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RADIONUCLIDES IN WATER, VEGETATION, AND TISSUES OF BEAVER (Castor Canadensis) FROM A WATERSHED CONTAINING U TAILINGS NEAR ELLIOT LAKE, CANADA, WITH CALCULATION OF 226Ra CONCENTRATION RATIOS

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RADIONUCLIDES IN WATER, VEGETATION, AND TISSUES OF BEAVER (Castor canadensis) FROM A WATERSHED CONTAINING U TAILINGS NEAR ELLIOT LAKE, CANADA, WITH CALCULATION OF ^{226}Ra CONCENTRATION RATIOS

F.V. Clulow*, M.A. Mirka*, N.K. Dave** and T.P. Lim+

ABSTRACT

Radionuclide levels were measured in tissues, gut contents, and diet items of adult beaver from the Serpent River drainage basin which contains U tailings at Elliot Lake, and from control sites in Ontario.

Levels of ^{222}Ra in beaver bone, muscle, and kidney were highest in animals from locations close to U tailings; liver levels did not vary by site. Environmental ^{226}Ra levels were within ranges previously reported at these or similar locations elsewhere; levels in beaver gut contents reflected levels in diet items. Concentration ratios exceeded unity only between some vegetation items and beaver bone at the Elliot Lake site and were less than 0.19 between vegetation and other tissues.

In two beaver with tissue levels of ^{226}Ra higher than others sampled, neither ^{232}Th nor ^{230}Th were detected in bone, muscle, or liver tissues. ^{238}U was measurable in bone, muscle, and liver; ^{228}Th in bone, ^{210}Po in bone, muscle, and liver, and ^{210}Pb was measurable only in bone. Estimated yearly intakes of radionuclides by people eating beaver were calculated to be below current allowable levels set by Canadian regulatory authorities.

The beaver is judged unsuitable as an indicator (biomonitor) of environmental radionuclide contamination as correlation between bone and ambient (water) levels of ^{226}Ra is low.

Key words: Radiation biology; Beavers; Contamination uptake: Uranium tailings.

*Department of Biology, Laurentian University, Sudbury, Ontario. **Research Scientist and +Physical Scientist, Elliot Lake Laboratory, CANMET, Energy, Mines and Resources Canada, Elliot Lake, Ontario.

INTRODUCTION

This study was carried out to improve understanding of radionuclide movements through components of a watershed ecosystem containing wastes from U mines and mills, and to assess radiological hazards, if any, faced by human consumers of wild game taken in the watershed. A subsidiary objective was to assess the beaver's suitability as an aquatic/amphibious indicator (biomonitor) of environmental radionuclide contamination.

Uranium mining and milling operations at Elliot Lake, Ontario, have produced extensive waste deposits, which include fractions of milled ore too poor in minerals to be treated further ('tailings', Lapedes 1974). Finely divided wastes, slurried with discharged mill water and neutralized, are piped to low-lying impoundment areas where they drain, compact, and dry. Approximately 150 x 10^6 t of U industry wastes have been deposited in this way since activities began at Elliot Lake in 1950 to the end of 1985. About two-thirds of these tailings are currently being added to; others are inactive or in the process of being decommissioned. Contract commitments (as of 1980) will result in 234 x 10^6 t of new U tailings within the life of the contracts; development of other reserves could add another 260 x 10^6 t to the total. Tailings deposits drain into the Serpent River which empties into the North Channel of Lake Huron (Figure 1).

Uranium tailings contain up to 85% of the radioactive material present in the U ore and because of their radioactivity are considered potential sources of radioactive and other chemical contaminants affecting the environment and man in general. The rock, originally solid, buried, and fixed in position, when transformed into finely divided tailings and deposited on the surface, is prone to weathering and dispersal. It is because of these changes that egress of radionuclides needs to be monitored, escape mechanisms

