CANADA

DEPARTMENT OF MINES AND TECHNICAL SURVEYS

GEOLOGICAL SURVEY OF CANADA

RADIOACTIVITY DIVISION

PROSPECTING FOR URANIUM IN CANADA

BY

Officers of the Radioactivity Division

EDMOND CLOUTIER, C.M.G., O.A., D.S.P.
QUEEN'S PRINTER AND CONTROLLER OF STATIONERY
OTTAWA, 1952

Price, 50 cents

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As thorium is not used at present for atomic energy purposes, emphasis has been placed on the search for uranium minerals, and more particularly for pitchblende vein deposits, which are the present chief source of uranium.

The subject matter covers, first, general information necessary for all uranium prospectors, including summaries of the requirements of the Atomic Energy Control Board in regard to reporting assays, discoveries, and exploratory work and its results. Regions favourable for prospecting are then outlined, and the nature and distribution of Canadian deposits are discussed. The various methods and instruments for detecting radioactivity and for testing for uranium are described, and their application to prospecting is considered in some detail. Radioactive minerals and their associations as found in Canada are described and tabulated, with brief references to others important in foreign countries. A concluding section deals with sampling and with the size and grade of pitchblende deposits in relation to economic possibilities, and contains some suggestions for prospectors working in remote areas.

Included as appendices are extracts relating to government purchasing policy for uranium, and prospecting and mining, from the original sources, and a copy of an Exploration Permit as issued by the Atomic Energy Control Board.

H. V. ELLSWORTH,
Chief, Radioactivity Division,
Geological Survey of Canada

OTTAWA, July 10, 1951

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URANIUM PROSPECTING IN CANADA

GENERAL INFORMATION NECESSARY FOR THE PROSPECTOR

The purpose here is to present a condensed review of information essential to the uranium prospector in Canada. Many of the topics touched on are discussed in more detail in later sections of the booklet.

Prospecting for uranium and thorium differs from other types of mineral prospecting in one important respect: due to the development of portable Geiger counters and scintillometers it is not at all necessary that the uranium prospector should be able to indentify radioactive minerals or even have any knowledge of mineralogy. It is desirable that he should have some slight knowledge of elementary geology, easily acquired by a little reading and observation, so that he can recognize disturbances in the rocks such as veins, faults, shear zones, intrusions of one rock into another, and so on, and it would also be useful to be able to distinguish some of the main types of rocks, but even this knowledge is not absolutely necessary. A person with no knowledge of geology but equipped with a Geiger counter or scintillometer could systematically traverse favourable prospecting areas, listening for indications from his instrument of the presence of radioactive minerals, or he could test all rock outcrops encountered, old mines, dumps, prospecting pits, etc., in a mining area. Having found a deposit that his instrument shows to be considerably more radioactive than the ordinary rocks of the area, he may send samples for free quantititave radioactivity tests and mineral identifications to the federal or provincial mines departments.

Thus, the amateur searching for uranium by means of modern equipment has a chance of finding uranium deposits even though lacking the expert knowledge and experience of the professional prospector.

Anyone can easily learn to operate Geiger counters and scintillometers. Perhaps the most important qualifications for a uranium prospector are: that he should have one of these instruments, should enjoy outdoor life, and should have some knowledge of bush-craft.

WHO MAY PROSPECT

Any resident of Canada may search for radioactive mineral deposits without obtaining a special permit. Restrictions in effect during the war have been removed, and prospecting and staking claims for uranium and thorium minerals are now on exactly the same basis as for the commoner minerals. The finder of a deposit of uranium or thorium minerals may sell, develop, mine, or otherwise dispose of his claim or claims just as in the case of other minerals.

IMPORTING PROSPECTING EQUIPMENT

Citizens of the United States and other countries admitted to Canada have the same prospecting and staking privileges as Canadian citizens. Prospectors engaged in exploratory or discovery work in search of minerals, oil, etc., are regarded by the National Revenue Department as manufacturers or producers, and are permitted to purchase or import Geiger counters, ultra-violet lamps, scintilloscopes, electroscopes, and the like, or their parts, without payment of duties or sales tax by certifying on their purchase orders or customs import entries, as the case may be, that they are to be used directly in the process of manufacture or production of goods and will not be resold in Canada. Prospectors' personal effects enter duty and sales tax free, but "tools of the trade" (apart from those specified) are dutiable at a valuation based on allowance for use and depreciation. Inquiries in regard to customs duties and sales tax on goods entering Canada should be addressed to the Deputy Minister of Customs and Excise, Department of National Revenue, Ottawa, Canada.

STAKING CLAIMS FOR URANIUM

Staking of mineral claims for uranium and thorium minerals or any other minerals is subject to the mining laws of the province or territory in which the prospecting is done.

In order to stake claims for uranium or other minerals, a prospector's licence must be obtained. These are issued by the various provincial governments for the provinces and by the Department of Resources and Development, Ottawa, for the territories. Information in regard to mining laws, prospectors' licences, staking claims, etc., may be obtained on application as below:

British Columbia—Deputy Minister of Mines, Mines Department, Victoria, B.C.
Alberta—Deputy Minister of Lands and Mines, Department of Lands and Mines, Edmonton, Alberta.
Saskatchewan—Director of Mineral Resources, Department of Natural Resources and Industrial Development, Regina, Saskatchewan.
Manitoba—Director of Mines, Department of Mines and Natural Resources, Winnipeg, Manitoba.
Yukon and Northwest Territories—Director, Development Services Branch, Department of Resources and Development, Ottawa.
Ontario—Deputy Minister, Department of Mines, Toronto, Ontario.
Quebec—Deputy Minister, Department of Mines, Quebec, Que.
New Brunswick—Deputy Minister, Department of Lands and Mines, Fredericton, N.B.
Nova Scotia—Deputy Minister, Department of Mines, Halifax, N.S.
Prince Edward Island—Deputy Provincial Secretary, Provincial Government Offices, Charlottetown, Prince Edward Island.
Newfoundland—Director of Crown Lands and Surveys, Department of Natural Resources, St. John's, Newfoundland.

FEDERAL GOVERNMENT SUPERVISION

Only after a deposit of radioactive minerals has been found is some degree of supervision exercised by the federal government. This supervision has been designed to cause as little inconvenience as possible to those wishing to develop deposits of radioactive minerals while at the same time enabling the Government to secure information as to the uranium resources of the country and to control the disposal of any important quantities of uranium or thorium minerals produced. This is effected through: the Atomic Energy Control Act, 1946; the regulations of the Atomic Energy Control Board; and orders issued by the Atomic Energy Control Board.

The Atomic Energy Control Act, 1946, established the Atomic Energy Control Board to deal with the practical aspects of atomic energy. Regulations and orders of the Board have the status of laws, and penalties may be imposed upon anyone convicted of failure to observe the requirements. Extracts from the Atomic Energy Control Act, 1946, and Regulations of the Atomic Energy Control Board, so far as they relate to prospecting, exploration, and mining, are quoted in appendices at the back of this booklet. Orders and press releases of the Atomic Energy Control Board are given in full in other appendices. So far as they affect the prospector, the regulations, orders, and press releases may be summarized as follows.

REPORTING REQUIRED BY THE ATOMIC ENERGY CONTROL BOARD

The Director, Geological Survey of Canada, acts as agent for the Atomic Energy Control Board in collecting and filing information required in regard to: (1) the results of assays or analyses made for uranium and thorium; (2) the localities from which samples analysed were obtained and the location of new finds; (3) the progress of exploratory work and its results on properties operating under Atomic Energy Control Board orders or exploration permits.[1]

Prospectors and those developing radioactive mineral deposits are responsible for supplying the information indicated by the section in heavy type below.

All assays or analyses[2] of materials showing a content of more than 0·05 per cent uranium or thorium element must be reported by the analyst, together with the name and address of the sender of the sample, to the Director, Geological Survey of Canada, Ottawa, Ontario. If the source of the material analysed is known, this must also be reported, *otherwise the sender of the sample is required to promptly inform the Director, Geological Survey of Canada, of the location of the deposit from which the sample assayed was taken and of the size and nature of the deposit so far as can be ascertained. A prospector who without having assays made, has reason to believe or suspect (as from high Geiger counter or scintillometer readings or identification of pitchblende in the deposit) that his discovery contains material of more than 0·05 per cent uranium or thorium content must also promptly report the location of his discovery to the Director of the Geological Survey of Canada, Ottawa.*

On request, time will be allowed for staking claims before reporting locality information.

The discoverer of a radioactive mineral deposit may make public his find *after* informing the Director, Geological Survey of Canada, of the discovery, but

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[1] Up to December 31, 1950, authorizations to explore radioactive mineral deposits by drilling, surface work, test pitting, and underground work were issued as orders of the Atomic Energy Control Board. They are now called exploration permits. A copy of an exploration permit is given in an appendix at the back of this booklet.

[2] By "assays or analyses" is meant any quantitative estimate or determination of uranium or thorium, whether made by chemical, spectrographic, radiometric, or other methods.

information supplied to the Director, as to analyses or localities, is held as confidential until released by those concerned, either by publication or by request.

Uranium or thorium assays made in the United States of America or other countries on materials from Canadian deposits must be reported to the Director, Geological Survey of Canada, by the senders of the samples.

APPLYING FOR EXPLORATION PERMITS

Anyone wishing to explore a radioactive mineral deposit by diamond drilling, surface work, test pitting, or preliminary underground work, or to ship large bulk samples for test is required to obtain an exploration permit from the Atomic Energy Control Board. Such permits are issued free of charge on application to the Secretary, Atomic Energy Control Board, Ottawa, and on supplying him with the following information:

1. The full name and address of the applicant and, if the applicant is a corporation, the manner of its incorporation and the names and addresses of all of its directors and officers;
2. The name and address of the person who will be in charge of the work on the ground;
3. A complete and accurate description by claim number, district and province, or by lot and concession number, township, county or district, and province of all property intended to be covered by the order;
4. A general description of the work contemplated; and
5. The names and addresses of all persons to whom it is proposed to send samples for assay and analysis or for mill tests.

Exploration permits specify that monthly reports shall be sent in duplicate to the Director, Geological Survey of Canada, Ottawa, showing fully and accurately the work done and the results of exploration of the property up to the end of the preceding month. The information required includes a summary report and copies of all diamond drill-hole logs, plans, reports of analyses, radiometric tests, and any other pertinent information.

TAKING SMALL SAMPLES FOR ANALYSIS OR DISPLAY

No permit is necessary to authorize taking small prospector's samples, such as hand samples, channel samples, or other such samples as are usually taken for analysis or display purposes and weighing no more than 5 or 10 pounds each. No amount of radioactive mineral-bearing material greater than is required for analysis or display purposes may be removed from a deposit without permission from the Atomic Energy Control Board.

DISPOSAL OF ORES AND CONCENTRATES

Ores or concentrates containing more than 0·05 per cent uranium or thorium may not be removed from the place of origin or sold to anyone except the Government without permission from the Atomic Energy Control Board.

GOVERNMENT PURCHASE OF ORES OR CONCENTRATES

Eldorado Mining and Refining (1944) Limited, as agent for the Government, will purchase acceptable ores or concentrates at prices fixed by the Government and guaranteed for a term of years. Acceptable ores or concentrates are defined as containing a minimum of 10 per cent of uranium oxide (U_3O_8), but under special circumstances consideration may be given to payment of a higher price or to acceptance of ores or concentrates of lower grade.

The maximum price that will be paid per pound of U_3O_8 contained in acceptable ores or concentrates is $7.25 for the first 3 years of production. Details of the schedule of prices will be found in Appendix I at the back of this booklet. Special inquiries in regard to price arrangements or other matters in connection with marketing ores or concentrates, etc., should be addressed to the President, Eldorado Mining and Refining (1944) Limited, Ottawa, Canada.

Thorium Ores Not Purchased. The Government does not purchase thorium ores, nor is any allowance made for a thorium content in purchasing uranium concentrates nor for the radium content of uranium minerals, but arrangements will be made for valuing any other constituents that can be recovered commercially.

Ores of metals or elements other than uranium or thorium carrying less than 0·05 per cent uranium or thorium are not subject to Atomic Energy Control Board orders and may be dealt with without regard to the uranium or thorium content. In doubtful cases, the Secretary, Atomic Energy Control Board, Ottawa, should be consulted.

SPECIMENS FOR SCIENTIFIC PURPOSES

Specimens of uranium-bearing or thorium-bearing minerals for mineralogical or other scientific purposes may be sold, presented, or exchanged within Canada, subject to the regulation that such dealings do not involve during any calendar year a total of more than 10 kilograms (22 pounds) of contained uranium or thorium element, and that any other regulations that may apply are observed. In doubtful cases, the Secretary, Atomic Energy Control Board, Ottawa, should be consulted.

FEDERAL NON-PARTICIPATION IN PRIVATE PROSPECTING AND DEVELOPMENT

No cash reward for the finding of radioactive mineral deposits is offered by the federal government or by any of the provincial governments. Earlier laws of Ontario and British Columbia providing a cash payment for the finding of radium ore in commercial quantity have lapsed or been repealed.

The Government does not ordinarily buy uranium-bearing deposits or assist financially in their development. Eldorado Mining and Refining (1944) Limited, the Crown company, as agent of the Government, however, has the same privileges as other companies, and may buy or sell uranium-bearing properties if it so desires.

Neither the Geological Survey of Canada nor other federal governmental organization assists prospectors in the search for radioactive mineral deposits by financial aid or by loaning or renting Geiger counters or other equipment.

PROVINCIAL AID TO PROSPECTORS

The provinces of British Columbia and Saskatchewan assist prospectors in various ways. In British Columbia, the "Prospectors' Grub-Stake Act", as amended in March 1944, provides for grub-stakes of up to $300 to prospectors, plus an additional amount of as much as $200 if travelling expenses are to be paid. Saskatchewan assists in other ways. Inquiries should be addressed to: the Deputy Minister, Department of Mines, Victoria, B.C., and the Director of Natural Resources, Department of Natural Resources and Industrial Development, Regina, Saskatchewan.

EXAMINATION OF DISCOVERIES BY GOVERNMENT GEOLOGISTS

Prospectors who have found a radioactive mineral deposit often ask the Geological Survey of Canada to send a geologist immediately to examine the discovery. Unfortunately, owing to the great number of small discoveries constantly being made and the limited number of field officers available, the Geological Survey cannot meet all such demands, although an effort is made to examine all the more promising new finds as promptly as possible. Prospectors may also apply to the Mines Department of the province in which they are working to have their discoveries examined by a provincial geologist.

FREE TESTING OF PROSPECTORS' SAMPLES BY THE GEOLOGICAL SURVEY OF CANADA

Prospectors may send their samples for testing to private analysts or to laboratories of provincial mining departments, or they may have their samples tested quantitatively for radioactivity without charge by the Geological Survey of Canada. Samples for test should be addressed to the Director, Geological Survey of Canada, attention Radioactivity Division, and should be plainly marked "for radioactivity test" on the tag or outside of the parcel. Transportation charges on samples must be prepaid by the sender. The sender's name and address should be marked on the tag or outside of the parcel or should be enclosed in the parcel. Letters pertaining to samples should be mailed when the samples are sent, or earlier, and should be addressed to the Director, Geological Survey of Canada, attention Radioactivity Division. Letters and reports addressed to the Director, Geological Survey of Canada, may be sent post free O.H.M.S.

Identifications of radioactive minerals not requiring chemical analysis will be made by the Geological Survey on request, without charge, according to priority ratings based on grade and origin of the sample. Such identifications will ordinarily indicate the group to which the mineral belongs, from which the range of content of the constituent elements may be inferred by reference to analyses of known members of the group concerned.

In sending samples for tests or radioactive mineral identifications it is advisable to designate each sample or lot of samples that is to be tested separately by a number or letter, along with any description or details of the occurrence that may be given. When a number of samples are sent for individual tests in one parcel, the different samples should be very securely wrapped and tied or, preferably, enclosed in cloth sample bags to avoid the possibility of breakage and mixing during shipment.

Samples sent to the Geological Survey for tests should ordinarily be at least a pound or two in weight. If identification of the radioactive mineral or minerals present is desired, a special sample of the richest and least altered material available will facilitate the work of separating some of the radioactive mineral in pure condition for the necessary tests. Other samples should, if possible, represent average grade over known widths.

A special effort is made by the radioactivity laboratory of the Geological Survey of Canada to send out the results of quantitative radioactivity tests to prospectors as quickly as possible. Most samples received are tested and results mailed the same day as received. On request, test results will be sent by telegram or phoned, charges to be paid by the senders of the samples.

Identifications of the radioactive minerals present in prospectors' samples ordinarily require more time than radioactivity tests. In many instances elaborate separation and concentration procedures are necessary in order to obtain some of the mineral responsible for the radioactivity in sufficiently pure form for identification tests. Hence, for this reason and because of the effect of priority ratings, it may not be possible to forward the results of identification tests until a considerable time after the sample is received.

Results of Tests Held as Confidential. Results of tests by the radioactivity laboratory of the Geological Survey of Canada are held as confidential by the Geological Survey until released by those concerned, by publication or otherwise.

NATURE OF RADIOMETRIC ASSAYS

The quantitative radioactivity tests made by the Radioactivity laboratory of the Geological Survey of Canada or by other laboratories should be considered as only a quick means of supplying the prospector with information to guide him in deciding whether his find is worth further attention. Such "radiometric" assays or determinations, unfortunately, for reasons given below, do not always indicate the true uranium content as accurately as could be desired when compared with results obtained by chemical analysis, which is the most accurate way of determining uranium. However, in the great majority of cases, the radiometric results are sufficiently accurate to be perfectly satisfactory for prospecting purposes, and with suitable material may be practically identical with results by chemical analysis. Nevertheless, owing to these occasional variations, it is always desirable that samples showing an encouraging content of U_3O_8 (say 0·1 per cent or better) by radiometric test should be submitted to chemical analysis as a check or confirmation.

An explanation of the reasons for occasional variations in results by the radiometric method requires reference to some of the properties of radioactive elements and their behaviour in minerals.

PROPERTIES OF RADIOELEMENTS

A radioactive element, or radioelement, is composed of atoms that decay or disintegrate, that is, they change by violent disruptions into atoms of a different element and at the moment of change throw out radiations that can be detected and counted or otherwise measured by Geiger counters and other devices. The individual phone clicks of most small portable Geiger counters, for instance, register the disintegrations of single atoms of radioelements. A few of the clicks, however, are caused by cosmic radiation coming from outside the earth.

Numerous highly active artificial radioelements are being made in atomic piles and by means of cyclotrons or related instruments, but the only natural radioelements that occur in rocks and minerals and are sufficiently active to affect the portable Geiger counter to an important degree are uranium and thorium in association with the radioelements resulting from their atomic disintegration. Of these disintegration products, radium, deriving from uranium, and mesothorium, from thorium, are well-known examples.

Potassium and rubidium are also appreciably radioactive, but the practical effects of potassium are limited to contributing somewhat to the radioactivity of granites and pegmatites in which it is present as a constituent of the feldspars. Rubidium, like potassium, is an alkali metal that may occur in small amounts in feldspars and micas, and where it does, will contribute slightly to the overall activity of the rock. A number of other natural elements, mostly rather rare, that have been found to be very slightly radioactive are of no significance to uranium prospecting.

Uranium and thorium are parent radioelements; each gives rise by its atomic decay to a series[1] of other radioelements, which are formed step by step by successive disintegrations until finally inactive lead[2] is formed as

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[1] Only three natural radioactive series are known: the uranium, thorium, and actinium series. Natural uranium, as it occurs in minerals, is made up of 99·274 per cent of uranium having an atomic weight of 238, 0·72 per cent of uranium of atomic weight 235, and 0·006 per cent of uranium of atomic weight 234. These three constituents of natural uranium, represented by the symbols U^{238}, U^{235}, U^{234}, are examples of what are called isotopes; each is an isotope or variety of uranium having a different atomic weight, but all have identical chemical properties. The U^{235} constituent, called actinouranium, is the head or parent of the actinium series. The U^{234} constituent is a radioelement of the uranium series resulting from the initial decay of U^{238}.

Natural thorium occurring in minerals is entirely composed of only one isotope, Th^{232}.

When separated in concentrated form, U^{235} can be caused to explode by chain-reaction fission, and was the element first used for this purpose.

[2] The leads resulting from atomic disintegration of uranium and thorium are similar to ordinary lead but have slightly different atomic weights.

the end product of the series. An atom of uranium of atomic weight 238 that has passed through all the transformations in its series will have changed to one atom of lead and eight atoms of the gas helium; an atom of thorium will have changed to one atom of lead and six atoms of helium. Each atom of each successive radioelement of the series emits radiation at the moment of its transformation to its daughter element. The lead and helium produced are not radioactive.

Radioactive Equilibrium. It is a characteristic of the relationships of the radioelements of both the uranium series and the thorium series that if, say, a newly formed mineral contained at first only pure uranium (or thorium) free from its atomic disintegration products, the various radioelements of the uranium (or thorium) series would gradually accumulate in the mineral until the number of atoms of each decaying in a given time was exactly the same as the number being formed from its parent in the same time. In this condition the uranium or thorium is said to be in radioactive equilibrium with its active disintegration products and no more of these would accumulate.

As each radioelement of a disintegration series in equilibrium emits radiation from each of its atoms that decays, it is not surprising that the total radiation from any given quantity of uranium or thorium in equilibrium in old minerals is several times greater than that of an equal quantity of pure uranium or thorium free from its disintegration products. This was one of the earliest observations made in the study of radioactivity, and led to the discovery and isolation of radium from pitchblende by the Curies.

Thus, most of the radiation from old uranium or thorium minerals actually comes from the disintegration products[1] rather than from the uranium or thorium it-

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[1] There are about forty radioelements altogether in the three disintegration series.

self, even though the amount of disintegration products, by weight relative to the uranium or thorium present, is so minute as to be negligible. This has a bearing on prospecting, and is especially important in the estimation of uranium by radiometric methods, but to fully understand why, it is also necessary to consider the nature of radioactive radiation.

Radioactive Radiation. All radioelements, natural or artificial, as they decay give off one or more of three types of radiation: alpha, beta, and gamma, often designated by the Greek letters α, β, and γ. Alpha radiation consists of electrically charged particles that eventually become atoms of ordinary helium gas. It has a maximum range of only about 3½ inches in air, and is stopped by aluminium foil or even, for the most part, by a sheet of paper. Beta radiation is composed of electrons, which are very small particles or units of negative electricity. It is much more penetrating than alpha radiation, and may travel 10 feet or more in air. Nearly ¼ inch of aluminium is needed to completely stop the fastest beta rays, but most of this radiation will be stopped by much less. The gamma rays are similar in nature to x-rays, but of shorter wave length and have greater penetrating power. A very small fraction of the gamma rays from a powerful source might travel ½ mile or more through air or through a foot of iron. For practical purposes about 90 per cent of most gamma radiation is stopped by 2 inches of lead or about 97 per cent by 3 inches.

Although all radiations of any one type are of the same nature, no matter what radioelement they come from, there is a very considerable difference in the speed (hence, resulting range and penetration) of alpha and beta particles and in the wave length (hence, range and penetration) of gamma rays from different radioelements. Some radioelements decay very much faster than others[1]. The faster an element decays the more radiation it produces for a given weight in a given time and the more energy its radiation has, more speed in the case of alpha and beta particles, or shorter wave length in the case of gamma radiation. Hence, radiation from the fastest decaying elements has much more range and penetration than similar radiation from slower decaying elements.

Each individual radioelement decays in a way and at a rate that is characteristic for it, producing radiation of a certain energy or range of energies that is also characteristic for the element. Uranium (U^{238}), thorium, and actinouranium (U^{235}) free from disintegration products decay by giving off alpha particles. All of the beta and gamma radiation and most of the alpha radiation[2] from old uranium and thorium minerals comes from the highly active radioelements such as, especially, the radium and mesothorium families that have accumulated over a long period of time and are being constantly replenished by the decay of the parent elements at the head of these series.

Relationship of Radiation to Uranium or Thorium Content. In prospecting for uranium deposits, it is the long-range, penetrating gamma radiation that is most useful, and most Geiger counters operate on this

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[1] U^{238} has a half life of 4·5 billion years, that is, half of any initial quantity would decay in that time. Other half lives are: thorium, 13·9 billion years; actinouranium or U^{235}, 707 million years; radium, 1,620 years; mesothorium, 6·7 years; radium C^1, 1·5 ten-thousandths of a second; thorium C^1, 3 ten-millionths of a second. The lives of single atoms of any radioelement, however, from the time they are formed until they decay, vary enormously. Hence, radioactivity measurements, like life insurance, are 'statistical', that is, it is necessary to measure a large number of disintegrations in order to get an accurate average life expectation or death rate.

[2] The alpha radiation of any quantity of uranium in equilibrium with its disintegration products is 4·7 times that of the uranium alone.

radiation though some detect both beta and gamma rays, and a scintillation-type alpha detector is also available (*See* pp. 57-73). Quantitative radioactivity determinations or radiometric assays are also usually made by comparison of the beta or gamma activities, or both, of the test samples against similar activities of standard samples containing known amounts of uranium. In these applications of radiation detection, or measurement, the presence of uranium in a deposit or in samples is thus only indirectly inferred from the normal equilibrium relationships; the radiation that is actually detected or measured comes from the disintegration products that in old, unaltered minerals are normally present in the definite proportions required for radioactive equilibrium with uranium (or thorium). These disintegration products, however, are not always present in exactly the equilibrium proportions if the mineral has been altered or subjected to disturbing geological processes, especially weathering and leaching at or near the surface of the exposure[1].

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[1] Disturbance of the normal radioactive equilibrium in the uranium series can be accounted for theoretically in the case of old, primary minerals by two main causes: (1) alteration of the mineral, by which some of the radioelements become soluble in circulating waters and are carried away relatively faster than others; (2) loss of radon gas from the mineral. This would be favoured by fracturing and alteration, and fracturing favours alteration.

The process of radioactive disintegration by itself has powerful effects in disorganizing the crystal structure of a mineral, changing its chemical constitution and causing incipient or actual internal shattering, all of which tend to favour the onset of geological alteration and loss of radon.

Radon, or radium emanation, a highly radioactive gas, is the daughter element of radium. Corresponding gases, thoron and actinon, occur in the thorium and actinium series respectively.

Secondary minerals may not be old enough to have reached equilibrium. An age of about a million years would be necessary for practically complete equilibrium in the uranium series, but surface alteration products in Canada have probably formed since the retreat of the glaciers not more than 20,000 or 30,000 years ago.

EFFECTS OF DISEQUILIBRIUM IN PROSPECTING AND ASSAYING

The effects associated with disequilibrium, that is, disturbed or abnormal equilibrium relationships, in minerals at the surface of radioactive deposits, on the whole are probably favourable for prospecting, as, by weathering of radioactive mineral exposures, there is a tendency for active materials to be spread over greater areas so that deposits may be somewhat easier to locate. In some instances, uranium seems to be more soluble and more easily leached away than the active products, resulting in a relative concentration of the latter, so that indications of the Geiger counter may give the impression that an occurrence is larger and richer in uranium than it actually is.

In the case of radiometric assays, it may be seen that disequilibrium could lead to either positive or negative errors in calculating the amount of uranium inferred to be present from the results of radiation measurements of a sample, even if the sample contained no thorium. If the highly active disintegration products of the radium family are present in greater or lesser proportion than they should be, relative to uranium, the radiometric result will indicate too high or too low a content of uranium, respectively.

INTERPRETATION OF RADIOMETRIC ASSAYS

A complete and detailed discussion of radiometric assaying[1] would be quite involved, but some further explanations may assist those receiving such reports to understand their significance.

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[1] Those interested in the details of making radiometric assays should secure a copy of "Radioassay of Uranium Ore with The Geiger Type Equilibrium Counter" by R. D. Wilmot and C. McMahon, available without charge on application to the Radioactivity Division, Mines Branch, Department of Mines and Technical Surveys, Ottawa.

Radiometric assay results are usually reported in some form in which the term "per cent U_3O_8 equivalent activity", or a phrase implying this, is used. The type of activity may be specified as, usually, beta or gamma. Such phrases do not mean that the activity of the sample is expressed in terms of the activity of chemically prepared uranium oxide, U_3O_8, or that it has been compared with a standard containing such material. The meaning is, that the beta or gamma activity of a definite amount of the ground sample has been measured and compared under exactly similar conditions to that of a similar amount of a standard sample containing pitchblende in which the uranium is believed to be in equilibrium with its disintegration products. Such standard samples are prepared in Canada by the Mines Branch, Department of Mines and Technical Surveys. The U_3O_8 content of such samples has been accurately determined by chemical analysis, and the thorium content similarly checked to prove that it is negligible. The various members of the sample series containing different percentages of pitchblende have also been compared among themselves radiometrically in regard to their activity relative to the U_3O_8 content of each.

For convenience, all samples tested are compared against such standards containing only the uranium series as active constituents, and the results are expressed in terms of the activity associated with a definite amount of U_3O_8 in such samples. If a sample tested carries a mineral in which both uranium and thorium are present and the radiometric comparison is made by using only one type of radiation, as, usually, beta or gamma, the radiation of both the uranium and thorium series will be reported in some such form as: "X per cent U_3O_8 equivalent activity" or "beta activity equivalent to that produced by a content of X per cent U_3O_8". The content of U_3O_8 inferred will be too high due to the activity contributed by the thorium series, but the result may, nevertheless, be very useful as a preliminary indication in prospecting.

