

A PROSPECTOR'S GUIDE TO URANIUM DEPOSITS IN NEWFOUNDLAND AND LABRADOR

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INTRODUCTION

WHY URANIUM?

- Uranium is an abundant source of concentrated energy.
- One pellet of uranium fuel (following enrichment of the U^{235} component), weighing approximately 7 grams (g), is capable of generating as much energy as 3.5 barrels of oil, 17,000 cubic feet of natural gas or 807 kilograms (kg) of coal.
- One kilogram of uranium²³⁵ contains 2 to 3 million times the energy equivalent of the same amount of oil or coal.
- A one thousand megawatt nuclear power station requiring 27 tonnes of fuel per year, needs an average of about 74 kg per day. An equivalent sized coal-fired station needs 8600 tonnes of coal to be delivered **every day**.

WHY PROSPECT FOR IT?

- At the time of writing (September, 2007), the price of uranium is **US\$90 a pound** - a “hot” commodity, in more ways than one! Junior exploration companies and major producers are keen to find more of this valuable resource.

As is the case with other commodities, the prospector's role in the search for uranium is always of key importance.

WHAT IS URANIUM?

- Uranium is a metal; its chemical symbol is U.
- In most rocks uranium occurs in (background) concentrations of 2 - 5 parts per million (ppm).
- Uranium occurs in highest concentrations in felsic rocks such as granites.
- Some intrusive rocks, (e.g. nepheline syenite) contain up to 600 ppm uranium as background concentration. Black shales can contain up to 1000 ppm uranium.
- Uranium is approximately five hundred times more abundant in the earth's crust than gold and is about as common as tungsten or molybdenum.
- Uranium in ore, commonly occurs as uraninite (U_3O_8) and as brightly coloured

secondary minerals, where exposed to weathering.

- Uranium is commonly associated in igneous rocks with Zirconium (Zr), Niobium (Nb), Tantalum (Ta), Titanium (Ti) and the Rare-Earth Elements (REEs).
- Commercial concentrations of uranium ore are 0.1% and higher.
- Australian uranium ores have grades up to 0.5% U_3O_8 .
- Canadian ores are higher grade on average, and can range up to 20% U_3O_8 (in the Athabasca Basin, Saskatchewan).
- Natural uranium consists mostly of a mixture of two isotopes (atomic forms) of uranium. Only 0.7% of natural uranium is "fissile", or capable of undergoing fission, the process by which energy is produced in a nuclear reactor. The fissile isotope of uranium is uranium 235 (U^{235}). The remainder is uranium 238 (U^{238}).
- Uranium dissolves readily in oxygen-rich waters, which accounts for its presence in surface water, groundwater and the sea.
- Uranium is radioactive – producing heat in the decay process. This heat is transferred to water, which produces steam and the steam is used to drive large turbines, which in turn produces electricity.

THE PRINCIPAL TYPES OF URANIUM DEPOSITS

- An economic uranium deposit is one where the concentration of uranium is high enough to make commercial extraction feasible.
- Uranium has formed economic deposits in a great variety of igneous, metamorphic and sedimentary rocks, ranging from very old (3 billion years) to relatively recent (less than 1 million years). *Consequently, there are a wide range of prospecting environments for uranium and some of these occur in Newfoundland and Labrador.*
- Uranium deposits can be grouped into 20 deposit types based on the geological setting of the deposits. Many Canadian deposits, like those of the Athabasca Basin, are unconformity-related.

Major deposit types or those which are of particular interest to Newfoundland and Labrador are described below.

URANIUM DEPOSITS RELATED TO UNCONFORMITIES

- Unconformity-related deposits constitute approximately 30% or more of the world's uranium resources and they include some of the largest and richest deposits.
- Deposits related to unconformities (See Glossary) occur above or below the unconformity that typically separates older deformed (folded, faulted and brecciated) rocks. These rocks were intensely weathered during an ancient geologic era and then covered by (typically red) sedimentary rocks.
- At present, all of Canada's uranium production is (or was) from unconformity-related deposits – (Key Lake and Cluff Lake, both now depleted), Rabbit Lake, McClean Lake and McArthur River deposits. Other large, exceptionally high-grade unconformity-related deposits currently being developed include Cigar Lake; there, average grades are 21% U_3O_8 , with some zones over 50% U_3O_8 .
- The deposits in the Athabasca Basin occur below, across and immediately above the unconformity, with the highest grade deposits situated at or just above the unconformity (for example Cigar Lake and McArthur River).
- Some deposits of this type are located where the unconformity is cut by faults.
- Minerals are uraninite, pitchblende, coffinite and brannerite.
- Other metals such as nickel (Ni), cobalt (Co), arsenic (As), gold (Au), platinum (Pt) and copper (Cu) are locally associated with the uranium.
- The main deposits occur in Canada (in the Athabasca Basin in Saskatchewan and in the Thelon Basin in the Northwest Territories).
- Unconformity-related deposits of the Athabasca Basin are the world's largest storehouses of high-grade uranium.

The Central Mineral Belt in Labrador is being actively explored for deposits of this type (for example, near Moran Lake). Potential also exists on the island portion of the province, for example, the Deer Lake Basin.

URANIUM DEPOSITS IN SANDSTONES

- Sandstone-hosted uranium deposits represent approximately 18% of the world's resources.
- They are commonly low- to medium-grade (0.05 - 0.4% U_3O_8).
- These deposits are usually considered to be secondary deposits because the uranium

has come from weathering and erosion of pre-existing uranium minerals from mostly igneous rocks.

- The uranium was dissolved and transported, in solution, to a variety of environments, most commonly associated with terrestrial sediments and unconformities.
- Almost all sandstone uranium deposits are in continental sediments; less than 5% occur in marine sedimentary rocks. Host sandstones formed in rivers, lakes, deltas and very shallow seas, but deposits in rivers and/or alluvial fans are most common by far.
- Sandstones act as excellent conduits for uranium-bearing groundwater. When that water passes from oxidising (oxygen-rich) to reducing (oxygen-poor) conditions, U can be deposited.
- Uranium mineralization in sandstones occurs where the uranium-bearing fluids came into contact with carbonaceous material such as plant matter or humates or hydrocarbons, or with pyrite or other sulphides or also with interbedded mafic volcanic rocks or other rocks with abundant biotite or chlorite (ferro-magnesian minerals). These so-called “reductants” cause the uranium to be deposited.
- Host rocks to sandstone-hosted deposits are usually light grey to green (reduced) or light brown to red (oxidized). Impermeable shale/mudstone units occur in the sedimentary sequence and can occur immediately above and below the mineralized sandstone.
- The primary uranium minerals are uraninite and coffinite.
- Anomalous concentrations of vanadium (V), molybdenum (Mo), selenium (Se), Rare earth Elements (REEs) and locally copper (Cu), silver (Ag), chromium (Cr) or radium (Ra) are associated with sandstone deposits.
- Sandstone uranium deposits have been found in the great sedimentary basins of the world.