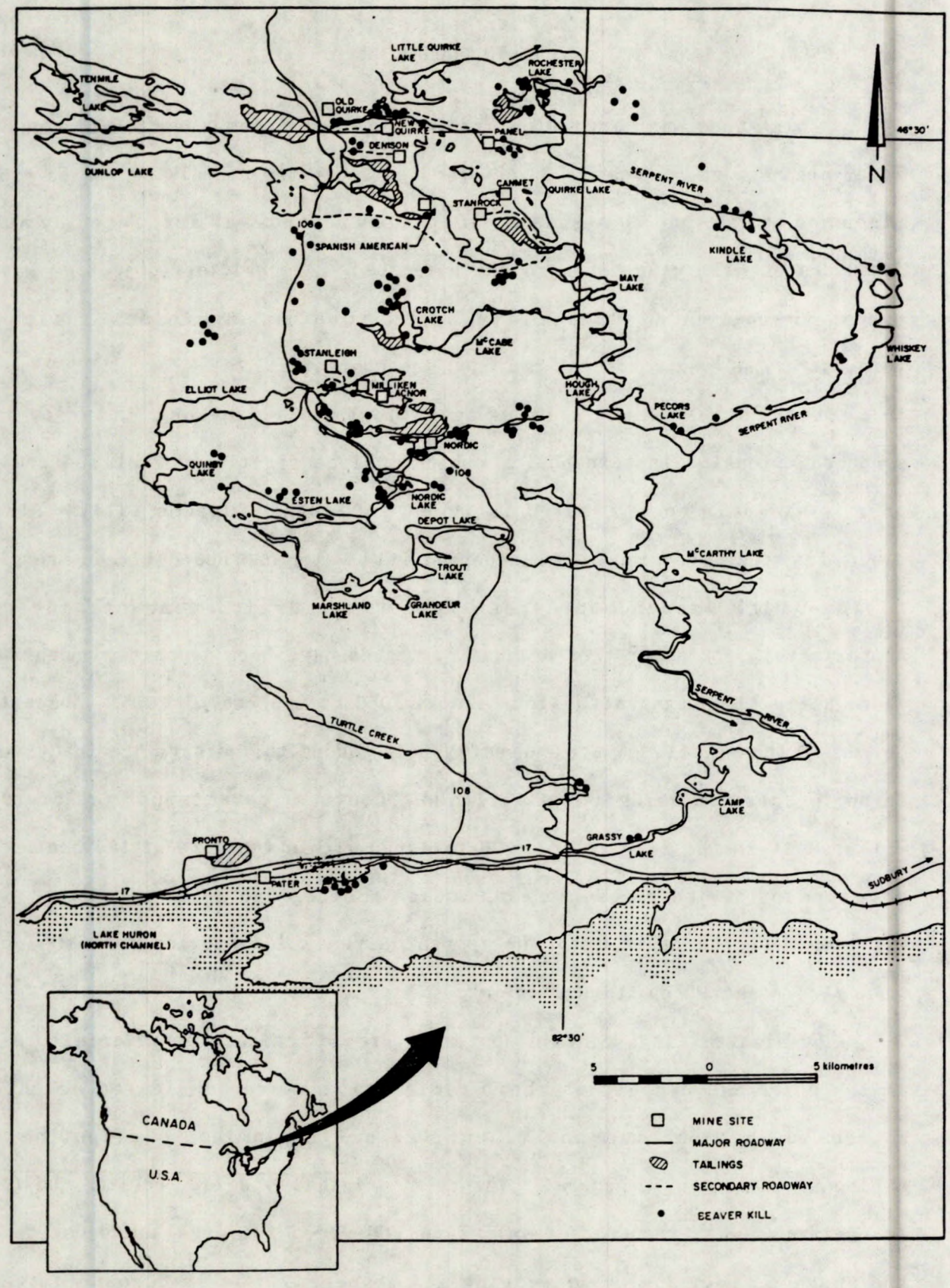

Fig. 1 - Location of beaver kill sites in the Serpent River watershed.

understood, and control procedures assessed. Information on the release and movement of radionuclides from the tailings through the ecosystem is scanty.

Many radionuclides are ecologically and biologically significant due to their high specific activities, long half lives, relatively high biological mobilization and chemical analogy to essential elements (Parker and Tudorancea 1985; Parker et al. 1986). Of particular concern are radionuclides produced by decay of ^{238}U, ^{235}U and ^{232}Th (Baweja et al. 1987). Of the U and Th series radionuclides, ^{226}Ra is particularly important in studies of tailings. Only 1% of the ^{226}Ra present in the ore is removed during processing; the rest is discarded in the slurry waste which may have concentrations 100 times the permissible level (MacLaren 1978). Furthermore, ^{226}Ra has a high specific activity, a long half-life (~1600 y), and chemical analogy to the essential element Ca which results in it seeking bone as a deposition site in the body (Friedlander and Kennedy 1962; Lloyd et al. 1976; Raabe et al. 1983). Concentration in soft tissue (Mahon 1982; Schlenker et al. 1982; Swanson 1983; Ruttenber et al. 1984) occurs, but to a lesser extent than in bone. Bound in calcium hydroxyapatite bone crystals, ^{226}Ra may cause tissue damage, possibly resulting in osteosarcoma, as it is an internal emitter of alpha and beta radiation (Van Dilla et al. 1958; Mays et al. 1975; Schlenker et al. 1982; Raabe et al. 1983).

Radium-226 leaves the tailings and moves through the environment as wind- and water-borne particulates and in water after solution from the deposits. Ablation of dried inactive tailings has contaminated an area with radius 22 km with particulates (Beckett et al. 1982). Dissolved ^{226}Ra may contaminate surface and ground waters and enter the watershed. Overflow or decant of tailings (required to discharge excess water from tailings ponds) and discharge of mill water to the watershed (McKee et al. 1985) also allow radionuclides to enter the watershed. Contamination from natural sources is

low compared to that resulting from human activity (Mahon 1982; Hesslein and Slavicek 1984; Baweja et al. 1987).

Impoundment methods employed in tailings management are still being assessed in the Elliot Lake area. Radionuclide contamination of terrestrial and aquatic systems persist, but has declined due to treatment measures started about 20 years ago with improved water quality and controls. Treatment methods include the addition of lime and barium chloride to tailings effluent to precipitate metals and ^{226}Ra (Hart and McKee 1985). Wind dispersal, associated with drained and dried inactive tailings, has been reduced through stabilization with vegetation and with other chemical treatments (Parker and Tudorancea 1985).

Assessment of tailings management and rehabilitation techniques requires knowledge of radionuclide movements through the ecosystem of which the tailing deposits are a part; modelling is used to assist understanding and to predict behaviour of the contaminated ecosystem. Such modelling requires calculation of transfer parameters among biologically connected compartments within the system. These compartments may be in either the abiotic (e.g., water and substrate, or the biotic (e.g., plants, herbivores, and predators) components of the ecosystem. Materials may move from one compartment to another by mechanisms varying from diffusion to active excretion against concentration gradients. Routes connecting compartments may be as short and simple as water absorption by plant root hairs from spaces in the surrounding substrate, or as long and involved as the movement of food through the complex stomach and intestines of ruminants, or the double pass through the gut of coprophagous animals as in beaver (see below).