Radiometric assays of radioactive mineral-bearing samples may be made in various ways and with varying degrees of elaboration according to the equipment available and the accuracy desired. The radioactivity laboratories of the Department of Mines and Technical Surveys have constantly endeavoured to improve the reliability of radiometric assays, and much research has been done in attempting to develop methods sufficiently quick, simple, and reliable for routine use in detecting the presence of thorium or disequilibrium in radioactive mineral samples. Much research on this problem has also been done in various other laboratories and various methods have been proposed. The procedure used at present in laboratories of the Department of Mines and Technical Surveys is simply to measure separately[1] both the beta and gamma radiations of a sample and compare them with similar radiations from a standard sample containing pitchblende. If only the uranium series, in equilibrium, is represented in a sample, the beta and gamma comparisons should both give the same, or nearly the same, results for the calculated uranium content of the sample within the limits of error of the radiation measurements. If both the thorium and the uranium series are represented in the sample, these results will be different, and, assuming the uranium series to be in equilibrium and the discrepancy entirely due to thorium, the approximate content of thorium can be calculated, as the relative intensities of the beta and gamma radiations of the two series are different. However, as the uranium series alone, out of equilibrium,

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[1] Pure gamma radiation can be isolated for measurement by absorbing the beta rays in a shield of aluminium. Scintillation equipment is much more efficient than Geiger counter tubes for detecting gamma rays. For the beta determinations special Geiger counter tubes with very thin windows are used, which are nearly 100 per cent efficient in detecting beta rays but register only a small percentage of the gamma radiation.

could produce the same effect as the presence of the thorium series, the method does not permit the positive detection of the presence of thorium.

SUMMARY OF RADIOMETRIC ASSAY INTERPRETATION

To summarize: results from radiometric assays in which only beta or gamma activity has been determined will include the effect of any thorium present in the sample, and hence may indicate too high a U_3O_8 content. When both beta and gamma determinations are made and both indicate nearly the same value for the U_3O_8 content, the result may, in general, be considered to be very close to the true value for U_3O_8 content. When the beta and gamma results disagree, disequilibrium or the presence of thorium is indicated.

In spite of the shortcomings of the radiometric method of assay, its speed and low cost render it indispensable. It is possible that equipment and methods suitable for speedy, routine analysis of the radiation spectrum of radioactive minerals may become available, which may permit making more accurate determinations of uranium and thorium radiometrically.

SPECTROGRAPHIC ANALYSES

Spectrographic determinations of uranium and thorium are much less accurate quantitatively, as a rule, than radiometric determinations, though the presence of uranium or thorium may be positively confirmed by this method if the elements are present in the sample in sufficient quantity. The method is relatively insensitive for low-grade material.

IDENTIFICATION OF RADIOACTIVE MINERALS AS A MEANS OF INFERRING URANIUM AND THORIUM CONTENT

It might be supposed that identification of the radioactive mineral or minerals present in a sample should indicate whether uranium or thorium, or both, are present or even permit an estimate of the approximate proportion of uranium and thorium if a mineral known to carry both is found to be present. This is true only to a limited degree for most uranium-bearing minerals, but, fortunately, it may be taken to be wholly true for practical purposes when pitchblende can be identified as the only primary uranium mineral present. Pitchblende, the chief ore mineral of uranium, is composed essentially of cryptocrystalline uranium oxide occurring typically in vein deposits. It is the only uranium mineral that has been found so far in Canada in sufficiently large and rich deposits to be workable at a profit, and it usually carries no more than traces of thorium. Further, thorium-bearing minerals very rarely occur in vein deposits. Thus, if pitchblende can be positively identified in a sample, it has so far been found to be safe to assume that no more than an insignificant amount of thorium, if any, may be present, and that the activity of the sample is due to uranium and its disintegration products.

On the other hand, radioactive minerals that occur in granites and the very coarse-grained granitic bodies called pegmatites almost always carry thorium, and most of them are very complex and variable in composition. Specimens of the same species from different localities or even from the same deposit, in some cases, may show wide variations in content of uranium, thorium, and other constituents (*See* pp. 90-107). Uraninite, composed, like pitchblende, mainly of uranium oxide, but crystallized, usually as cubes, is found in some pegmatites, and such crystals from pegmatites usually carry appreciable quantities of thorium as well as rare earths, though some showing very low thorium have been analysed. Minutely crystallized uranium oxide has also been found, in very small amount, in some vein-type pitchblende deposits in Canada and elsewhere.

DISTINGUISHING PITCHBLENDE AND URANINITE

Pitchblende and uraninite in some instances can be distinguished by x-ray tests if the minerals are not too much altered, even if the uraninite has no crystal form, but the distinction may sometimes be difficult. The prospector with some knowledge of geology should be able to decide for himself in most cases as to whether he is dealing with a vein deposit or a pegmatite, and if the former he may be encouraged by the fact that the primary mineralization of radioactive vein-type deposits is usually pitchblende, even though only secondary alteration products occur near the surface. Unfortunately, altered pitchblende and secondary uranium minerals derived from it may be out of radioactive equilibrium, so that the uranium content of such material cannot always be accurately determined by the usual routine radiometric measurements.

NECESSITY FOR CHEMICAL ANALYSES

For these various reasons, samples that show encouraging results by radiometric assay should be submitted to chemical analysis, as the uranium content can be determined with the most complete certainty in all cases only by such analysis.

The Geological Survey of Canada does not make chemical analyses for uranium and thorium for the public. A list of private analysts who make these determinations will be found in the footnote below[1].

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[1] The following is a list of assayers known to have performed chemical analyses for uranium; some also make thorium determinations:

G. S. Eldridge and Co., Ltd., 537 Hornby St., Vancouver, B.C.
J. R. Williams and Son, 580 Nelson St., Vancouver, B.C.
E. W. Widdowson and Co., 301-305 Josephine St., P.O. Box 610 Nelson, B.C.
Milton Hersey Co. Ltd., 233 Fort St., Winnipeg.
Sudbury Assay Office, 256 Oak St., Sudbury, Ont.
Temiskaming Testing Laboratories, Cobalt, Ontario.
Thomas Heys and Sons, Room 77-79 Toronto Arcade, Yonge St., Toronto.
Toronto Testing Laboratory Ltd., 73 Adelaide St. W., Toronto.
Lakefield Research, Ltd., Lakefield, Ontario.
Mr. H. Weller, Cobden, Ontario.
Milton Hersey Co. Ltd., 980 St. Antoine St., Montreal.

The laboratories of the provincial mines departments of British Columbia, Manitoba, Ontario, and Quebec also make chemical analyses for uranium, as well as radiometric tests on prospectors' samples.

The Mines Branch, Department of Mines and Technical Surveys, Ottawa, does not make free radiometric and chemical assays for uranium, except those related to concentration and extraction tests. This is because several firms now offer adequate radiometric and analytical services. It has always been the policy of the Mines Branch to make assays and analyses for gold and other metals when these are desired for some special reason, and to charge slightly more than commercial rates in order to avoid competition with commercial firms. This policy now applies to assays for uranium, which will be made only for special reasons and at a charge of $10 each.

Chemical assays for thorium are usually costly and difficult, and will not normally be undertaken by the Mines Branch. However, in some cases estimations can be made from radiometric measurements, and such estimates will be made free of charge, upon request, when the Mines Branch has been satisfied that the material is of sufficient interest.

FREE CONCENTRATION AND EXTRACTION TESTS BY THE MINES BRANCH

Those wishing to test the possibilities of a promising discovery by further development and bulk sampling should communicate with the Mines Branch, Department of Mines and Technical Surveys, in regard to having concentration and extraction tests made on representative material from the deposit.

The Radioactivity Division of the Mines Branch is equipped to carry out, free of charge, concentration and extraction tests on uranium ores that warrant such work being performed. These tests will determine the average uranium content of the sample, its suitability for treatment, and the percentage of recovery.

Preliminary test work may be done on samples containing between 0·05 and 0·1 per cent U_3O_8 in order to determine their adaptability to concentration; however, as a general rule, ore should assay more than 0·1 per cent U_3O_8 to warrant full-scale concentration test work being performed. In general, factors that determine whether a uranium-bearing rock can be classed as ore are location, grade, size, and general characteristics of the deposit. These factors should be borne in mind when submitting samples for concentration work.

Samples submitted for such work should be as representative as possible of the deposit that is to be mined, and they should be blasted from fresh material so as to contain a minimum of alteration products. *Each* sample should be at least 300 pounds in weight. *Exploration permits authorize taking bulk samples to a total not exceeding 10 tons in weight for mill tests.* Samples should be shipped prepaid.

Before shipping bulk samples for concentration tests, permission to remove the samples should be obtained from the Secretary, Atomic Energy Control Board, Ottawa, and specific information regarding the location, approximate grade, and size of the deposit should be submitted to the Mines Branch. Shipments should not be made until the Mines Branch has agreed to undertake the test work. Letters and samples should be addressed to: The Chief, Radioactivity Division, Mines Branch, 30 Lydia Street, Ottawa, Canada.

JUDGING A NEW DISCOVERY

As the Government does not buy thorium[1] ores or pay for thorium contained in uranium ores or concentrates, the value of a uranium ore in most cases will depend solely upon the uranium content. *What minimum uranium content may be considered as promising or encouraging for further work on a discovery at the present time?* The answer to this question for any particular deposit will depend ultimately on the results of concentration and extraction tests on representative bulk samples, such as are made by the Mines Branch, along with other factors such as the price paid for uranium as acceptable concentrate, location and size of the deposit, and possibly, in some instances, the presence along with uranium of other recoverable minerals of commercial value. However, much of this information can only be obtained after considerable work has been done on the deposit. Prospectors, when they have received the results of radiometric tests by the Geological Survey of Canada on samples from a new find, often ask for advice as to whether the deposit from which the samples were

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[1] Thorium is used commercially, as for making gas-light mantles and for various other purposes, and there is a moderate demand in the United States and the United Kingdom for thorium concentrates of grades suitable for extraction of the element. A producer in Canada who wishes to sell thorium concentrate would be required to secure a permit from the Atomic Energy Control Board and could sell only to an approved purchaser. The price paid would be subject to private negotiation, but in order to give an idea of approximate values the following may be quoted: in U.S.A.: monazite—per pound, f.o.b. Atlantic ports, 65 per cent total rare earth oxides, including thorium oxide and cerium oxide, 17½ cents (Engineering and Mining Journal Market Report, March 1, 1951); in the United Kingdom: in 1949-50, prices offered for monazite concentrate carrying a minimum of 6 per cent ThO_2 work out to about $1.15 a pound of contained ThO_2, and prices for thorite concentrate carrying a minimum of 15 per cent ThO_2 work out to about 88 cents a pound of contained ThO_2.

The greater relative price for monazite ore is due probably to the large content of cerium earths, which also have value.

obtained is worth staking or further attention. The answer to such questions may depend largely on the nature of the deposit. Owing to the abundance of pegmatite dykes and pegmatitic materials in the Canadian Shield and the fact that such bodies commonly carry scattered radioactive minerals, they are very likely to attract the attention of uranium prospectors. More than 70 per cent of prospectors' samples tested by the Radioactivity Division, Geological Survey of Canada, are from such occurrences. Unfortunately, so far in Canada, pegmatites have not been found to be profitable commercial sources of uranium. In a few instances, it appears that appreciable quantities of uranium minerals might have been produced as a by-product of feldspar or mica mining operations, but the estimated total uranium content of any individual pegmatite dyke that has been extensively worked for feldspar or mica in Canada has not been sufficient to have enabled it to be profitably worked for uranium alone. There is also the difficulty with many of the complex uranium minerals characteristic of pegmatites that even the pure minerals themselves may not carry as much as 10 per cent U_3O_8, which is the minimum content specified for an acceptable uranium concentrate to be purchased by the Government. On the other hand, should a pegmatite dyke or group of dykes be found carrying, besides uranium minerals, other rare element minerals of commercial interest, such as columbite-tantalite or beryl in considerable quantity, the chances of a profitable commercial operation might be more favourable. Pegmatite deposits of somewhat unusual type, now being explored in the Charlebois Lake region of Saskatchewan, show more promise than most pegmatite deposits. If further work on them is successful, prospecting for similar deposits would be desirable. However, in general, uranium deposits of pegmatitic or granitic type are unlikely to be capable of profitable commercial production of uranium under present conditions.

In Canada, therefore, it appears that, for the present at least, the uranium prospector would be well advised to concentrate on the search for vein-type deposits of pitchblende. Initial discoveries of even what may appear to be rather small radioactive veins or shear zones showing more than 0·05 per cent U_3O_8 equivalent activity might be considered to encourage thorough prospecting of the locality. Deposits showing 0·1 per cent U_3O_8 or better across widths of 3 feet or more, with reasonable length, should be worth staking, especially if pitchblende has been identified. The location of the discovery with regard to transportation facilities might be the main factor in deciding whether to stake or not. At the present maximum price for uranium ($7.25 per pound of U_3O_8) material of 0·1 per cent U_3O_8 grade contains $14.50 worth of uranium a ton and 0·05 per cent U_3O_8 grade material carries $7.25 worth of uranium. Thus, deposits of average grade between 0·05 and 0·1 per cent U_3O_8 could only be considered as long-term speculations based on the hope of an advance in the price of uranium or improvements in the methods of uranium extraction. It would appear that only an exceptionally large deposit of this grade, well situated, would be worth holding for speculative purposes. Some gold mines with very large orebodies, operating on a large scale and with the benefit of some government subsidy, are able to make a profit on ore of about this value ($7.50 or more a ton), but the processes for extracting gold are very efficient and less costly than those at present available for uranium extraction.

THE OUTLOOK FOR THORIUM

Although it has been stated that thorium is still being studied as a possible source of atomic energy, there has been no official statement (up to June 1951) that would seem to indicate the likelihood of any change, in the near future, in governmental purchasing policy regarding this element. Increasing use of the cerium group of rare earth elements in steel making, and for other purposes, might lead to a greater commercial demand for monazite as a source of these elements irrespective of its thorium content, but the recent discovery of large vein deposits of bastnäsite[1] in California will doubtless help to supply this demand in the United States. Monazite, the chief source of thorium and the cerium earths, is recovered commercially as a concentrate from sea beach and placer sands in which it occurs as detrital grains, chiefly in India, Ceylon, Brazil, and Malaya. In Canada, the mineral has been found as crystals in pegmatites, which are not likely to be commercial sources, and in very small amount in a few sands, chiefly in British Columbia. River and coastal beach sands and reworked glacial deposits would seem to offer the only hope of finding monazite in workable deposits, but any monazite-bearing sands so far found in Canada have been very low in grade. Other thorium-bearing and cerium-bearing minerals such as uranothorite, thorite, allanite, and others occur in some Canadian pegmatites and schists, but whether such deposits could be worked at a profit for these minerals is doubtful. Radioactive minerals occurring in pegmatites almost always carry an appreciable thorium content.

OTHER SERVICES OF THE GEOLOGICAL SURVEY OF CANADA

Literature on Canadian uranium deposits, data on portable Geiger counters and scintillation type equipment, copies of regulations of the Atomic Energy Control Board relating to prospecting, and related information may be obtained on application to the Director, Geological Survey of Canada, attention Radioactivity Division. Geological maps and reports are supplied by the Geological Survey of Canada, and geological maps,

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[1] **Bastnäsite is a fluocarbonate of the cerium group of rare earth elements.**

reports, and information on mining laws may also be obtained from provincial mines departments.

Small specimens of pitchblende ore for testing Geiger counters, etc., may be obtained by applying to the Director, Geological Survey of Canada, attention Radioactivity Division. These are sent postpaid on receipt of the amount of the charge (50 cents) in the form of a postal note or money order made out to the Receiver General of Canada. Stamps and cheques are not acceptable.

Prospectors wishing to search for minerals other than those of uranium and to study the general principles involved in searching for mineral deposits will find the set of four textbooklets on "Mining" prepared by the Canadian Legion Educational Services very interesting and useful. The set may be obtained from the Publications Officer, Geological Survey of Canada, at a cost of $1. The individual volumes comprising the set are not sold separately. Payment should be by postal note or money order made out to the Receiver General of Canada. Stamps and cheques are not acceptable.

REGIONS FAVOURABLE FOR PROSPECTING

A question often asked is, whether a certain region, usually the home locality of the inquirer, would be worth prospecting for uranium. This is a point of special interest to amateurs who may wish to do some spare-time prospecting, perhaps partly as a form of recreation, but do not contemplate making extended, expensive trips for full-time prospecting in distant regions. The answer to such questions, so far as the present state of geological knowledge of Canada permits an answer, may depend on factors discussed here and, in more detail, on pages 34 to 57 of this booklet.

It is generally considered, of course, that areas already known to contain vein deposits of pitchblende offer the most favourable opportunities for finding uranium deposits of commercial grade. However, with the growing interest in uranium, the best ground in such localities may eventually become almost solidly staked and the tendency to concentrate prospecting on these older areas, in such a large country as Canada, may result in failure to find deposits that may occur in virgin, unprospected territory.

Only two types of deposits have produced most of the world's supply of uranium up to the present. These are, in order of importance: (1) vein-type deposits of pitchblende originating from igneous rocks; and (2) carnotite-bearing sandstones. The carnotite and related uranium-bearing minerals occur cementing the grains of sandstones and associated with fossilized wood and organic matter contained in the sandstones. They are not primary products of igneous rocks, like pitchblende, but have been formed by precipitation from solutions carrying uranium and vanadium, which may have travelled a long way from the original source of the uranium.

Other types of sedimentary rocks that have been found to carry a little uranium are black bituminous shale and phosphate rock. The latter is a limestone carrying calcium phosphate, and is used to make superphosphate fertilizer. No Canadian examples of these rocks have been found to carry as much as 0·01 per cent U_3O_8, but in some countries very large formations occur, some parts of which may carry as much as 0·03 per cent U_3O_8. Any possibility of extracting uranium profitably from black shale seems very remote, but it may prove to be feasible to recover uranium as a by-product from phosphate rock used in making fertilizer. Some low-grade phosphate rock occurs in western Alberta and British Columbia, but our commercial supplies are imported.

For various reasons it seems unlikely that workable deposits of uranium will be found in any surface sedimentary rocks in Canada that have not been intruded by igneous rocks. Consequently, the more favourable prospecting ground is confined to areas in which igneous rocks occur, and, fortunately, there are enormous areas in Canada in which such rocks are found. They are of various ages, from the oldest known rocks, about 2,000 million years old, in southeastern Manitoba, to others probably less than 100 million years old. The igneous rocks of British Columbia and the eastern Maritime Provinces are mostly much younger than those of the Canadian Shield.

Judging from past experience, the most favourable prospecting region in general in Canada is that included in the Canadian Shield, the vast area of ancient igneous and metamorphosed rocks, supposed to be mainly if not entirely of Precambrian age, that encircles Hudson Bay. Wherever such rocks have been faulted, fractured, disturbed, or mineralized in any way they should be worth testing with a Geiger counter, and there is some ground for believing that areas of folded younger Precambrian or Proterozoic rocks within the Canadian Shield are especially favourable.

The areas of younger igneous rocks in British Columbia and the Maritime Provinces have also produced known uranium deposits, and may be considered worth prospecting, though no deposits in these areas have yet developed into producers.

Pegmatites are abundant in the Canadian Shield in particular, and to a lesser degree in the younger igneous areas of British Columbia and the Maritimes. These are bodies of coarse-grained rock composed mainly of feldspar and quartz derived from granitic intrusions. They may be irregular in shape, but commonly are vein-like and are then called dykes. Such dykes may be only an inch or so, or more than 100 feet, in width. Like veins, they may cut through any type of rock. Pegmatites often carry a small, widely scattered content of radioactive minerals but these as a rule are very irregularly distributed. From past experience in Canada the total uranium content of any one pegmatite dyke or even of a group of neighbouring pegmatites would rarely justify the expense of a concentrating plant for uranium minerals alone, whereas, on the other hand, the grade of any considerable quantity of uranium-bearing material that could be selectively mined or hand-cobbed at reasonable cost would seldom be high enough to be worth shipping to a distant concentrating plant.

The sketch map of Canada at the back of this booklet shows the general regions in which igneous rocks occur. Areas underlain by undisturbed[1] sedimentary rocks are of little or no present interest for uranium prospecting.

More detailed geological maps of particular areas in which prospectors are interested may be obtained from the Publications Officer, Geological Survey of Canada, Ottawa, or from the mines department of the province in which the area is located. Standard topographic maps are available from: Survey Records and Map Distribution, Department of Mines and Technical Surveys, Ottawa.

Air photographs for many areas are available from the National Air Photographic Library, Ottawa, at a charge of 50 cents each. The exact area for which photographs are desired should be very definitely described by reference to land subdivision or, preferably, by submitting a map with the area outlined on it. Whether stereoscopic coverage is desired or not should also be mentioned, as such coverage involves about a two-thirds overlap. In the case of areas for which the National Air Photographic Library has no photographs, the inquirer will be advised of any provincial or other air photographs available.

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[1] The term is relative, as compared with the sedimentary rocks of much of the Canadian Shield and igneous regions, and the areas of 'undisturbed' sedimentary rocks outlined on this small-scale map include undifferentiated parts where much folding and faulting have occurred.

THE NATURE AND DISTRIBUTION OF CANADIAN RADIOACTIVE MINERAL DEPOSITS

Considered as constituents of the earth's crust, uranium and thorium are not extremely rare elements; they have been estimated recently to be more abundant in the igneous rocks than gold, silver, and platinum, and less abundant than cobalt, tin, gallium, and cerium. Unfortunately, however, uranium and thorium are much less commonly found concentrated into workable deposits than are even the more rare gold and silver. Most of the total uranium and thorium content of the earth's crust is widely dispersed as a minute percentage of enormous masses of certain rocks, especially granites, pegmatites, and related acidic rocks of igneous origin, and in sedimentary formations of marine origin such as shales and phosphate rock, or in various other sorts of mineral deposits of low uranium and thorium content. The more basic igneous rocks, such as diabase, gabbro, basalt, dunite, etc., carry much less uranium and thorium than the granitic rocks. Undisturbed sandstones and limestones of marine origin also as a rule have very low uranium and thorium contents. Black, carbonaceous shales and phosphate rocks may carry more uranium than do granites.

Veins and related types of deposits containing pitchblende have been the only commercial source of uranium in Canada, and deposits of this nature have produced most of the world's supply of uranium. Pitchblende is the most important uranium mineral, not only because the mineral itself has a high uranium content, which is relatively easily and cheaply extractable, but also because it is found to occur concentrated into vein-type deposits of size and grade such as to permit production of uranium at a reasonable cost. However, uranium deposits of several other types occur in Canada, and deposits of still other types known in other countries may yet be found here. All of the known

Canadian types are, therefore, discussed and the more important foreign types are mentioned briefly.

Numerous occurrences of uranium and thorium minerals have been found in Canada. Many of these deposits are too small or of too low grade to be of present commercial importance, but others show promise and are being tested actively. About nine-tenths of all the known Canadian occurrences of uranium and thorium are in the Canadian Shield; most of the others are in British Columbia, but a few are in the Maritime Provinces of eastern Canada. The discoveries within the Canadian Shield are grouped in a remarkable way near its western and southern margins; almost without exception, they are in a belt extending from the east side of Great Bear Lake through the eastern part of Great Slave Lake to Lake Athabasca, thence including the Lac la Ronge region of Saskatchewan and the Flin Flon and Bird River regions of Manitoba, and extending eastward from Kenora along the north shores of Lakes Superior and Huron, and, finally, occupying that part of the Shield called the Grenville region, which extends from Georgian Bay to the Gulf of St. Lawrence. Although certain parts of this belt may be more favourable for the occurrence of uranium and thorium than the Shield as a whole, it is believed that the distribution of discoveries is at least partly attributable to the greater accessibility of the Grenville region and of the regions near the large lakes that border the Shield. The whole of the Shield can, therefore, be considered as not unfavourable for the occurrence of uranium and thorium, and it is possible that future prospecting will show that the present pattern of discoveries was only temporary. The discoveries in British Columbia are widely scattered, but to date all are in the southern half of the province and all are west of the Rocky Mountains. In Yukon Territory, the thorium-bearing minerals allanite and monazite have been identified in concentrates from placer deposits, but no essentially uranium-bearing minerals have been reported. General geological conditions there, however, are similar to those of British Columbia.

In classifying the types of radioactive mineral deposits recognizable in Canada, uranium and thorium will be considered together, as these elements occur together in most primary minerals found in some of the deposits listed below. The types are arranged from the point of view of the geological origin of the various deposits, beginning with the granitic and pegmatitic types, of igneous origin, which contain primary radioactive minerals, and ending with the secondary and placer types, in which the radioactive element content has been derived directly or indirectly from the decomposition of primary minerals or the weathering of igneous rocks. The arrangement also represents the descending order of approximate temperature ranges at which the deposits are presumed to have formed; granites at about 800°C. or lower, pegmatitic deposits around 500°C. to 600°C. or lower, hydrothermal deposits from 500°C. to 100°C. or lower, and the remaining types at ordinary temperatures.

In this discussion the term 'deposit' is used loosely as implying any body of rock, not necessarily of economic importance, in which uranium or thorium is relatively more concentrated than in other rocks of the earth's crust.

TYPES OF CANADIAN DEPOSITS

(1) Granitic deposits
(2) Pegmatitic deposits
    (a) Granite pegmatites
    (b) Pegmatitic schist deposits, or migmatites
    (c) Diorite pegmatites
    (d) Calcite-fluorite pegmatites
(3) Hydrothermal deposits
    (a) Uraninite-bearing base metal deposits
    (b) Pitchblende-bearing veins, with simple mineralization
    (c) Pitchblende-bearing veins, with complex mineralization
    (d) Disseminated, or replacement deposits

(4) Sedimentary deposits
(5) Secondary deposits
(6) Placer deposits

(1) *Granitic Deposits*

Known granites carry too little uranium and thorium to be of commercial interest at present. They are discussed in some detail because of their relationship to other deposits and their great abundance in Canada, and also to indicate the quantitative significance of Geiger counter readings commonly obtained over granite outcrops.

Granites are usually relatively light-coloured, reddish or greyish rocks that, because they are well crystallized, are considered to have been formed by slow cooling at considerable depth from molten rock or magma. They cut into any older rocks, and may outcrop ovei great areas where the rocks that were originally above them have been removed by erosion. Granites proper are composed mainly of potash feldspar and quartz, with commonly some mica, hornblende, or augite. Generally they contain some soda-lime feldspar (plagioclase), and where this becomes an important constituent the rock grades into quartz monzonite, or, if the rock contains little or no quartz, into monzonites. Where quartz is lacking, and the rock consists mainly of potash feldspar, it is called syenite. All these are commonly referred to as granitic or acidic rocks.

Many bodies of granite and related rocks show about 0·003 per cent, and some up to as much as, or a little more than, 0·01 per cent U_3O_8 equivalent beta activity. It has been estimated recently that the granites of the earth's crust contain on an average 3·96 grams of uranium and 13 grams of thorium a ton. This is 0·16 ounce of U_3O_8 and 0·52 ounce ThO_2 a ton, or 0·0005 per cent U_3O_8 and 0·0016 per cent ThO_2, respectively. The ratio of thorium to uranium seems to vary with the acidity, that is, with the quartz content, from an average of about 3 to 1 in true granites to 4 to 1 in less acidic rocks. Individual granites, of course, show quite wide variations from the average ratio. The granite-pegmatites, more acidic than granites, probably carry more uranium than thorium on the average, judging from studies of Canadian examples.

A considerable proportion of the total beta and gamma activities of granites is due to potassium[1] contained chiefly in the potash feldspar, which is one of the main constituents of granites, and to a much lesser extent in any muscovite (light) or biotite (black) mica present. It has been estimated that the average granite carries 4·11 per cent of potassium oxide (K_2O) chemically combined in the feldspars and micas. The average potash feldspar of granites has been estimated to carry 11·7 per cent K_2O, and the potash feldspars of pegmatites may sometimes carry as much as 14 per cent K_2O; hence, areas of pegmatite outcrops composed mainly of potash feldspar may be expected to show correspondingly greater beta and gamma activity due to potassium alone, without regard to any possible uranium or thorium content. The more rare alkali metal rubidium, less active than potassium, may also

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[1] Natural potassium is composed of three isotopes of atomic weights 39, 41, and 40 in decreasing order of abundance. Its activity is due solely to the K^{40} isotope estimated to be present to the extent of 0·012 per cent. Isotope K^{40} produces only beta and gamma radiation, and decays to form, mainly, inactive calcium isotope Ca^{40}; a little inactive argon A^{40}, a rare gas, is also produced. It is believed that the beta radiation is associated with the production of Ca^{40} and the gamma radiation with the production of argon. The results of different investigators of the radioactivity of potassium do not agree very closely. However, there seems no doubt that the gamma rays from potassium have as much penetrating power as many of the gamma rays from the radium family. Their intensity or number per unit weight of potassium is, of course, very much less than that from an equal weight of uranium or thorium in equilibrium with their decay products.

be present in small amounts in feldspars and micas and hence contribute in some slight but insignificant degree to the overall activity.

From field studies of the radioactivity of areas of very pure potash feldspar in pegmatite dykes, made by F. E. Senftle[1] of the Mines Branch, it appears that in the case of an average granite carrying 4 per cent K_2O the potassium might be responsible for gamma activity resulting in a reading on a portable counter of nearly twice the minimum background. Results of other investigators indicate that for the average granite carrying 4 per cent K_2O the potassium may contribute between 0·001 and 0·002 per cent U_3O_8 equivalent gamma activity.

Thus it may be seen that activities of two or three times the lowest background count do not indicate a deposit of possible economic importance, nor can they be considered as particularly encouraging for more detailed prospecting of an area, unless there are also other favourable indications.

