migration is reduced as a function of temperature and icy conditions.

In Alaska where the surficial geology is characterised by transported soil covers, permafrost, ice lensing and other conditions which detract from radiometric exploration techniques "Track Etch" appears to have considerable attraction for reconnaissance as well as detailed site-specific programs.

A major disadvantage for "Track Etch" is the necessity to send the retrieval cups away for interpretation--a procedure which consumes valuable time.

There are systems in use which monitor radon emission in soils over a period of several days, sufficient to overcome some of the abberations (problems) associated with climatic variability, which have the advantage of providing on-site information and consist of reusable units. This system is not amenable to surveys involving a large number of stations but on a limited site-specific basis--perhaps in relation to identifying a borehole site etc.,--useful on site data is generated. The 'alpha sticks' utilise an alpha-sensitive silicon detector housed in the instrument which is deployed in much the same way as 'Track etch' cups.

Helium is an inert gas which, because of its lightness, has excellent diffusion characteristics. Being readily diffusible it travels through rocks etc., in a basically upward path. Anomalous helium concentrations found in soil gas should signal the presence of buried radioactive source rocks more precisely and effectively than any other sensing method. Because helium is a stable isotope the halo of anomalous concentration around a source body is a function of diffusion rather than isotopic stability. Helium halos should be more extensive than the radon anomaly around a uraniferous body.

In ground water systems, sealed from atmospheric influences, helium may travel or migrate laterally from the source. Methods of detecting anomalous helium in the atmosphere leaked from buried source lithologies are being investigated and airborne sensing may well evolve as a primary reconnaissance tool. Helium in ground waters is another exploration concept and the testing of water wells in many districts could be undertaken as a relatively cheap means of obtaining baseline data.

Just as the property of rapid diffusion characterises the usefulness of helium so also does it pose sampling problems. Helium containment is difficult and the contamination risks in sampling soil gas are relatively high. One method of sampling which addresses this problem is to insert or drive a small diameter tube into the soil at the sample site. The tube should penetrate into moist or relatively densely packed sub-soil. The sample tube is covered at the emergent end with an airtight septum through which a syringe can be inserted in order to collect samples. The first syringe full of evacuated gas, amounting to 10cc, is discharged. The syringe is then inserted again and the soil gas sample is collected for analysis. Plastic syringes retain helium quite well but quantitative analyses must be determined with a minimum of delay.

Orientation studies have shown that in most soil profile conditions the sample should be taken from +18" (50 cms) below the surface.

Helium soil surveys should be used as a complementary technique to radon monitoring methods in target identification programs--the method appears to have little application in regional reconnaissance programs.

Soil and Stream Sediment Methods

Soil geochemistry has found little application in exploration programs aimed at finding uranium. This is partly due to the availability of other effective techniques such as soil-gas monitoring and radiometrics, but it is also a reflection of spurious effects generated by organic complexing of uranium especially in humus rich soils. In cold climates an additional factor detracting from the use of soil geochemistry concerns the prevalence of weathering veneers which comprise transported allochthanous components. Glacial drift, outwash gravels and loess fall into this category in valley and terrace situations, whilst solifluction creep on slopes induces local but significant detachment of supra soils from their bedrock origin assuming their residual nature in the first place.

Where the existance of true residual soils can be demonstrated soil geochemistry could have some application in target definition and the more advanced stages of exploration programs. Geochemistry could be useful in providing data for metallogenic analysis by determining levels of concentration of pathfinder elements such as Co, Pb, Zn, Cu, V, Ni and even Au. This information would be valuable in identifying possible ore controls.

Stream sediment and lake sediment geochemistry has been used successfully in regional reconnaissance type programs aimed at defining districts of anomalous uranium enrichment rather than restrictive site specific studies. In Canada the selection of geochemical method was made broadly on the basis of terrane type. In the Canadian Shield and extensive sheet glaciated areas characterised by local restrictive drainage systems emphasis was placed on the collection and analysis of lake bottom sediments. An important consideration here is the relative frequency of lakes in this type of terrane which is generally sufficient to satisfy a primary sampling density. Lakes represent easy access sites and sampling can be undertaken at any time of the year except during initial freeze-up and throughout the break-up period. The optimum position for collecting lake samples is from the median axis of the lake however this may not be feasible due to overdeepening etc. A median position is best since there is less likelihood of local spurious influences.