In Newfoundland and Labrador, the Deer Lake and St. George basins contain potential host rocks for this type of deposit. Note that only rocks of Devonian and Carboniferous age in Newfoundland and Labrador contain plant remains.

URANIUM DEPOSITS IN VOLCANIC ROCKS

- It is estimated that about 16% of the world’s uranium reserves are found in volcanic rocks.
- They are commonly low-grade deposits (0.02 - 0.25% U_3O_8).

- Volcanic uranium deposits are commonly associated with caldera complexes in both extrusive and intrusive volcanic rocks.
- Uranium can occur in both mafic and felsic volcanic rocks and in many examples the uranium is associated with faults or shear zones.
- The uranium mineralization generally occurs as veins, stock-works or filling fractures near the surface. It is also found as disseminations within permeable flows, flow breccias, tuffs and intercalated pyroclastic and clastic sedimentary rocks.
- The typical uranium minerals are pitchblende and coffinite.
- Uranium is commonly associated with molybdenum and fluorine. Minor amounts of Arsenic (As), bismuth (Bi), mercury (Hg), lithium (Li), lead (Pb), antimony (Sb), tin (Sn) and tungsten (W) may be present.

A significant resource of this type occurs in the Michelin deposit in the Central Mineral Belt in Labrador.

URANIUM DEPOSITS IN GRANITIC ROCKS

- It is estimated that about 12% of the world's uranium resources are found in granitic or associated rocks.
- They are commonly low- grade deposits, generally less than 0.1% U_3O_8 .
- High concentrations of uranium (>10 ppm) occur in many types of intrusive igneous rocks. Generally the uranium content of large igneous bodies does not exceed 20 ppm. However, the last part of the intrusion to crystallize may show significant enrichment of uranium in relation to the average value for the entire body.
- Hence when prospecting in granitic rocks always look out for the pegmatitic (very coarse-grained) or aplitic (very fine-grained) rocks as these may contain the highest uranium concentrations.
- The main host rocks are alaskitic granite, quartz monzonite, carbonatite, peralkaline syenite and pegmatite. An alaskitic granite is one with little or no plagioclase feldspar.
- Some well known deposits include Rossing (alaskite-hosted, Namibia) and Bancroft (pegmatite-hosted, Ontario).
- Minerals occurring in this deposit type include uraninite and uranothorite.

Alaskitic granites in Newfoundland and Labrador include the southern portion of

the Ackley Granite and the St. Lawrence Granite on the southern Burin Peninsula. Both of these granites are associated with airborne radiometric anomalies and lake sediment anomalies for uranium. Notably, volcanic rocks of the same age (related to the intrusions) are associated with uranium anomalies in lake-sediment (e.g. Grand Beach Porphyry).

URANIUM DEPOSITS IN HEMATITIC BRECCIA

- The best known deposit of this type is the huge Olympic Dam Cu-Au-U mine in Australia which accounts for approximately 40% of the known world's uranium reserves.
- This deposit is part of a broad class known as IOCG or Iron Oxide-Copper-Gold.
- Uranium grades are low, from 0.08 to 0.04% U_3O_8 .
- The primary uranium mineral is pitchblende.
- The deposit occurs in a hematite-rich granite breccia complex. Virtually all the economic copper-uranium mineralization is hosted by these hematite-rich breccias. This broad zone is surrounded by granitic breccias extending up to 3 km beyond the outer limits of the hematite-rich breccias.
- The deposit contains iron, copper, uranium, gold, silver, rare-earth elements (mainly lanthanum and cerium) and fluorine.
- Much of the brecciation occurred in near-surface eruptive environment of a crater complex during eruptions caused by boiling and explosive interaction of water (from lake, sea or groundwater) with magma.
- The Olympic Dam deposit has a distinctive geophysical signature of coincident gravity and magnetic highs.
- *Exploration companies are actively exploring in the Central Mineral Belt in Labrador for this type of deposit.*

OTHER URANIUM DEPOSIT TYPES

- Oil shales (also called alum shales or kerogen shales) in Sweden host the largest resource of uranium in Europe. The early Paleozoic black shales also contain V, Ni and Mo. Similar facies shales of the same age are preserved in the Avalon Zone of eastern Newfoundland.
- Other deposit types include quartz-pebble conglomerate, (for example, Blind River-Elliot Lake, Ontario), surficial, metasomatic and metamorphic deposits.

NEWFOUNDLAND AND LABRADOR: SIGNIFICANT DISTRICTS FOR URANIUM PROSPECTS AND DEPOSITS

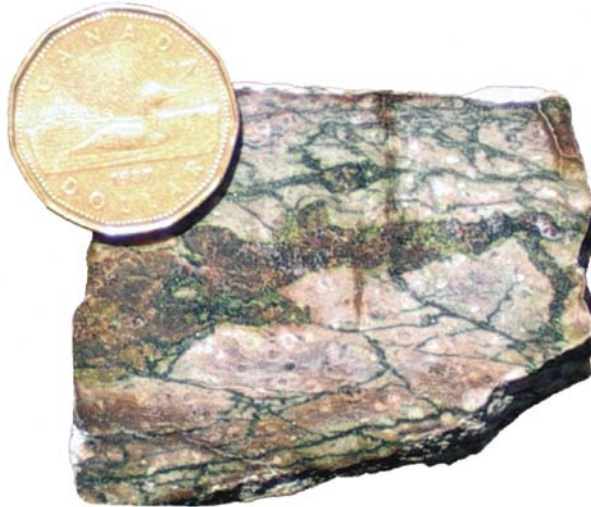
- To date, there are over 210 known occurrences of uranium in Newfoundland and Labrador. The number is increasing, due to intense exploration activity geared towards this metal.
- The most prolific area for uranium mineralization is the Central Mineral Belt (*Glossary*) of Labrador, where there are more than 140 known occurrences, to date.
- Uranium exploration is also focused on several districts in insular Newfoundland, such as the Hermitage Flexure and the Deer Lake Basin.