In the field, and in the laboratory, pink to reddish granites tend to show greater activity than the grey granites.

The distribution of alpha activity (due to uranium and thorium only) in granites has been studied, and it is found that, if the minerals composing fairly active granites are separated, one from another, in as pure condition as possible, the biotite is usually more active than the feldspar, which in turn is much more active than the quartz. Study of thin sections by means of autoradiographs or alpha track photographs often reveals, particularly in the biotite, minute, microscopic crystals or grains of minerals showing activities that may be, relatively, many thousands of times greater than that of the quartz, feldspar, and pure mica itself.

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[1] Canadian Mining Journal, November 1948.

The most common of these active inclusions are: zircon, titanite, monazite, allanite, apatite. Less often, and perhaps only in somewhat pegmatitic granites, uraninite and thorite or uranothorite may be present. Active secondary decomposition products occurring in minute or larger fractures also contribute to the total activity. The greater activity of the biotite is due mainly to the fact that it is the host of the highly active inclusions; it is estimated that these, in some instances, account for a large part of the total activity due to uranium and thorium.

Such studies are of interest and practical value, as granites and their relatives appear to be the primary source of all other uranium and thorium deposits, and it is worth while to know the general behaviour and tendencies of uranium and thorium under various conditions of temperature and association with other elements. They indicate that in the molten mother rock or magma from which granites form, uranium and thorium have relatively little tendency to be absorbed in, or combined with, the common rock-forming minerals, quartz, feldspars, micas, pyroxenes, etc., as silicate compounds. On the contrary, any excess that cannot be held in solution as the granite crystallizes (supposedly at around 800°C.) tends to associate itself with any available zirconium, titanium, rare earths, especially those of the cerium group, calcium, and/or phosphorus, which precipitate out at high temperatures to form the active minerals mentioned. From the way in which these active minerals occur as inclusions in the other minerals it would seem that they are the first minerals to precipitate from the magma. Thorium, perhaps because of its chemical affinities with zirconium, rare earths, and calcium, precipitates to a relatively greater degree than uranium at high temperatures, so that the average ratio of thorium to uranium in granites is 3 to 1 or greater. At a lower temperature range, believed to be mainly around 550°C., the pegmatites crystallize from the residual mother liquor from the granite, in which uranium has become relatively more concentrated compared with thorium, and most, or practically all, of the remaining thorium is precipitated along with uranium as complex radioactive minerals, in the pegmatites. The magmatic solutions remaining after the pegmatites have crystallized seem to have been almost completely freed of thorium; they may travel considerable distances away from the granites and pegmatites and deposit the remaining uranium as 'hydrothermal', that is, hot water, pitchblende vein deposits in cracks and zones of weakness in any sort of rock. From some known examples in the Goldfields area, Saskatchewan, it appears that wall-rocks of basic composition may be more favourable for this deposition than others.

(2) Pegmatitic Deposits

Pegmatites constitute by far the most abundant type of deposit in Canada in which uranium and thorium minerals may be concentrated in amounts easily visible to the naked eye. All pegmatites, however, do not carry uranium and thorium minerals in appreciable quantity, though very few known pegmatites in the Canadian Shield that have been mined at all extensively for feldspar or mica would not reveal by careful search at least a few small crystals or concentrations of radioactive minerals.

Pegmatites carrying small amounts of radioactive minerals occur abundantly in the better known parts of the Canadian Shield as previously outlined, and others are known to occur in British Columbia and Nova Scotia.

The single word pegmatite, as commonly used, refers to a rock that the geologist might describe more exactly as granite pegmatite, composed mainly of coarsely crystallized potash feldspar (microcline, almost invariably, in pegmatites of the Canadian Shield), quartz, and, in some cases, considerable mica. This was the original meaning of the word, but it has been found convenient to apply the term, with qualifying adjectives, to a number of other rocks composed of relatively coarsely crystallized products formed from an intrusive mass of molten rock or magma, even though of composition more basic than granites, during the later stages of cooling and solidification.

Pegmatites may occur as segregations within the parent rock, or as irregular masses or vein-like bodies cutting through the parent rock or any older rocks. Those that over a limited length may appear to be vein-like in form are usually found to become narrower toward each end and, finally, to pinch out, if a complete exposure of the whole body can be seen. Such vein-like, or actually lens-shaped, bodies are commonly called dykes to distinguish them from veins of hydrothermal origin. They may vary in width from an inch or so to over 100 feet. The term pegmatite dyke is also used loosely, but not very correctly, for a pegmatite of almost any shape.

The large amount of solid quartz in some pegmatite dykes has sometimes led prospectors to believe they were dealing with a true vein. Quartzose bodies of this sort can usually be recognized as pegmatites by the occurrence of feldspar next to the side-walls. In some cases these bands may be quite narrow relative to the quartz, which has a tendency to occur in the middle of the dyke, but may waver from side to side and displace the marginal feldspar in places. The presence of an occasional crystal of mica in the quartz, or areas of 'smoky', that is, dark-coloured to almost black, quartz or of rosy-coloured quartz, is also an indication of pegmatitic origin. However, as previously mentioned, there is believed to be a very intimate relationship between pegmatite dykes and quartz veins, the latter representing the final material from the cooling magma, carried in hot water solution and deposited later than the pegmatites, under cooler conditions, and usually farther from the parent intrusion. This conception can explain why veins are sometimes found in areas in which no granite outcrops are visible, the intrusive magma presumably having cooled at a considerable depth below the exposed rocks. Pegmatites, on the other hand, are usually found closer to, and more intimately associated with, outcrops of granite. Instances of pegmatite dykes passing into quartz viens have also been described.

Pegmatites may be of various geological ages. Even those derived from the same granite mass may cut one another. They are especially abundant in the Canadian Shield, perhaps because the Precambrian period was very long, nearly two billion years, and there was plenty of time for repeated magmatic invasions. They also occur, but less abundantly, with the younger granites of British Columbia and the eastern Maritime Provinces.

Granite Pegmatites. As previously mentioned, these are the most common and typical pegmatites, composed mainly of potash feldspar and quartz, and in some cases carrying considerable mica. They are important for other reasons than their uranium and thorium content, as they are the direct commercial source of feldspar, muscovite mica, high purity quartz, beryl, columbite-tantalite, lithium minerals, and some gem materials. They have doubtless also contributed by their weathering, especially in unglaciated tropical countries, to the formation of monazite-bearing sand deposits.

Many granite pegmatites, especially in the Canadian Shield, have been found to carry small amounts of radioactive minerals, and a large percentage of such discoveries in Canada have been of this nature.

Various sorts of granite pegmatites are distinguishable by the arrangement of the quartz and feldspar and the coarseness of crystallization. Some simply resemble a coarse granite, with the quartz and feldspar grains of more or less equal size but much coarser than in granite. Others have the quartz and feldspar arranged in such a way as to form a pattern resembling oriental writings, and are called 'graphic' granite or pegmatite. This texture may vary greatly from fairly fine to very coarse. In a less common type the quartz and feldspar are separated into very large, relatively pure masses; this is the type of pegmatite that is sought as a source of commercial feldspar and muscovite mica, and, judging by past experience in Canada, is the sort most likely to contain appreciable amounts of radioactive minerals and other rare-element minerals as fairly large crystals or masses. Such 'segregated' pegmatites may have a fairly regular arrangement of the various minerals in zones parallel with the length of the dyke, with relatively narrow bands of soda-lime feldspars bordering the side-walls, followed within by wider bands of potash feldspar, which are separated by massive quartz in the middle zone of the dyke. It can be assumed that the order of crystallization was: soda-lime feldspars first, followed by potash feldspar, and lastly, by massive quartz. There may be a similar crude zoning of common and rare-element accessory minerals following the major structure of the dyke. Thus, in Parry Sound district, Ontario, a dyke worked for feldspar carried columbite-tantalite and monazite, most of which was confined to a zone composed mainly of scaly mica averaging about a foot wide next the side-walls. A dyke in the Bancroft area, central Ontario, that was worked for feldspar, contained large masses of intergrown quartz and calcite, in parts of which very considerable quantities of complex radioactive minerals were concentrated. In this case, the quartz, calcite, and radioactive minerals were apparently the last to crystallize. Such localization of deposition of rare-element minerals in pegmatites might permit them to be recovered economically in some instances, but in general pegmatites are not favourably regarded as possible commercial sources of uranium for reasons already mentioned.

The radioactive minerals found in pegmatites are likely to carry both uranium and thorium, and most of them are of very complex chemical composition. The commoner ones are members of the euxenite, fergusonite, samarskite, and pyrochlore groups composed largely of oxides of the rare earths, titanium, tantalum, columbium, uranium, thorium, and commoner elements in widely varying proportions. Uraninite, thorite, uranothorite, and monazite are also fairly common. Allanite is perhaps the most widespread radioactive mineral of all in pegmatites, and it occurs as minute crystals in some granites. Individual examples of any of these minerals from different places vary so much in uranium and thorium content that identification of one of them as belonging to a certain group does not necessarily allow the uranium and thorium contents to be very closely inferred, though these do vary within certain limits for species and groups. In some instances it is difficult or impossible to identify some of these minerals without more or less complete chemical analyses.

Radioactive minerals in pegmatites may usually be easily recognized as such and distinguished from inactive minerals without a Geiger counter by: (a) the occurrence of a reddened area surrounding the mineral, if it is in feldspar, and (b) by cracks radiating in all directions from the active mineral if it is in quartz, feldspar, or mica. These indications show best on freshly broken surfaces, and may not be easily recognized on old weathered outcrops without careful examination. Other indications pointing to the possible presence of radioactive minerals in a pegmatite are the occurrence of smoky quartz and very dark purple or almost black fluorite.

There may be a family resemblance among pegmatites of certain areas as to their general nature and mineralization. Some instances may be mentioned: many pegmatites of the Yellowknife area, Northwest Territories, carry columbite-tantalite, cassiterite, and beryl in small quantities, but no radioactive minerals have yet been found in them; the pegmatites of southeastern Manitoba carry relatively large amounts of lithium minerals, with a little beryl, and instances of cassiterite-bearing pegmatites are also known in Manitoba. The so-called Grenville area of the Canadian Shield in southern Ontario and Quebec, on the other hand, is characterized by pegmatites showing a much more varied assemblage of rare-element minerals, and some of them have been relatively rich in radioactive minerals. Such areas might be called geochemical provinces, and in some instances there may be local sub-provinces, as in the case of the Bancroft-Wilberforce area in central Ontario, where calcite-bearing granite pegmatites and calcite-fluorite-apatite pegmatites are characteristic of a relatively small area.

Pegmatitic Schist or Migmatitic Deposits. Radioactive minerals have been found in several localities disseminated as rather fine crystals or grains in pegmatitized biotite gneisses or schists. These may consist of thin, alternating bands of pegmatitic material and gneissoid rock rich in biotite or, in other instances, the bands or alternating bodies of pegmatite and gneiss may be wider and more distinct. The biotite-rich bands may carry more of the radioactive minerals than the pegmatite in such instances. Deposits of this nature have been found in the central Ontario area, in the Black Lake (or Charlebois Lake) area of Saskatchewan, and in the Great Slave Lake area.

Diorite Pegmatites. The use of the term pegmatite for coarse-grained, later phases of almost any deep-seated igneous rock has been noted previously. A deposit in the Northwest Territories in which fractures have been filled mainly with rather coarse, fibrous, high-iron actinolite and minor calcite, magnetite, fluorite, and apatite, is believed to be the product of a magma from which granodiorite rocks in the area were derived. Granodiorites are more basic rocks than granites, composed mainly of plagioclase feldspar and iron-magnesium minerals such as hornblende, augite, and biotite, with minor potash feldspar, and quartz. The active minerals identified from this occurrence are uraninite and radioactive apatite. The latter is fluor-apatite carrying some rare earths. It is quite abundant in places.

Calcite-Fluorite Pegmatites. A rather unusual sort of radioactive mineral deposit is typical of the Wilberforce-Bancroft area. Bodies in the form of veins or dykes combine features of both pegmatites and veins, and have been called pegmatitic vein-dykes. The bodies are very irregular, pinching and swelling, and in places including horses of country rock. The filling is mainly intimately interbanded, sheared calcite and fluorite. The fluorite is a very dark purple variety that may be almost black in places when freshly mined, and some of it may give off a peculiar odour when hammered. Other minerals that occur with the calcite-fluorite intergrowth are: feldspar, apatite, black hornblende, pyroxenes, magnetite, molybdenite, titanite, zircon, uraninite, uranothorite, and allanite. The feldspar is mainly confined to relatively narrow bands next to the side-walls. Very large crystals of uraninite up to 5 pounds in weight have been found in the blackish fluorite of one of these deposits.

These bodies seem to combine some of the features of pegmatites, contact metamorphic deposits, and hydrothermal veins, yet they appear to be essentially pegmatitic in origin. They probably represent a relatively low temperature pegmatitic phase characterized by an abundance of hot solutions.

It cannot be said that this type of deposit has yet been sufficiently well explored to fully determine the economic possibilities of combined production of fluorite and uranium minerals.

(3) *Hydrothermal Deposits*

Vein deposits are supposed to have been formed by precipitation of the minerals composing the vein-filling from hot water solutions. Such hot water solutions may be actually in vapour form in their earlier, hotter stages. They are believed to carry elements such as fluorine, boron, sulphur compounds, and gaseous carbon compounds, which act as 'mineralizers' by helping to keep some elements in volatile form or in solution. Cooling intrusive granite magmas are believed to be especially productive of such residual mineral-bearing solutions or vapours, more so than magmas composed of more basic rocks. This, together with the greater uranium content of granitic rocks leads to the general belief that pitchblende vein deposits are derived from granitic magmas. However, in order that such deposits can be formed there must be channels to carry the hot liquids or vapours from the cooling magma to still cooler places in the surrounding rocks where the vein minerals can be precipitated. Such channels for circulation of mineralizing solutions result from strains or movements in the crustal rocks causing shearing, fracturing, or faulting. Without such openings there can be no vein-type deposits of appreciable size or grade. The prospector should, therefore, above all, look for and carefully examine any areas of rock showing indications that such fracturing has occurred.

Pitchblende may occur in veins, systems of veinlets, or disseminated as minute grains in the rock near veins or veinlets. Many Canadian deposits consist of a series of veinlets or lenses lying either parallel with one another or occupying two or three sets of fractures, with each set at an angle to the others. The individual stringers and lenses in such deposits are rarely large enough to be of importance, but if they are spaced closely enough they may, altogether, form orebodies of workable size and grade, especially if pitchblende is also disseminated between them.

Many of the most important pitchblende discoveries in the Northwest Territories and in Saskatchewan occur either within strong northeasterly trending fault zones or in fracture systems and crushed zones close to such fault zones. Such zones, many of which are shown on geological maps, offer favourable localities for prospecting. Air photographs are often useful in suggesting the possible presence of faults, although by no means all lineaments appearing on air photographs are faults.

Some deposits contain small lenses and veinlets of almost pure pitchblende. Most deposits, however, have a gangue of quartz, or carbonate minerals, or both. Most deposits, also, contain hematite, which may be very intimately associated with the pitchblende. Not only does hematite occur in the veins, it also commonly impregnates the adjoining rocks to form the brick-red alteration zones and red, feldspathic rocks that characterize many pitchblende deposits. The hematite of some deposits is, in part, the variety specularite. Some pitchblende deposits carry native silver, complex cobalt-nickel minerals, chalcopyrite, pyrite, and galena. A few carry gold, platinum, molybdenite, selenium minerals, and other minerals. Primary radioactive minerals other than pitchblende that are known to occur in Canadian pitchblende deposits are relatively rare. Thucholite has been found in a few deposits in the Northwest Territories and Saskatchewan and may eventually prove to be more widespread than it appears to be at present. A few microscopic crystals of the crystallized form of uranium oxide have been identified in one of the deposits of the Goldfields area, Saskatchewan.

Almost all known Canadian pitchblende occurrences are in the Canadian Shield, and most of these are confined to three main regions: a belt extending from the east side of Great Bear Lake to the vicinity of Yellowknife; a belt along the north shore of Lake Athabasca extending eastward to Black Lake; and a region at the east shore of Lake Superior near the mouth of Montreal River.

It is not possible to make any country-wide generalizations as to the kind or age of rocks most favourable for the occurrence of pitchblende, but what appear to be the most favourable rocks in some individual regions may be noted. At Great Bear Lake, the most favourable rocks are altered sedimentary and volcanic rocks; at Lake Athabasca, many of the better deposits occur in basalt and other dark-coloured rocks, locally called 'mafic' rocks, or in altered limestone or dolomite. In the Lake Superior region, most of the deposits are associated with diabase dykes that cut granitic rocks, the pitchblende occurring as fracture fillings either in the diabase itself or in the granite adjacent to the dykes. It is, perhaps, also significant that most of the known pitchblende deposits, whether they occur in rocks believed to be of late Precambrian age or in the older Precambrian rocks, are in areas that have been affected by folding, faulting, and fracturing, considered by geologists on the basis of field observations to have occurred in late Precambrian time. However, there has not yet been enough age determination work done on the pitchblende deposits, by methods using atomic disintegration, to decide whether this view is correct or not.

Pitchblende has been found as a minor constituent in gold-bearing deposits and associated with ores of silver, copper, lead, zinc, tin, and molybdenum in veins and related deposits. The possibilities of recovering uranium as a by-product along with the more important valuable metals present should not be overlooked in considering such deposits, even if they are low grade, provided the deposits are large. An example of the possible importance of such deposits is the case of the gold deposits of the Rand area, South Africa, which have been considered by competent authorities to constitute the greatest reserve of economically extractable uranium known anywhere. The uranium occurs mainly as extremely minute inclusions of pitchblende in thucholite. Owing to the fact that the ore carries sufficient gold values to be workable for the gold alone, it is believed that the uranium can be extracted also at relatively little extra cost.

Uraninite-bearing Base Metal Deposits. Certain mineralized bodies in British Columbia that were opened up originally because of the presence of such minerals as gold, cobalt-nickel-bearing arsenides, and molybdenite, have been found to carry microscopic grains or, rarely, what appear to be crystals, of uraninite. These deposits have been classed as veins by some geologists, as pegmatites by others. It would seem that they have some characteristics of both, but because of the high content of metallic minerals they have usually been considered to be vein deposits.

Pitchblende-bearing Veins with Simple Mineralization. Pitchblende may occur alone as a vein filling, but more commonly it is associated with hematite and usually with quartz or carbonate or both. Very small amounts of sulphides or other minerals may be present, but the mineralization on the whole is relatively simple. The pitchblende deposits of the Sault Ste. Marie, Ontario, region, many of those in Saskatchewan, and the 'giant quartz veins' of the Northwest Territories belong to this class.

The rather unusual, huge, quartzose bodies called 'giant quartz veins' are abundant in Northwest Territories. They are large bodies of quartz and silicified rock, commonly 100 feet or more in width and traceable for miles. Many of them lie in northeasterly trending fault zones. It is not unusual for these bodies to carry thin seams of pitchblende and hematite in small fractures, and some of them contain small masses of pitchblende as well. Deposits of this sort have not yet proved to be important as the amounts of pitchblende found in them have usually been relatively small.

Pitchblende-bearing Veins with Complex Mineralization. Some vein-type deposits such as those of the Eldorado mine and the Contact Lake deposit in Northwest Territories and the Nicholson and one of the Fish Hook Bay deposits in Saskatchewan, carry a great variety of minerals other than pitchblende. Quartz, calcite or other carbonate minerals, and hematite are common; native silver, cobalt-nickel minerals, pyrite, chalcopyrite, selenide minerals, vanadium minerals, gold, and platinum have been known to occur.

Selenium minerals also occur in small amount in the Sault Ste. Marie area.

Disseminated or Replacement Deposits. Some deposits near the south shore of the east arm of Great Slave Lake consist of radioactive zones or bands in dolomite. Such zones on the average carry much more thorium than uranium. The active minerals that have been identified are very minute grains of monazite and pitchblende or uraninite. It is not yet known for certain whether these dolomites are entirely of sedimentary origin, with the active minerals as original constituents, or whether the active minerals have been introduced into the dolomite by hydrothermal solutions. The dolomite itself, in places at least, has much the appearance of a hydrothermal deposit. A few uranium deposits in other parts of Canada are classed tentatively as replacement deposits.

(4) *Sedimentary Deposits*

Some Canadian black shales and low-grade phosphate rocks that have been tested showed a low radioactivity comparable to that of granites.

The radioactive dolomite of Great Slave Lake may be of sedimentary origin, according to some geologists.

(5) *Secondary Deposits*

Known Canadian occurrences of secondary uranium minerals consist mainly of relatively small amounts of such material in the near-surface parts of primary deposits, coatings on rock in mine workings and dumps, and, occasionally, in soil or gravel near outcrops of primary deposits from which uranium has been leached by surface waters, carried into the soil, and reprecipitated there.

There is, of course, in many cases, evidence of much alteration at and near the surface of pitchblende deposits, and even to considerable depth in some instances. The pitchblende may be almost completely altered to a material much lighter in weight that contains water and silicic acid, and coatings of yellowish, orange, or greenish minerals may be present. These brightly coloured films are mostly sulphates, carbonates, and uranates of uranium, with other elements. The bright yellow coatings are in some instances thought by prospectors to be carnotite, but this mineral is rarely identifiable among such coatings, in Canada. For practical purposes it is sufficient to refer to such materials as uranium stain, uranium ochre, or coloured uranium alteration products.

The secondary uranium minerals carnotite, torbernite, and autunite, which have been known to form relatively small but workable deposits in some more southern, unglaciated countries, are less apt to be found in important commercial quantity in Canada.

No deposits of secondary thorium minerals are known in Canada, nor does there appear to be any record of the occurrence of such deposits elsewhere. Apparently thorium minerals are less easily altered by surface waters, and any thorium that does go into solution is probably much more quickly precipitated than is uranium, so that secondary thorium does not travel far. This is confirmed by the fact that sea water has been found to contain at least three times as much uranium as thorium.

(6) *Placer Deposits*

Most radioactive samples from placer deposits in British Columbia have been found to contain thorium rather than uranium, but a few showed uranium by chemical analysis.

Very large deposits of monazite-bearing beach and stream sands and gravels occurring in India, Ceylon, and Brazil have been the world's main sources of thorium because of the ease of separating and concentrating the monazite at low cost. Other thorium minerals, thorianite and thorite, may also be present in minor amount, and other saleable products from the concentration treatment may be ilmenite, zircon, rutile, and in some instances a little gold. Some monazite and zircon concentrates are also produced as a by-product of alluvial tin mining in Malaya. The primary thorium minerals of the sands or gravels have, no doubt, been derived from the weathering of granitic rocks in the first instance, and have been greatly concentrated by natural water action. Small, low-grade deposits of monazite of this nature have been found in British Columbia and the Northwest Territories, but have not been promising commercially.

Pitchblende and uraninite have not been found in commercial quantities in placer deposits in any part of the world, probably because they are too easily decomposed.

Prospectors and placer operators should not overlook the possibility of finding radioactive minerals in placers. Even though they may occur in only very small quantities they might suggest the possible presence of primary deposits in the area from which the placer material was derived. Placer concentrates can be tested with a portable Geiger counter, and if found to be noticeably radioactive, samples should be submitted for laboratory examination. A rough concentration can often be effected by panning with a gold pan. When forwarding samples to the Geological Survey for testing, both original unconcentrated material and concentrates should be sent, if possible.

Summary of Data Applicable to Prospecting for Canadian Pitchblende Deposits

(1) Within the Canadian Shield, vein-type deposits of pitchblende are largely in areas in which late Precambrian (Proterozoic) rocks are found.

(2) Lack of outcrops of granite in a Precambrian area does not necessarily mean that the area is unfavourable for prospecting. The uranium-bearing, hydrothermal solutions that form pitchblende deposits are believed to be able to travel long distances laterally and upwards from their granitic sources.

(3) Particular attention should be given to areas in which major faults occur; not only the larger breaks, but also minor, subsidiary fractures in the general vicinity should be investigated.

(4) Pitchblende deposition may be simple or associated with abundant and complex sulphide and arsenide mineralization, with minerals of cobalt-nickel, iron, copper, lead, zinc, molybdenum, and, in some instances, with minor amounts of selenides, silver, gold, platinum, and tin. Quartz and carbonate are the usual gangue.

In the western part of the Canadian Shield particularly, pitchblende is very commonly, and in some instances very intimately, associated with hematite and its variety, specularite. Red wall-rock alteration near fractures, due to impregnation by hematite, quartz, and/or feldspar, is especially noteworthy.

(5) In general, pitchblende deposition appears to favour rocks unlike granite in composition, such as basalts, amphibolites, greenstones, and dolomites. There are, however, small deposits in other rocks such as granite-gneiss and quartzite.

FOREIGN URANIUM DEPOSITS

The chief types of deposits known to occur in foreign countries but up to the present not of proved importance in Canada are: deposits of carnotite and related minerals; deposits of torbernite and autunite; black, carbonaceous, bituminous or oil shales; and phosphate rocks. Most of these have been mentioned previously, but may be summarized here.

The carnotite-bearing sandstones of Colorado and Utah, United States, are well known. They produced very important amounts of uranium, radium, and vanadium intermittently over a long period of years and are still producing. The sandstones themselves are mostly of Jurassic age and are believed to be continental deposits, that is, formed in lakes, etc., rather than on the open sea bottom. Nothing is definitely known as to just how the carnotite got into the sandstone, whether precipitated there by solutions carrying uranium and vanadium, or deposited as such along with the sand grains. Nor is the location of the primary sources of the uranium and vanadium definitely known. The individual deposits are not large nor of very high grade, but there seems to be almost unlimited possibilities of their occurrence, the difficulty being to find them.

Torbernite and autunite are secondary micaceous phosphate minerals that have occurred in deposits of workable grade in a few places, notably in Portugal. They may be found, rarely, in very small amount as mineralogical specimens among other alteration products of Canadian primary uranium minerals. There are also two instances of the occurrence of torbernite or meta-torbernite in some quantity in Canadian deposits, one in the Northwest Territories and the other in Nova Scotia. Autunite occurs in Precambrian sandstone in Saskatchewan.

In other countries, commercial grade phosphate rock used for making fertilizer may eventually prove to be a source of by-product uranium. The only known Canadian deposits of such material in western Alberta and British Columbia are low grade with respect to both phosphate and uranium content, and are not being used to make fertilizer. In phosphate rock, the uranium content is likely to be proportional to the phosphate content.

Black shales have also been mentioned previously. No Canadian examples carrying much over 0·005 per cent U_3O_8 equivalent activity have been found, but in Sweden a black, carbonaceous material called 'kolm', occurring with alum-bearing shales, is reported to carry up to 0·5 per cent or more of uranium in places.

DEVICES AND METHODS FOR DETECTING RADIOACTIVITY

Although radioactivity may be detected in a number of ways, the most practical instruments for prospectors' use at present are Geiger counters and scintillation instruments. These instruments will, therefore, be described first, and the others will be referred to briefly.

PORTABLE GEIGER COUNTERS

Applications and Selection

In recent years, improvements in portable Geiger-Mueller counters have made them the most useful and practical aid in prospecting for radioactive minerals that is available at a moderate cost. Gamma scintillation equipment so far available is more sensitive and efficient in detecting gamma radiation, but is much more expensive.

The fact that these instruments are still in course of development has resulted in a diversity of types, models, and prices of portable Geiger counters, which, judging from the number of letters received by the Geological Survey, is rather confusing to prospectors who wish to purchase one. In order to help the prospector unfamiliar with these instruments in selecting one to suit his particular needs and pocket-book, and to save him the time and trouble of personally applying to the different manufacturers or selling agents, the Geological Survey, Radioactivity Division, has assembled and tabulated the data pertaining to instruments offered for sale in Canada. Copies of these Geiger-counter Data Sheets may be obtained free on application to the Director, Geological Survey of Canada, Ottawa.

Use of Geiger Counters by Amateurs

Letters received from those interested in using Geiger counters for prospecting often imply that the inquirer has some doubt as to his ability to take care, or make good use, of the instrument. It may be said that no one should hesitate to acquire a counter for such reasons. Anyone capable of turning a switch or changing dry batteries in a portable radio can understand the simple mechanics of operating a counter, and the ability of the instrument itself to detect radioactive radiations puts the amateur prospector almost on a par with the most experienced veteran so far as the chances of finding uranium are concerned. The manufacturers supply instructions for operating their instruments, but if the purchaser of a portable counter is in any doubt as to details of its operation he should write the manufacturer or agent who sold it.

In testing the action of the instrument, a watch or compass with luminous dial or small specimen of radioactive mineral is very useful. For this purpose, the Geological Survey offers for sale, at 50 cents each, small specimens of the pitchblende ore from Great Bear Lake. These are sent postpaid to bona fide prospectors in Canada upon receipt of the amount of the charge in the form of a postal note or money order made out to the Receiver General of Canada. Requests for these specimens should be addressed to the Director, Geological Survey of Canada, Ottawa. Stamps or checks are not acceptable.

In making use of these specimens, care should be taken not to contaminate the hands, clothing, or instrument with radioactive fragments or dust from the specimen. It is best not to carry or handle the specimen directly, which is not necessary if it is kept in a small metal box with cover.