In the study, ^{226}Ra levels were measured in: a) bone, muscle, liver, and kidney tissues of beaver (Castor canadensis) taken in the Serpent River basin, and from control sites, b) vegetation items consumed by the animals,

and their gut contents, and c) water used by the animals for drinking and as their living medium. Other radionuclides (^{238}U, ^{232}Th, ^{230}Th, ^{228}Th, ^{210}Pb and ^{210}Po) were measured in tissues of two beaver with the highest tissue levels of ^{226}Ra observed in the study. Levels of ^{226}Ra recorded in the study were used to calculate concentration ratios from plants and water to animal tissues. Estimated annual radionuclide intakes by human consumers of wild meat, were calculated from the radiological data. Samples from control sites provided background values of ^{226}Ra in animals, vegetation, and water not associated in any way with U wastes.

The concentration ratio (CR) is a transfer parameter calculated as the ratio between steady-state concentrations in connected compartments of a model under equilibrium conditions (ICRP 1978). Compartments include vegetation comprising the diet and the tissues of an animal (e.g., bone). The CR is used to model equilibrium conditions. Information on radionuclide movements in the progression substrate-vegetation-animal (tissue) are known in only a few contaminated ecosystems. Food and tissues of small terrestrial mammals (voles, Microtus pennsylvanicus) and larger game animals (deer, Odocoileus virginianus, moose, Alces alces) associated with Elliot Lake U tailings or their drainage, have been studied in wild or captive specimens to provide data useful in this regard (Burns et al. 1986; Cloutier et al. 1983, 1985a,b, and 1986; MacLaren 1978, 1987). ^{226}Ra levels in faeces of hares (Lepus americanus) from the area have been reported (Clulow et al. 1986) as have levels in cutworms (Agrotis ipsilon) eaten by gulls (Larus argentatus) visiting the tailings (Clulow et al. 1988). MacLaren (1978) gives levels of ^{226}Ra in muscle tissue of four beaver from the vicinity of Quirke Lake.

The work reported here provided data allowing calculation of ^{226}Ra CRs between water and vegetation on one hand, and tissues of beaver, on the other. In addition, other radionuclides in the animal tissues were measured. Animals

are eaten by trappers and hunters of the area, including members of the Serpent River Indian Band near the mouth of the river, and information on tissue ^{226}Ra and other radionuclide levels were sought to assess human exposure to radionuclides by ingestion of wild game.

Several mammals have been examined as prospective biomonitors of radionuclides (Cloutier et al. 1984). Desirable features of biomonitor species include widespread distribution, abundance, limited migration distance, ease of procurement, and ability to reflect accurately differences in environmental radionuclide concentrations. It has been demonstrated that ^{226}Ra accumulates in bones of meadow voles (Microtus pennsylvanicus) resident on U tailings. Larger terrestrial mammals such as moose (MacLaren 1987) and coyote (Arthur and Markham 1982) taken from contaminated areas have measurable levels of radionuclides in their tissues. Aquatic mammals have received less attention. Measurable bone levels of ^{226}Ra have been reported in otter (Wren et al. 1987) from the Elliot Lake area. No other studies are known on radionuclides in aquatic mammals associated with mine tailings.

Although beaver, Castor canadensis, is one of the principle aquatic mammals of the Elliot Lake area, it has not been considered previously as an indicator of radionuclide contamination although it meets several of the desirable criteria listed above. The animals have widespread distributions (Hill 1982) and are abundant around highly contaminated tailings areas and adjacent watershed systems. They do not commonly move extreme distances and may remain in the vicinity of their native colony most of their lives. Although wholesale movements of groups of beaver and dispersal of young adults do occur (Hill 1982), with travel of 200 km or more reported for some tagged and released beaver, dispersal (especially of two-year old) is usually less than 16 km in a straight line (Jenkins and Busher 1979). Knowledge of beaver movement suggests that animals reported on in this study may have been long-

term residents at their places of capture. Beaver carcasses are easily acquired as a by-product of the fur harvest. The only unknown is the degree to which their tissue radionuclide burdens reflect environmental levels.

The natural history of the beaver, especially its food habits, was a consideration in the design of the study and subsequent interpretation of results. The animals are relatively long-lived: Van Nostrand and Stephenson (1964) report they live up to 16 years. Beavers consume plant species in proportions varying with location and season; they do not take appreciable amounts of animal material in their diets. In his review of the species, Hill (1982) indicated that the numbers of plant types used range from three in northern populations, to 38 in South Carolina. Animals eat vegetation from about four weeks of age and exhibit coprophagy - the habit of eating faecal pellets direct from the anus and passing food through the gut a second time. Beaver prefer such trees as aspens* (='poplars', Populus spp.) and willows (Salix spp.) when available, but frequently take birch (Betula spp.), maples (Acer spp.), and alders (Alnus spp.). Plants (leaves, buds, twigs, branches, roots, bark, and fruit) are consumed fresh in the growing season. In winter, material is eaten which has been stored from the previous summer and autumn in floating caches. Belovsky (1984), studying beaver in Michigan (Isle Royale, Lake Superior) calculated an adult beaver (15 kg) requires about 1,213 $kcal.d^{-1}$, and that some 625 g dry weight of vegetation may be consumed to meet this daily requirement. Adult beaver have a calculated maximum digestive capacity of approximately 3,458 g wet weight of vegetation per day. Belovsky, observing beaver cutting woody vegetation up to 48 m from the edge of the water in which they lived, reported that some species of maple (Acer spp.) and birch (Betula spp.) were preferred over others, but that alder, dogwood

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*Plant names follow Anonymous, 1961.