The following are just a few examples of deposits or significant prospect areas currently under investigation.

SOME LABRADOR EXAMPLES

KITTS AND MICHELIN

- Uranium in the form of pitchblende was first discovered near Makkovik in eastern Labrador by Brinco personnel in 1954. Follow-up work by prospector Walter Kitts in 1956 led to the discovery of the Kitts Deposit. Exploration efforts continued and in 1968, following an airborne survey, the Michelin Deposit was discovered by prospector Leslie Michelin.
- At Michelin, most of the mineralization is largely confined to a 150-200 metre thick zone of hematite alteration within a coarse-grained feldspar-porphyritic quartz-mylonite unit. Uranium occurs as disseminations of uraninite associated with strong hematization.
- At the time of writing (September 2007), a measured and indicated resource of 58 million pounds of uranium had been identified at Michelin, with an additional inferred resource of 38 million pounds of uranium (Aurora Energy Resources, press release, February 13, 2007). Michelin is the most advanced uranium project in Newfoundland and Labrador. Aurora has also discovered several new uranium prospects in the same region, including one at Jacques Lake.



A sample from the Michelin Deposit
(Courtesy of Altius Minerals Corporation)

MORAN LAKE

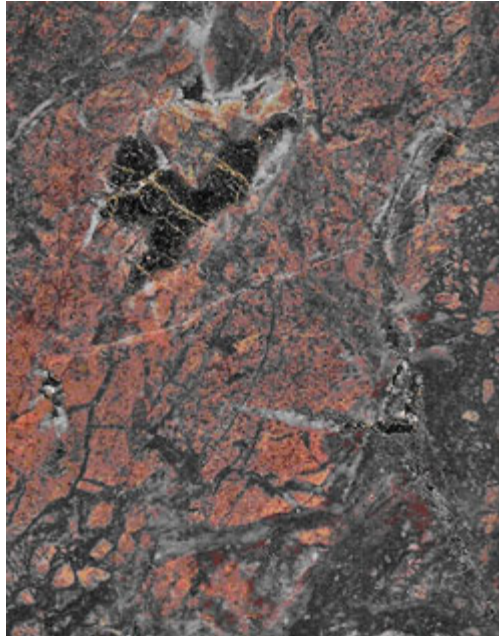
- The Moran Lake showing was discovered in 1957 by prospectors A. Montague and L. Montague, while prospecting the area for Brinex.
- Several companies explored the Moran Lake area for uranium up until the mid-1980s. Shell Canada Resources Ltd. held the property from 1976 to 1978 and reported a resource of 1,100,100 pounds U_3O_8 in the Upper "C" Zone.
- The area witnessed no further uranium exploration prior to Crosshair Exploration and Mining Corp. optioning the Moran Upper C Zone property from prospector Lew Murphy in 2004.
- The most recent independent NI 43-101 resource estimate on the C Zone gives an indicated resource of 3.19 million pounds of uranium (U_3O_8) and an additional inferred resource of 4.59 million pounds of uranium. (Crosshair Exploration and Mining, press release, July 31, 2007).

At least three styles of U mineralization occur in this part of the Central Mineral Belt.

- ***Unconformity-related:*** Uranium is associated with the unconformity between a mafic volcanic unit and a sedimentary unit. This geological environment has been compared to that of the Athabasca Basin (see above). The large radiometric anomaly known as Area 51, as well as Moran Heights, lies along this unconformity. The Moran Heights area contains over 300 uranium-bearing, sedimentary rock boulders grading up to 4.5% U_3O_8 .
- ***Hematite-breccia style:*** The Upper C Zone has uranium and copper mineralization in a style which has been interpreted as comparable with that of the Olympic Dam deposit of Australia (see Deposit Types above). The Moran Lake area lies near the

margins of an ancient continental craton, where there was much volcanic activity, forming rocks with high background uranium content. Such a setting (geologists call it an area of high heat flow) is critical to the formation of uranium-rich IOCG (iron oxide copper-gold) deposits like Olympic Dam. Chalcopyrite-bearing, hematite-rich breccias, locally with "streamed textures" at Moran Lake, closely resemble portions of the Olympic Dam breccia complex, and are an important characteristic of these deposits. The mineralization at Moran Lake lies on the flanks of a significant gravity anomaly. See Crosshair's website for further details;

<http://www.crosshairexploration.com/s/CentralMineralBelt.asp>



Mineralized breccia with hematite and chalcopyrite – Moran Lake
(Courtesy of Crosshair Exploration)

- ***Shear zone-related:*** In the southern portion of the property, near Croteau Lake, bedrock uranium was discovered late in 2005, while conducting ground follow-up. The samples were taken from the vicinity of an unconformity. Mineralization in this area occurs in shear zones.

MELODY HILL

- Radioactive boulders were first discovered in the Melody Hill area by Amok Ltee. in 1965. Follow-up work by Brinex (1978) led to the discovery of boulders which assayed from 2 - 18% U_3O_8 . This project area is currently held by Aurora Energy Resources.

SOME NEWFOUNDLAND EXAMPLES

DEER LAKE BASIN

- Uranium exploration in the Deer Lake Basin (See Glossary) started as a result of the discovery of radioactive anomalies by Hudson's Bay Oil and Gas in the mid-1970's. This was followed by the discovery of high-grade uraniferous boulders by Westfield Minerals Ltd. in 1976 and 1978.
- Historic assays from drill core from the same area gave values of up to 0.03% U_3O_8 . At Wigwam Brook, one high grade boulder assayed 11.5% U_3O_8 . Samples from trenches assayed up to 1.28% U_3O_8 .
- The radioactive bedrock and mineralized boulders found at Wigwam Brook are medium- to coarse-grained red and gray, arkosic sandstones of the Humber Falls Formation, one of the youngest members of the Deer Lake Group. The uranium occurs as pitchblende.
- Radioactivity is also associated with carbonaceous material consisting of carbon and sulphide. The primary uranium minerals are uraninite and coffinite; the secondary mineral uranophane also occurs there.
- Limestone beds within the Deer Lake Group also host uranium.
- The surrounding felsic igneous rocks (granitic and volcanic rocks) are the probable sources for the uranium which was transported and deposited in the relatively flatly-dipping sandstones of the Deer Lake Group.