Essential Components of a Geiger Counter

The fundamental part of a portable Geiger counter is the Geiger tube or counter tube itself, which is affected by certain radiations from radioactive substances. The rest of the working part of the instrument is simply an electronic device, much like a radio set, to amplify and register the indications received by the counter tube, either as clicks in earphones or by means of a meter. It is possible to construct a counter without amplifying tubes, but most models have one or more of these. Much of the total weight and bulk of many models is due to the dry batteries used to supply current to the Geiger tube and the amplifying tubes. The amplifying tubes are the same as those used in ordinary radios or hearing aids. They require low voltage current to heat their filaments, and are supplied by the A battery, which, consequently, is exhausted relatively quickly when the instrument is in use, as the amplifying tubes are using full current whenever the instrument is in operating condition, whether weak or strong radioactive radiations are being tested. The high voltage supply delivers a current of, usually, 900 to 1,000 volts, but in some counters at about 300 volts, to the Geiger tube, and when only background or weak radiations are being received the drain on the B battery is relatively slight. In any case, with reasonable use the amount of high voltage current used is relatively little; hence the B batteries ordinarily last much longer than the A supply. Some portables use enough B batteries in series to build up the required high voltage for the

Geiger tube entirely from the batteries, which implies considerable bulk, weight, and cost for the batteries. Others use a smaller and relatively low-voltage B battery associated with a device called a vibrator circuit, which delivers the required high voltage. Thus, a saving in battery size, weight, and cost is effected by use of the vibrator circuit when the high voltage load is relatively heavy.

The Geiger tube or counter tube, which is the heart of the device, is usually an elongated cylindrical glass tube, closed at both ends, with a thin wire centred longitudinally and a cylindrical metal electrode (gamma type) or metal plating, usually silver (beta-gamma type), on the inside surface of the glass wall of the active part. This is called the cathode. The gamma type of counter tube is made throughout of fairly thick glass or, in some instances, of metal; the beta-gamma type has the glass walls of the sensitive area drawn out very thin; hence this type is more fragile. However, some beta-gamma tubes are being made of very thin metal, and there is an end window type, which has a very thin window, usually of mica. The centre wire and outer electrode are insulated from each other and are connected in the circuit in such a way that the high voltage current passes momentarily between them when radiations strike the tube, penetrate it, and render the low pressure gas contained in the tube conductive to electricity for a small fraction of a second. The tube is filled with a mixture of gases under low pressure, the function of which is to prevent this high voltage discharge between the electrodes from continuing for more than a very minute fraction of a second. This repressive action is called quenching. Most portable Geiger counters use self-quenching tubes of this type. With use, the gas that does the work of quenching the discharge gradually becomes decomposed and the tubes have to be refilled or replaced, but the tubes should give several seasons of ordinary service before needing replacement, unless broken or otherwise mechanically damaged. Operating them at too high a voltage will tend to decrease their life. In operation, each passage of high voltage current between the electrodes of the counter tube is registered as a click on the earphone or helps build up the reading on the meter, when the instrument has one. Each click thus indicates that one atom has disintegrated and has been detected by the counter tube. Because in any given quantity of uranium, thorium, or potassium a definite percentage of the atoms disintegrate per minute on the average, and a given counter tube will detect a fairly constant percentage of the radiations passing through it, the number of clicks a minute gives an indication of the amount of radioactive element that is affecting the instrument. The meter that is supplied on the larger, more expensive, instruments serves the same purpose. It is connected with an electrical circuit designed to show on a dial the rate at which the clicks occur. It may be noted, when using the earphones in testing, that the response of the instrument, as shown by the increase in the rate of clicking when brought near an active source, is instantaneous, whereas the meter requires considerable time, usually 1 minute to 3 minutes, to reach its full reading. For this reason the earphones should always be used in prospecting. The meter circuit is essentially an averaging device. It can be built to react quickly to a change in radiation intensity, but the more quickly it reacts the more widely the needle will fluctuate, so that it would be difficult to take an average reading under such conditions. The longer the time during which the meter circuit builds up an average the steadier the needle will be and the more accurate the reading. In some instruments, for example the scintillometer, this time can be varied by a suitable control. Meters are usually connected with a switch by which they can be used to read three or more ranges of radiation intensity, usually increasing by a factor of ten. In some models the meter can also be used to check the A batteries and the high voltage applied to the counter tube. The calibration on meters may represent electrical units, milliroentgens, or counts per minute. The latter type seems to be preferred by many prospectors, as it is simple and dial readings can be directly related to earphone counts.

Most portable Geiger counters have the batteries, high voltage supply, amplifying circuit, and meter, if there is one, contained in a metal case, which in many models also houses the counter tube or tubes. When the counter tube is inside the case it is generally at the bottom, but in at least one model it is at one side of the case. It is worth while learning the exact location of the counter tube so that small or low grade specimens may be brought up as close as possible to the most sensitive part of the tube when testing. Some models, however, have the counter tube contained in a metal cylinder called a 'probe' and connected by a cable to the circuit inside the case. The most sensitive part of such a probe will be, usually, about the middle region of its length if the counter tube is of the usual cylindrical type. If the tube, however, is of the highly sensitive end window type, the end of the probe will be the most sensitive area. A model offered for sale in the United States has the counter tube at the end of a 3-foot, cane-like, aluminium tube, enabling the operator to carry it close to the ground or hold it near, or on, the rock without stooping.

Some instruments are built in such a way as to be, except for the headphones, completely waterproof. Such instruments also usually have a drying agent inside the case, and they may be, in some respects, of superior construction. Instruments intended for use in the tropics are of this nature.

The overall weight and bulk of prospecting counters are important considerations. Several models of about

2 pounds weight and small enough to go into a pocket are now available in Canada and the United States. Such models are equipped only with earphones, but are suitable for prospecting, and their lighter weight and lower cost make them popular with many prospectors.

Most portable Geiger counters used for prospecting in Canada up to the present have been equipped with gamma type counter tubes. These are affected only by the highly penetrating gamma radiation, which is much like x-rays, and which is capable of penetrating several inches of rock. Even the best specialized gamma tubes are very inefficient in detecting gamma radiation; only a relatively small number of the gamma pulses that pass through the effective volume of the tube cause it to register. Although such things as the nature and pressure of the gas filling of the tube, the thickness and nature of the cathode, the voltage applied to the tube, the operating temperature, and perhaps other factors, affect the efficiency of the tube to some extent, for practical purposes, assuming the efficiency of commercial tubes to be more or less equal, the sensitivity of a portable Geiger counter will depend on the effective area[1], that is, the size of the counter tube or tubes. The smaller and lighter Geiger counters generally have rather small counter tubes with effective areas varying from 1·4 to 2 or 3 square inches, whereas a large 3-tube model on the market has 18 square inches of effective tube area. Needless to say, such a counter is much more sensitive than one having only a small tube. Thus, if a prospecting project involved working in country with few rock exposures, widespread overburden, or

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[1] The effective area or, more properly, effective projected area, is the product of the length and diameter of the sensitive part of a cylindrical tube. It represents approximately the area that would be receptive to radiation from a point source. For a tube placed close to a large area showing more or less uniformly distributed activity, the receptive area of the tube becomes very much greater than the projected area.

with snow and ice on the ground, the most efficient detector would be one with the greatest possible effective counter-tube area. Such a counter should also pick up radioactive radiations at a somewhat greater distance from the source than one having a smaller effective area.

On the other hand, any portable counter, even those with the smallest tubes, will readily detect uranium deposits of much lower than commercial grade if these are exposed at the surface. Their smaller size, weight, and cost recommend them to many prospectors. The upkeep for batteries and repairs is also very much less for this type.

The beta or, more correctly, the beta-gamma type of counter tube is sensitive to both beta and gamma radiation, but is likely to be less efficient on gamma radiation than a regular gamma-type tube.

The effectiveness of a tube for gamma detection depends largely on the thickness and density of the material of the metal cylinder or coating that forms the cathode just inside the glass envelope. This should be of considerable thickness for best gamma results. On the other hand, both tube and cathode must be very thin for high efficiency in beta detection. The efficiency of a beta tube for beta radiation may be very high provided the thin or 'window' part of the tube is thin enough to allow the greater part of the beta energy spectrum to penetrate into the interior of the tube. Beta particles have relatively little range in air or penetrating power compared with gamma rays, hence a beta counter is most effective when used close to the unshielded radioactive source. When so used, however, beta counters are several times as sensitive as gamma counters, and, therefore, are much more suitable for testing small hand specimens of rocks and minerals, small isolated grains of radioactive minerals, or for locating small areas of relatively low activity, than are gamma counters. Meter-type beta counters that have the tube in a heavy, lead-shielded probe are especially useful for this purpose or for taking readings across a mineralized vein or orebody. Such readings, taken where channel samples are cut, may be subsequently compared with the assay results on the channel samples and thus permit rough grade estimates to be made by means of the Geiger counter alone at other places in the deposit.

The ability of a gamma-type Geiger counter to detect radiations from shielded material will depend on a number of factors:

(1) The effective or sensitive area of the counter tube
(2) The efficiency of the counter tube or tubes
(3) The nature and thickness of shielding material
(4) The amount and grade of radioactive material that is shielded, that is, the content and distribution of uranium or thorium and their associated disintegration products occurring close to the shielding material
(5) Distance of counter from the deposit

Little need be said in regard to 1 and 2; their bearing is obvious.

The effectiveness of any sort of shielding material is greater, the greater the atomic number and density of its constituents. Solid pitchblende is thus a good shield for its own radiations. Experiments indicate that the average Geiger counter will not be much affected by a moderate amount of radioactive material that is more than 3 or 4 inches below the rock surface, and that about 1 foot to 1½ feet of rock should give nearly complete shielding. These figures, doubled to allow for the difference in density, might apply also to overburden, unless the overburden itself is radioactive, as is sometimes the case. Overburden might become somewhat active due to one or both of two possible causes: radon gas or thoron gas might escape from radioactive minerals underneath, diffuse into the overburden, and there complete its transformations to solid elements; or active products such as radium or its descendants derived from decomposing radioactive minerals might be carried by surface waters into the overburden and be deposited there.

In considering the effect of shielding, however, it must be remembered that the gamma rays from the various members of the uranium and thorium series differ considerably in energy and penetrating power. Although a moderate amount of shielding will make a very noticeable difference in the intensity of radiation from a given source, much more is necessary in order to approach complete shielding. The results are such that a sort of 'law of diminishing returns' applies, and, theoretically, a few high-energy rays from a powerful source, or induced secondary radiation might get through great thicknesses of shielding. This conception has, apparently, been proved to be true by exact scientific experiments using very special equipment, but such results would seem to be entirely outside of the field of the ordinary portable Geiger counter. Nevertheless, it could be inferred that a very rich deposit might produce a sufficient number of such highly penetrating rays as to be detectable through quite thick overburden provided the detection equipment had sufficient intercepting area and efficiency in detection.

The effect of distance of the Geiger counter from the radioactive source is extremely important. No doubt every purchaser of a Geiger counter soon learns that the closer the counter tube of the instrument is to active material the greater the number of counts or reading on the meter, and it seems natural that it should be so. Actually, the intensity of radiation from a 'point source', that is, a source of activity that is very small in size relative to the distance of the counter tube from it, follows the same 'inverse square law' that applies in the case of light, that is, the intensity varies inversely as the square of the distance from the source.

For example, if a counter tube one unit of distance away from a point source gave a reading of 900 counts per minute, at three units distant it would give a reading of $\frac{1}{3^2} \times 900$, or 100 counts per minute, and at five units distant it would give a reading of $\frac{1}{5^2} \times 900$, or 36 counts per minute. This is illustrated by Figure 2, in which the small black rectangle represents a counter tube at different distances from a point source and connected to dials that give the corresponding theoretical readings. The unit distances might be in inches, feet, or yards, or any multiples of these, such as 10 feet or 100 feet. This effect of distance is worth remembering in prospecting, because it shows that the Geiger counter must be quite close to an active deposit in order to detect it. At greater distances the deposit becomes in effect a point source, and the inverse square law comes into operation; rays from the deposit may be reaching the counter, but they are so thinly dispersed and irregularly timed and spaced that their presence may not be noticeable above other variations in the background count. Also, where considerable distances are concerned, the shielding effect of the air, especially on the less energetic gamma rays, would tend to weaken the intensity of radiation at a distance, whereas close up this effect is negligible. Further, as a deposit is closely approached it becomes no longer a point source but a source with a much greater radiating area relative to the position of the counter tube, and the intensity of radiation detected is, accordingly, very much increased.

The preceding theoretical treatment of this subject seems worth while in order to obtain a clear idea as to why small, portable counters cannot be expected to detect active deposits at any great distance. The very small sensitive areas of their counter tubes do not cover enough space to intercept an easily noticeable number of rays at any considerable distance from the source. In most instances, noticeable reactions may not be obtained until within 25 or 50 feet of a deposit;

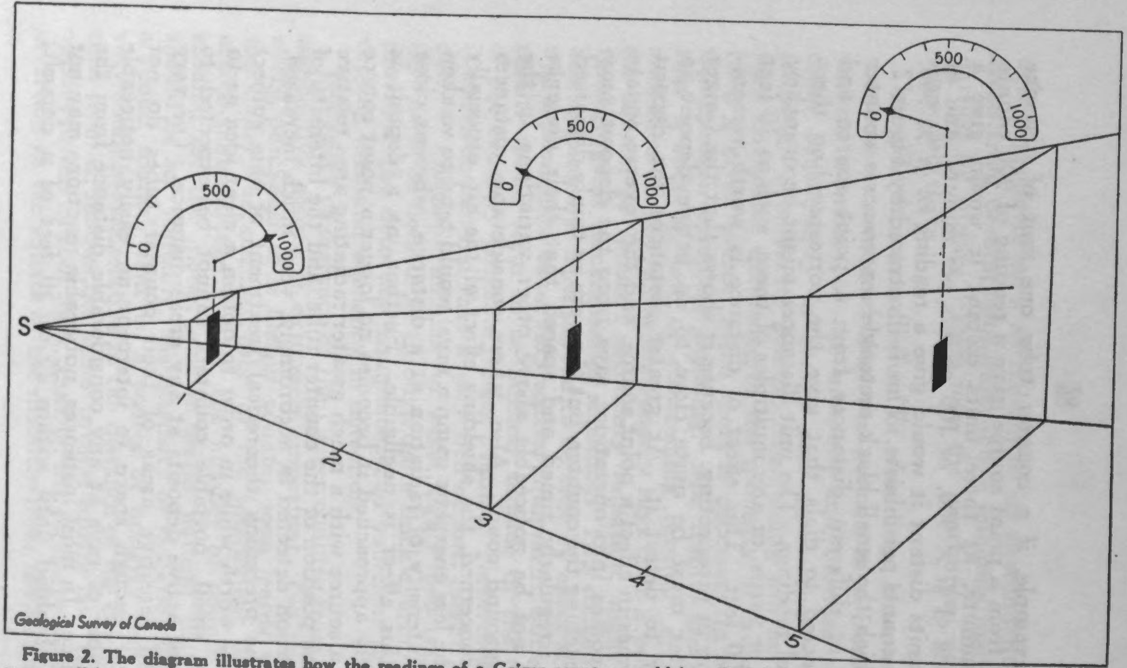

Figure 2. The diagram illustrates how the readings of a Geiger counter would be affected theoretically at varying distances from a very small 'point source' of radiation, S, due to the operation of the inverse square law. Gamma rays from S radiate in all directions, as from the centre of a sphere, forming a sphere of radiation. The same rays that pass through the first square at unit distance 1 spread out into the larger squares at unit distances 3 and 5. The small black rectangles and dials represent a Geiger counter with its readings of 900, 100, and 36 counts per minute at distances 1, 3, and 5 units respectively from the source S.

depending on local conditions and the richness of the deposit, it may be necessary to get even much closer than this. The time lag in response of meter instruments, too, is such that in walking, slight reactions may be missed, or attributed to variation in background, if the meter is being used. The earphones give a quicker and more sensitive indication once the ear has had some practice in judging the rate of clicking.

Temperature Effects

Some earlier types of counter tubes were subject to temperature effects. They would not operate at very low temperatures, and might be erratic at high temperatures. Newer tubes are better in this respect, and will operate at zero or lower temperatures. If the prospector in purchasing a counter expects to use it in very cold weather it might be well to have assurance from the manufacturer that the counter tube will operate properly at low temperatures. Batteries also lose their efficiency with increasing cold, and may need to be insulated or kept warm.

The usual effect of increased temperature on counter tubes is to slightly increase the number of counts received in unit time.

Effect of Light

Most glass counter tubes are affected by light, and may register at a very high rate when exposed to light. Some tubes may have a black coating on the outside to exclude light, and care should be taken not to scratch or injure this. In many tubes an internal metal coating serves as light shield and cathode.

Electro-magnetic Effects

Most counter tubes are somewhat affected by electro-magnetic rays produced by electric sparks, thunder storms, etc. In prospecting, bad weather conditions may render the portable Geiger counter useless for a time. Near operating mining machinery, too, it may be found that the counter is slightly affected. One type of Geiger counter was found to be quite noticeably affected by the starting and stopping of an electric elevator in a building, and it was also found to be slightly affected by a portable gasoline air-compressor at a mine, the high-tension ignition system of the engine no doubt being responsible.

Recording and Reporting Geiger Counter Readings

In recording readings it is always well to make full notes as to make, model, and serial number of the instrument, scale on which the reading is made, latest background reading, position of the instrument with relation to the rock exposure, that is, whether resting directly on the rock or held at some known distance from it, nature and shape of the rock exposure, and anything else that it is thought might influence the readings.

Samples for laboratory assay should be taken from the exact places where readings have been made on the rock exposure and should be tested by removing them to a locality where the background is normal and taking readings with the sensitive part of the instrument centred over the sample and actually in contact with it. Possible contamination of the instrument may be avoided by interposing a sheet of paper between samples and instrument, or the samples contained in a clean bag may be tested. Each sample should be turned in all directions and readings taken for each position and averaged. The size and approximate weight of samples should be noted.

Detailed notes of this sort along with the results of laboratory assays of the samples will assist in the interpretation of readings obtained with the particular instrument in use.

As the number of counts per minute or meter readings of different models of Geiger counters will vary considerably under identical conditions of exposure to radiation, due to differences in size and kind of counter tubes, calibration of meters, and for other reasons, it is desirable to have some way of comparing readings taken on different instruments. For this reason readings are often reported as so many times background, the background being a reading taken the same day where the instrument is away from noticeably active material. Actual tests of this method with various models indicates that though some models give fairly agreeable results, others may show wide variations.

Sample Testing and Assaying in the Field with the Portable Geiger Counter

It would be a great help to prospectors, especially in remote areas, if they were able to make quick, rough, on the spot, radiometric assays of raw materials in which they are interested. This can be done with a suitably sensitive Geiger counter of either beta or gamma type provided it has a meter. The scintillometer would also be well adapted for this use.

Hand specimens or rock broken up with a hammer can be very roughly tested, but for best results the samples should be crushed and ground to a reasonably fine powder, like very fine sand or finer, in a hand mortar. The procedure for the more accurate, fine-powder type of assaying requires considerable equipment, time, and the exercise of many precautions. It seems unlikely that many prospectors will wish to go this far in field testing, but those who do should write to the Radioactivity Division, Mines Branch, Department of Mines and Technical Surveys, Ottawa, for a copy of "Determination of Uranium in Ores by Field Analysis" by F. E. Senftle and C. McMahon, in which this subject is discussed in detail, and methods for testing solid specimens are also described.

The rough testing of hand specimens held near a Geiger counter can give some idea of their possible range of uranium content if suitable standards for comparison are available. There are so many complications involved, however, that the subject cannot be discussed in detail here.

The Use of Geiger counters and scintillometers in prospecting is described on pages 80 to 90 of this booklet.

SCINTILLATION-TYPE DETECTORS

Scintillation-type detectors are based on the fact that alpha, beta, and gamma rays will cause microscopic flashes of light in certain natural and artificial crystalline substances. Some substances, such as activated zinc sulphide, react only to alpha rays, whereas others are very efficient beta and gamma detectors. Much research devoted to this subject has resulted in the discovery of some very efficient scintillators. Those commonly used are specially grown artificial crystals.

As each alpha, beta, or gamma ray that strikes an appropriate scintillator causes only a single flash of very short duration, it is possible, by suitable means, to count the flashes or have them register on a meter. The scintillating crystal is the primary detector in these instruments as the counter tube is in Geiger counters, but in order to utilize scintillators in electronic circuits the light flashes must be converted to pulses of electricity. This is done by a 'photomultiplier' tube, which has a light-sensitive window fixed in contact with the scintillator. This tube delivers a highly amplified pulse of electricity for each flash that occurs. The rest of the circuit is for further amplification and registration of the electric pulses, as in the Geiger counter.

Scintillation-type equipment is now produced commercially. Two types, a portable gamma model with meter, and a portable alpha model, with earphones only are available in Canada. Both have some important advantages over ordinary portable Geiger counters for specialized uses. The gamma 'scintillometer', as it is called, is much more sensitive than a portable Geiger counter. It is especially well adapted for making detailed surveys, and it is credited with having detected radioactive mineral deposits under considerable thicknesses of overburden. The high sensitivity of the instrument and the location of the scintillator in the end of a large probe also make it very suitable for rough field assaying of samples. This could be done by making a support for the probe to hold it in a fixed vertical position. Crushed samples contained in trays could be placed in a fixed position just beneath the probe and compared with standard samples under similar conditions.

The 'alpha scintillation monitor', as it is called, is a small portable instrument with an alpha-sensitive probe. This detector has the advantage of being almost entirely free from interference by other types of radiation, so that there is almost no background. It is, therefore, particularly well adapted to detailed study of the distribution of radioactive material exposed at the surface of deposits, especially underground or in openings, where beta and gamma radiations from many directions may affect a Geiger counter. As the range of most alpha radiation is not much more than 3 inches in air, the probe must be held very close to the source of activity for best results. The face of the probe in this instrument contains the scintillating screen, which is covered by extremely thin aluminium foil to exclude light. Care should be taken to avoid the slightest injury to this aluminium foil as this would permit light to enter and prevent operation of the instrument. Unfortunately, too, the aluminium foil prevents the less energetic alpha particles from striking the screen, so that instruments of this type are usually only about 50 per cent efficient.

PHOTOGRAPHIC TESTS

Radioactive radiations affect photographic plates or films in much the same way as light does. This fact provides a relatively simple way of detecting the presence of uranium and thorium in rocks and minerals, and of locating a radioactive mineral in a specimen.

Any photographic plate or film may be used, but it is absolutely essential that the plate or film be completely protected from light. In a dark room, a roll of film may be cut into pieces of convenient size, say 3 by 4 inches, and each piece sealed in an envelope made of black, photographic paper, in which it should remain until developed. It would be all the better to place this envelope inside a similar but larger one. It is best to keep the envelopes with enclosed films in a light-proof metal box well away from any radioactive material.

As the effect of radioactive minerals on a photographic plate is slow, it is advisable to first concentrate them from gangue or rock by crushing and panning before making the test, unless the material to be tested is a fairly pure single mineral suspected to be pitchblende or a radioactive mineral from pegmatite. By panning a crushed rock the radioactive minerals will, in most instances, be concentrated in the heavy tail. To make the test, an envelope with enclosed film may be placed on a flat surface, where it will be undisturbed, with a small, flat metal object, such as a coin or key, on top of the envelope. The heavy tailing or other crushed material to be tested may then be distributed as evenly as possible over the coin and around it but not over the whole plate, and a box or can placed over the whole to protect it further from light or disturbance. Pure pitchblende will produce a 'radiograph' or outline of the coin in about 12 hours, but it is advisable to leave the test undisturbed for a week or longer, if possible.

When sending film to be developed, it is well to mark on each envelope the sample number or other description of the test, and in the covering letter to explain what the film was used for, the kind of film, and to request that contrast developer be used to develop it. It is not necessary to have prints made, as any effect on the film should be visible.

The photographic method is particularly useful for locating radioactive minerals in a specimen, if a dark room or suitable substitute is available. The specimen is ground flat on one side, using alundum, carborundum, or emery powder and water on a glass plate or flat metal surface, finishing with a fine grade of abrasive. It is not so easy to produce a flat surface by rubbing the specimen on an abrasive stone, but a small specimen might be prepared in this way. The specimen is thoroughly cleaned and dried, and the ground side is placed directly on the emulsion coated side of the plate or film and held in position by adhesive tape. With a pencil or other point, an outline of the flat surface may be drawn on the emulsion, which will show the position of the specimen later on when the film is developed. Black or dark areas on the developed film will indicate the position of the radioactive minerals in the flat surface of the specimen.

VISUAL SCINTILLATION TEST

When alpha particles from radioactive substances strike a screen coated with activated zinc sulphide, each produces a tiny flash of light or scintillation. These can be readily seen in the dark with a low-power microscope. A scintilloscope is a small instrument consisting of a zinc sulphide screen and focusing tube magnifier by which this interesting phenomenon may be observed. The instrument can be used only in the dark after the operator's eyes have been in darkness for some time. Specimens may be tested for radioactivity by this method, but it is necessary to wait for some time for flashes from low-grade material to occur. The rate might be only one or less per minute. With suitable arrangements, the method can give quantitative indications, but it is not well adapted for practical use by prospectors. It, of course, does not distinguish between uranium and thorium, as both give off alpha radiations. In using such instruments care should be taken not to contaminate the screen with radioactive material, nor to expose it to light, which renders it fluorescent and useless for many hours after the exposure.

An instrument of this sort is available from the Central Scientific Company, Toronto, under the name 'Radioscope'. Another model of this type recently offered for sale is the Clarkstan Model 501 Alpha Counter obtainable for $5 (U.S.) from Clarkstan Corporation, Los Angeles 64, California, U.S.A.

ELECTROSCOPIC TESTS

The electroscope is one of the oldest instruments used for investigating radioactivity. It also was one of the most useful devices in such investigations previous to the introduction of electronic equipment. In a suitable form it could still be useful in certain applications, such as the field assay of prospectors samples.

The simplest form of electroscope, sometimes stocked by scientific supply houses, is called the gold leaf electroscope. It consists of two strips or 'leaves' of very thin gold or aluminium foil hanging from a metal support that is fitted into the neck of a glass bottle. The leaves are charged with electricity by touching the metal support with a rod of vulcanite, glass, or plastic that has been rubbed with silk, wool, or fur. The charge of static electricity on the rod is transferred to the leaves, and, as both are charged with the same kind of electricity, they repel each other and separate. If radioactive material is now brought near the supporting rod the leaves will fall at a rate depending on the intensity of radiation from the active source. The instrument does not distinguish between uranium and thorium.

A type that is more expensive but would be of more use to prospectors consists of three main parts: a head, containing the leaves and charging knob; a bottom compartment, in which trays containing samples can be placed; and an attached tube magnifier with a scale, permitting quantitative readings of the position of the leaf. By using analysed standard powders for comparison, rough quantitative estimates of grade could be made under favourable weather conditions.

The ordinary electroscope works best, unfortunately, in winter, when the air is very dry and not disturbed by electrical storms, which ionize the air and increase the rate of natural leak. To be of practical use in summer, an electroscope must include means of maintaining a dry atmosphere in the leaf chamber.

The principle of the electroscope is still applied in various refined forms, but no available commercial model seems to be worth while for the prospector.

TESTS FOR URANIUM ELEMENT

It may be noted that most devices or methods for detecting radioactive minerals are indirect; they detect, not uranium or thorium as such, but radioactive radiations coming mainly from the active radioelements produced by the atomic disintegration of uranium and thorium.

COLOURED URANIUM MINERAL ALTERATION PRODUCTS

Perhaps the simplest direct method of detecting uranium as distinguished from thorium, is by recognition of the bright yellow, orange, and green colours of certain alteration products of uranium minerals. These colours do not quite resemble any others commonly shown by minerals, and once seen are easily recognized again, even when somewhat dulled or changed by contamination with other alteration products. No thorium mineral alteration products are so coloured unless they contain uranium and are coloured by it.

FLUORESCENCE TESTS

Unaltered pitchblende, uraninite, or other primary uranium and thorium minerals do not themselves fluoresce under ultra-violet light, but may by alteration give rise to thin patches or coatings or tiny crystals of secondary minerals that will fluoresce under short-wave ultra-violet light such as is produced by the Mineralight lamp. However, it is not considered worth while for a prospector to purchase an ultra-violet light for the sole purpose of prospecting for uranium, in Canada, though it is useful in making fluorescent bead tests, and it is indispensable in prospecting for the tungsten ore mineral scheelite.

Portable models of ultra-violet lamps designed for prospectors' use are: the 'Mineralight', sold by Ultra-Violet Products Inc., 145 Pasadena Ave., South Pasadena, California, and the 'Menlo Fluoretor', a small model that operates on flashlight batteries, sold by Camera and Instrument Crafts, 122 Eleventh Avenue West, Calgary, Alberta, and by Photographic Stores Limited, 65 Sparks Street, Ottawa.

FLUORESCENT BEAD TEST

This test is based on the fact that a fused bead of sodium fluoride or lithium fluoride, in which a little uranium is dissolved, will fluoresce under ultra-violet light. It is useful because it will work with all important uranium minerals, and is sensitive enough to detect the presence of very small amounts of uranium in most cases. However, minerals such as monazite and allanite, containing only very small amounts of uranium with much cerium, will not yield fluorescent beads by this test. Minerals containing tungsten or columbium may yield fluorescent beads with weaker fluorescence and bluish in colour.

Equipment. This is not elaborate; it consists of:

(1) Wire, to hold the bead, and wire-cutting pliers. Iron stovepipe wire, obtainable at most hardware stores, is satisfactory. Platinum wire, of course, is better, but expensive.

(2) Means for producing a small, hot flame, such as a pressure gasoline stove or torch. The use of an alcohol lamp and mouth blow-pipe has also been suggested. Alcohol torches that have been tried do not give enough heat to be satisfactory.