(Cornus spp.), mountain ash (Sorbus spp.), fir (Abies spp.) or cedar (Thuja spp.) were not selected to any degree. He also noted the animals consumed quantities of aquatic macrophytes. Jenkins and Busher (1979) cited work indicating that roots, rhizomes, and runners of water lilies (Nuphar sp. and Nymphea sp.) contribute to winter diet in some parts of the beaver's geographic range. Trappers in the vicinity of Elliot Lake and Sudbury report: that beaver in the area favour aspen, birch, and willow, but also take white pine (Pinus strobus) readily; that animals consume branches up to 1 cm in diameter in their entirety, and that caches of winter food are contained in cribs consisting of branches of species not favoured for eating. Personal observation confirmed these reports. Signs of beaver activity (felling, gnawing and tooth marks) were sought at each field collecting site and samples were taken as close as possible to the damage.

METHODS AND MATERIALS

SAMPLING LOCATIONS

All investigations took place in the Sudbury-North Bay and Timagami sections (L.4e, L.9) of the Great Lakes - St. Lawrence Forest Region of Canada (Rowe 1959). This part of Ontario has numerous rivers and lakes situated among rugged outcrops of Canadian Shield bedrock devoid of vegetation, and wet flats and lowlands of acidic podzols or calcareous soils variably covered with mixed hardwoods and conifers. Pioneer species (aspen, Populus tremuloides, and white birch, Betula papyrifera) predominate and limited numbers of tolerant forms such as sugar maple (Acer saccharum) and yellow birch (betula lutea) are to be found. Red, white and jack pine (Pinus resinosa, P. strobus, and P. banksiana), balsam fir (Abies balsamea), black spruce (Pinea mariana) and white spruce (P. glauca) are scattered through the forest.

Study areas in the Serpent River drainage, three in number, were defined as follows: a) 'Elliot Lake', is a triangular area with points at Ten Mile Lake to the Northwest, Rochester Lake in the Northeast, and Nordic Lake to the South, containing the Town of Elliot Lake, U tailings deposits, and several lakes and waterways. Substantial variation in ^{226}Ra concentration in these water bodies has been reported (see below). b) 'Mid-Serpent', is the watercourse down stream from the river's exit from Quirke Lake, containing Bear, Whiskey, and Pecors Lakes. Land adjacent to this stretch of the river, unpopulated except for fishing camps, contains several registered traplines. c) 'Low-Serpent', is the lower reach of the river, below its exit from Pecors Lake, passing through the territory of the Serpent River Indian Band, whose members trap along it, before emptying into the North Channel of Lake Huron.

Control areas were at two locations: a) 'Control-local', encompassing Tweedle, Sagard, and Poulin Townships, located about 40 km NW of Elliot Lake, upwind and in a different watershed, was chosen because of accessibility, location and lack of U industry operations. Occurrences high in Th-series radionuclides are known in this general area (W. Meyer, Resident Geologist, Ministry of Northern Development and Mines, Government of Ontario, Sudbury, personal communication). b) The second, 'Control-distant', 40 km NE of Sudbury and more than 130 km E of Elliot Lake, contains Lakes Wanapitei, Boot, Rathbun, Portage and Matagamasi, and was chosen for its remoteness from Elliot Lake and its ease of access. Several U occurrences have been reported in the area, but none have been developed (W. Meyer, personal communication).

Water quality records of the Ministry of the Environment of the Province of Ontario (MOE) (MOE 1981, 1982, 1987) indicate substantial variation in ^{226}Ra concentration from place to place and over time at MOE sample stations in the vicinity of Elliot Lake. Each water sampling station within the study area at Elliot Lake was assigned to one of three classes

based on the average radionuclide levels of water sampled at the station. Average total ^{226}Ra concentration was calculated by summing all total ^{226}Ra water values for the years 1984 to 1987 and dividing by the number of samples. Only filtered ^{226}Ra values were available prior to 1984, these values were not used in this study. Site classes within the study area were defined as follows:

Elliot Lake-high, with ^{226}Ra levels $\geq$ 148 $mBq.L^{-1}$ (included are all tailings deposits and portions of the Serpent River below an effluent discharge site at the Quirke mine waste management area).

Elliot Lake-medium, with ^{226}Ra levels from 75 to 147 $mBq.L^{-1}$ (included Quirke, Nordic and North Nordic lakes).

Elliot Lake-low, with ^{226}Ra levels $\leq$ 74 $mBq.L^{-1}$ (included Dunlop and Elliot Lakes).

Beaver trapped within the Elliot Lake area were assigned to an MOE water sampling station, and a corresponding site class, as follows. The location of capture of each animal was recorded on a map indicating the locations of MOE water sampling stations (with their associated average total ^{226}Ra concentrations), and water flow vectors. Animals collected close to an MOE water sampling station were assigned to that station and subsequently included in the appropriate site class (-high, -medium, or -low) corresponding to its average total ^{226}Ra water value. In cases where animals were taken at a location influenced by water passing two MOE sample stations, an average water quality value of the intermediate location was calculated using all sample data available from both MOE stations. Specimens from areas lacking sampling stations were assigned to the closest MOE station down-stream in the water course.

ANIMAL SAMPLES

As tissue levels were expected to vary from animal to animal, a goal of

ten or more beaver specimens was set as the sample size (n) for each location studied. Measurements were made of ^{226}Ra levels in muscle, bone, kidney, liver, and gut content (when sufficient material was present) of each animal. As information was available on radionuclides in water and vegetation of the study areas, estimates were restricted to four water samples and four samples of plans used by the animals for food in each area. Estimations of total and dissolved ^{226}Ra in the water samples were made. Ra-226 levels in aliquots of vegetation samples (pooled by species) were measured.