FLAT BAY BROOK AREA

- Numerous anomalous boulders were found in the Lost Pond area by both Shell Canada Resources in 1980/81 and by Ucore in 2006.
- The uraniferous mineralization is hosted by a gneiss which is brecciated and fractured and has hematite and chlorite alteration. Fractures and matrix are filled or replaced by hematite, magnetite, chlorite and carbonate.
- Best uranium values in drill core were 0.432% U_3O_8 over 0.5 m. The uranium is associated with anomalous thorium and Rare Earth Elements.

HERMITAGE FLEXURE

- Uranium anomalies were first discovered in the Hermitage Flexure (See Glossary) area by Shell Canada in the mid 1960's.
- Uranium mineralization occurs mainly in Ordovician volcanic and sedimentary rocks in a region in which major faults, unconformities and locally radioactive intrusive rocks have been mapped.
- Recent drill results (Commander Resources Ltd. Press Release April 9, 2007) from the **Blue Hills Main** showing in the western Hermitage Flexure, indicate that uranium mineralization is hosted by a thick sequence of brecciated felsic volcanic rocks associated with strong silica and sericite alteration.
- The **White Bear** area, 30 km to the east of Blue Hills, has clusters of angular sedimentary boulders with uranium values up to 3.1% U_3O_8 in composite chip samples. Coarse-grained arsenopyrite is locally associated with radiometric anomalies in this area.



Secondary uranium mineral stain
White Bear River area,
Hermitage Flexure - Southern Newfoundland

- A further 3 km west, the **Doucette** target contains angular magnetite-bearing boulders with assays ranging up to 1.3% U_3O_8 .

BURIN PENINSULA

- In 1970, Radex Minerals Ltd. discovered minor uranium mineralization (Radex Showing) on the Burin Peninsula; this is the first documented occurrence of pitchblende on the island.
- The Radex Showing at Little Lawn Harbour is a Pb-Zn-U vein up to 13 cm wide

that occurs in a narrow shear at the intrusive contact between porphyry and black hornfels. A grab sample assayed 0.33% U₃O₈ (Pearse, G.H.K., 1971, Unpublished Report for Radex Minerals). The mineralization occurs as traces of pitchblende and secondary minerals associated with purple fluorite (Strong *et al.*, 1978).

BAY ST. GEORGE SUB-BASIN

- The geology of the Bay St. George Sub-Basin (see Glossary) is similar to that of the Deer Lake Basin and is being actively explored for its sediment-hosted and unconformity – related uranium potential.

HAVE PROSPECTORS BEEN SUCCESSFUL IN OPTIONING URANIUM PROPERTIES IN NEWFOUNDLAND AND LABRADOR?

YES!

- The following is a list of properties optioned in recent years to both major and junior mineral exploration companies:
- Moran Lake – Labrador
- Blue Hills – Hermitage Flexure
- East River – Northern Peninsula
- Portland Creek – Northern Peninsula
- Carrol's Hat – South Central Newfoundland
- Lawn – Southern Burin Peninsula
- Cormack – Deer Lake Basin

And others are pending as this article goes to press.

ARE URANIUM DEPOSITS A VIABLE TARGET FOR PROSPECTORS IN NEWFOUNDLAND AND LABRADOR?

The short answer is yes.

- That being said, however, prospecting for uranium is a very different process from prospecting for volcanogenic massive sulphides, where it is relatively easy to recognize the metallic minerals involved.
- The principal tools used in uranium prospecting - the scintillometer or the spectrometer - are expensive, and range in price from \$5,000 to more than \$10,000.

- Occasionally, used instruments are available for purchase; sometimes instruments can be rented or borrowed. The Geological Survey of the Newfoundland and Labrador Department of Natural Resources currently has one instrument which is available for borrowing for short periods from the Mineral Exploration Consultant.
- The Geiger-Mueller Counter is considerably less expensive than either scintillometer or spectrometer but is not as sensitive to certain types of radiation, particularly alpha rays. Care must be taken to read the specifications when purchasing one.
- And uranium assays are not cheap. At the time of writing, a rough estimate of a uranium analysis only by Delayed Neutron Count is \$28 to \$33 including crushing and milling of the sample. The Provincial Department of Natural Resources, Mines Branch, does provide limited free assaying for prospectors who have not applied for prospector grants in any given year.
- Despite these challenges, prospectors in Newfoundland and Labrador have been exploring for uranium and successfully optioning properties. The rapidly rising price for uranium has been driving the search for new deposits and junior exploration companies in Newfoundland and Labrador are quite willing to look at prospectors' properties.

URANIUM PROSPECTING METHODS

THE COUNTER:

- The essential tools in prospecting for uranium is the scintillometer, the spectrometer and the Geiger-Mueller counter. These simply measure the radioactivity of the material in question whether it is rock or soil.

BACKGROUND RADIOACTIVITY:

- It is important to be aware of the background levels of radioactivity in the area being prospected. Different rock types will have different background levels; for example, granites typically have higher average count rates than basalts.
- Ideally, once the background is known, the prospector will be able to distinguish between changes due to radioactive material and those due to difference in rock type.
- Prospectors should be aware that bogs can also be extremely radioactive as a result of leaching of uranium from nearby rock sources. Bogs in Sweden, for example, can contain up to 5% uranium (Northern Miner, April 30 – May 6, 2007).

- Fluctuation in cosmic radiation activity can also affect readings but these change quickly over time.

THE METHOD:

- The best method of prospecting for uranium with a scintillometer or spectrometer consists of simply walking over the ground with the instrument on and held at a constant distance from the ground.
- Walk slowly to give time for the counter to register narrow veins or spotty concentrations of radioactive minerals that might be significant.
- Counters have audio devices built in which allow the user to keep track of radioactivity levels in the area. Some come with earphones.

ANOMALIES:

- If you find anomalous radioactivity (at a minimum of two or three times the background) move the instrument slowly over the rock or ground surface in order to find the exact source of radioactivity.
- The anomaly may be caused by a small vein or pocket of high-grade material, a Boulder, or a larger area with sparsely distributed minerals of low radioactive content which, because of the mass effect, have caused the higher reading.
- If you get readings much higher than background, you may wish to take readings of one minute or more. Consistent increase in readings, not related to a change in rock type, indicate the need for detailed, follow-up prospecting. If radioactivity at any particular place is four or more times background, take a sample.
- If prospecting during the winter, minimal snow cover will block certain types of radiation. Therefore it is better to prospect when the ground is exposed. Bogs or water will also block the signal unless, as mentioned above, the bog is mineralized.