(3) A supply of sodium fluoride or lithium fluoride. These are dry powders obtainable from chemical supply houses. They are poisonous if taken internally, so should be well labelled and kept apart from baking soda or similar materials used in foods.

(4) A source of ultra-violet light, the 'Mineralight' or 'Menlo Fluoretor' (*See* page 78) could be used, or a powerful flashlight fitted with a dark blue ultra-violet filter glass[1] in place of the regular glass has been reported to be satisfactory. However, a three-cell type tested in this way was not strong enough for the purpose.

Procedure. The specimen to be tested is finely powdered and well mixed. A loop with an inside diameter of ⅛ inch or a little more is formed on the end of a piece of wire, heated, dipped into the fluoride powder, and again heated until the fluoride melts. This is repeated until the loop is completely filled with the melted fluoride 'bead'. While still hot, the bead is brought into contact with the sample powder so that some adheres to it. The bead is then reheated until the sample powder is thoroughly melted into the bead. After the bead has cooled it is examined in darkness under ultraviolet light, or it may be cut off the wire and examined

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[1] Obtainable from the Corning Glass Works, Optical Sales Department, Corning, New York. A 2-inch square of violet ultra No. 5860 standard thickness sells for $1.60 (U.S. funds).

in daylight with the Menlo Fluoretor.[1] If any uranium is present the bead will fluoresce with a bright yellow-green colour.

In the case of radioactive materials occurring as very fine grains disseminated in rock, it may be advisable to concentrate some of the heavy material in a tail by panning, remove magnetic materials with a magnet, and make a bead test on the residue.

In making tests, suitable precautions must be observed to prevent contamination of the wire or fluoride powder with uranium-bearing material from previous assays.

It has been stated that "minerals containing tungsten will fluoresce when treated with lithium fluoride (but not with sodium fluoride), and minerals containing columbium will fluoresce when treated with sodium fluoride (but not with lithium fluoride). The fluorescence produced by these elements, however, is generally weaker than that produced by uranium and is distinctly bluish".[2]

USE OF GEIGER COUNTERS AND SCINTILLATION INSTRUMENTS IN PROSPECTING

Of the various known devices or methods for detecting radioactive substances, portable Geiger counters and scintillometers are by far the most suitable for prospect-

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[1] The portable 'Mineralight' type of ultra-violet lamp may be used to test beads in daylight by placing the bead on the glass filter of the lamp and viewing it through a small cardboard tube held closely against the glass to exclude daylight. A tube about 1½ inches in diameter is suitable; its length should be such that the bead can be seen clearly when the operator's eye is applied closely to the open end, usually 6 to 12 inches. The inside of the tube should be blackened; this may be done with charcoal.

[2] From "Prospecting for Uranium", published by the United States Atomic Energy Commission and the United States Geological Survey, obtainable from the Superintendent of Documents, United States Government Printing Office, Washington 25, D.C. Price, 30 cents.

ing. A radiation detector of any kind is not absolutely necessary for prospecting for radioactive minerals; tests such as previously described (*See* pages 74-80) might be applied to suspected materials, or samples might be sent away for assay as is done in ordinary prospecting. However, experience has shown that recognition of radioactive raw materials by means of simple physical properties observable in the field may be very difficult or impossible, even by trained mineralogists. There is no doubt that most of the numerous uranium discoveries of the past decade were made with the help of Geiger counters, and that most of them would not have been made by ordinary prospecting methods. For serious uranium prospecting, therefore, a prospector should have a Geiger counter.

The portable scintillometer, now available commercially, is much more efficient than Geiger counters in detecting gamma radiation, but the relatively high cost, both of the instrument itself and of batteries for it, as also its greater weight, may restrict its general use by prospectors. In this section, therefore, the use of the Geiger counter will be described more particularly, but with the understanding that the scintillometer may be used similarly to, or instead of, the gamma type Geiger counter in every way mentioned, with even greater effectiveness.

Geiger counters have been discussed in some detail on pages 57 to 71, and early in the booklet something was said of the nature of radioactive disintegration and the radiation from uranium and thorium minerals. In considering the applications of various types of Geiger counters in prospecting, it is important to remember the nature of the three very different kinds of radiation given off by radioactive minerals: the alpha particles, with little range or penetration; the beta particles, with much more range and penetration; and the gamma rays, with very much greater penetration than the beta rays. Thus the most effective instruments for searching for radioactive deposits are those that detect the highly penetrating gamma radiation most efficiently, and for this the scintillometer and models of Geiger counters having gamma-type counter tubes are best. The alpha scintillation detector and beta-gamma types of Geiger counters with shielded probes are best for close work in localizing the radioactive mineralization and studying its distribution in detail at the surface of deposits, or in mines and openings, where the gamma-type instruments are likely to be much more affected by general gamma radiation.

So far as their use in prospecting is concerned, commercially available Geiger counters differ mainly in the following particulars:

(1) Some are equipped only with earphones, others have meters, or, usually, both meter and earphones. Still others have small neon lamps that light up momentarily as each ray is detected.

(2) Many models come equipped with gamma-type counter tubes; others have beta-gamma tubes. In some instances, the manufacturer offers a choice of gamma or beta-gamma tubes on a given model.

(3) In perhaps most Geiger counters, the Geiger tube or tubes are enclosed within the metal case that houses the batteries and amplifying circuit, but some have the tube enclosed in a metal cylinder and connected by a short cable to the circuit inside the case. The tube in this so-called 'probe' may be cylindrical or may be of the end-window beta type.

The types that have only earphones range from small, relatively light instruments that can be placed in a pocket to those weighing about 7 pounds; but most of them are smaller, lighter, and cheaper than meter-equipped models, and they are satisfactory for ordinary prospecting purposes. The models with meters in some instances may have larger counter tubes or more than one counter tube, and hence be more sensitive than the cheaper, meterless types. They are desirable for detailed surveys of deposits, especially those of higher grade where the counting rate is too high to be estimated by ear.

Geiger counters that detect only gamma radiation are satisfactory for almost all prospecting purposes. They are not as sensitive as beta counters, however, for testing small or low-grade hand specimens of radioactive material.

Geiger counters without probes are satisfactory, but a probe has certain advantages. The main part of the instrument can be carried by means of a sling placed over one shoulder, and only the probe need be carried in the hand. The probe is particularly useful for testing crevices and other small openings. Some probes are waterproofed and can be thrust into shallow water to test a deposit that may be at the bottom of a pit or in the bed of a stream. A probe also permits greater selectivity for determining the exact source of radioactivity or for noting the differences in radioactivity for short intervals across a deposit, if it is of the lead-shielded beta type.

CARE OF THE INSTRUMENT

The following notes are not intended to cover all the instructions contained in the pamphlets supplied with most instruments, but merely to outline the main precautions that should be observed.

(1) Geiger counters are fairly rugged, considering the delicacy of some of their parts, but hard jars should be avoided, and the instrument should be padded for shipping. A wooden case lined inside with sponge rubber is very satisfactory.

(2) Instruments that are not waterproofed should be protected from moisture. Some operators of the larger models, even when these are protected by a canvas case, place waxed paper on the bottom and sides of the case so that it can be set on wet ground without getting wet. Wetting of the earphones should be avoided. For wet weather use, instruments having the counter tube contained in the case and using earphones may be easily waterproofed by putting them into a small plastic bag obtainable at 10-cent stores. The bag is tightly closed around the phone cord.

(3) The instrument should not be overheated.

(4) Care should be taken to see that dust or larger fragments from radioactive minerals do not contaminate the instrument or its case. Waxed paper is useful for this reason as well as to prevent wetting.

(5) The instrument should not be kept switched on for any length of time if near a highly radioactive specimen or deposit, as this would shorten the life of tubes and batteries. In general, instruments used for surface work should not be taken underground in high-grade uranium mines or into treatment plants for uranium ore.

(6) Care should be taken to see that the instrument is switched off when not in use.

(7) Batteries should not be left in the instrument when it is shipped or stored for long periods because swelling, leakage, or corrosion may result. A batteries, especially, should be checked daily and removed promptly when they show swelling or other indications of exhaustion.

(8) Most types of counter tubes may give very misleading results when they are nearly worn out; therefore, it may be necessary to have a tube replaced before it is completely "dead". It is impossible to state the effective life of a tube, but it would be advisable to have the tube replaced before beginning a long trip in a remote district or as soon as the instrument consistently showed abnormally high background counts.

(9) Batteries can be changed, and loose or broken connections can be repaired by the operator, but other servicing should be done by a qualified person. Spare batteries should be taken on long trips including the small bias batteries that are soldered into some circuits and might be overlooked.

(10) If extensive work in a remote district is planned, it is desirable to have two or more Geiger counters to prevent loss of time in the event of failure or damage of one instrument.

USE OF THE INSTRUMENT

A Geiger counter will register occasional counts if it is switched on at any locality. This is partly because the instrument is sensitive to cosmic rays, which reach the earth from outer space, and partly because almost all materials contain minute amounts of radioactive substances. These low counts are called *background counts*. When the instrument is being used, the background must be determined from time to time during the day by switching the counter on at localities well away from any possible radioactive deposit or specimens. Background counts of up to about 80 per minute may be heard in the earphones, or the needle of the meter will be seen to fluctuate between two low dial readings. The number of background counts per minute depends on the effective area of the counter tube in the instrument, its efficiency and the voltage applied to it, as well as on the local conditions. Therefore, normal minimum backgrounds will be different for different instruments. The average count for periods of 1 minute to 3 minutes should be recorded either as counts per minute or as the average dial reading. Some instruments are provided with a voltage control, which should be turned only a very little past the point where clicks are first heard. The background may vary from time to time at any given locality, because of changes in the amount of cosmic energy penetrating the atmosphere and changes in weather conditions. It will also vary from place to place—for example, it is generally higher over granitic rocks than over limestone. It may be increased during damp weather or in a damp mine.

The principal ways in which the Geiger counter is used in the field are as follows:

General Prospecting. For this type of work the instrument is usually slung low over the back and the earphones are worn. The switch is kept on except when crossing large areas of deep overburden. The prospector walks *slowly* over rock or shallow overburden and listens for 'anomalies', that is, appreciable increases in the number of clicks, and stops to investigate these. After a little practice he will not need to count the clicks continually, as he will learn to distinguish almost automatically between background and anomaly. To this end, a novice may practice with a radioactive specimen or over a known radioactive deposit. For investigating anomalies the prospector should take the instrument or the probe in his hand, hold it within an inch or so of the rock, and move it slowly to locate the source of the radioactivity. He should be equipped with a pick or grub-hoe, as the radioactive minerals may not be exposed. Anomalies should be checked by walking away and returning to the site at least once, because anomalies are occasionally caused by bursts of cosmic rays or by short circuits. Care should be taken to see that radioactive specimens, contaminated clothing, or watches or compasses with luminous dials are not carried where they may affect the instrument. If an anomaly is proved, the position is marked by paint, a pile of rocks, a stake, or a blaze, and specimens are taken.

It has been generally considered that twice the background count, or more, constitutes an anomaly. However, of the thousands of samples sent to the Geological Survey during the past 2 years, 86 per cent showed radioactivity equivalent to less than 0·05 per cent U_3O_8; therefore, it would appear that very low anomalies are unimportant, and that samples need not be taken unless anomalies of four times background or more are obtained. It is impossible to be definite in this matter, because a large, low-grade uranium deposit causing low anomalies might be important, whereas a small isolated crystal of uraninite or stringer of pitchblende would cause a very high anomaly but be worthless.

There is some difference of opinion as to whether it is best to record anomalies as multiples of background or as direct readings. Some companies prefer to show direct readings on records for their own use, because they know what instrument was used, and because they believe that variations in background make the other method undesirable. In general, however, records intended for publication or for submission to the Geological Survey are more informative if the readings are shown in multiples of the average background.

An inexperienced prospector will pay equal attention to all rocks and all geological conditions. In some respects this may be an advantage, as discoveries may be made under conditions that are not at present known to be favourable. A more experienced prospector will, however, select an area that he believes may be favourable; and he will pay greatest attention to favourable rocks and structures.

Testing Old Workings. Old workings should be tested for the occurrence of radioactive minerals, because they are at localities that are favourable in a general way for mineral deposition, and because it has been found that uranium may accompany other types of mineral deposits. Pits, dumps, drill core, and underground workings may be readily tested with the help of a Geiger counter in the same way as described above.

Detailed Prospecting. The Geiger counter is used in detailed prospecting either by holding the instrument or probe very close to the rock and walking very slowly both along and across favourable formations or structures, or it is used for making systematic surveys called Geiger surveys or grid surveys.

Grid surveys are generally made, or supervised, by engineers, geologists, or geophysicists. They are made by recording readings along lines at evenly spaced intervals called stations, and are commonly used to prospect claims systematically after staking. In such surveys the lines may be picket lines 100 feet or more apart, along which the operator will not only take readings at the stations but will also listen for anomalies while walking between stations. For particularly favourable localities, smaller areas may be surveyed with grids at 5- to 50-foot intervals. Such very detailed surveys are generally made by a crew of two or more men, using more than one Geiger counter; one tape may be laid along a base line and another be used to indicate the traverse lines at right angles to it; one man may act as recorder.

In making grid surveys, the instrument is either held close to the ground, placed on the ground, or placed on two sticks carried for the purpose. The background count is recorded from time to time. Readings may be taken with an instrument equipped only with earphones, in which case low anomalies will be recorded as multiples of the background count and high anomalies as "continuous buzz", but use of a metered instrument is less tedious and permits more accurate data on higher anomalies. When using a metered instrument, it is important to record both the dial reading and the setting used, as well as the serial number of the instrument; thus 16(2) would indicate a reading of 16 on the second setting. Because of differences in the background and differences in instruments, reports and plans are more informative if these readings are converted to factors of the background count; thus, if the background was 8 and the second setting had a factor of 10, a reading of 16(2) would be reported as 20 times background. Anomalies that are greater than the limit of the meter are recorded as 'O.S.' meaning 'off scale'.

Grid surveys may be plotted to form a plan, and lines called 'isocounts', resembling contour lines or the lines on weather maps, may be drawn through anomalies that are even multiples of the background. The zones between these lines may be coloured or patterned differently, thus depicting the distribution of various ranges of radioactivity.

Samples for testing or analysis should be taken from all anomalous stations or from a suitable proportion of them.

Examination of Properties. The Geiger counter is very useful to examining engineers and geologists for indicating whether a property contains significant amounts of radioactive minerals and for helping to outline the distribution of such minerals. Closely spaced grid surveys can be made, or the instrument can be used continuously along and across deposits. Use of a Geiger counter, however, does not avoid the necessity of taking samples, unless it indicates no appreciable radioactivity and, therefore, no necessity for sampling. After one has become familiar with the characteristics of a particular instrument and a particular tube in relation to properties that he has sampled, he can form a rough idea of the probable grade of another occurrence by the use of the Geiger counter alone; but, in general, an examination requires the same kind of chip, channel, panel, or bulk sampling as would be desirable for, say, a comparable type of gold deposit. Radioactive deposits that have been evenly mineralized may, however, be appraised by interpolating Geiger counter readings between a reasonable number of sampling results, and such practice may be possible for deposits containing erratically distributed high-grade minerals if a probe and a lead shield are used. At the least, it would be necessary to take enough samples to indicate the uranium-thorium ratio, the equilibrium factor[1], and the characteristics and variation of the instrument.

OTHER CONSIDERATIONS

The following general information is additional to the foregoing considerations.

Radioactivity from minerals of low uranium or thorium content or from deposits containing small quantities of minerals with higher content may be shielded by a few inches of rock or overburden. Radioactivity from larger quantities of the most radioactive minerals are shielded by 2 or 3 feet of rock or overburden. Discoveries have been made with ordinary Geiger counters where overburden was deeper than this, but in these instances it is believed that fragments or secondary

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[1] This expression is explained in the next section.

minerals derived from the deposits were incorporated in the overburden, or that radon gas emanating from the deposits was trapped in the overburden. Discoveries have been made over 4 feet of snow, but wet snow has about the same shielding effect as overburden.

Geiger counters are sometimes affected by electrical storms, and should not be used during such storms.

Radioactive material may be scattered by blasting; therefore, it is desirable to make Geiger counter investigations before blasting, if possible, or to watch for such effects if it is necessary to use the instrument near where blasting has been done.

Potassium is weakly radioactive: F. E. Senftle has pointed out that such minerals as the potash feldspar commonly occurring in pegmatite may cause anomalies of two or three times the background count.

Many radioactive deposits and many samples or specimens from such deposits emit radioactivity that is not consistent with their true uranium or thorium content because the primary elements are out of equilibrium with their disintegration products. This effect is called the "equilibrium factor". This effect is not of great importance in dealing with Canadian pitchblende deposits, although minor adjustments may have to be made between the true uranium content and the content as estimated with a field Geiger counter or by laboratory radiometric tests.

RADIOACTIVE MINERALS IN CANADA

GENERAL STATEMENT

Uranium and thorium are widely distributed in natural materials of the earth's crust. With sufficiently delicate tests it has been found that almost all natural products such as rocks, soil, sea water, and plant and animal organisms contain at least minute traces of these elements. (A trace as usually defined is less than

0·01 per cent, but there is much less than 0·01 per cent uranium and thorium in most of the substances mentioned.) Uranium and thorium nearly always, if not always, occur together in minerals formed in high temperature deposits, such as granites and pegmatites. The pitchblende of vein deposits, its alteration products, and the various secondary minerals deposited by uranium-bearing waters are usually, for practical purposes, free from thorium, though minute traces could probably be found by refined methods in most of such materials.

Names have been given to a large number of minerals carrying uranium and thorium in amounts greater than a trace. Besides these, such common minerals as zircon, titanite, apatite, garnet, and biotite, not classified as radioactive minerals, may be radioactive, due either to chemically combined uranium or thorium or inclusions of radioactive material. A recent publication lists 164 names of uranium- and thorium-bearing minerals, of which 44 are secondary alteration products. Another late publication gives detailed mineralogical descriptions of 64 well-defined secondary uranium minerals alone.

Of the numerous names that have been applied to radioactive minerals, it is probable that in some instances what is essentially one mineral species has been described under more than one name; and it is equally probable that new species will be found when sufficient precise detailed work has been done on these minerals.

With the exception of a few of the simpler uranium and thorium minerals such as pitchblende, uraninite, thorianite, monazite, thorite, and some of the secondary uranium minerals, the identification and precise naming of these minerals is difficult and may be impossible even in a well-equipped laboratory.

The difficulty in naming radioactive minerals, especially those of primary granitic and pegmatitic origin, is due mainly to the following factors: their extreme complexity of composition; the great variability in percentage content of constituent elements, even among those that contain the same elements in appreciable quantity; the fact that they are rarely found as accurately measurable crystals; the fact that the original crystal structure of most of the primary minerals has been disorganized due to radioactive disintegration, so that it is often difficult or impossible to obtain conclusive optical or x-ray data; the difficulty, in many instances, of obtaining sufficiently pure material for tests, due to alteration, the presence of inclusions, or intergrowths of more than one mineral; and, finally, the difficulty of making exact chemical analyses of these complex compounds.

To illustrate the variability in composition of radioactive minerals some analyses are given here showing the variations in composition of uraninite, chemically the simplest radioactive mineral occurring in pegmatites and granitic rocks, and one of the best-defined radioactive species. Uraninite has been found in many pegmatites as well-developed crystals consisting of practically unaltered pure material free from inclusions or intergrowths with other minerals. Only uranium oxide, U_3O_8; thorium oxide, ThO_2; rare earth oxides, R.E.; and lead oxide, PbO, are shown, in percentages, in the table; small amounts of common elements are also present in all uraninites. Three analyses of thorianite are also shown for comparison. Thorianite is an equally well-recognized species occurring as good crystals of well-preserved pure material, in pegmatites. Both uraninite and thorianite crystallize in the cubic system, and both give exactly the same x-ray diffraction patterns except that they may have very slightly different dimensions. It is clear from the analyses that oxides of uranium and thorium can substitute for each other in either of these species, and, in the case of analysis No. 5, it may be seen that both uranium and thorium oxides are present in about equal amount. There is no special name at present for such a compound, but it has been classified under thorianite. Specimens containing mainly uranium, with appreciable thorium, have been called thorian uraninite; those containing mainly thorium, with appreciable uranium, have been called uranoan thorianite.

—	1	2	3	4	5	6	7
U_3O_8 ...	95·12	86·16	72·44	64·86	37·15	12·33	4·92
ThO_2 ...	0·20	0·10	10·60	13·94	38·47	76·229	3·02
R.E. ...	5·14	0·79	4·02	1·47	2·49	8·04	......
PbO ...	0·40	11·69	10·95	16·71	5·21	2·87	1·80
S.G.[1] ...	10·63	8·96	9·06	8·97	6·68	9·5	9·33

[1] S.G. = specific gravity.

1. Uraninite, from placer de Guadalupe, Chihuahua, Mexico.
2. Uraninite, from near lake Pied des Monts, Saguenay district, Quebec.
3. Uraninite, from near Wilberforce, Haliburton county, Ontario.
4. Uraninite, from the Huron claim, Winnipeg River area, southeastern Manitoba.
5. Thorianite, from Easton, Pennsylvania, U.S.A.
6. Thorianite, from Ceylon.
7. Thorianite, from Madagascar.

The lead shown in above analyses is derived from the atomic disintegration of uranium and thorium. It may be noted that the uraninite from Mexico (analysis No. 1) has a very low lead content and is the youngest known uraninite, whereas the uraninite from Manitoba (analysis No. 4), with its high lead content, is the oldest known uraninite.

As previously mentioned, this is the simplest possible illustration of one of the difficulties mineralogists encounter in attempting to define species of pegmatitic radioactive minerals and apply names that mean something definite in relation to chemical composition. It also shows why the identification of a radioactive mineral by physical means, and applying a name to it, does not imply that anything very definite is known of its actual percentage composition, in the absence of a chemical analysis. Unfortunately, chemical analysis of these minerals takes too long and is too expensive to be used for routine examination of prospectors' samples.

As has been said, the more complex pegmatitic radioactive minerals rarely occur as crystals suitable for accurate measurement, even though rough faces may be present; their original crystal structure, also, in almost all cases has been destroyed by atomic alteration, so that they do not yield optical data of diagnostic value; they appear to resemble glass in having no definite arrangement of their atoms. For this reason also, they do not yield x-ray patterns in their natural state[1]. It is true that x-ray diffraction patterns can commonly be obtained from them after they have been heated, but these patterns may vary depending on the temperature of heating and other factors, and may be contradictory in some cases. For these reasons many of the names given to these minerals are based solely on their chemical composition, whereas, for strict mineralogical classification, the crystal system or x-ray pattern of the mineral must be known, as, for purposes of classification, mineralogists consider the crystal form and associated atomic arrangement of a mineral to be of greater importance than its chemical composition. A simple ex-

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[1] Minerals that must originally have possessed crystal structure as they still show crystal form, but are now in this condition, are said to be 'metamict'.

ample of this is the classification of natural titanium oxide, TiO_2. This substance occurs in nature in three different forms, and in texts on mineralogy is, accordingly, classified as three different mineral species, rutile, octahedrite, and brookite, though all three have exactly the same chemical composition. Both rutile and octahedrite are tetragonal in crystallization, but with different crystal measurements and different arrangements of the atoms, whereas brookite is orthorhombic in crystallization. Among the radioactive minerals, euxenite-polycrase and eschynite-priorite, as examples, are comparable to rutile and octahedrite in regard to classification. Both groups have proved to be orthorhombic in crystallization, in instances where good crystals have been measured, but have different crystal constants. The numerous, highly complex minerals included under these groups are highly variable in quantitative chemical composition, and can rarely be distinguished one from another, or positively named, without elaborate research.

As, in general, the chemical composition of minerals is of chief economic importance, except where, in the case of gemstones, quartz crystals for radar, and a few other instances, the physical properties are more important, it might seem that mineralogists are unduly concerned with defining mineral species in terms of crystal and atomic structure. It may be noted, however, that one of the chief reasons why mineralogists try to classify minerals into definite species is that, once the range of physical properties of given species has been accurately determined on chemically analysed examples, it is, in the case of the non-radioactive minerals at least, much quicker, easier, and cheaper to identify a mineral by means of the properties of its crystal form or structure than by chemical analysis. Once the mineral has been thus identified as to species, the variations in its composition to be expected can be ascertained by looking up analysed examples of the same species. This is not quite as satisfactory as a chemica analysis of the particular specimen concerned, but may be all that is necessary for many purposes.

In the case of the many primary radioactive minerals that occur in pegmatites, it is not always possible, for the reasons given, to identify a given specimen as belonging to a single definite species, and when, or if, it is possible to do so, the identification still does not afford the fairly definite information as to composition expected in the case of ordinary non-radioactive minerals, such as rutile, quartz, pyrite, galena, etc. Actually, in the case of the more complex radioactive minerals, it is commonly only possible by physical tests to identify a mineral as belonging to a group rather than to a single, well-defined species.

From the foregoing remarks, the prospector may surmise that the identification of radioactive minerals is the field of the specialist in this most difficult branch of mineralogy, and that he cannot hope to accomplish much by the simple observations of physical properties that can be made in the field. It would, therefore, be useless to give here elaborate descriptions of the numerous radioactive minerals that have been described and named. Only those that are known to occur in Canada and a few others will be mentioned.

URANIUM MINERALS

From here on in this booklet a distinction will be made between those minerals usually carrying more uranium than thorium, which will be called uranium minerals, and those that ordinarily carry more thorium than uranium, which will be called thorium minerals.

It is customary to divide uranium minerals into two groups, the primary minerals formed in pegmatites, veins, etc., and the secondary minerals that have been formed as a result of alteration of the primary minerals by near-surface weathering processes. In Canada, heavy glaciation has, presumably, swept away most of any weathered zones or secondary deposits that may have existed previously, and the relatively cold and wet climate has not been favourable for the formation of such deposits since the Ice Age.

From the economic point of view in Canada, a division of uranium minerals according to the type of deposit in which they are found is much more useful. Pitchblende, found typically in veins, is of major importance, whereas the minerals occurring in granitic rocks and pegmatites are of only minor interest under present conditions. Uranium deposits in sandstones, and uranium-bearing shales and phosphate rock, which occur in other countries, are also less likely to be of importance in Canada.

Vein Minerals of Uranium

Pitchblende. This is much the most important ore of uranium. It occurs only in vein-type deposits, and consists mainly of oxides of uranium and the associated atoms of lead resulting from the atomic decay of uranium. Thorium is usually almost wholly lacking and the content of rare earths is small, usually less than 1 per cent. It does not occur as crystals, but is massive, or occurs in some instances in rounded, mammillary or botryoidal forms, which may show fine banding or radiating structure, as in hematite. It is dark steely to pitch black in colour when reasonably fresh, but may be greenish black when much altered; powder black to greenish black when altered. Not magnetic; shows no cleavage, but breaks with a conchoidal fracture like glass. Does not fluoresce under ultra-violet light, but some of its alteration products may do so; these products may be bright canary-yellow, orange, green, or various shades of these colours. When fresh, pitchblende may be as hard as steel and as heavy as iron, but by alteration it becomes softer and lighter.

Pure pitchblende may contain, theoretically, well over 90 per cent U_3O_8, but actual specimens are likely to contain inclusions or intergrowths of other minerals present in the veins, such as quartz, carbonates, hematite, sulphides, arsenides, selenides, etc. By alteration, it changes to softer, hydrated and silicated materials, usually mixtures of somewhat indefinite composition that are commonly called *gummite*, when the silica content is low, and *uranophane*, when the silica content is higher. These materials may be yellow, orange, brownish, or black, depending on the completeness of alteration and the purity of the compounds.

In textbooks on mineralogy, pitchblende is classified as a variety of uraninite, but for practical purposes it is usual to restrict the name uraninite to the crystallized uranium oxide mineral that occurs in high temperature deposits such as granites and pegmatites. Some authors, however, do not make this distinction, and may refer to pitchblende as uraninite.

Thucholite is a jet-black, uranium- and thorium-bearing carbon, which is very light in weight and looks like pitch or brilliant, black, hard coal on a freshly broken surface. It has a conchoidal fracture and is easily broken. It may occur as rounded lumps or, in some instances, intimately associated with pitchblende, as though it had formed by replacing the latter. Thucholite can be burned by heating in a crucible, but will not support combustion by itself; it simply burns like very hard coal without giving off any smoky, tarry, or oily substances. In other words, heavy hydrocarbons, such as occur in soft coal, are lacking, but thucholite, when heated without burning, does give off a large amount of invisible gases, which are mainly hydrogen and carbon monoxide. The ash content is variable both as to amount and in content of uranium and thorium. Varieties that occur in vein deposits carry little thorium; those that are found in pegmatites may carry more thorium than uranium.

Thucholite occurs in both vein deposits and pegmatites in Canada; in pegmatites in Sweden and Karelia, Russia; and in the gold-bearing conglomerate of the Witwatersrand, South Africa, where it carries microscopic inclusions of pitchblende. Although the average content of thucholite-pitchblende is very small in the South African deposits, the possibility of recovering it as a by-product of the gold extraction, and the enormous extent of the deposits, have caused this area to be rated as potentially the greatest source of recoverable uranium known.

Torbernite-metatorbernite. These are hydrous, copper-uranium phosphates containing around 60 per cent uranium oxide. When well crystallized, they may occur as small tabular crystals, scales, or micaceous masses of a greenish colour. Metatorbernite contains less water than torbernite, and is said to be the variety more usually found. Minerals related to metatorbernite have been found as the chief radioactive constituent at the surface in two vein-type deposits in Canada, but these minerals are not likely to be widespread or important in this country. However, although they appear to have always been considered as merely alteration products of primary uranium minerals, it would seem possible that in some instances they may also be deposited by hydrothermal action; if so, there might be a greater possibility of their occurrence in appreciable amount in Canadian deposits.