Beaver carcasses were purchased from registered trappers. Most were taken in season as part of the fur harvest, others were removed as 'nuisance' animals at other times of the year. The Elliot Lake area was sampled from Fall 1985 through late winter of 1988; Mid-Serpent and Low-Serpent collections were made in winter 1987-1988. Control samples of beaver were taken in the spring of 1986. Animal samples were labelled as received and their source indicated on a master map.

Carcasses, usually received frozen and intact except for fur (removed for sale) and tails (snapped off inadvertently in several cases) were weighed to 1 g on an OHAUS^{TM} heavy duty balance, and then thawed. The skull was removed and preserved for later use in age assessment. Specimens were dissected, sexed by examination of reproductive organs, and samples of the liver, both kidneys, spleen, the right hind leg (for muscles and bone), and chyme (stomach contents), were removed and separately bagged and frozen for later study. The right femur of each beaver was prepared by removing most muscle (with scissors) then placing it (in a sealed plastic bag) in boiling water for 1 h to facilitate removal of the remaining adherent tissue by scraping with a scalpel when cool.

Beaver were aged to one of five classes on molar and premolar teeth eruption, the degree of closure of basal openings, and molar fluting. Age

categories and criteria were (after Van Nostrand and Stephenson 1964): 0.5 to 1.0 y - primary premolar, if present, forming a cap over the permanent premolar. Crown of the emerging premolar below that of the first molar, 1.5 to 2.0 y - single large opening present in the base of each of the four cheek teeth, some advanced cases with partial constriction of the openings; 2.5 to 3.0 y - basal opening of first molar markedly restricted and in some specimens may appear to be closed, basal cavity of the premolar typically has two openings, while the second and third molars each have one small restricted basal opening; 3.5 to 4.0 y - opening of the basal cavity of the first molar is usually closed, basal openings in the other cheek teeth usually conspicuous although well constricted (animals of age categories 2.5 to 3.0 y and 3.5 to 4.0 y were pooled for this study forming age class 2.5 to 4.0 y); 4.5 y and older - basal cavities of all the cheek teeth usually completely closed by 4.5 y. Aging of beaver beyond 5 y, requiring examination of annual layers in cementum, was not performed in this study.

PLANT SAMPLES

Woody plant material was collected from Elliot Lake, Mid-, Low-Serpent areas between 27 August and 15 September 1987. Plant material was taken within 15 m of high water mark of the Serpent River or Whiskey Lake, usually where signs of beaver clipping and damage were seen and close to places where animals had been trapped or shot. Collections from the Control-distant area were made on the eastern shore of Lake Wanapitei on 19 October 1987. Branches with leaves (and buds, flowers, and fruit if present) were collected from woody plants in each area. On return to the laboratory, field identifications were confirmed, and fresh material was partitioned, as appropriate, into stem and leaf (including petioles) samples. Ten 10 x 1 cm pieces of branch and up to 500 g of leaves were pooled from several plants of the same species and allowed to air dry in paper bags pending further analysis. Some stems and

leaves were analyzed as received, others were washed gently under running water in the laboratory to remove adherent material, prior to analysis. Samples were labelled on receipt and their source marked on a master map.

WATER SAMPLES

Water was collected as follows: a) Elliot Lake samples were taken at the bridge over the Serpent River, near the Panel Mine collecting location of beaver captures, at 1400 h on 28 August 1987; analysis of total and dissolved ^{226}Ra in these samples started at 1500 h of the same day. b) Mid-Serpent samples were collected from the east shore of Whiskey Lake at 1200 h, also on 28 August 1987; analysis of their total and dissolved ^{226}Ra similarly started at 1500 h on the same day. c) Low-Serpent samples were collected from the intersection of the Serpent River and Hwy 17 at 1300 h on 27 August 1987, and from the Serpent River at the Serpent River Village (in the vicinity of the derelict 'Atomic Drive In' movie theatre) at 1400 h on the same day; analyses of total and dissolved ^{226}Ra in these samples started at 1500 h on the day collected. d) Control-distant samples, obtained from the eastern shore of Lake Wanapitei at 0800 h on 6 November 1987, were kept at 2-5^{o}C during transport to the laboratory to limit biological activity causing uptake or release of ^{226}Ra by organisms contained in the samples; radiological analyses of these samples started at 1230 h on the day of collection.

Water samples (4 x 1 L from all locations except Low-Serpent which provided 8 L, in two collections, taken at the locations just described) were taken in acid-washed, triple-rinsed 1 L plastic bottles 30 cm beneath lake or river surfaces in places where animals had been captured. Analyses started within hours of collection: 2 L were analyzed for dissolved ^{226}Ra after filtration and 2 L were analyzed for total ^{226}Ra content after acidification with 10 ml 1N HCl. Water samples were tagged on receipt and their point of origin marked on a master map.

ANALYTICAL METHODS

All glassware, porcelain crucibles and lids were cleaned by washing in an industrial detergent (Alconox^{TM} or Sparkleen^{TM}), rinsing in distilled water and soaking for 24 h in 50% HCl. On removal from the acid bath, glassware was rinsed three times in distilled water and then placed in a drying oven at 70 to 80^{o}C. Crucibles and lids were cooled in desiccators, then weighed and placed in a drying oven, drying and weighing continuing until constant weights were recorded (to 0.01 g).