BOULDERS:

- Successful prospecting for uranium includes checking all boulders!
- Several important boulder fields have been discovered in the province – Melody Hill in Labrador, the Deer Lake Basin and the Hermitage Flexure are examples. Some important boulder fields remain unsourced.
- Newfoundland and Labrador were heavily glaciated during the last ice age and any

boulder of interest must be assessed based on local ice flow directions (typically there is more than one!) and possible source bedrock.

SOURCES OF RADIOMETRIC ANOMALIES

- If anomalous radioactivity is found, three elements, uranium, thorium (Th) and potassium (K), either alone or in combination, are most likely to be the cause.
- It's important to identify what is causing the radioactivity. For example, if the radioactivity is due to K, the anomaly can be disregarded in the search for uranium (but if looking for copper mineralization associated with K-feldspar-rich porphyries, then it may be very important). K is a major constituent in some granites (hence granites generally have higher background levels of radioactivity).
- Airborne radiometric maps allow you to differentiate relative levels of each of these three elements. A hand-held spectrometer will do the same.

ESTIMATING GRADES

- If a radioactive vein or bed is discovered, systematic measurements can be made across its thickness and along its strike length. Make a sketch map to record locations and readings.
- For detailed study, three-minute readings can be taken at regular intervals, about every 1.5 metres, along the vein or bed. Some authorities suggest taking samples for geochemical assay every 10 to 15 metres, as a start.
- Results of your assays can be used to calculate the uranium content at the locations in the outcrop where samples were not taken. Keep the instrument in the same position relative to the mineralization to standardize the readings.

RADIOMETRIC ASSAYING

- The only completely reliable way to determine the exact uranium or thorium content of a sample is to obtain a geochemical analysis. This determines either or both elements directly and is not affected by the proportions of each or its daughter products present (Glossary).
- Analyses are expressed in terms of uranium oxide, U_3O_8 , or thorium oxide, ThO_2 .

TRACK ETCH SURVEYS

- These are generally conducted by mineral exploration companies but it is useful for prospectors to be knowledgeable about the method.

- Track etch surveys are designed to locate anomalous concentrations of Radon gas. Radon is one of the decay products of the breakdown of uranium (also called a daughter product).
- Radon gas detectors (Track Etch Cups) placed in the ground for a period of time can be used to detect buried uranium mineralization.
- The Track Etch cups were effective in detecting buried radioactivity that was subsequently confirmed during drilling by Aurora Energy on their Jacques Lake Project in Labrador.

WATER SAMPLING

- Water samples can be collected from streams, seepage zones and small ponds. This type of geochemical survey has been found to be highly effective at providing evidence of subcropping uranium mineralization in other areas of eastern Canada.

WHERE DO I START MY SEARCH FOR URANIUM IN NEWFOUNDLAND AND LABRADOR?

- Uranium exploration uses most techniques employed in the search for all other minerals, as well as some unique to uranium.
- Geology, remote sensing, geophysics, geochemistry, geobotany and exploration drilling can all be used at the same time. Geological mapping and basin analysis helps in the choice of geological environments which are potentially favourable for uranium occurrences.
- Geochemical surveys of stream and lake sediments are commonly used to detect broad uranium anomalies and provide information on sub-surface environments. Results from a government lake sediment sampling program in the 1980's have been very successful in Newfoundland and Labrador in identifying areas of interest for uranium exploration.
- Many lake sediment uranium anomalies defined by this survey have been staked by prospectors and subsequently optioned to exploration companies. Stream and lake sediment surveys enable the systematic sampling of the uranium content of bedrock terrain over large areas and in any kind of vegetative and soil cover.
- Till uranium anomalies are also important. Till surveys have been carried out in selected areas of the province; check the uranium results from these.

- Airborne gamma-ray spectrometry surveys are commonly used by companies in Newfoundland and Labrador to define multiple target areas for ground follow-up. A good website to start a search would be - http://gdr.nrcan.gc.ca/gamma/index_e.php This website is the storehouse for free airborne radioactivity data collected by Natural Resources Canada.
- Satellite imagery and aerial photography may be used in the initial stages of your prospecting to locate faults, for example.

Here are a few tips to consider as you plan your prospecting for uranium in Newfoundland and Labrador:

- Check the Resource Atlas (<http://gis.geosurv.gov.nl.ca/>) on the Geological Survey of Newfoundland and Labrador website and research the results of the lake sediment surveys; these cover the entire province.
- Much historical work has been carried out by mineral exploration companies. Detailed results of this work are readily available from assessment files located at the Geological Survey. Many of these are also available online and can be downloaded from the Survey's website.
- There is a mine waiting to be discovered in these assessment files!
- Use available geophysical data to help define target areas – for example, look for distinct gravity anomalies like that at Crosshair's C-Zone in Labrador.
- Read the press releases from companies actively developing prospects (for example, Crosshair Exploration and Mining Corp. and Aurora Energy Resources in Labrador and Commander Resources Ltd. in Southern Newfoundland).
- Find out the types of rocks that host the mineralization in these prospects and look for that rock type in your own area.
- Check the geology of the area of interest – look for rock types such as felsic volcanics or peralkaline granites, for example.
- Look for unconformities particularly where they intersect fault structures. If the rock type is sedimentary, see if there is any record of plant remains in it or if there are grey beds present.
- Call, email or drop by the Geological Survey in St. John's. Contacting the Matty Mitchell Prospectors Resource Room or the Mineral Exploration Consultant's office at the Geological Survey is always a good starting plan.

URANIUM MINERALS

- URANINITE

Uraninite is the primary ore mineral of uranium. It is a black to brownish black mineral which rarely has good crystal form. The chemical composition is basically UO_2 ; however, the component UO_3 is also invariably present and the chemical formula is generally written as U_3O_8 . It is also an ore of radium, which is found in trace amounts. Helium was first discovered on the earth in samples of uraninite. Radium and helium are found in uraninite because they are daughter products (Glossary) of uranium's decay process.

- PITCHBLLENDE

A variety of uraninite, *pitchblende* is a combination of mostly uraninite and some other minerals. It is generally softer and less dense and usually botryoidal or earthy in appearance. Deposition of pitchblende is usually accompanied by strong alteration of the wall rock along the mineralized veins. The presence of hematite extending from the pitchblende a few inches to a few feet into the wall rock is the most characteristic feature. The formation of hematite has occurred in all of the major pitchblende vein deposits and in many minor deposits. Other wall-rock alteration features often associated with pitchblende deposition are the formation of kaolin, chlorite, sericite, and silica minerals.