Autunite-metaautunite. These are hydrous, calcium-uranium phosphates corresponding to torbernite-metatorbernite, but with calcium instead of copper. They occur as small yellow or greenish yellow tablets or scales, which fluoresce bright green under ultra-violet light. They are found with, and under the same conditions as, torbernite in other countries, and have been found in Precambrian sandstone in Canada.

Uranium Minerals of Pegmatites

Most of the known primary uranium minerals occur only in pegmatites and granitic rocks. It is only in pegmatites, however, that they are found as crystals or masses of appreciable size or in quantities that might in some instances be worth recovering as a by-product of feldspar or mica mining.

The radioactive minerals of pegmatites almost always contain both uranium and thorium. Some are relatively simple in composition, but many are very complex, containing, besides uranium, thorium, and lead; titanium, tantalum, columbium[1], zirconium, and the cerium and yttrium groups of rare earths as major constituents, with various commoner elements in smaller amounts. The members of this class of complex minerals rarely carry quite as much as 10 per cent U_3O_8, but a few may, in some instances, contain up to 20 per cent U_3O_8. As chemical compounds, they may be considered to be titanates, tantalates, columbates, zirconates, or solid solutions of the various oxides. They are always metamict[2] in Canadian Precambrian occurrences.

Uraninite consists mainly of uranium oxide, but usually contains several per cent of thorium and rare earths, and, in the case of uraninites of Precambrian age, a large content of lead derived from the uranium and thorium by atomic decay. It occurs typically as well-developed, steely to black, cubic or octahedral crystals; though

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[1] This element has usually been called columbium on this continent, but recently it has been proposed to call it niobium hereafter in accordance with European practice. Both columbium and niobium are, therefore, likely to be used as names of the element in the near future.

[2] *See* p. 94, footnote, for definition of this term.

the mineral is not always in crystal form it always has crystal structure. Uraninite is usually harder, heavier, and less altered than pitchblende, and on the average it is much purer, more homogeneous, and freer from inclusions and intergrowths of other minerals than is pitchblende. The one primary mineral with which it is fairly commonly closely associated is thucholite, which in some instances seems to partly replace the uraninite. Uraninite, like pitchblende, alters to gummite and uranophane, which are thoriferous when the uraninite contains thorium, as it usually does. A young uraninite could carry more than 90 per cent U_3O_8, but Canadian Precambrian examples usually carry around 80 per cent U_3O_8. Some analyses are given on page 93.

Uraninite in small amounts is of fairly common occurrence; it is widely distributed in pegmatites of the Canadian Shield and has been found in British Columbia.

Thorianite (uranoan) may be mentioned here, although it usually contains much more thorium than uranium, because it commonly carries a considerable content of uranium and because uraninite and thorianite appear to be end members of a series in which the uranium and thorium are mutually replaceable. Thorianite crystallizes in cubes resembling uraninite.

Thucholite has been referred to under uranium vein minerals. It is also quite common in pegmatites, especially in association with uraninite. Varieties from pegmatites may carry more thorium than uranium.

Euxenite-polycrase. Many minerals found in Canadian pegmatites could be included under these species, and, next to allanite, they are probably the most abundant and widespread of radioactive minerals in Canadian pegmatites. They contain uranium, thorium, rare earth oxides of the yttrium and cerium groups, titanium, tantalum, columbium, iron, calcium, and various other common elements. The percentage of any one of the main constituents may vary considerably in specimens from different pegmatites or even in specimens from the same pegmatite. These minerals are black when fresh, yellowish to reddish brown to brownish black when altered, and when powdered are generally yellowish to reddish or greyish brown. Their specific gravities are likely to be close to 5. They show no cleavage, are brittle, and break easily with a conchoidal fracture. They may or may not show rough crystal forms, and are considered to be orthorhombic in crystallization but are invariably metamict.

Minerals of this type usually carry less than 10 per cent U_3O_8, though some may carry a very little more.

Minerals of the *eschynite-priorite* series are very closely related to euxenite-polycrase, but usually carry more thorium than uranium.

Quantitative chemical analyses are necessary to ascertain the percentage composition of any of these two groups of minerals.

Pyrochlore-microlite. Minerals classed in this group are essentially columbates and tantalates of calcium, sodium, rare earths, uranium, and thorium. The content of uranium and thorium is extremely variable, but uranium is usually in excess of thorium. Members of this group, ellsworthite and hatchettolite, found in Ontario pegmatites, carry more than 10 per cent U_3O_8 (up to 20 per cent U_3O_8 in one instance), with less than 1 per cent ThO_2. They would be saleable ores of uranium if found in quantity.

Members of this group show a fairly strong tendency to crystallize in rounded, garnet-shaped forms of the isometric system, or, if not crystallized, they are likely to occur as rounded or globular nodules. Colours vary from yellow to brown to black, depending on the degree of alteration, the black types being the less altered. The lustre is vitreous, resinous, or waxy.

Fergusonite-formanite. These are essentially columbates and tantalates of the rare-earth elements. The U_3O_8 content is always less than 10 per cent, and thorium is low. Minerals of this group are tetragonal in crystallization, and fairly commonly show rough crystal form or may be massive. The colour on a fresh fracture is black, and the lustre vitreous. Fergusonite is known from Ontario pegmatites.

Samarskite is essentially a columbate-tantalate of the rare earths, calcium, iron, uranium, and thorium. The U_3O_8 content is usually greater than 10 but less than 20 per cent. The mineral may occur as rough orthorhombic crystals, but is commonly massive. The colour is black or brownish black, and the lustre vitreous and brilliant. Samarskite has been found in pegmatites in Quebec and Ontario.

Uranothorite is a hydrous silicate of thorium and uranium, and is included here because it has been known to contain more than 15 per cent U_3O_8, though thorium is likely to be present in greater amount than uranium. The mineral is usually found as black tetragonal crystals, but may occur as rounded masses. It may alter to a brownish, massive material.

Zircon-cyrtolite. Common zircon may or may not be appreciably radioactive, but the variety cyrtolite, with distorted, curved, crystal faces, is believed to be always radioactive. Analyses of Canadian examples show less than 1·5 per cent U_3O_8. Cyrtolite is of common occurrence in Canadian pegmatites as rounded masses of radiating crystals; also, but less commonly, as single crystals. Zircon and cyrtolite crystallize in the tetragonal system, and are almost invariably found crystallized. Cyrtolite is usually greyish in colour. It carries appreciable amounts of the rare element hafnium.

Apatite is commonly, if not always, slightly radioactive, but the U_3O_8 content is negligible for practical purposes.

Columbite-tantalite usually shows slight radioactivity but not enough, of itself, to be of commercial interest as a source of uranium. In Ontario, it is in some instances very closely associated with masses of radioactive minerals of the columbate-tantalate type; in the Yellowknife area it is associated with cassiterite.

Gummite and uranophane, previously mentioned under vein minerals, also occur as alterations of uraninite.

A few minerals not previously mentioned have been found in foreign deposits of sufficient size and grade for commercial production. Of these the most important are carnotite and tyuyamunite.

Carnotite and tyuyamunite are hydrous uranates and vanadates of potassium (carnotite) and calcium (tyuyamunite). They carry up to about 62 per cent uranium as U_3O_8 and 20 per cent vanadium oxide and, hence, are a valuable ore of both these elements. They are soft, yellow, powdery, micaceous, secondary minerals that occur cementing the grains of sandstones, in localized concentrations, over large areas in the southwestern United States, and have been responsible for a large production of uranium and vanadium from that region. It is believed that they have been precipitated from circulating waters in continental deposits under semi-arid conditions. They also have been mined in Ferghana, Russia, and Olary, Australia.

Betafite and ampangabeite. These are minerals of the complex columbate-tantalate type carrying about 20 per cent or more of U_3O_8, with about 1 to 2 per cent ThO_2. They have been mined in relatively small amount from weathered pegmatites in Madagascar.

THORIUM MINERALS

Thorium minerals are of primary origin in pegmatites, granitic rocks, and migmatites. The occurrence of thorium in vein deposits is rare and negligible in amount.

As previously noted, all thorium minerals carry at least traces of uranium. Those listed below usually contain much more thorium than uranium.

Monazite is the chief ore of thorium. It is obtained commercially by concentrating it from enormous beach sand deposits in India, Ceylon, and Brazil, and some is also recovered as a by-product of stream placer tin mining in Malaya. Other minerals of value are also obtained in the concentration of the monazite. The large content of cerium group rare earths in monazite adds to its value. Some thorianite and thorite are also recovered from placers.

Monazite is essentially a phosphate of the cerium group of rare earths, and generally carries from about 5 to 14 per cent ThO_2. The Brazilian monazite usually contains about 6 per cent ThO_2; the Indian and Ceylon concentrate, about 10 per cent ThO_2. The average U_3O_8 content is less than 0·5 per cent.

Monazite occurs in pegmatites, usually as crystals that are wedge shaped in section, resembling those of titanite. The colour is most commonly reddish brown or yellowish brown, like titanite, and if the mineral is not too much altered it may be more or less translucent. It has a good cleavage and a resinous lustre, and is scratched by steel. From these properties it is one of the few radioactive minerals that can be relatively easily recognized in the field.

Monazite crystals have been found in Canadian pegmatites, and it has been found as grains in small amount in some Canadian sands, but nowhere so far in encouraging quantities or grades.

Allanite is probably the most commonly occurring radioactive mineral in Canada. Mainly, it is a silicate of rare earths, aluminium, calcium, and iron. The ThO_2 content may be very small or may reach as much as 3·5 per cent, whereas the U_3O_8 content is rarely more than 0·2 per cent. The mineral is common in granitic rocks, especially in any pegmatitic phases, and has been known to form very large crystals in pegmatites. The crystals are usually of long tabular form. When little altered, allanite is black, with a glassy lustre, but it alters easily, typically around the margin of the crystals, to a brownish material. Many varieties of allanite have been described and analysed.

Because of its content of cerium group rare earths, a large and rich deposit of allanite might be of interest, but experience suggests that such deposits are not very likely to be found.

Thorite is essentially a silicate of thorium, the purest examples containing about 70 per cent ThO_2 and 1 per cent U_3O_8. The mineral resembles zircon in crystal form, and is commonly associated with it, occurring usually as small, square, tetragonal prisms. It is most commonly yellowish or orange, but may be black or brown. Thorite is usually altered, and as such shows conchoidal fracture and resinous lustre.

Thorite is commonly found as tiny crystals in Canadian pegmatites and associated rocks.

Uranothorite, thorianite, thucholite, and the eschynite-priorite group have been listed under the uranium minerals. Ordinarily they carry more thorium than uranium.

Titanite (or sphene), a calcium, titanium silicate, is not ordinarily classed as a radioactive mineral, but samples from some Canadian deposits show appreciable activity. Those that have been analysed have been found to contain rare earths and thorium.

Although the prospects of producing from pegmatites acceptable concentrates carrying the minimum 10 per cent U_3O_8 content required for purchase by the government does not, in general, appear too bright, it may be noted that the complex columbate-tantalate minerals of pegmatites carry commercially valuable constituents besides uranium and thorium. These are, chiefly and in most important quantity, columbium and tantalum and the cerium group of rare-earth elements.

The following tables list some of the properties of the commoner radioactive minerals for convenient reference.

TABLE I

The More Common Uranium Minerals

Mineral	Chief elements present[1]	U_3O_8 Per cent	ThO_2 Per cent	Usual colour	Usual lustre	Hardness	Specific gravity	Habit
Vein Minerals								
Pitchblende	Uranium Lead	To 91 Usually to 80 in Canada	Negligible	Steely black Black Greenish black Greyish black	Pitchy Dull	5–6	6–8	Massive Rounded Botryoidal Banded
Thucholite	Carbon Hydrogen Oxygen	Variable	Negligible	Jet black	Brilliant Dull	3·5–4	1·77	Massive Nodules
Gummite	Uranium Lead	To 76	Negligible	Yellow Orange Black	Dull Greasy	2·5–5	3·9–6·4	Massive Rounded Crusts Films
Uranophane	Uranium Silicon Calcium Lead	To 60	Negligible	Yellow	Greasy Pearly	2–3	3·8–3·9	Massive Fine fibrous Crusts Films

Torbernite Metatorbernite	Uranium Copper Phosphorus	To 60	Negligible	Green	Pearly Greasy	2–2·5	3·2–3·6	Small square tablets Micaceous Scaly
Autunite Meta autunite	Uranium Calcium Phosphorus	To 60	Negligible	Yellow	Pearly	2–2·5	3·0–3·2	Like torbernite
Pegmatite Minerals								
Uraninite	Uranium Thorium Rare earths Lead	To 95 Usually to 80 in Canada	To 15	Black	Steely Dull Pitchy	5–6	8–10·6	Crystals Cubes Octahedra
Thorianite (uranoan)	Thorium Uranium Rare earths Lead	To 37 Usually less	To 93	Black Greyish or brownish black	Sub-metallic	5–7	6·7–9·7	Crystals Cubes
Euxenite Polycrase Eschynite Priorite	Columbium Tantalum Titanium Rare earths Uranium Thorium	To 15 Usually less than 10	To 17	Black Brown	Glassy Resinous	5·5–6·5	4·5–5·7	Massive Rough Crystal forms

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[1] Besides oxygen.

TABLE I—Continued

Mineral	Chief elements present	U_3O_8 Per cent	ThO_2 Per cent	Usual colour	Usual lustre	Hardness	Specific gravity	Habit
Pyrochlore Microlite Ellsworthite Hatchettolite	Columbium Tantalum Titanium Uranium Calcium	To 20	To 5	Black Brown Yellow	Vitreous Resinous	5–5·5	4·2–6·4	Rounded octahedral crystals or nodules
Fergusonite Formanite	Columbium Tantalum Rare earths	To 9	To 5	Black Brown	Vitreous Resinous	5–6	4–6	Tetragonal crystals Masses
Samarskite	Columbium Tantalum Rare earths Uranium Iron	To 20 Usually 8–15	To 3·6	Black Brown	Vitreous Resinous	5–6	4–6	Rough crystals Massive
Uranothorite	Thorium Uranium Silicon Rare earths	To 27	To 50	Black Brown	Vitreous Dull	4–5	4–5	Tetragonal crystals Grains
Zircon Cyrtolite	Zirconium Silicon Rare earths	To 1·5	To 1	Brown Reddish Greyish	Vitreous Dull	3–7·5	3·6–4·7	Tetragonal crystals

Thucholite	Carbon Hydrogen Oxygen	Variable	Variable	Black	Brilliant Dull	3·5–4	1·77	Nodules Rough cubes
Gummite	Uranium Thorium Lead	To 76	To 25	Orange Yellow	Dull Waxy	2·5–5	3·9–6·4	Massive Rounded
Uranophane	Uranium Silicon Calcium Thorium	To 60	To 3	Yellow	Greasy Pearly	2–3	3·8–3·9	Massive Fine fibrous

TABLE II

The More Common Thorium Minerals

Mineral	Chief elements present	ThO_2 Per cent	U_3O_8 Per cent	Usual colour	Usual lustre	Hardness	Specific gravity	Habit
Monazite	Rare earths Phosphorus Thorium	To 14	To 0·5	Brown Yellow	Resinous	5–5·5	4·6–5·3	Crystals Grains
Allanite	Rare earths Aluminium Iron Calcium Silicon	To 3·5	To 0·2	Black Brown	Vitreous Pitchy Resinous	5–6	2·7–4·2	Long tabular crystals
Thorite Uranothorite	Thorium Silicon	To 71	To 27	Yellow Orange Black	Vitreous Greasy	4·5–5	4·1–6	Tetragonal crystals
Thorianite Eschynite Priorite Thucholite	See Table I							

SAMPLING AND EVALUATION OF URANIUM DISCOVERIES

The following suggestions on preliminary sampling of new finds are intended for amateurs who may never have had occasion to 'size up' or sample a discovery. More detailed sampling of deposits showing some promise is usually done under the direction of mining engineers or geologists. Eldorado[1] does its exploratory work on promising prospects mainly by diamond drilling, paying relatively little attention to surface rock trenching, etc.

The prospector who has found a radioactive showing is immediately faced with the problem of deciding what is the best way to find out, with his limited facilities, if the deposit is likely to be worth further attention or staking. Presumably the discovery was made by means of a Geiger counter, but unless the instrument has a meter it may be difficult to judge the intensity of the radioactivity, assuming it is more than three or four times the normal background. In such circumstances, the next step should be to determine the nature of the radioactive material, whether granite, pegmatite, gneiss, or a vein or shear zone. The rock should be cleaned as thoroughly as possible by brushing or washing and carefully examined. If the activity appears to follow a vein or streak in the rock, or several of these, having greater length in one direction than another, the occurrence may be assumed to be of vein type or gneissic material, and may be expected to have much greater length than width; the direction of greatest length, or 'strike', should be carefully noted by sighting or compass bearing, and extensions of the active body should be sought for in both directions along the strike. The

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[1] "The Exploration and Development of Canadian Uranium Deposits by Eldorado Mining and Refining (1944) Limited", by B. S. W. Buffam and E. B. Gillanders. Available on request from Eldorado Mining and Refining (1944) Limited, Ottawa.

outcrop, of course, should also be carefully examined in a direction at right angles to the apparent strike, to determine the full width of the radioactive material exposed. The possibility of parallel veins or radioactive zones at greater distances from the original discovery should also be checked by slow and careful Geiger counter traverses across the direction of strike.

Having satisfied himself that the occurrence is not merely a slight local concentration of radioactivity in a granite mass or a crystal or concentration of radioactive mineral in pegmatite, but is a deposit having length and more or less continuity, the next problem is how best to take samples for radiometric or chemical tests. As radiometric tests are made without charge and very quickly by the Radioactivity Division, Geological Survey of Canada, the prospector will save himself much initial expense by taking advantage of this free testing service, or of similar services offered by provincial mining departments.

Decision as to the method of taking initial samples might depend largely on the immediate circumstances, such as time, equipment, and labour available, size and nature of the deposit, time required to send out samples and receive a reply, costs, and doubtless other special local or personal considerations. Generally, the net result of such factors, in the case of a new discovery, is that the prospector takes what may be called selected grab, lump, or chip samples from the material showing the highest radioactivity on the Geiger counter. This procedure has something in its favour for preliminary sampling, as it is quick and easy, and if the best material that can be found does not show at least as much as 0·05 per cent U_3O_8 equivalent activity, the showing cannot, in most instances, be considered promising. However, if the indications are that the deposit is in a strong break, with good length, or if there are several showings on the line of strike, or if so much of the rock in the direction of strike is concealed by overburden that it cannot be reasonably well tested at intervals along its full length without stripping, it still might be worth a little further attention. With higher values from sampling, this would be even more advisable, and if as much as 0·1 per cent U_3O_8 equivalent was reported on initial samples, staking could be considered, especially if pitchblende was identified in the samples.

If encouraging results are obtained from the preliminary, selected chip or grab samples, stripping and cleaning of the rock along the strike of the deposit should be done to whatever extent is possible under the circumstances. With fairly heavy overburden, it might be easier to trench at intervals across the strike as far as the structure can be followed by this method or as far as encouraging radioactivity can be detected by the Geiger counter. At the cleared sections, or at other suitable intervals available, it would then be desirable to take measured chip or channel samples across the strike of the active material. Channel samples, if carefully taken, can yield more information than grab samples or chip samples, but require more time and labour. The extra trouble of taking at least one or two good channel samples across the best-representative part of the deposit, however, is well repaid.

Tools that may be used for sampling are: the prospectors' hand pick, cold chisels, moils[1], 3-pound short-handled hammer, and full-size pick. The prospector is usually his own blacksmith, and able to sharpen, harden, and temper his own steel. However, the larger sizes of cold chisels available at hardware stores may be used and sharpened with a large, coarse file of the best quality. Horsehide gloves are almost indispensable. A

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[1] Moils are usually pieces of discarded drill steel 6 inches to a foot long by about $\frac{3}{4}$ or $\frac{7}{8}$ inch diameter that have been forged down to a tapering, four-sided point at one end, with a slightly blunter taper near the point for greater strength. They are used like chisels.

fairly good paint or varnish brush 2 inches or more wide is also very useful. A simple folding magnifying lens of good quality, 1¼ inches or more in diameter, is about all that is necessary for optical equipment, and is inexpensive. A magnification of 3·5 is a suitable power that does not give too much distortion on rough surfaces. If higher powers such as 10 or 15 are desired the "Hastings Triplet", costing about $15, gives best results. Lenses should be carried in a chamois or plastic bag to exclude dust. An alnico magnet is also useful.

Professional prospectors usually have drills, sledges, and dynamite for hand-drilling short holes for 'pop-shots' to expose fresh surfaces of rock as an aid to examination and sampling. Gasoline-driven core drills are also available for boring to moderate depths; the use of such drills, however, would necessitate first obtaining an exploration permit from the Atomic Energy Control Board.

Samples taken in various ways are described as: grab, selected grab, chip, channel, bulk, diamond-drill core, etc. A term not found in text-books, but which is used, and probably should be recognized, is the 'lump' sample. This term has no recognized meaning, but probably applies, in most cases, to one of the richest fragments that can be readily picked up or knocked or pried off.

A grab sample, by strict definition, is one taken at random, without selection, as from an ore pile or a dump, and is not presumed to represent any particular width, length, or depth of the deposit. The term has considerable elasticity in ordinary usage, however, and probably most samples so described represent a fairly high degree of selection as to place and grade, and should be called selected grab, chip, or lump samples.

Chip samples are obtained by taking a series of chips with a moil, usually over a definite distance, as across a vein or other mineralized zone. To be as representative as possible the chips should be of about the same size, and about equally spaced, so as to approximate channel sampling as nearly as possible. If pop-shots have been put in, it may be possible to take chip samples by chipping the edges of suitable large fragments with a hammer.

Channel sampling consists in cutting a channel, usually 2 inches or more wide and ½ inch or more deep, across the width to be sampled, and saving as much as possible of the material from the channel. The edges of the proposed channel should be marked on the rock, and a narrow cut, ¼ inch or more wide, made along these lines to the required depth and cleaned. The sample material between these cuts should then be removed with great care so as to lose as little as possible. In all sampling operations involving uranium minerals there is likely to be loss due to the friability of these minerals, and special care should be taken to avoid losing small particles and powder, which may be relatively richer in uranium than the rest of the sample.

The foregoing types of sampling come under prospecting as defined by the Atomic Energy Control Board, and no permit is required. Bulk sampling, however, as it might involve removing considerable quantities of uranium, must be authorized by first securing an exploration permit from the Secretary of the Board. In bulk sampling, relatively large samples are taken, usually for concentration tests. For this purpose the Mines Branch requires that each sample be at least 300 pounds in weight, and exploration permits limit the total of such samples to 10 tons from one property. Bulk samples are taken in various ways. Each sample may represent a mining width across the vein or zone of mineralization, and thus resemble a large channel sample, or samples may be taken by blasting out for definite lengths and widths along the vein at various points.

Although the first sampling undertaken by the prospector at a new discovery may be done hurriedly for the purpose of deciding whether to stake or not, it would be worth while, even in the roughest of sampling, to attempt to represent a definite width across the vein or mineralized zone and to take several separate samples at different places along its length, so far as possible, including the richest part and the poorest part exposed. If possible, pop-shots should be put in, and a chip or channel sample taken from the fresher material at the bottom of the holes, or possibly from the blasted fragments. Otherwise, the surface should be cleaned, the surface material scaled off as well as possible by chiselling or chipping, and the sample taken by chipping or channelling for a definite distance on the scaled surface, across the vein or zone.

Grades are usually estimated for mining widths of at least 3 feet. Suppose a deposit is found in which the uranium content is confined to a vein of pitchblende $\frac{1}{8}$ to $\frac{1}{4}$ inch wide, which might occur as a streak in a larger vein filling or as the chief filling of a small fracture. If it could be proved that this pitchblende vein extended for several hundred feet in length and depth, it can be shown that it should be workable. However, in order to mine this narrow vein, a mining width of 3 feet of barren rock must be taken out and, in addition, shafts must be sunk to provide for the underground workings. In sampling this theoretical veinlet, it would only be necessary to take very short channel samples across the vein, or for definite lengths along it, if it was certain that there was no uranium in the rock on each side of it. In actual practice it would not always be safe to make this assumption, and it would be advisable to take some samples representative of say 2 feet of the supposedly barren rock on each side of the vein.

As the ordinary gamma type portable Geiger counter is affected by radiations from all directions it is not very suitable for studying the distribution of radioactivity near a highly active source, such as a pitchblende-bearing vein, and it may be difficult to decide from its behaviour whether the wall-rock near the vein is radioactive or not, or how much of the vein material itself is actually radioactive. In any case, surface rock near an outcrop of radioactive mineral may show activity due merely to contamination by alteration products from the outcropping radioactive mineral. The shielded, end-window beta counter and the alpha scintillation monitor are most suitable for localizing radioactive materials at the rock surface. As the alpha rays have almost negligible penetrating power the alpha monitor can only detect active material actually exposed at the surface. The end-window beta counter is not sufficiently shielded to be entirely unidirectional, but is much better than a gamma counter for this purpose.

The possible use of the meter type Geiger counter as a quantitative instrument to determine the grade of radioactive materials, either in place or as samples, has doubtless occurred to many. The idea is very attractive, and it might seem that it should be possible to calibrate a particular instrument on a sampled outcrop so that it would give rough indications of grade at other places. This is true only to a very limited degree; there are so many variable factors influencing the response of ordinary gamma type prospecting counters that it is best not to put too much reliance on their indications as a means of quantitative estimation of the grade of outcrops. An exposed vein of pitchblende, of course, will give such high readings as to be almost unmistakable, when the counter is brought close to it. Essentially barren rock contaminated by surface alteration products can also give high readings in some instances. The assay of samples in the field by means of suitable Geiger counters or the scintillometer is more practicable, and procedures for such assaying have been described by Senftle and McMahon[1].

It may be of some interest to calculate the grade across a mining width of 3 feet for imaginary deposits showing pitchblende veins of various dimensions. Such calculations can be readily made from the following data.

Reasonably pure pitchblende varies in specific gravity from about 6 to 8. As a cubic foot of water weighs 62·5 pounds, a cubic foot of pitchblende of specific gravity 8 would weigh 8 × 62·5 = 500 pounds; with specific gravity 6, a cubic foot would weigh 375 pounds. Suppose a vein of pitchblende averages 1 inch in width; then, for a length and depth of 1 foot there is a square foot of pitchblende 1 inch thick, or $\frac{1}{12}$ cubic foot, or 31·25 pounds of pitchblende, using the value of 6 for specific gravity. The U_3O_8 content of pure pitchblende might be as high as 80 per cent or more, but assume that it is 50 per cent for this pitchblende of specific gravity 6; the U_3O_8 content of the vein section 1 foot by 1 foot by 1 inch is then 50 per cent (or 50/100) of 31·25 = 15·625 pounds.

The grade for this same vein section for a 3-foot mining width can be worked out as follows: the mining width is not accurate to an inch, but suppose it is, then with each vein section, 1 foot by 1 foot by 1 inch, of pitchblende, there is also removed $2\frac{11}{12}$ or 2·92 cubic feet of barren rock. Assume that this has a specific gravity of 2·8. The weight of barren rock removed is then 2·8 × 62·5 = 175 pounds per cubic foot or 2·92 × 175 = 511 pounds across 2 feet 11 inches. Add to this the weight of the pitchblende that goes with it,

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[1] "Determination of Uranium in Ores by Field Analysis", obtainable on request from the Radioactivity Division, Mines Branch, Department of Mines and Technical Surveys, Ottawa.

namely, 31·25 pounds, and the total weight of barren rock and pitchblende removed is 542·25 pounds.

In the section of rock and pitchblende 1 foot by 1 foot by 3 feet, weighing 542·25 pounds and containing a 1-inch vein of solid pitchblende, there is 15·625 pounds of U_3O_8. The grade is, therefore, 100 × 15·625 divided by 542·25 = 2·882 per cent U_3O_8.

From the above data, or by similar calculations, the grade for narrower or wider veins or the total pitchblende or U_3O_8 content of deposits of known surface dimensions for given depths can be roughly estimated.

Suppose, for example, that it is known or estimated that the 1-inch wide pitchblende-bearing vein instead of being solid pitchblende is really only one-third pitchblende by volume; the grade is then only one-third of 2·882, or 0·96 per cent U_3O_8.

Or, if the vein is only $\frac{1}{8}$ inch wide and one-third pitchblende by volume, the grade is then one-third of one-eighth of 2·882 or 0·12 per cent U_3O_8.

While on this subject, it may be worth while to calculate values for some of these examples, applying the price formula given in Appendix I.

The 1-inch wide vein of solid pitchblende with a mining width of 3 feet is of 2·882 per cent U_3O_8 grade.

Price Calculation for 2·882 per cent Grade Ore

Grade of ore 2·882 per cent or 57·64 pounds a ton: 57·64 pounds at \$2.75 a pound × \$2.75.	\$158.51
Milling allowance...........................	\$ 7.25
Value of ore per ton........................	\$165.76
Recovery of 70 per cent of 57·64 pounds = 40·348 pounds.	
Price to be paid for the U_3O_8 content of concentrates is \$165.76 ÷ 40·348 or..............	\$ 4.11 a pound
Special development allowance of \$1.25 a pound U_3O_8 for the first 3 years production........	\$ 1.25
Price to be paid..................	\$ 5.36 a pound

Therefore, the return from concentrates produced at 70 per cent recovery for the first 3 years of production[1] is 40·348 × $5.36 = $216.26 per ton of ore milled, for the 1-inch wide solid pitchblende vein.