Stream sediment coverage was used in the Cordilleran environment by the Canadians as the preferential technique because the drainage system is both active and well-developed and lake distribution density mitigates against bottom sediment sampling.

In Alaska a similar regional approach could be adopted. With the high incidence of transported superficial material resulting from glacial and periglacial processes noise levels could be high in stream and lake sediment sampling. The method does have regional and more restrictive applications especially in areas where stream loads and surficial sediments are representative of the drainage area.

Geobotanical Methods

There is no evidence to suggest that geobotanical prospecting methods involving possible metal indicator plants, toxic responses or tissue sampling have any realistic application in uranium prospecting in Arctic and Subarctic conditions.

Water Sampling--Hydrogeochemical Methods

The solution chemistry of uranium in its different valency states is as well understood as the radiochemistry of uranium and its daughter products. Hydrogeochemical uranium sampling has proven to be a sound technique for regional reconnaissance type surveys. The excellent dispersal characteristics of uranium in its hexavalent form in ground waters promotes the formation of broadly defined geochemical aureoles. Hydrogeochemistry has inherent capabilities beyond those of radiometric methods for detecting possible buried deposits--it is a good means of identifying anomalous tracts of permissive terrane.

Many factors influence the concentration of elements in natural waters. The variability of uranium in natural waters as a function of time and space is in general greater than its variability in soils or stream sediments. In some situations appropriate simple or multiple correlations can be made between other dissolved constituents and uranium. In this way variable factors attributable to short duration environmental influences can be resolved or eliminated.

The hydrologic regime in cold climates can be extremely complex partly as a consequence of interupted season drainage but also due to the restriction of movement, of much of the precipitation that falls as rain or snow, to a run-off component confined to a thin active surficial layer. This certainly suggests reduced interaction of surface waters and ground water in Arctic and Subarctic regimes. One consequence is a weaker signal in stream waters of geochemical anomalies attributable to bedrock mineralization. Since the run-off component of stream water has had little or no contact with possible bedrock hosts to mineralization.

The ground water component will be less dynamic and this will affect the strength and extent of uranium dispersal in bedrock aquifers.

Organic material present in the surficial veneer of soil constitutes an effective scavanger of uranium and distorts the possible development of aureoles about a mineralized body. In muskeg, tundra and hummocky glacial terrane passive drainage systems prevail which promote the localisation and patchy distribution of uranium buildups attributable in the main to spurious anomalies coincident with organic rich sediments and peat.

Stream waters comprise two components; one is a ground water component which has had reactive contact with bedrock and carries the geochemical signature of that interaction, the other is the more transient component which represents run-off from snow melt and precipitation. Further complications to the hydrologic regime arise from the oft mentioned high incidence of transported soil cover in a variety of forms in cold regions.

In a ground water geochemical context the most meaningful data should be obtained from spring lines which represent genuine intercepts of the water table with the present land surface. Careful orientation studies must be incorporated in any serious study.

Drainage sampling of secondary and tertiary courses will incorporate a component of environmental noise which could mask variability due to significant mineralization within the catchment drainage. To minimize environmental components of the signal stream water sampling should be completed in a minimal time span. In Alaska the best time to conduct hydrogeologic/chemical surveys would appear to be late summer prior to winter freeze-up.

In regional hydrogeochemical surveys a sample density ranging from 1 per 5 to 50 km should be adequate. Surveys with this density format would involve random spacings of from 2 to 10 kms between sample sites.

Hydrogeochemical sampling is especially valuable in areas where overburden and few outcrops conceal bedrock lithologies but within which water sampling can be undertaken through boreholes. There are few areas in Alaska where cultural activity has generated a sufficient density of boreholes from which samples could be collected.

In conjunction with helium diffusion in soils water sampling provides probably the best method of identifying concealed uraniferous bodies. Its usefulness is most apparent in areas where radiometric methods fail.

Other Methods

Portable instrumentation using neutron activation is currently being developed as a site specific in-situ uranium assay tool. Commercial units will soon be available providing the explorationist with an accurate means of conducting field assay of exploration, samples and borehole cores. The instrumentation will have limited use as a reconnaissance aid and will have its main area of application in detailed quantitative studies.