Pitchblende

- COFFINITE

Coffinite is a silicate mineral $[\text{U}(\text{SiO}_4)_{1-x}(\text{OH})_{4x}]$. It is a glass-like black material, dark brown or pale-brown in color, possibly with grayish black streaks. It occurs as small crystals, and in colloform to botryoidal incrustations in which the crystals are fibrous and

radiate from a centre. In the Colorado Plateau, coffinite occurs in black, unoxidized uranium – vanadium deposits where it replaces organic material in sandstone. It also occurs in other sedimentary and hydrothermal vein uranium deposits. Uraninite, thorite, pyrite, clay minerals and amorphous organic matter may be associated with coffinite.

- **AUTUNITE**

Autunite is a hydrated calcium and uranium phosphate [$\text{Ca}(\text{UO}_2)_2(\text{PO}_4)_2 \cdot 10\text{--}12\text{H}_2\text{O}$], and is an ore of uranium. It forms translucent to transparent, yellow to pale-green crystals, scaly masses, or crusts in hydrothermal veins and pegmatites, where it occurs as an alteration product of uraninite.

- **TORBERNITE**

Torbernite is a hydrous copper uranium phosphate ($\text{CuO} \cdot 2\text{UO}_3 \cdot \text{P}_2\text{O}_5 \cdot n\text{H}_2\text{O}$). It has a bright emerald green color, a pearly luster, hardness of 2-2.5 (about the same as a fingernail), and specific gravity of about 3.5 (a little heavier than quartz). Torbernite crystals are flat, square and translucent and usually fluoresce with a faint green color. Torbernite is one of the most common of the secondary uranium minerals that are found associated with primary deposits where oxidation has occurred and are common in nearly all such deposits except pegmatites, which usually do not contain the necessary copper to form them. Torbernite occurs with other secondary uranium minerals in oxidized secondary deposits whenever copper has been present in the depositing solutions or surrounding rocks. Torbernite is commonly associated with autunite. The principal non uranium minerals associated with torbernite are the clay minerals, limonite, quartz, pyrite, and the copper sulfides and carbonates.

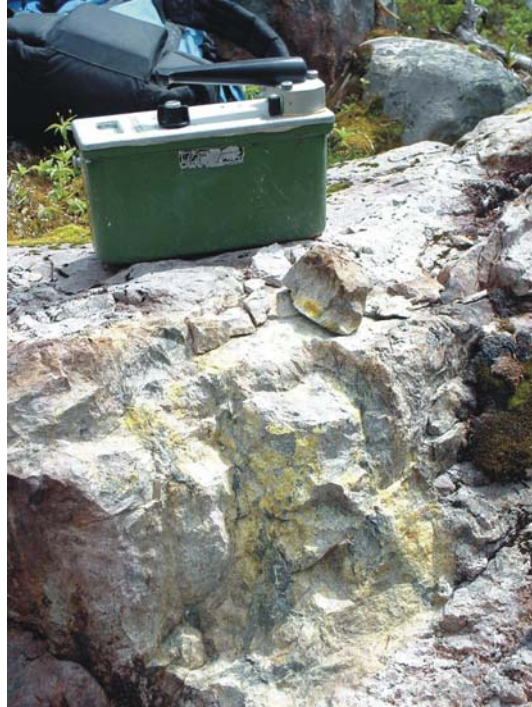
- **CARNOTITE**

Carnotite [$\text{K}_2\text{O}_2\text{UO}_3\text{V}_2\text{O}_5 \cdot n\text{H}_2\text{O}$] a potassium uranium vanadate, is the most important of the secondary uranium ore minerals, having provided possibly 90 percent of the uranium production from secondary deposits. It is a lemon-yellow mineral with an earthy luster, a yellow streak, and a specific gravity of about 4. It occurs most commonly in soft, powdery aggregates of finely crystalline material or in thin films or stains on rocks or other minerals. It can be easily scratched with the fingernail. Carnotite is not fluorescent. One important association of carnotite has an important bearing on prospecting for uranium deposits; in many carnotite deposits, the carnotite is intimately associated with silicified or carbonized fossil wood and a variety of coal-like and asphaltic materials, all of which are good indicator substances for carnotite. In the Temple Mountain district, Utah, carnotite occurs in sandstones so impregnated with asphaltic material that the deposits are considered a special type and are called uraniferous asphaltite deposits. Elsewhere, fossil wood in the form of logs or accumulations of branches and twigs, locally called trash pockets, is the most common type of associated organic material.

- **URANOPHANE**

Uranophane [$\text{CaO} \cdot 2\text{UO}_3 \cdot 2\text{SiO}_2 \cdot 6\text{H}_2\text{O}$] is a hydrated calcium uranium silicate containing silica in place of the phosphate of autunite. It is brightly coloured in varying shades of yellow and may occur as stains or coatings without apparent crystal form or as finely fibrous or radiating crystal aggregates. The origin and occurrence of uranophane are very

similar to autunite and torbernite. At least two of these three minerals are almost always found together, in proportions varying with availability of copper and phosphorus; uranophane is predominant where these two elements are scarce or absent. It is the most common secondary uranium mineral found in the noncommercial deposits in granite and pegmatites in the eastern United States.



Scintillometer and secondary uranium minerals
Burnt Emben Prospect, Labrador
(courtesy of Altius Minerals Inc.).

- **DAVIDITE**

Davidite is a rare earth-iron-titanium oxide and is a dark brown to black mineral with a glassy to sub-metallic luster. It occurs most commonly in angular, irregular masses, sometimes with crystal outlines. When exposed to weathering, a thin yellow-green coating of carnotite or tyuyamunite may form on its surface and this provides an easy means of tentative identification in the field. Davidite is deposited in hydrothermal veins, which have many of the characteristics of pegmatites. The associated vein minerals are ilmenite, hematite, biotite, mica, quartz, calcite, and pink feldspar.