It might be mentioned that a recovery of 70 per cent is about average for simple gravity concentration applied to a suitable ore. By leaching[2] the whole or part of the ore it is not unusual to reach 80 per cent or even 90 per cent or more total recovery. The return from a 90 per cent recovery in the case of the 1-inch vein of solid pitchblende would be 51·88 × $5.36 = $278.08 a ton of ore milled during the first 3 years of production.

However, the possible value of a 1-inch vein of solid pitchblende as calculated above is only of theoretical interest for purposes of calculation, as a vein of such purity is unlikely to occur.

Suppose that the 1-inch vein is estimated to be one-third pitchblende by volume. A rough estimate of values could be obtained by taking one-third of the above figures for the solid vein; for example, one-third of $216.26 (or $72.09) would represent the approximate return per ton of ore milled during the first 3 years of production at 70 per cent recovery. However, owing to the effect of the price formula the actual return would be somewhat greater, as shown below.

The 1-inch wide pitchblende-bearing vein is assumed to contain one-third pitchblende by volume. The grade is, therefore, one-third of 2·882 = 0·96 per cent U_3O_8.

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[1] Or any part thereof. That is, any amount of acceptable concentrate produced during any time period included within the first 3 years of production will be entitled to the development allowance of $1.25 a pound of U_3O_8. Prices as derived from the price formula are guaranteed to April 1960.

[2] Leaching is a method of treating the ore with acid or alkaline solutions, which dissolve the uranium. The final product is a chemical precipitate containing the uranium in concentrated form.

Price Calculation for 0·96 per cent Grade Ore

Grade of ore, 0·96 per cent or 19·2 pounds a ton: 19·2 × \$2.75	\$ 52.80
Milling allowance	\$ 7.25
Value of ore per ton	\$ 60.05
Recovery, 70 per cent of 19·2 pounds = 13·44 pounds.	
Price to be paid for the U_3O_8 content of concentrates is \$60.05 ÷ 13·44 or	\$ 4.47 a pound
Special development allowance of \$1.25 a pound U_3O_8 for the first 3 years production	\$ 1.25 a pound
Price to be paid	\$ 5.72 a pound

Therefore, the return from concentrates produced at 70 per cent recovery for the first 3 years of production is 13·44 × \$5.72 = \$76.88 a ton of ore milled, for the vein 1-inch wide carrying one-third pitchblende by volume. The difference between this result and the approximate figure \$72.09 above, is due to the effect of the price formula. This effect is relatively greater for ores of 0·25 per cent grade or lower, as will be shown.

Suppose now, that a vein $\frac{1}{8}$ inch wide is composed of solid pitchblende, or there is a streak of solid pitchblende $\frac{1}{8}$ inch wide in a larger vein filling of gangue material. The grade over a mining width of 3 feet is approximately one-eighth of 2·882 = 0·36 per cent U_3O_8. Taking one-eighth of the \$216.26 return from the 1-inch wide vein of solid pitchblende at 70 per cent recovery gives \$27.03 return per ton of ore milled. The actual return after applying the price calculated for this grade is considerably greater, as shown below.

The $\frac{1}{8}$-inch vein is assumed to be solid pitchblende of specific gravity 6 and 50 per cent U_3O_8 content, as in all these calculations. Grade for a 3-foot mining width is one-eighth of 2·882 = 0·36 per cent U_3O_8.

Price Calculation for 0·36 per cent Grade Ore

Grade of ore 0·36 per cent, or 7·2 pounds a ton: 7·2 × \$2.75	\$ 19.80
Milling allowance	\$ 7.25
Value of ore per ton	\$ 27.05
Recovery of 70 per cent of 7·2 pounds = 5·04 pounds.	
Price to be paid for the U_3O_8 content of concentrates is \$27.05 ÷ 5·04 or	\$ 5.37 a pound
Special development allowance of \$1.25 a pound U_3O_8 for the first 3 years production	\$ 1.25 a pound
Price to be paid	\$ 6.62 a pound

Therefore, the return from concentrates produced at 70 per cent recovery during the first 3 years of production is 5·04 × \$6.62 = \$33.36 per ton of ore milled, for the solid pitchblende vein $\frac{1}{8}$ inch wide. At a recovery of 90 per cent, the return under the same conditions would be 6·48 × \$6.62 = \$42.90 a ton of ore milled.

Assuming that the $\frac{1}{8}$-inch vein actually carries only one-third pitchblende by volume, the grade becomes one-third of 0·36 = 0·12 per cent U_3O_8. One-third of \$27.03 is \$9.01, of \$33.36 is \$11.12, or of \$42.90 is \$14.30, but as the grade is now less than 0·25 per cent, the maximum price of \$7.25 per pound of U_3O_8 will be paid for acceptable concentrate produced during the first 3 years of production, and the actual return will be somewhat greater, as shown below.

Price Calculation for 0·12 per cent Grade Ore

Grade of ore 0·12 per cent or 2·4 pounds a ton: 2·4 × \$2.75	\$ 6.60
Milling allowance	\$ 7.25
Value of ore per ton	\$ 13.85
Recovery of 70 per cent of 2·4 pounds = 1·68 pounds.	

Price to be paid for the U_3O_8 content of concentrates is the maximum of \$6.00 per pound, as \$13.85 ÷ 1·68 is greater than \$6.00......	\$ 6.00 a pound
Special development allowance of \$1.25 a pound U_3O_8 for the first 3 years production..	\$ 1.25 a pound
Price to be paid..................	\$ 7.25 a pound

Therefore, the return from concentrates produced at 70 per cent recovery during the first 3 years of production is 1·68 × \$7.25 = \$12.18 a ton of ore milled, or, at 90 per cent recovery is 2·16 × \$7.25 = \$15.66 a ton of ore milled, for the vein $\frac{1}{8}$ inch wide carrying one-third pitchblende by volume. Thus, the return of \$12.18 per ton of ore milled is \$12.18 − \$9.01 = \$3.17 per ton greater than would be obtained at the price calculated for ore of 2·882 per cent grade in the case of the 1-inch vein of solid pitchblende.

It might be mentioned that in all these calculations of prices to be paid per pound for the U_3O_8 content of acceptable concentrates, the reference to 70 per cent recovery is merely a prescribed part of the price formula and does not mean that a producer would be penalized as to price for a lower or higher recovery. Thus, a producer working on 0·12 per cent ore would receive \$7.25 a pound of U_3O_8 content of acceptable concentrates produced during the first 3 years of production whether his recovery was 40 per cent or 97 per cent. The latter figure has been reached in experimental work using leaching methods.

CALCULATING THE SIZE OF DEPOSITS NECESSARY TO PROVIDE ORE OF ANY REQUIRED AMOUNT OR VALUE

The foregoing data can also be readily used for making rough estimates of ore and values present in an imaginary deposit assuming the body contains pitchblende veins of known dimensions and grades. Or, the dimensions of veins necessary to produce a given return can be roughly estimated, assuming they are of known grade.

The prospector, of course, can only judge a discovery from surface outcrops or strippings and the strength of the break in which it occurs. The grades at the surface can be estimated, to some degree at least, by sampling, but the depth to which values may go, and grades at depth, can be estimated only after much exploration and development and can be completely known only when the deposit has been worked out. Nevertheless, such theoretical calculations are useful in order to gain an idea of what grades and dimensions may be necessary to make a deposit attractive for capital outlay on exploration and development.

For example, the 1-inch vein already considered, that averages one-third pitchblende by volume, and is of 0·96 per cent grade (*See* page 122) will contain one-third of 15,625 pounds or 5·208 pounds of U_3O_8 per foot of length and depth. If these values hold for 200 feet of length and 100 feet of depth this block will contain 200 × 100 × 5·208 pounds = 104,160 pounds of U_3O_8. With 70 per cent recovery at 0·96 per cent grade for the 3-foot mining width, the return from concentrates from this block, if recovered during the first 3 years of production, would be 0·7 × 104,160 × \$5.72 = \$417,056.64. At 90 per cent recovery, the same block under the same conditions would yield 0·9 × 104,160 × \$5.72 = \$536,215.68.

The $\frac{1}{8}$-inch vein that is one-third pitchblende by volume and of 0·12 per cent grade for a mining width of 3 feet, will hold one-third of one-eighth of 15·625 pounds or 0·651 pounds U_3O_8 in a section of the vein 1 foot long and 1 foot deep. Assuming this is the average for 200 feet of length and 100 feet of depth, the block will contain 200 × 100 × 0·651 = 13,020 pounds U_3O_8. At 70 per cent recovery, the return from milling this block would be 0·7 × 13,020 × \$7.25 = \$66,076.50, if recovered during the first 3 years of production. At 90 per cent recovery, the same block under the same conditions would yield $0{\cdot}9 \times 13{,}020 \times \$7.25 = \$84{,}955.50$.

The foregoing figures, summarized in Table II, will give some idea of values that might be contained in pitchblende-bearing veins of known widths. The imaginary veins used for the calculations are not likely to be duplicated as to continuity and uniformity of grade by real veins, but they afford an idea of the amount of pitchblende that must be present to produce ore of various grades. The necessity for exposure of fresh material and extremely careful sampling over measured widths is obvious. The positive identification of pitchblende as a constituent of the vein filling is also of great importance[1]. A prospector without access to assay facilities but able to recognize pitchblende might be able to make grid estimates of areas of visible pitchblende sections over measured lengths and widths on cleaned or blasted surfaces, add them up and convert them to the equivalent of a solid vein of corresponding length and area. This might not be too difficult in cases where pitchblende is the chief or almost the only metallic mineral in the vein, but would be impossible in many cases where the vein filling is very complex or where the pitchblende is very intimately mixed with hematite.

The general value and versatility of the grid method of estimation might be emphasized. It is applicable on any scale, from estimating large areas or crystals in pegmatites down to measurements of minute particles

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[1] For this reason prospectors sending samples of vein material to the Geological Survey for test should always include a separate sample, even if quite small, of the freshest and richest material available, marked 'for identification'. Vein material is given first priority over other types of radioactive raw materials in making identification tests and, therefore, results of such tests are reported more quickly than in the case of tests requested on other types of materials.

TABLE III

Summary of Pitchblende Vein Calculations

Vein width of pitchblende, S.G. = 6 50% U_3O_8	Pounds of U_3O_8 per 1-foot length and depth	Approximate grade in per cent U_3O_8 over 3-foot width	Maximum price per pound of U_3O_8	Return per ton at		Return per block 200 × 100 × 3 feet at	
				Recovery of 70%	Recovery of 90%	Recovery of 70%	Recovery of 90%
			$ cts.	$ cts.	$ cts.	$	$
1 inch, solid pitchblende......	15·625	2·88	5 36	216 26	278 08	1,172,500	1,507,500
1 inch, one-third pitchblende......	5·208	0·96	5 72	76 88	98 84	417,056	536,215
⅛ inch, solid pitchblende......	1·953	0·36	6 62	33 36	42 90	181,004	232,719
⅛ inch, one-third pitchblende......	0·651	0·12	7 25	12 18	15 66	66,076	84,955

under the high-power microscope. Its application is limited only by the necessity of being able to positively identify the desired constituent and distinguish it from all others. Corrections must be made for curved surfaces.

Mining and milling costs, and especially the latter, of course, are very important factors in determining whether a deposit, especially a small or low-grade one, could be worked at a profit. The subject of milling costs has been discussed in a recent paper[1] by Arvid Thunaes, Chief of the Radioactivity Division, Mines Branch, Department of Mines and Technical Surveys, Ottawa. This is obtainable on request. As the present trend of costs is upwards, it would be advisable to consult Mr. Thunaes in regard to possible revisions of these estimates.

Some data from Mr. Thunaes' paper may be abstracted here. In producing concentrate containing 10 per cent U_3O_8 by simple gravity concentration from rich ores of pitchblende or uraninite, not disseminated, and suitable for such treatment, 60 to 75 per cent of the values may be recovered as 10 per cent U_3O_8 concentrate. The estimated operating costs for a daily tonnage of 100 tons are $2 to $3 a ton; for a daily tonnage of 500 tons, $1.75 to $2.50 a ton. This does not include mining costs. Capital costs are $750 to $1,200 per ton of daily capacity depending on location, ore characteristics, and tonnage. In the case of pitchblende ores requiring special treatment, for example those in which pitchblende is very intimately mixed with hematite, additional expenditure will be required, but such expenditures will be relatively minor.

Leaching may be applied to all of the ore, or to a reduced tonnage resulting from preconcentration. The estimated costs for leaching all the ore are: for a daily

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[1] "Notes on Treatment of Low Grade Uranium Ores, with Notes on Approximate Costs for Treatment of Uranium Ores", March 1951.

tonnage of 100 tons, \$6 to \$11 a ton, average \$8 to \$9; for a daily tonnage of 500 tons, \$4.50 to \$9, average \$6.50 to \$8.50.

Capital cost of plant for leaching will vary from \$2,500 to a high of \$5,000 per ton, the higher figure referring to very remote localities and including plant for producing acid. In reasonably central localities, \$3,000 per ton could be used for the preliminary estimates.

With preconcentration and leaching of the reduced tonnage, the estimated costs for a daily tonnage of 300 tons mined and 150 tons leached is \$4.50 to \$7 a ton mined. The capital cost will be as for leaching, plus the cost of the preconcentration section.

Leaching, either of all the ore or combined with preconcentration, gives total recoveries of 70 to 97 per cent.

The foregoing estimates do not include capital costs of mining plant nor mining costs.

Mr. Thunaes states that "An ore containing 0·1 per cent U_3O_8 may be sufficiently rich to be treated at a profit if the indicated daily tonnage is very substantial and the locality and treatment costs are favourable. For a small tonnage 0·3 to 0·4 per cent U_3O_8 may often be required to allow sufficient margin of profit, and in very remote areas an even higher grade must be mined. ". . . If uranium occurs in ores that contain a substantial amount of other recoverable values, then the economic limit for ore grade will of course be lower".

S. N. Kesten, in an article[1] on "Radioactive Occurrences in the Sault Ste. Marie Area", assumes that the minimum requirements for a mining operation are 100,000 tons of ore valued at \$11 a ton in place.

Mining costs for pitchblende deposits would probably be comparable to those of gold mines of equivalent tonnage. Mining costs, usually including development

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[1] Canadian Mining Journal, August 1950.

and associated costs, as for haulage, hoisting, etc., as shown in the annual reports of Canadian gold mines range from about $2 a ton to a high of about $8 a ton.

Much of this section has been written not only for the amateur prospector but also with the idea of aiding the more experienced prospector, who has to depend on his own resources, in remote areas, to arrive at a rough estimate of the economic value of his discoveries, when it is impracticable to have regular assays or other laboratory tests made during the prospecting season. The method of field assaying with the Geiger counter previously referred to (page 71) would be a very valuable aid in such circumstances; use of the fluorescent bead test would serve to confirm the presence of uranium in radioactive material, and a final suggestion might be the possible value of panning as an aid in isolating pitchblende or other radioactive minerals for test and identification by these or other methods. If, by panning crushed vein material, a highly active, heavy, black, non-magnetic concentrate were obtained, which evidently was heavier than the other minerals of the vein filling, such as quartz, carbonates, sulphides or arsenides, hematite, etc., this by itself would constitute a reasonably good identification of pitchblende. Panning should also be helpful in isolating the active mineral or minerals from schistose deposits, granites, or pegmatites carrying the active minerals disseminated as minute grains. Any heavy concentrate obtained could be examined with the lens and tested with the Geiger counter or by the fluorescent bead test.

In a concentrate from these types of deposits, heavy, black, highly active minerals might be uraninite, thorianite, uranothorite, or black, complex columbate-tantalate minerals, such as euxenite, etc. Yellowish, brownish, or reddish active grains might be thorite, gummite, or uranophane, monazite, or altered phases of complex columbate-tantalate minerals. In general, the specific gravities of pitchblende, uraninite, and thorianite may be considered to be from 6 to 9, and of most of the other radioactive minerals from 4 to 6. Uraninite and pitchblende thus are heavier than any of the commoner minerals except galena (which has a specific gravity from 7·3 to 7·5) and can be readily concentrated by panning. Thorianite is relatively so rare that the chance of encountering it is almost negligible. The specific gravities of some of the commoner minerals of interest in this connection are: quartz, 2·66; carbonates and micas, 2·7 to over 3; feldspars, 2·5 to 2·7; barite, 4·5; garnet, 3 to 4·3; and pyrite, hematite, magnetite, and ilmenite, about 5. Columbite-tantalite, a heavy, black, non-magnetic mineral that may be encountered in pegmatitic material, and valuable for its content of columbium and tantalum, has a range of specific gravity from about 5 to 7.

For the best results in panning, the material panned should be as nearly as possible of uniform grain size, and if a prospector intends to do much panning it would be worth while to take along two or more nested brass sieves about 6 to 8 inches in diameter of the type sold by laboratory supply houses. Use of the sieves would permit crushing the material a little at a time with frequent sifting, so as to produce as little very fine powder as possible, a procedure that would be desirable in testing for radioactive minerals, which are very friable and in crushing may be more readily reduced to fine powder than some of the other minerals with which they are associated. Highly altered pitchblende from near the surface, especially, is thus easily powdered. Such material may have a specific gravity as low as 3 or 4, but cores or particles of less altered, harder and heavier material may be included in the highly altered material. Such soft, light material, of course, is no longer pitchblende, but is a hydrated, oxidized, silicated product that may consist of several secondary minerals.

In panning crushed radioactive material it is advisable, as previously mentioned, to work on fairly closely sized fractions if possible. Owing to the friability of radioactive minerals, they will be, to some degree, reduced to very fine powder, which on panning will tend to stay in suspension. This fine, suspended powder or 'slimes' may in some instances comprise a rather large fraction of the total active material, and it should be saved for testing by pouring it off into another pan or receptacle for settling and drying. Thucholite, specific gravity about 1·7, if present, would probably pass largely into the slimes, and any larger particles would mostly come off ahead of the quartz and other lighter gangue minerals. It would be advisable to have several pans or receptacles in which all the products of the panning could be settled and dried for testing. If a number of pans are available, it is also possible to repeat the panning treatment of any product to any desired degree. Aluminium pans are preferable because they are light and rust free. It might be well not to try to produce a perfectly clean heavy concentrate in one operation, but, after pouring off the slimes, to endeavour to produce as clean a discard as possible of the lighter gangue minerals such as quartz, carbonates, or feldspar, without panning down too close to the heavy materials. An effort could then be made to find if it is possible to remove non-radioactive heavy minerals without too much loss of the radioactive materials.

A very small amount of a wetting agent added to the water used in panning facilitates the operation and prevents floating of fine particles. The household powder 'Vel' is suitable, but the amount added should not be sufficient to produce frothing[1]. An alnico magnet is useful for removing magnetic material.

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[1] A few drops of a 10 per cent solution are enough for a pan of water. A half teaspoon of the powder dissolved in one or two tablespoons of water should be made up and added by drops.

Panning is essentially the same sort of simple gravity concentration as is done in the laboratory, by mechanical equipment such as Wilfley tables and the superpanner. An experienced panner can, in many instances, obtain comparable results.

Stream sands or reworked glacial sands could also be tested by panning for monazite or other radioactive minerals that might be present.

APPENDIX I

GOVERNMENT PURCHASING POLICY FOR URANIUM ORES AND CONCENTRATES

As several announcements have been made in regard to the purchase of uranium ores and concentrates, the later ones are more easily understood by considering all of them in order, commencing with the first announcement by the Right Honourable C. D. Howe, on March 16, 1948, as follows:

"The government will purchase through Eldorado Mining and Refining (1944) Limited, or other designated agency, acceptable uranium bearing ores and concentrates on the following basis:

1. A minimum uranium content equivalent to 10 per cent by weight of uranium oxide (U_3O_8) in the ores or concentrates will normally be required.
2. Price will be based upon the uranium content of the ores or concentrates and will be at the minimum rate of $2.75 per pound of contained (U_3O_8) f.o.b. rail and will be guaranteed for a period of five years.
3. This price includes all radioactive elements in the ores or concentrates, but consideration will be given to the commercially recoverable value of non-radioactive constituents by adjustment of price or by the redelivery of the residues containing such constituents.
4. Under special circumstances, consideration may be given to payment of a higher price or to acceptance of ores or concentrates of lower grade.
5. All operations will be carried on subject to the provisions of the Atomic Energy Regulations of Canada."

On December 20, 1948, the expiry date for the guaranteed floor price was extended to March 31, 1955.

A further amendment to the purchasing policy was announced by Mr. W. J. Bennett[1], President and Managing Director, Eldorado Mining and Refining (1944) Limited, at the Annual Meeting of the Canadian Institute of Mining and Metallurgy, Toronto, April 18, 1950. This was designed to encourage the development of low-grade deposits and efficiency in ore dressing by payment of a milling allowance on ore treated. The formula for determining the price to be paid for the U_3O_8 content of concentrates is based upon four factors:

(1) $2.75 a pound for the average U_3O_8 content of the ore or mill feed
(2) A milling allowance of $7.25 a ton of ore milled
(3) A maximum price based on a mill head of 0·25 per cent U_3O_8
(4) A minimum extraction of 70 per cent

Eldorado Mining and Refining (1944) Limited will purchase, f.o.b. rail, acceptable concentrates, which normally will be required to contain a minimum uranium content equivalent to 10 per cent by weight of uranium oxide (U_3O_8) and will pay for the U_3O_8 content at a price per pound determined in accordance with the following formula:

> The price per pound to be paid for the U_3O_8 content of acceptable concentrates containing 10 per cent or more by weight of U_3O_8 shall be the product obtained by multiplying the average number of pounds of U_3O_8 per ton of mill feed by $2.75 a pound, adding to this a milling allowance of $7.25 per ton of ore milled, and dividing the sum of the two by 70 per cent of the average number of pounds of U_3O_8 per ton of mill feed.

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[1] Remarks of W. J. Bennett on Purchasing Policy at Annual Meeting of C.I.M.M., Toronto, April 18, 1950; obtainable on application to the Secretary, Atomic Energy Control Board, Ottawa, Ontario.

The maximum price per pound for the U_3O_8 content of acceptable concentrates that will be paid under this arrangement is that based upon the formula applied to an ore with an average grade of 0·25 per cent or 5 pounds per ton.

As the price is based upon the average grade, Eldorado reserves the right to adjust the contract from time to time to bring it into conformity with actual operating results.

The formula is designed to encourage efficiency in ore dressing. Although the minimum extraction of 70 per cent is used in the formula, it will be apparent that if recovery exceeds 70 per cent there will be more pounds of U_3O_8 to be purchased. Hence the value per ton of ore mined and milled will be greater.

Although the price includes all radioactive elements in the concentrates, arrangements will be made for valuing other constituents that can be recovered commercially.

The following examples show how the formula is applied:

(1) Grade of ore, 0·25 per cent, or 5 pounds a ton 5 × \$2.75	\$13.75
Milling allowance	7.25
Value of ore per ton	\$ 21.00
Recovery, 70 per cent of 5 pounds = 3·5 pounds	
Price to be paid for the U_3O_8 content of concentrates: \$21.00 ÷ 3·5	\$ 6.00 a pound

(2) Grade of ore, 0·5 per cent, or 10 pounds a ton 10 × \$2.75	\$ 27.50
Milling allowance	7.25
Value of ore per ton	\$ 34.75
Recovery 70 per cent of 10 pounds = 7 pounds	
Price to be paid for the U_3O_8 content of concentrates: \$34.75 ÷ 7 =	\$ 4.95 a pound

(3) Grade of ore, 0·75 per cent, or 15 pounds a ton 15 × \$2.75	\$ 41.25
Milling allowance	7.25
Value of ore per ton	\$ 48.50
Recovery 70 per cent of 15 pounds = 10·5 pounds	
Price to be paid for the U_3O_8 content of concentrates: \$48.50 ÷ 10·5 =	\$ 4.62 a pound

The Right Honourable C. D. Howe, on April 17, 1950, announced the extension of the guaranteed price period to March 31, 1958.

On March 6, 1951, Mr. Bennett[1] announced a further revision in the price schedule by which the price paid per pound of U_3O_8 content for mill products produced during the first 3 years of production, or any part thereof, will be increased by $1.25 a pound. Thus, for example, the U_3O_8 content of a concentrate produced from an ore with an average grade of 0·25 per cent or lower will be paid for at the rate of $7.25 a pound during the first 3 years of production. In the case of a concentrate produced from ore of 0·5 per cent average grade, the new price will be $6.20 a pound of U_3O_8 content, for the first 3 years, and so on.

The period during which these prices are guaranteed was also extended to April 1, 1960.

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[1] Address of W. J. Bennett, President, Eldorado Mining and Refining (1944) Limited, at the Annual Convention, Prospectors and Developers Association, and Fourth Annual Meeting, Geological Association of Canada, Toronto, March 6, 1951; obtainable on application to the Secretary, Atomic Energy Control Board, Ottawa, Ontario.

APPENDIX II

EXTRACTS RELATING TO PROSPECTING AND MINING, FROM THE ATOMIC ENERGY CONTROL ACT, 1946

1. This Act may be cited as The Atomic Energy Control Act, 1946.

2. In this Act, unless the context otherwise requires,

   (a) "atomic energy" means all energy of whatever type derived from or created by the transmutation of atoms;

   (b) "Board" means the Atomic Energy Control Board established by section three of this Act;

   (c) "Chairman" means the Chairman of the Committee of the Privy Council on Scientific and Industrial Research as defined in the Research Council Act;

   (d) "Committee" means the Committee of the Privy Council on Scientific and Industrial Research as defined in the Research Council Act;

   (e) "company" means a company incorporated pursuant to paragraph (a) of subsection one of section ten and any company the direction and control of which is assumed by the Board pursuant to paragraph (b) of subsection one of section ten of this Act;

   (f) "member" means a member of the Board;

   (g) "President" means the President of the Board; and

   (h) "prescribed substances" means uranium, thorium, plutonium, neptunium, deuterium, their respective derivatives and compounds and any other substances which the Board may by regulation made under this Act designate as being capable of releasing atomic energy, or as being requisite for the production, use or application of atomic energy.

3. (1) There is hereby constituted a body corporate to be called the Atomic Energy Control Board for the purposes hereinafter set out and with powers exercisable by it only as an agent of His Majesty.

(2) The Board may on behalf of His Majesty contract in the name of His Majesty and property acquired by the Board is the property of His Majesty except shares in the capital stock of a company which shall be vested in the name of the Board in trust for His Majesty.

4. (1) The Board shall consist of the person who from time to time holds the office of President of the Honorary Advisory Council for Scientific and Industrial Research as defined in the Research Council Act and four other members appointed by the Governor in Council.

7. The Board shall comply with any general or special direction given by the Committee with reference to the carrying out of its purposes and shall advise the Committee on all matters relating to atomic energy, which, in the opinion of the Board, may affect the public interest.

8. The Board may,—

(a) undertake or cause to be undertaken researches and investigations with respect to atomic energy;

(b) with the approval of the Governor in Council utilize, cause to be utilized and prepare for the utilization of atomic energy;

(c) with the approval of the Governor in Council acquire or cause to be acquired by purchase, lease, requisition or expropriation, prescribed substances and any mines, deposits or claims of prescribed substances and patent rights relating to atomic energy and any works or property for production or preparation for production of, or for research or investigation with respect to, atomic energy;

(g) with the approval of the Committee, disseminate or provide for the dissemination of information relating to atomic energy to such extent and in such manner as the Board may deem to be in the public interest;

(h) with the approval of the Governor in Council license or otherwise make available or sell or otherwise dispose of discoveries, inventions and improvements in processes, apparatus or machines, patent rights and letters patent of Canada or foreign countries acquired under this Act and collect royalties and fees thereon and payments therefor; and

(i) without limiting the generality of any other provision of this Act, establish, through the Honorary Advisory Council for Industrial and Scientific Research as defined in the Research Council Act, or otherwise, scholarships and grants in aid for research and investigations with respect to atomic energy, or for the education or training of persons to qualify them to engage in such research and investigations.

9. (1) The Board may with the approval of the Governor in Council make regulations,—

(c) respecting mining and prospecting for prescribed substances;

(d) regulating the production, import, export, transportation, refining, possession, ownership, use or sale of prescribed substances and any other things that in the opinion of the Board may be used for the production, use or application of atomic energy;

(e) for the purpose of keeping secret information respecting the production, use and application of, and research and investigations with respect to, atomic energy, as in the opinion of the Board, the public interest may require; and

(g) generally as the Board may deem necessary for carrying out any of the provisions or purposes of this Act.

10. (1) The Board may with the approval of the Governor in Council,—

(a) procure the incorporation of any one or more companies under the provisions of Part I of The Companies Act, 1934, for the objects and purposes of exercising and performing on behalf of the Board such of the powers conferred upon the Board by paragraphs (a), (b), (c) and (h) of section eight of this Act as the Board may from time to time direct and all the issued shares of the capital stock of each such company shall be owned or held in trust by the Board for His Majesty in right of Canada except shares necessary to qualify other persons as directors; or

(b) assume, by transfer to the Board in trust for His Majesty in right of Canada of all the issued share capital thereof except shares necessary to qualify other persons as directors, the direction and control of any one or more existing companies incorporated under the provisions of Part I of The Companies Act, 1934, all the issued share capital of which is owned by or held in trust for His Majesty in right of Canada except shares necessary to qualify other persons as directors and may delegate to any such company any of the powers conferred on the Board by paragraphs (a), (b), (c) and (h) of section eight of this Act.