Sample Processing: After being weighed fresh, tissues were placed into porcelain crucibles (prepared as described above); bones were broken with a hammer to allow the entire sample to be fitted into the crucible, and to facilitate drying of marrow. Tissues were then dried to constant weight at 70 to 80^{o}C. Ashing was done in a muffle furnace (Lab Heat Muffle Furnace^{TM}, Blue M Electric Co., Model No. M25a-1a) by raising the temperature to 500^{o}C over 6 h: maximum temperature was maintained for 24 h. Samples were cooled to room temperature (~25^{o}C), soaked with NH_4NO_3 (30%) and oven dried at 70^{o}C overnight. Ashing was repeated for 24 h if signs of carbon remained after the first processing. Ashes were crushed, then placed into glass beakers for complete digestion by 30% HCl while being stirred on a hot plate at 70^{o}C. The quantity of HCl used depended on the quantity of tissue ashed. Digested samples were diluted to 1 L with distilled water stored in plastic bottles until analyzed.

Plant tissues were air-dried. then aliquots (unwashed or rinsed gently in water to remove particles) were placed in individual porcelain crucibles and dried at 70 to 80^{o}C to constant weight as for animal tissues. Dry-ashing and digestions were conducted as for animal tissues except silica inclusions required treatment with HF and strong acid mixtures to ensure solution in several cases.

Half the water samples were analyzed as collected, the rest were filtered to remove particulates, within hours of collection.

ANALYSIS OF ^{226}Ra

Measurement of ^{226}Ra in duplicate solution samples by the alpha-spectroscopic method of Lim and Dave (1981) involved counting the 4.78 MeV alpha-decay peak of ^{226}Ra following precipitation of Ra-Ba sulphate. A ^{133}Ba tracer solution, added to starting solid samples, allowed measurement (and appropriate correction for) the overall analytical recovery of ^{226}Ra analysis. Recovery rates of 80% or more of the amount of ^{133}Ba added by spiking were usual in the study.

ANALYSIS OF OTHER RADIONUCLIDES

Duplicate samples (~1 g each) of dried bone, muscle and liver from two beaver were sent for radionuclide measurement to the laboratories of Atomic Energy of Canada Limited (AECL), Kanata (neutron activation analysis) and Monenco Science and Technology (MONENCO), Calgary (chemical separation and alpha-spectroscopy). AECL reported results of neutron activation analyses of ^{238}U and ^{232}Th (delayed neutron counting) in ppm, with threshold values at 1 ppm. MONENCO reported values in $mBq.g^{-1}$ with threshold values at 5 $mBq.g^{-1}$ for ^{226}Ra, ^{232}Th, ^{230}Th, ^{228}Th and ^{210}Po, and 50 $mBq.g^{-1}$ for ^{210}Pb. In the case of ^{210}Pb, analysis was performed by ^{210}Bi measurement and its daughter, ^{210}Po, after 42 d in-growth to the samples.

QUALITY ASSURANCE

Several approaches assured reliability of the ^{226}Ra data reported here. First, analyses were carried out in the laboratories of CANMET, Elliot Lake, where routine procedures require calibration of the analytical system itself by certified NBS calibration standards. Second, the Quality Assurance Program of the CANMET Laboratory has the following checks made as a matter of routine: a) Certified CANMET tailings samples DL-1 and DL-2 are analyzed. b) Standards

and blanks are analyzed along with samples. c) Cross-checks on liquid, solid, and biological sample measurements by CANMET are carried out by MONENCO Analytical Laboratories (Calgary). These three checks indicated variation was $\leq$10%. Third, the standard method, involving recovery of the gamma-emitter (^{133}Ba) added to samples prior to digestions to measure analytic recovery of the radiological procedure, when applied to samples of cow shank bone (NBS material) spiked with known amounts of ^{226}Ra and ^{133}Ba, showed a recovery rate of 98 $\pm$10%.

The following checks were added as part of the current study: two fragments of each of two beaver bones were analyzed at separate times at CANMET; two fragments of each of two bones were analyzed independently (blind) by MONENCO Analytical Laboratories of Calgary, and at CANMET.

DATA

Statistics and Transformations: As it was expected that the data were unlikely to be normally distributed, initial examination of differences among groups of animals divided by sex and age was performed using nonparametric tests making no assumptions about underlying distribution: Mann-Whitney U tests (two-tailed) were used to compare pairs of subgroups (significance was indicated ($P < 0.05$) when $U_{calculated} > U_{table}$ (alpha = 0.05) (Lapin 1975)).

Statistical analyses started with groups subdivided by what was considered the least significant variable: sex. When no significant differences were found at the 5% level, sex categories were pooled, and data reanalyzed in age categories. Pooling of age classes was also found to be appropriate, as no significance among age classes emerged during testing. Subsamples of beaver taken on Control-local and Control-distant areas were not included in these comparisons owing to small sample sizes. Seasonal variations could not be tested due to gaps in the data and to smallness of sample sizes when all sub-divisions were made. Establishment of a hierarchy

of importance for variables allowed focus on the principle objective of this study: comparison of radionuclide concentrations in animals from different locations.

Data sets of ^{226}Ra in bone of beaver from sites in the Experimental area (Experimental-high, -medium, and -low), and Control-local and -distant areas, were inspected for distribution both graphically and numerically. As an example, Figure 2 shows the extreme skew (S_k = 3.146) seen when raw data on 57 bone ^{226}Ra levels of beaver taken at Elliot Lake-low sites were plotted (left). This suggestion that data were distributed log normally was confirmed by a closer approximation to the normal curve when data were $\log_{10}$-transformed and replotted (right). Transformation of the data brought mean and median values into proximity: before transforming, their respective values were 48.38 and 38.00, after transformation they were 1.56 and 1.58. With this change, skewness fell from 3.146 to 0.471.