ADDITIONAL NOTES OF INTEREST FROM VARIOUS SOURCES

CONVERSION FACTORS FOR URANIUM:

- 1% U_3O_8 = 10 000 ppm
- 0.1% U_3O_8 = 1000 ppm
- 0.01% U_3O_8 = 100 ppm
- Assays for uranium are usually returned as percent U_3O_8 .
- To convert $\text{U}_3\text{O}_8\%$ to uranium %, multiply by 0.848;
therefore 1% U_3O_8 = 0.848% uranium
- To convert uranium % to $\text{U}_3\text{O}_8\%$, multiply by 1.1792;
therefore 1 % uranium = 1.1792% U_3O_8
- 1 metric tonne = 2204.622 pounds;
therefore 1% U_3O_8 = 22.046 pounds.
- 1 pound U_3O_8 = 0.4536 kg U_3O_8 = 0.3846 kg U

WHAT IS RADIOACTIVITY?

You should acquire some basic understanding of the meaning of radioactivity, both for successful prospecting and for good health. What follows is a short primer on radioactivity. You are strongly encouraged to learn more about working safely with radioactive material.

RADIOACTIVE DECAY

- Atoms are the basic building blocks of matter. Some atoms are stable, but others have excess internal energy and are continually changing towards a more stable form. This is called **radioactive decay**.
- Atoms of the elements potassium, thorium and uranium all undergo radioactive decay.
- Elements exist in the form of atoms with several nuclei of different sizes called isotopes. Some isotopes are radioactive, most are not.
- **Radioactivity** arises naturally from the decay of particular isotopes.
- Uranium has 16 isotopes and all of them are unstable and radioactive.

RADIATION

- When radioactive decay occurs, radiation is given off from the nucleus of the atom.
- Radiation occurs as high-energy rays and particles.
- When prospecting and handling rocks or core samples, it is important to be aware of three kinds of radiation: *alpha*, *beta* and *gamma*. Different types of radiation require different forms of protection.

Alpha particles.

- These have little penetrating power and can be stopped by the first layer of skin or a sheet of paper. However, if alpha sources are taken into the body (for example by breathing or swallowing radioactive dust) alpha particles can affect the body's cells. Therefore, when taking samples, particularly channel samples, where one uses a rock saw, take extra care in order not to ingest the dust; wear a face mask which extracts fine particles.

Beta particles.

- These particles are much smaller than alpha particles and can penetrate up to 1 to 2 centimetres of water or human flesh. They can be stopped by a sheet of aluminium a few millimetres thick.

Gamma rays.

- Unlike light, gamma rays have great penetrating power and can pass through the human body. Thick barriers of concrete, lead or water are used as protection from them.

Background radiation

- Background radiation is that which is naturally present in our environment; levels of this can vary greatly. People living in areas underlain by granite, for example, receive more terrestrial (source is in or on the earth) radiation than others, while people living or working at high altitudes or who are regular air commuters receive more cosmic (source is outer space) radiation. Much of our natural exposure is due to radon, a gas which seeps from the earth's crust and is present in the air we breathe. Measuring radon is one way to explore for U (see above – Uranium Prospecting Methods).

Safe Handling of Radioactive Minerals

- A starting point to learn more about working with radioactive rocks could be Cameco's website at http://www.cameco.com/uranium_101/uranium_sask/radiation_protection.php and that of the Canadian Nuclear Workers Council at <http://www.cnwc-cctn.ca/factrecent.html> or <http://www.nuclearsafety.gc.ca>

URANIUM: FROM ORE TO NUCLEAR FUEL

MINING

- Uranium ore is usually mined from either surface (open pit) or underground mines, depending on the depth of the ore body. Some mines in Australia, USA and Kazakhstan use in situ leaching (ISL) to extract the uranium from a porous underground ore body in situ and bring it to the surface in solution. In South Australia, the Olympic Dam deposit is mined underground; this mine produces copper, gold, silver and iron. The newest Canadian mines are underground.

MILLING

- The uranium ore is sent to a mill where the ore is crushed and ground to a fine slurry which is leached in sulfuric acid to allow the separation of uranium from the waste rock. It is then recovered from solution and precipitated as uranium oxide (U_3O_8) concentrate known as "yellowcake", ammonium diuranate. This is then "calcined" (heated) to produce Uranium Oxide, a dark grey-green powder that assays better than 99 % U_3O_8 . This is the form in which uranium is sold.

CONVERSION

- Uranium has to be in the form of a gas before it can be enriched. The U_3O_8 yellowcake is therefore converted into the gas uranium hexafluoride (UF_6) at a conversion plant.

ENRICHMENT

The vast majority of all nuclear power reactors in operation and under construction require 'enriched' uranium fuel in which the proportion of the U^{235} isotope has been raised from the natural level of 0.7% to 3 to 5 %. Some reactors (a minority), notably the Canadian CANDU reactors, do not require uranium to be enriched.

FUEL FABRICATION

- Enriched UF_6 is transported to a fuel fabrication plant where it is converted to uranium dioxide (UO_2) powder and pressed into small pellets. These pellets are inserted into thin tubes, usually of a zirconium alloy (zircalloy) or stainless steel, to form fuel rods. The rods are then sealed and assembled in clusters to form fuel assemblies for use in the core of the nuclear reactor. Some 25 - 27 tonnes of fresh fuel are required each year for a 1000 MW reactor.

SOME URANIUM TRIVIA

- Uranium is the heaviest of all naturally occurring elements.
- Uranium was discovered in 1789 by Martin Klaproth, a German chemist, in the mineral called pitchblende.
- Uranium was named after the planet Uranus.
- Uranium is 18.7 times as dense as water
- Uranium's slow radioactive decay provides the main source of heat inside the earth, causing convection which drives plate tectonics.
- Most of the radioactivity associated with uranium in nature is in fact due to its daughter products which are the other minerals derived from it by radioactive decay processes, and which are left behind in mining and milling.
- The high density of uranium means that it can be used as counterweights in yacht keels and in aircraft control surfaces and for radiation shielding.
- The melting point of U is 1132°C.
- Uranium occurs in seawater (about 3 ppb) and could be recovered from the oceans if prices rose significantly.
- Uranium occurs naturally as a mix of two main isotopes - U^{238} (99.28%) and U^{235} (0.71%)
- In the 1800s, the only use for uranium was to colour glass and ceramics. Glassmakers used uranium to produce a yellow-green colour. Ceramic glazes, ranging from orange to bright red, were used on household crockery and architectural decorations.
- Another radioactive element, produced in minute quantities from the decay of uranium, is radium. It was thought (quite erroneously!) to have health-giving properties and products containing radium, such as radioactive earth, went on sale. It was used in tonics (!) and also in paint on clocks and watches to make them luminous.