Optimal Exploration Method Selection

The selection of appropriate exploration techniques is critical in any exploration program but nowhere more so than in Arctic and Subarctic environments. Seasonal freeze-thaw cycles, permafrost and ice lenses, saturated surficial active zones in weathered profiles, extent of lakes and rivers, thick veneers of transported unconsolidated sediment, frequent restricted drainage patterns and vegetation characteristics all contribute to a greater or lesser extent to complicate, sometimes nullify, responses from buried source units which form the basis of the exploration methods.

For many exploration methods there has been insufficient careful orientation work undertaken to ascertain the capabilities and shortcomings of technique. Certainly in cold climatic regions such as Alaska there are problems in so far as the performance of virtually all procedures are concerned. An inventory of well-documented case history studies should be compiled as an aid and a guide to explorationists in the future.

Despite multiple constraints most of the reconnaissance methods will identify broad areas of anomalous radioelement concentration. It is mainly in the refinement process of identifying 'hot spots' and specific anomalies that the poor resolution characteristics imparted by environmental features and sources of error in the respective methods create fudging and masking effects. Dependent upon characteristics of the environment the task of locating concealed ore units may be beyond our present capabilities over large areas of Alaska.

Before embarking upon high cost exploration within an area known to possess favorable regional geochemical or radiometric responses or known to have potentially uraniferous host rock assemblages a quantitative or semi-quantitative geomorphological analysis based upon best available air photographs and maps should be attempted. The extent of bedrock exposure and terrane covered by thin residual profiles should be quantified and contrasted with areas covered by water/ice, transported weathering products and other influences which complicate or nullify geochemical and/or radiometric responses. Where terrane characteristics are such that a substantial percentage of the area is composed of outcrop or residual debris, traditional well established exploration methods can be used and should generate reliable data.

A multiple method approach to uranium exploration is probably the best way to proceed given the restriction and distortions imparted by natural environmental features. This applies especially to exploration phases following upon regional reconnaissance. Combinations of radiometric and geochemical methods have the greatest merit. Helium gas sampling which capitalises on the diffusion characterics of the gas is less restrained by constraints than radon monitoring. Radon migration can be restricted by various influences however simple methods which employ monitoring times of several weeks, even months, appear to have considerable promise in cold regions.

There is no panacea for the uranium exploration geologist in cold regions. Careful assessment--a value judgement--and the effectiveness of methods in the light of terrane and procedural influences must be made on a case by case basis if exploration effort and money is not to be wasted.

In the following table the exploration methods discussed in this report are shown with reference to their appropriate use in cold regions in the stages of a phased exploration sequence.

The table is intended to serve as a guide to the correct position within an exploration sequence for different methods. Methods may or may not be effective depending upon a range of factors repeatedly stated in this report.

Well founded exploration programs will in many instances be generated from conceptual ideas based on analogies to known deposits. Certain terranes, tectonic settings, rock assemblages may or may not display attributes of the analogous ore deposit model. A primary selection can be made quite effectively in uranium exploration to eliminate certain areas or at least reduce their priority rating before radiometric and or geochemical programs are initiated. This type of selection could apply to certain areas of Alaska where the gross geology is sufficiently well understood to sustain a reasoned judgement.

Rating

A = Major Application
B = Fair Application
C = Minor Application

Category	Method	Regional Reconnaissance	Strategic Semi-Detailed Prospecting	Detailed	Target Investigation	Mine Site Evaluation
RADIOMETRIC	Air-borne. High resolution spectrometry (as other systems)	A				
	Air-borne—basic spectral capability	B	A	B		
	Car-borne—spectrometry or total count	C	C			
	Hand held scintillometry	C	A	C		
	Hand held spectrometry		C	A	A	A
SOIL & GAS	Radon Probe (Alpha probe)		C	B	B	
	Pump Monitors			B	B	
	Track Etch (soils)	C	B	A	A	
	Track Etch (bottom seds)		A	C		
	Helium (soil gas)		A	A	B	
GEOCHEMISTRY Soils & Seeds	Elemental Geochemistry (soils)		C	C		
	Stream sediment	A	B			
	Lake Bottom sediments	A	B			
	Geobotanical Methods		C			
WATER	Water—elemental sampling run-off	B	A			
	Water. Ground water Radon		B	B		
	Water. Groundwater Helium		B	A		
	Neutron Activation Probe			C	A	A

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