A Chi-square, goodness-of-fit test of normal distribution of the same data (Zar, 1974) indicated that assumptions of an underlying normal distribution were not warranted ($X^2_{calculated} = 810.9 > X^2_{tabulated} = 11.07$). The test, repeated on the data after $\log_{10}$-transformation, indicated no significant divergence from normality ($X^2_{calculated} = 9.6 < X^2_{tabulated} = 11.07$).

Transforming bone values from animals taken from other sites in 1987 and 1988 produced similar effects: distributions approximated normality to the extent that the use of parametric statistical tests were justifiable. Differences among site categories and areas were tested at the 5% level using a one-way analysis of variance (ANOVA) on $\log_{10}$-transformed data. Significance of the differences among groups was tested by Fisher's protected least significance difference (PLSD) method.

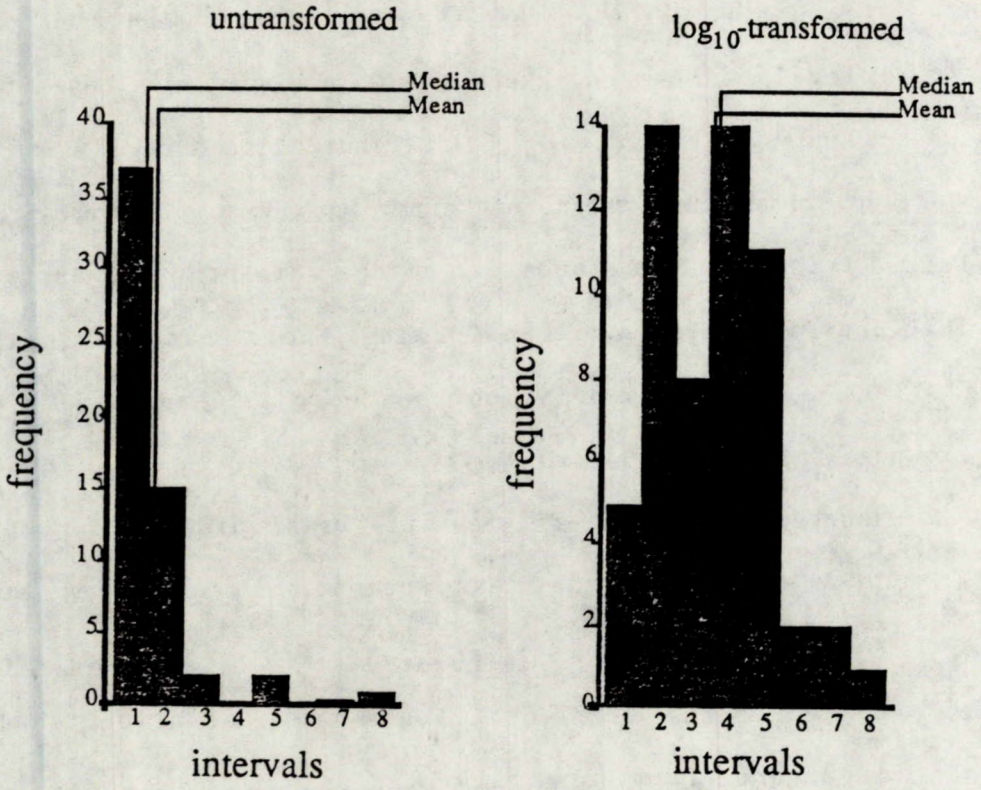

Fig. 2 - Frequency distribution of 57 estimates of ^{226}Ra levels in bone of beaver taken at Elliot Lake-low sites before (left) and after (right) $\log_{10}$ transformation.

PRESENTATION AND CALCULATIONS

To facilitate comparison with findings of other workers, values are expressed throughout as $mBq.g^{-1}$ dry weight of plant or animal tissue and $mBq.L^{-1}$ of water, except in the calculation of concentration ratios, where the use of values based on wet or fresh weight, and $mBq.g^{-1}$ of water, is called for by convention.

Graphical presentations are of back-transformed data. Sample means and their associated standard errors were antilogged to ensure that units on the vertical axis are familiar, this procedure accounts for asymmetric error bars in some cases.

CONCENTRATION RATIOS

When calculating the ^{226}Ra concentration ratio (f_{1e}), the following formula (after ICRP 1978) was employed:

$$f_{1e} = X_1/X_e$$

where X_1 = radionuclide concentration in animal tissue ($mBq.g^{-1}$ wet weight)

and X_e = radionuclide concentration in water ($mBq.mL^{-3}$) or vegetation ($mBq.g^{-1}$ wet weight).

For these calculations, radionuclide concentrations were expressed as $mBq.g^{-1}$ wet weight as required by the standard formula. Mean animal tissue and gut content ^{226}Ra concentrations were calculated on transformed data and concentration ratios were based on their back-transformed values. Radionuclide concentrations in diet items needed to be calculated as the level at the time of consumption. This presented a problem since moisture content of vegetation varies with time of day and season due to water stress (Wilson et al. 1953; Boyer 1968), and with changes resulting from absorption or loss of water after removal from the living tree. Particularly troublesome is the habit beaver have of felling trees and consuming them after a delay which may

range from minutes to months. During this time, leaves and branches may lose or gain water by evaporation or absorption if left exposed on the bank, or may take up water during storage in floating caches until eaten during winter. Tissue moisture is also lost in varying amounts due to differences in handling, and the time and method of sample storage prior to analysis.