GLOSSARY

- **BASINS: DEER LAKE AND BAY ST. GEORGE**

Carboniferous (see below) rocks occur in two main regions in Newfoundland and Labrador – the Deer Lake and Bay St. George basins. Carboniferous sedimentary rocks were deposited in lowlands or depressions (hence the term basins) located along major faults, elongated parallel to the fault zone. They are also called grabens or rift valleys. Large tropical lakes developed in these basins and are similar to the modern day lakes in the Great Rift Valley of East Africa.

There are a number of occurrences of economic minerals (term used in the broad sense to include oil) in these basins. These include gold, copper, zinc, lead, silver and uranium. Thin, uneconomic coal seams occur in both basins as well as oil shales which contain abundant kerogen or solid hydrocarbons. Natural gas and oil also occur in the Bay St. George Basin. Deposits of evaporites also are known from this area and some have been mined. These include gypsum ($\text{CaSO}_4 \cdot \text{H}_2\text{O}$) near Flat Bay, salt (Halite = NaCl) and potassic salts (Sylvite = KCl) near Fischell's Brook, Barite (BaSO_4) and Celestite (SrSO_4) near Boswarlos.

- **CALDERA**

A caldera is a large cauldron formed at the top of a volcano by the collapse of land following a volcanic eruption.

- **CARBONIFEROUS PERIOD**

This geological age lasted from 350 to 280 million years ago and takes its name from the fact that enormous deposits of coal (carbon) were formed then.

- **CATACLASIS**

This term refers to rocks which have been deformed in a brittle way so that individual crystals are cracked or broken.

- **CENTRAL MINERAL BELT**

The Central Mineral Belt (CMB) of Labrador is a 260 km by 75 km region in central and coastal Labrador, occupying the area stretching from Cape Makkovik to roughly Kanairiktok Bay and then west-southwest almost to the Smallwood Reservoir and then east to Nipisish Lake and then northeast to the coast at the Adlavik Islands. The rocks in the CMB range from 1.3 billion to 2 billion years old and include volcanic, sedimentary and intrusive igneous types. A wide variety of metallic mineralization including uranium, copper, molybdenum, nickel, platinum group elements, lead, zinc, niobium, beryllium and rare earth elements is known from the Central Mineral Belt. Most notably, this belt is one of the most prolific areas for uranium in Canada.

- **DAUGHTER PRODUCTS**

These are the products of the radioactive decay of uranium, for example, radon. As it, too, is radioactive, radon will have daughter products. This process constantly repeats until the element lead is reached; lead is stable and therefore has no daughter products.

- **FELSIC ROCKS**

Felsic rocks are those igneous rocks rich in feldspar and quartz, such as granite and (quartz-feldspar) porphyries. These generally light-coloured rocks are also referred to as acid because they are typically rich in SiO_2 .

- **HERMITAGE FLEXURE**

The Hermitage Flexure refers to an arcuate distribution of rocks in South Central Newfoundland.

- **MAFIC ROCKS**

Mafic rocks are those rocks rich in the ferromagnesian minerals such as biotite, hornblende and pyroxene and are generally dark in colour.

- **MYLONITE**

A mylonite is a deformed rock produced by movement, where different blocks of rock slide past each other. If this sounds like a fault, it is! However, the slippage takes place at great depths in the earth's crust where the rocks behave like putty; similar movement close to the earth's surface where the rocks are brittle would produce a fault with fault breccia etc. A mylonite zone can be much wider than brittle fault zones.

- **UNCONFORMITY**

An unconformity is a surface or geological contact that typically exists between different rock strata; this surface or contact represents a missing interval in the geologic record of time. The simplest example is indicated by folded rocks below the surface and flat-lying strata above; in this case, the unconformity represents a period of time when the older rocks (below) were subjected to deformation, then uplift and erosion followed by sediments being deposited over the eroded surface.

Also see www.santoy.ca/s/UraniumFacts.asp for a comprehensive glossary on uranium and

<http://www.uraniumminerals.com/Notes/Glossary.htm> - this site has an excellent general geological glossary.

BIBLIOGRAPHY, AND SOME SUGGESTED READING

In addition to material listed below, general papers on uranium are available for reading at the Matty Mitchell Prospector's Resource Room. This material includes course notes from two recent workshops on uranium deposits.

Lambert, I., McKay, A., and Miezeitis, Y., 1996: *Australia's uranium resources: trends, global comparisons and new developments*, Bureau of Resource Sciences, Canberra, with their later paper: *Australia's Uranium Resources and Production in a World Context*, ANA Conference October 2001.

Wilton, D.H.C. and Cunningham-Dunlop, I., 2006: *The exploration activities of Aurora Energy Inc. on the CMB uranium property, Labrador, Canada, during the period June 2005 to December 2005*, Form 43-101f1, Technical Report. Prepared for: Aurora Energy Inc., Suite 1640, 1066 West Hastings Street, Vancouver, BC, V6E 3X1

Australian IMM, *Field Geologist's Manual*, 1989.

There is a vast amount of material on the internet on uranium – the following sites were reference sources for some of the content in this article.

<http://www.dangerouslaboratories.org/rprospect.html>
<http://www.dangerouslaboratories.org/radore.html>

UIC Educational Resource Papers
Uranium Information Centre, Melbourne, Australia:
<http://www.uic.com.au/uran.htm>
<http://www.uic.com.au/uicchem.htm>
<http://www.uic.com.au/wast.htm>
<http://www.uic.com.au/whyu.htm>
<http://www.uic.com.au/nfc.htm>
<http://www.uic.com.au/ral.htm>
<http://www.uic.com.au/nip34.htm>

Sources of information for fuel comparison

<http://www.euronuclear.org/info/encyclopedia/f/fuelcomparison.htm>
<http://www.nuclear tourist.com/basics/reasons1.htm>

Safe handling of radioactive minerals

<http://www.uraniumminerals.com/Notes/Handling.htm>
<http://www.nuclearsafety.gc.ca>

Also see:

<http://www.gov.sk.ca>

<http://www.labour.gov.sk.ca/safety/>

<http://www.whscc.nl.ca>

<http://www.uic.com.au>

<http://www.cna.ca>

<http://www.cns-snc.ca>

<http://www.nei.org>

<http://www.world-nuclear.org>

<http://www.geigercounters.com/>

GOOD LUCK WITH YOUR PROSPECTING!