(2) Every company shall keep and maintain such books and records, in addition to those required by The Companies Act, 1934, as the Board may prescribe and shall make such reports and returns to the Board as the Board may require.

(3) The accounts of a company shall be audited by the Auditor General.

14. Whenever any property has been requisitioned or expropriated under this Act and the compensation to be made therefor has not been agreed upon, the claim for compensation shall be referred by the Minister of Justice to the Exchequer Court.

20. Any person who contravenes or fails to observe the provisions of this Act or of any regulation made thereunder shall be guilty of an offence and shall be liable on summary conviction to a fine not exceeding five thousand dollars or to imprisonment for a term not exceeding two years or to both fine and imprisonment, but such person may, at the election of the Attorney General of Canada or of the province in which the offence is alleged to have been committed, be prosecuted upon indictment, and if found guilty shall be liable to a fine not exceeding ten thousand dollars or to imprisonment for a term not exceeding five years or to both fine and imprisonment; and where the offence has been committed by a company or corporation every person who at the time of the commission of the offence was a director or officer of the company or corporation shall be guilty of the like offence if he assented to or acquiesced in the commission of the offence or if he knew that the offence was about to be committed and made no attempt to prevent its commission, and in a prosecution of a director or

officer for such like offence, it shall not be necessary to allege or prove a prior prosecution or conviction of the company or corporation for the offence.

APPENDIX III

EXTRACTS RELATING TO PROSPECTING AND MINING FOR URANIUM AND THORIUM FROM THE ATOMIC ENERGY REGULATIONS OF CANADA (REGULATIONS OF THE ATOMIC ENERGY CONTROL BOARD MADE UNDER THE ATOMIC ENERGY CONTROL ACT, 1946, NOVEMBER 3, 1949)

101. Interpretation

(1) In these regulations, unless the context otherwise requires:

(a) "Act" means The Atomic Energy Control Act, 1946;

(b) "atomic energy" means all energy of whatever type derived from or created by the transmutation of atoms;

(c) "Board" means the Atomic Energy Control Board established by the Act;

(d) "deal in" includes produce, import, export, possess, buy, sell, lease, hire, exchange, acquire, store, supply, operate, ship, manufacture, consume and use;

(e) "fissionable substance" means any prescribed substance that is, or from which can be obtained, a substance capable of releasing substantial amounts of energy by nuclear chain reaction;

(f) "member" means a member of the Board;

(g) "order" means any general or specific order, licence, permit, direction or instruction made, given or issued by or under the authority of the Board;

(h) "person" includes firm, corporation, company, partnership, association or any other body and the heirs, executors, administrators, receivers, liquidators, curators and other legal representatives of such person according to the laws of that part of Canada applicable to the circumstances of the case, and includes any number of persons acting in concert or for a common purpose;

(i) "prescribed equipment" means any property, real or personal, other than prescribed substances, that in the opinion of the Board may be used for the production, use or application of atomic energy;

(j) "prescribed substances" means uranium, thorium, plutonium, neptunium, deuterium, other elements of atomic number greater than 92 and radioactive isotopes of other elements and any substances containing any of the said elements or isotopes;

(k) "President" means the President of the Board;

(l) "produce" includes develop, drill for, mine, dredge, dig, sluice, mill, extract, concentrate, smelt, refine, purify, separate, enrich and process;

(m) words of one gender include all other genders.

(2) Elements of atomic number greater than 92, radioactive isotopes of other elements and substances containing any of the elements or isotopes mentioned in paragraph (j) of subsection one of this section are designated as being capable of releasing atomic energy.

(3) The Interpretation Act is applicable to and in respect of every order.

(4) The grammatical variations and cognate expressions of a word defined in these regulations shall have meanings corresponding to the meaning of the word so defined.

200. Prescribed Substances and Prescribed Equipment Generally

(1) No person shall deal in any prescribed substance or prescribed equipment except under and in accordance with the provisions of these regulations or of an order.

(2) Where any person controls or directs any dealings by any other person in prescribed substances or prescribed equipment, whether such control is exercised through share ownership, trusteeship, agreement, duress or otherwise howsoever, all dealings in prescribed substances or prescribed equipment by such other person may be treated, for the purpose of these regulations or of any order, as dealings by the person who controls or directs such dealings.

(3) Any order may

(a) Impose conditions as to furnishing information, preventing disclosure of information, control of, disposition of, price of, inspection of, access to or protection of any prescribed substance or prescribed equipment, or otherwise in relation to any prescribed substance or prescribed equipment;

(b) regulate, fix, determine or establish the kind, type, grade, quality, standard, strength, concentration, or quantity of any prescribed substance or prescribed equipment that may be dealt in under the order or that may be dealt in by any person either generally or for any specified use and either generally or within a specified period of time.

201. Continued Possession

No order shall be necessary to authorize the continued possession by any person of any prescribed substance (whether or not in such quantity or concentration that an order would be required to authorize other dealings therein) or prescribed equipment acquired prior to the date of the coming into force of these regulations, if full information as to the nature, kind, location, ownership, possession and use or intended use of such prescribed substance (if in such quantity or concentration that an order would be required to authorize other dealings therein) or prescribed equipment is furnished to the Board within 60 days after the said date.

202. Uranium

(1) No order shall be necessary to authorize dealings within Canada by any person as regards uranium

(a) contained in any substance that contains less than 0·05 per cent by weight of the element uranium; or

(b) contained in any substance and which dealings do not involve during any calendar year a total of more than 10 kilograms of contained uranium element.

(2) Nothing in this section shall authorize any dealings in any substance that contains any of the uranium isotope U-233 or that contains uranium having any greater percentage of the isotope U-235 than is normally found in nature.

203. Thorium

No order shall be necessary to authorize dealings within Canada by any person as regards thorium

(a) contained in any substance that contains less than 0·05 per cent by weight of the element thorium; or

(b) contained in any substance and which dealings do not involve during any calendar year a total of more than 10 kilograms of contained thorium element.

204. Radioactive Isotopes

(1) No order shall be necessary to authorize dealings within Canada by any person as regards radioactive isotopes of elements of atomic number less than 90 contained in any substance if such dealings do not involve buying, selling, leasing or hiring.

(2) No order shall be necessary to authorize dealings by any person as regards radioactive elements of atomic number less than 80 contained in any substance that does not contain any greater percentage of any radioactive isotope of any such element than is normally found in nature.

300. Records

Every person dealing in any prescribed substance (otherwise than as may under Part II of these regulations be done without an order) or in any prescribed equipment shall

(a) keep fully and accurately such books, accounts and records as are necessary adequately to record all dealings by such person in or with any prescribed substance or prescribed equipment including such books, accounts and records as may from time to time be required by order;

(b) furnish to the Board in such form and within such time as may from time to time be required by order such information as the Board may deem necessary in relation to the dealings of such person in any prescribed substance or prescribed equipment;

(c) produce to any person authorized in writing for the purpose by the Board all or any books, records and documents in the possession or control of such person; and

(d) permit the person so authorized to make copies of or take extracts from the same and, if so authorized by the Board, to remove and retain any such books, records and documents.

301. Prospecting

Every person not operating under an order who finds in situ any mineral deposit that he believes or has reason to believe contains more than 0·05 per cent by weight of the element uranium, or more than 0·05 per cent by weight of the element thorium, shall forthwith notify the Board of the place of origin and character of such mineral, together with all other information in the possession of such person indicative of the character, composition and probable extent of deposits containing uranium or thorium at or near the place of origin of such mineral.

302. Assaying and Analysis

(1) Every person who otherwise than

(a) on behalf of a person operating under an order and as incident to a dealing permitted by such order; or

(b) as incident to a dealing authorized under Part II of these regulations to be done without an order performs any assay or analysis of any material that indicates that such material contains more than 0·05 per cent by weight of the element uranium or more than 0·05 per cent by weight of the element thorium shall forthwith report to the Board full particulars relating thereto including the name of the person from whom such material was received, the purpose of the assay or analysis, the origin of the material so far as known to the person making the report, and the results of the assay or analysis, and shall not disclose, except to the Board, the result of such assay or analysis, until otherwise directed or permitted by order.

(2) Every person who, otherwise than on behalf of a person operating under an order and as incident to a dealing permitted by such order, performs any assay or analysis of any material that indicates that such material contains any plutonium, neptunium or other element of atomic number greater than 92 or any uranium containing any of the isotope U-233 or any greater proportion of the isotope U-235 than is normally present in nature shall retain such material and shall not disclose, except to the Board, the result of such assay or analysis until otherwise directed or permitted by order.

303. Import and Export

No person shall import into Canada or export from Canada any prescribed equipment for the time being specified by order for the purposes of this section or any prescribed substance without first producing to the Collector of Customs and Excise at the proposed port of entry or exit an import or export permit from the Board, and no Collector of Customs and Excise shall permit any such prescribed equipment or any prescribed substance

(a) to be released for delivery to an importer in Canada; or

(b) to be exported from Canada, unless the appropriate permit from the Board is produced to him.

304. Assistance by other authorities

Where a person by virtue of any statute or order or regulation thereunder has power to obtain information relating to prescribed substances or prescribed equipment

(a) such person shall if so requested by the Board exercise that power for the purpose of assisting the Board to obtain such information; and

(b) any such information possessed or obtained by such person whether upon a request of the Board or otherwise shall, upon the request of the Board, be communicated to the Board.

305. Inspection

Every person dealing in or who proposes to deal in any prescribed substance or prescribed equipment shall permit the Board or any person thereunto authorized by the Board

(a) to enter any land, premises or place where such dealing is or is proposed to be carried on; and

(b) to inspect and control such prescribed substance, prescribed equipment or dealing in such prescribed substance or prescribed equipment to such extent as may in the opinion of the Board be necessary to ensure compliance with the terms of these regulations and of any order relating thereto.

306. Disclosure of Information by Board

No information with respect to an individual business that has been obtained by the Board under or by virtue of these regulations or of an order shall be disclosed without the consent of the person carrying on such business, except

(a) to a department of the Government of Canada or of a province or to a person authorized by such department requiring such information for the purpose of the discharge of the functions of that department; or

(b) for the purposes of any prosecution for an offence under the Act or these regulations.

600. Expropriation

The Board may with the approval of the Governor in Council enter on and acquire by expropriation any mines, deposits or claims of prescribed substances and any works or property (not being chattel property) for production or preparation for production of, or for research or investigation with respect to, atomic energy in the same manner that the minister (as defined in the Expropriation Act) may enter on and acquire by expropriation land (as defined in the Expropriation Act); and all the provisions of the Expropriation Act shall apply in relation to such entry and acquisition by the Board as if the words "department" and "minister" were defined in the said Act as including the Board and the words "public work" or "public works" were defined in the said Act as including the mines, deposits, claims, works and property hereinbefore in this section mentioned; provided, however, that where compensation to be made in respect of any such entry or acquisition has not been agreed on, the claim for compensation shall be referred by the Minister of Justice to the Exchequer Court.

601. Requisition

(1) The Board may with the approval of the Governor in Council requisition the title to, or any interest in, any prescribed substance and any patent rights relating to atomic energy and any works or property (other than real or immovable property) for production or preparation for production of, or for research or investigation with respect to, atomic energy, by serving the owner or the person in possession thereof, with notice of the Board's intention to requisition the title to or any specified interest in such prescribed substance, patent rights, works or property, or if no Canadian address of the owner or person in

possession thereof is known to the Board, by taking possession of, or posting a notice of the Board's intention to requisition on, such prescribed substance, works or property, or in the case of patent rights by filing with the Commissioner of Patents a notice of the Board's intention to requisition such patent rights.

(2) The Board may use or deal with, or authorize the use or dealing with, or hold, sell or otherwise dispose of, any property requisitioned under subsection 1 of this section as if it were the owner thereof, or of the interest therein specified in the notice.

(3) The compensation to be made for any property or interest therein, if not agreed upon, shall be referred by the Minister of Justice to the Exchequer Court and shall be paid to such person and upon such terms as the Exchequer Court shall direct, and upon such payment being made, His Majesty and the Board and all persons acting under authority of the Board shall be discharged from all liability in respect of such requisition.

800. Exercise of Powers

(1) Any order authorized by these regulations may be made by the Board, by any such officer or member of the Board or other person as the Board may designate.

(2) Every order made under these regulations shall be final and binding unless and until it has been reviewed and varied or vacated by the Board.

802. Service and Publication of Orders

(1) Any order may be served on any person by sending a copy of such order by registered post to the last known residence or place of business of such person or if such person is a corporation by so sending it to the head office or to any branch

or place of business of such corporation in Canada.

(2) The Board may cause any order made under these regulations to be published in the Canada Gazette and every person shall be deemed to have had notice of such order as from the date of publication of the issue of the Canada Gazette in which it appears.

APPENDIX IV

PRESS RELEASES OF THE ATOMIC ENERGY CONTROL BOARD, ETC.

ATOMIC ENERGY CONTROL BOARD

THE FOLLOWING IS A COPY OF A PRESS RELEASE ISSUED RECENTLY BY THE DEPARTMENT OF TRADE AND COMMERCE

Ottawa, December — 20 — With a view to the encouragement of further prospecting for radioactive minerals, two years have been added to the period during which the government will guarantee a floor price for uranium, Right Honorable C. D. Howe, Minister of Trade and Commerce, announced today.

Earlier this year, the government announced the establishment of a guaranteed floor price for uranium ores and concentrates during the subsequent five years. The expiry date for this guarantee has now been extended to March 31, 1955.

The original terms of the floor-price guarantee have not been changed. By these terms, the government-owned Eldorado Mining and Refining (1944) Limited will purchase acceptable ores and concentrates with a minimum uranium content equivalent to 10 per cent by weight of uranium oxide (U_3O_8). The Crown company will pay a minimum of $2.75 per pound of contained uranium oxide, f.o.b. rail.

"Since the announcement of a floor price last March, prospectors and mining companies have been very active and have made several discoveries which appear to be important", said Mr. Howe. "However, because of winter conditions and transportation difficulties, the men responsible for discovery of the ore bodies will encounter unavoidable delays in developing the new properties. In view of this, the Advisory Mining Committee on Radioactive Minerals recommended the extension of the guarantee period and the government agreed."

ATOMIC ENERGY CONTROL BOARD

INFORMATION FOR THE PRESS FOR IMMEDIATE RELEASE

OTTAWA

2 November, 1948

Recent discoveries of radioactive deposits containing small amounts of thorium, usually accompanied by uranium, have given rise to queries as to whether the Canadian Government is interested in the purchase of thorium. Consequently, it has been considered advisable to outline the present position in this respect.

Thorium has long been recognized as a possible source of nuclear fuel. For this reason, it was declared a prescribed substance by The Atomic Energy Control Act, 1946, and all dealings in it are subject to the provisions of the Atomic Energy Regulations of Canada.

Many complex problems must be solved before thorium can be regarded as an available source of nuclear fuel. Since the solving of these problems may take several decades, it was decided that it would not be practicable at the present time to work out a basis for the purchase of thorium in Canadian ores or concentrates. This decision, however, will be reviewed from time to time in the light of progress in the solving of the problems of utilization and of any new information as to occurrences of thorium bearing ores in Canada.

At the present time the main uses of thorium in Canada are for research and for the manufacture of incandescent gas mantles, for which purposes supplies of thorium are being obtained from the monazite sands of India and Brazil.

ATOMIC ENERGY CONTROL BOARD

INFORMATION FOR THE PRESS BACKGROUND INFORMATION
OTTAWA, June 24, 1948. FOR IMMEDIATE CIRCULATION

Prospecting and Exploration for Radioactive Minerals.

This is by way of supplement to the Board's press release of April 5, 1948, which related particularly to communication of the results of analyses of ore samples and dealings in ore samples in connection with prospecting and exploration for uranium-bearing minerals.

Questions have arisen as to the extent to which other information relating to uranium prospects and properties may be made public.

Generally speaking, the only such information that is restricted, is information which by itself, or taken with other published information, discloses the amount of uranium reserves or the amount or rate of uranium production at a producing property.

It may therefore be taken that any information relating to a mining property that has not reached the stage of commercial production may be published.

ATOMIC ENERGY CONTROL BOARD

INFORMATION FOR THE PRESS FOR IMMEDIATE RELEASE
OTTAWA
5 April, 1948

Prospecting and Exploration for Radioactive Minerals.

In order to carry into effect the policy with regard to private prospecting, exploration and mining for radioactive minerals announced by the Right Honourable C. D. Howe in the House of Commons on 16 March, 1948, it is necessary that prospectors and others concerned be informed of and be able to communicate to others the results of analyses of ore samples and to have hand samples for the usual purposes. Accordingly, a general order has been issued under the Atomic Energy Regulations of Canada permitting these things to be done.

Under this order:

(a) Persons performing analyses of radio-active minerals may report the results to the persons for whom the analyses were performed, provided that (where the analysis is not done by the Department of Mines and Resources) a similar report is at the same time sent to the Chief[1], Geological Survey, Department of Mines and Resources, Ottawa, which for this purpose acts for the Atomic Energy Control Board.

(b) The persons for whom such analyses were made may (subject to any specific order of the Board in the case of actual mining operations) make public the results.

(c) It is still necessary that the Board be informed of the place of origin and character of radioactive minerals discovered by any person. If the necessary information is sent in to the analyst, it may be forwarded with the results of the analysis to the Chief[1], Geological Survey, Department of Mines and Resources, Ottawa, for the Board. Otherwise this information should be sent to the Chief, Geological Survey, as soon as the results of the analysis are known.

(d) No special order of the Board will be required to permit prospecting so long as no mineral other than samples for analysis and hand samples for the usual purposes are removed from the claims.

(e) Specific orders of the Board will be required to authorize exploration by diamond drilling, surface work, test pitting and preliminary underground work. Such orders will contain appropriate pro-

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[1] Now Director.

visions as to the handling of samples and the furnishing of information to the Board and will permit the operator to receive and communicate information as to the results of analyses.

(f) Specific orders of the Board will be required to permit mining operations involving removal of radioactive material in excess of sample quantities. These orders will contain appropriate provisions with regard to security both as to material and as to information.

ATOMIC ENERGY CONTROL BOARD

Dated 5 April, 1948. Order No. 1/301/48
1/302/48
2/400/48

Order made under the Atomic Energy Regulations of Canada respecting prospecting, exploration and mining

1. (a) Authority is hereby given for any person who performs any assay or analysis of any mineral that indicates that such mineral contains more than 0·05 per cent by weight of the element uranium or more than 0·05 per cent by weight of the element thorium, to disclose to the person from whom such mineral was received, the result of such assay or analysis provided that the person who performs such assay or analysis shall forthwith report to the Chief[1], Geological Survey, Department of Mines and Resources, Ottawa, the name and address of the person from whom such mineral was received, the purpose of the assay or analysis, the origin of the mineral so far as known to the person making the report and the results of the assay or analysis.

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[1] Now Director.

(b) Subject to the provisions of any specific order, permission is hereby given to any person who receives the result of any assay or analysis of any mineral that indicates that such mineral contains more than 0·05 per cent by weight of the element uranium or more than 0·05 per cent by weight of the element thorium, to communicate to any person the information so received and information as to the location and probable extent of deposits containing uranium or thorium at or near the place of origin of such mineral, provided that the person who receives the result of such assay or analysis shall forthwith inform the Chief[1], Geological Survey, Department of Mines and Resources, Ottawa, of the place of origin and character of such mineral together with all other information in the possession of such person, indicative of the character, composition and probable extent of deposits containing uranium or thorium at or near the place of origin of such mineral.

(c) Permission is hereby granted for the removal from their places of deposit in nature of samples of minerals containing more than 0·05 per cent by weight of the element uranium or more than 0·05 per cent by weight of the element thorium, for the purpose of assay and analysis and of hand samples of such minerals for exhibition purposes; but nothing in this order shall authorize any use of any such sample for sale, export, manufacture, consumption or production, or any dealing in any such sample except as incident to assay, analysis or exhibition.

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[1] Now Director.

2. Nothing in this order shall apply in relation to any assay or analysis of or other dealing in any material that contains any uranium containing any of the isotope U-233 or any greater proportion of the isotope U-235 than is normally present in nature.

ATOMIC ENERGY CONTROL BOARD

BY G. M. Jarvis
Secretary.

STATEMENT OF RIGHT HON. C. D. HOWE REGARDING THE RESCINDING OF ORDERS IN COUNCIL P. C. 7167 AND 7168, HOUSE OF COMMONS 16 MARCH, 1948

It will be recalled that orders in council passed in 1943 reserving title to radioactive minerals on Crown lands in the Northwest Territories and the Yukon were extended under the Continuation of Transitional Measures Act, 1947, largely because the question of ownership of ores in the ground was still under discussion in the United Nations Atomic Energy Commission and it was felt that no action should be taken here that might embarrass those discussions. Since then, the Second Report of the United Nations Commission has been published, and that Report does not contemplate ownership of ores in the ground by any international authority which may be established. As I told the House on March 25 last, the policy of the government is that radioactive material be controlled after it has been mined and the Atomic Energy Regulations of Canada provide for this sort of control.

While the orders in council were in effect and until the Atomic Energy Regulations had been passed, it was necessary that mining operations be exclusively in the hands of the government. The whole situation has been reviewed in the light of present circumstances and changed conditions, and the government is now satisfied that it is in the best interests of Canada that restrictions against private prospecting and private development of radioactive minerals should be removed and has accordingly revoked the orders in council which reserved to the Crown title in these minerals in the Territories.

The policy decided upon is as follows:

The government will purchase through Eldorado Mining and Refining (1944) Limited, or other designated agency, acceptable uranium bearing ores and concentrates on the following basis:

1. A minimum uranium content equivalent to 10 per per cent by weight of uranium oxide (U_3O_8) in the ores or concentrates will normally be required.
2. Price will be based upon the uranium content of the ores or concentrates and will be at the minimum rate of $2.75 per pound of contained (U_3O_8) f.o.b. rail and will be guaranteed for a period of five years.
3. This price includes all radioactive elements in the ores or concentrates, but consideration will be given to the commercially recoverable value of non-radioactive constituents by adjustment of price or by the redelivery of the residues containing such constituents.
4. Under special circumstances, consideration may be given to payment of a higher price or to acceptance of ores or concentrates of lower grade.
5. All operations will be carried on subject to the provisions of the Atomic Energy Regulations of Canada.

This constitutes the new policy. As noted, the new policy permits private exploration and private mining and proposes to encourage both by putting on the ores a definite minimum value, which will be the minimum value for the next five years. I might say that I was interested to note that the semi-annual report of the United States Atomic Energy Commission to the Senate and the House of Representatives, which reached me only yesterday, contains the following two paragraphs:

> The Commission believes new reserves of source materials can best be developed by competitive private industry, under the stimulus of profits, and the means of accomplishing this are under study.
>
> In general it will be Commission policy to purchase ores for its program from private sources and limit direct government production as far as possible.

It would seem that, although we arrived at the Canadian policy independently, the policy of the United States will follow parallel lines.

APPENDIX V

ATOMIC ENERGY CONTROL BOARD, OTTAWA, CANADA

EXPLORATION PERMIT

Dear Sir:

This permit is your authorization to explore the property later mentioned, by diamond drilling, surface work, test pitting and underground work; to remove from the property samples for assay and analysis, hand samples for exhibition purposes and bulk samples not exceeding in all ten tons for mill tests; and to make public any information you may receive from assays and analyses or from exploration work on the property, up to the producing stage.

It is most important, in order that an inventory of Canada's uranium resources may be built up and that geological information on uranium occurrences may be organized for the benefit of prospectors and mine operators as well as of the Government, that the Board be kept fully informed of the progress and results of the work on the property. This permit, therefore, is granted upon condition that monthly reports be sent in duplicate to the Director of the Geological Survey of Canada, Department of Mines and Technical Surveys, Ottawa, who for this purpose acts for the Board. Each report is to include a summary report and copies of all diamond drill hole logs, plans, reports of analyses, radiometric tests and mill tests and other information necessary to show fully and accurately the work done and the results of exploration of the property up to the end of the preceding month, the first of such reports to be sent by the 10th of the month following the date of this permit. "Nil" reports are to be made if no work is done in a particular month, but if no work is to be done for an extended period, the Geological Survey may be notified and the sending of reports suspended until work is resumed.

The monthly reports are treated as confidential and should be sent in sealed envelopes addressed as follows:

THE DIRECTOR,
GEOLOGICAL SURVEY OF CANADA,
OTTAWA.

ATTENTION: Radioactivity Section[1].

A duplicate of each report on mill tests performed on samples from the property is to be sent to the Secretary, Atomic Energy Control Board, Ottawa, promptly after it has been prepared.

All work on the property is to be conducted according to good standard mining practice and records kept so that the place of origin of all samples and other radioactive materials removed shall be clearly identified.

Samples from the property may be sent to any of the persons hereafter mentioned or hereafter designated by the Board for the purpose. Advance arrangements should, of course, be made before any material is sent.

If samples are sent to the Mines Branch, transportation charges are to be prepaid since the Mines Branch cannot undertake to assume such charges.

Such matters as the staking of claims and mine safety are regulated by the provincial governments and by the administration of the Northwest Territories and Yukon. It is, therefore, a condition of this permit that, subject to the Atomic Energy Regulations of Canada, any applicable provincial statutes and regulations, or the regu-

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[1] Now "Division".

lations affecting mining in the Northwest and the Yukon, as the case may be, are to be observed and complied with in relation to the property and to all operations undertaken in connection therewith.

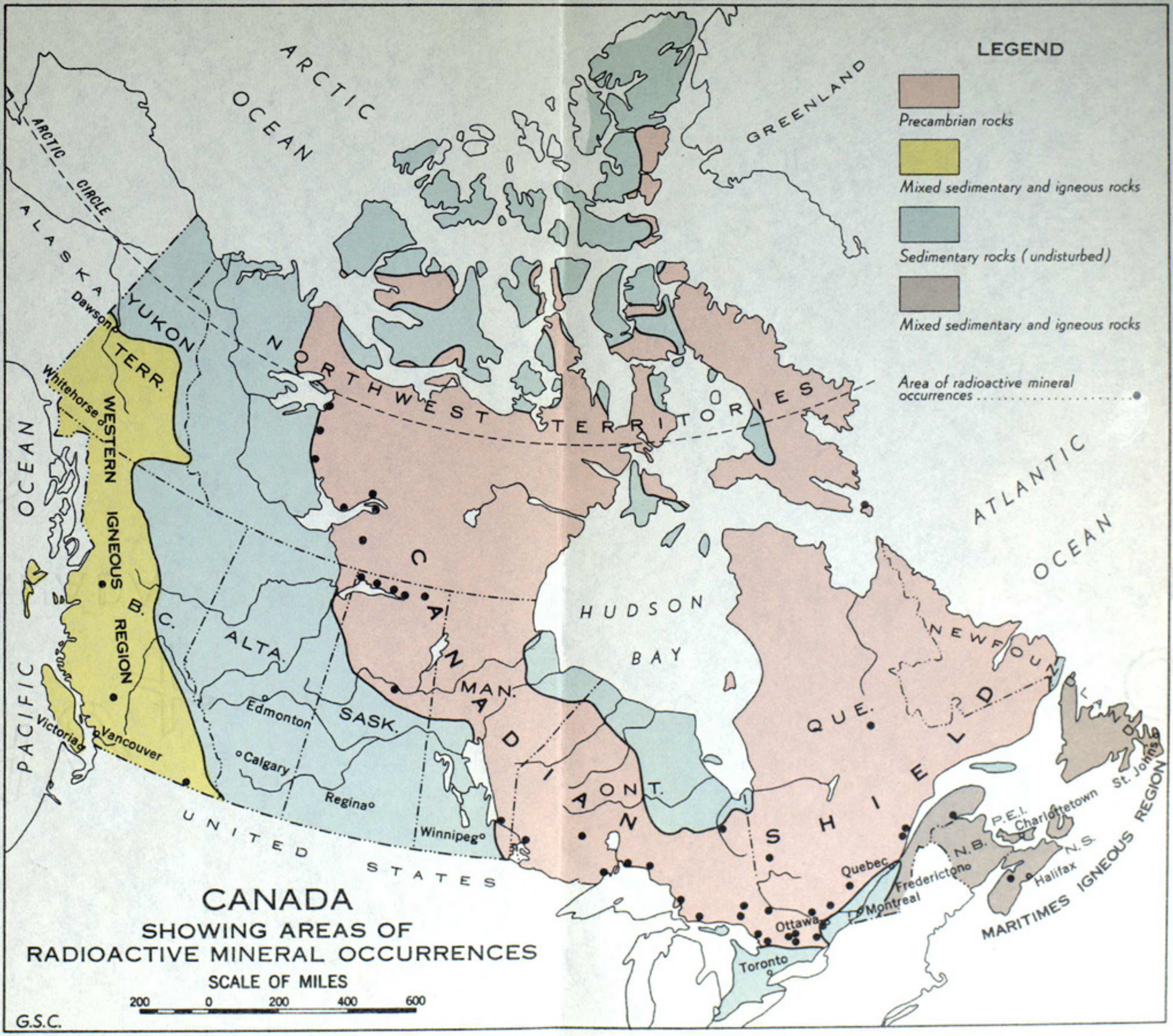
Yours faithfully,
ATOMIC ENERGY CONTROL BOARD

BY

Secretary.

Canada. Geological survey. Radioactivity division.
Prospecting for uranium in Canada.

1952. 167p.



CANADA
SHOWING AREAS OF RADIOACTIVE MINERAL OCCURRENCES