To reduce variation attributable to variation in moisture content, values for vegetation samples, originally expressed as $mBq.g^{-1}$ dry weight, were adjusted to standard moisture contents. In a study of moisture in leaves picked in the vicinity of Sudbury, Ontario, in September, G.M. Courtin of Laurentian University (personal communication) observed the moisture content of aspen leaves to be 69.1 $\pm$ 1.67%, n = 4, of their fresh weight, and that of birch leaves to be 72.6 $\pm$ 2.68%, n = 4, of their fresh weight. Leaves left in protective net bags on the forest floor for 42 d absorbed water: 10.2 $\pm$ 8.39%, n = 3, of their fresh weight in the case of aspen and 25.4 $\pm$ 3.49%, n = 3, in the case of birch. In calculating radionuclide levels in leaves used as diet items in the present study, a value of 70% moisture content was used as a standard value for woody plants.

The following standard moisture contents were used as the basis for calculation in the case of woody stems: 48.5% for aspen, 49.7% for largetooth aspen, 58.2% for willow, and 49.5% for alder (Wangaard 1950). For white birch the value of 47.1% was used. This value is midway between the 54.8% moisture content reported in the same area for moose browse stems (MacLaren 1987) and 39.4% reported for birch wood (Wangaard 1950).

RESULTS AND DISCUSSION

Ra-226 IN ANIMAL TISSUES AND CHYME

Numbers of specimens collected and processed are indicated in Table 1 and kill locations are indicated in Figure 1. The goal of n $\geq$10 specimens per

sample collection was surpassed in all cases. For reasons of economy, not all beaver tissue and gut content samples from all locations were analyzed for radionuclides. All beaver (120) collected in the Experimental area in 1986, and half the Control-local animals (9) taken in 1986 were analyzed only for their bone levels of ^{226}Ra; bone of all Control-distant beaver (18), but muscle, liver and kidney tissues of only ten (10) were analyzed; all tissues (and chyme) of all beaver taken in 1987 at Elliot Lake (10), Mid-Serpent (11), and Low-Serpent (15) were analyzed.

Not only were differences in ^{226}Ra concentration among control and study sites tested for significance, but differences among subgroups of beaver, from sites in the Elliot Lake region with different levels of ^{226}Ra in the water, were examined. Information on ^{226}Ra values of tissues and chyme is summarized in Figures 3 to 7.

Levels of ^{226}Ra in bone tissue of beaver taken from each site category and area are indicated in Figure 3. As one-way ANOVA indicated significant difference(s) among the groups ($F_{7,175}$ = 18.90, P <0.0001), Fisher's PLSD test was applied to the log-transformed values with the following outcome:

	Elliot Lake 1986 - high	Elliot Lake 1987 - all	Elliot Lake 1986 - med.	Control-local	Elliot Lake 1986 - low	Mid-Serpent	Low-Serpent	Control-distant
Mean [^{226}Ra] $mBq.g^{-1}$ =	112.7	107.2	85.5	50.6	36.0	29.0	24.2	18.8

(back-transformed means presented, those sharing same underline are not significantly different , $P \geq 0.05$)

Levels of ^{226}Ra in muscle tissue of beaver taken from each area are indicated in Figure 4. One-way ANOVA indicated significant difference(s) among the groups ($F_{3,42}$ = 4.49, P <0.01). Fisher's PLSD test, when applied to the log-transformed values, indicated the following:

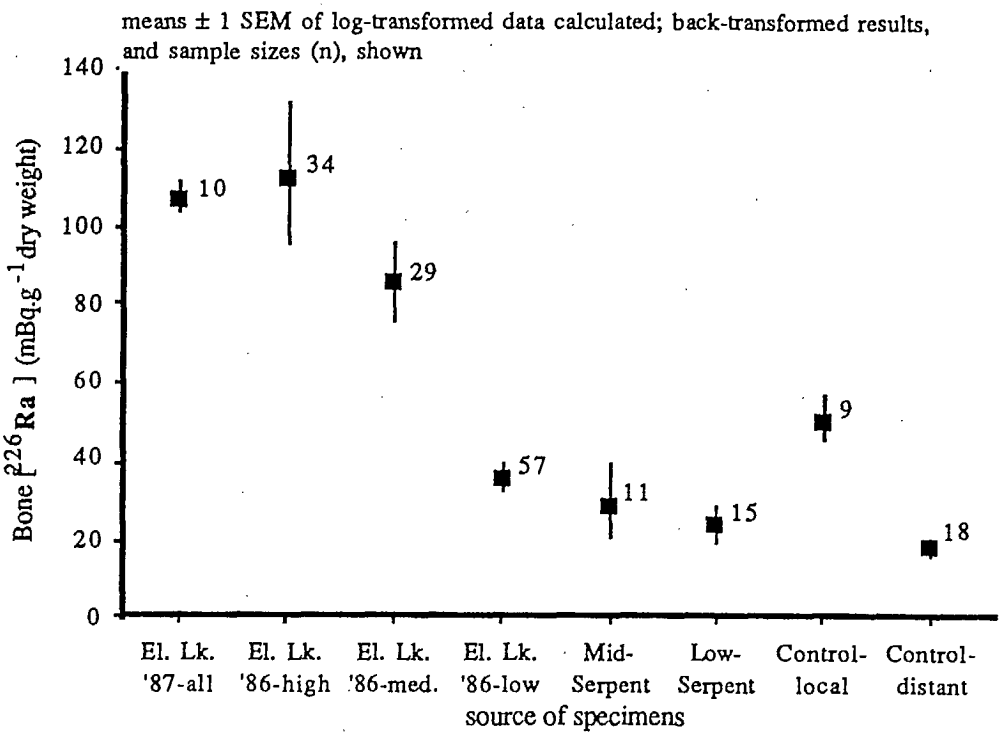

Fig. 3 - Levels of ^{226}Ra in bone tissue of beaver from study and control areas (mean ±1 SEM of log-transformed data calculated; back-transformed result, and sample size (n), shown in each case).

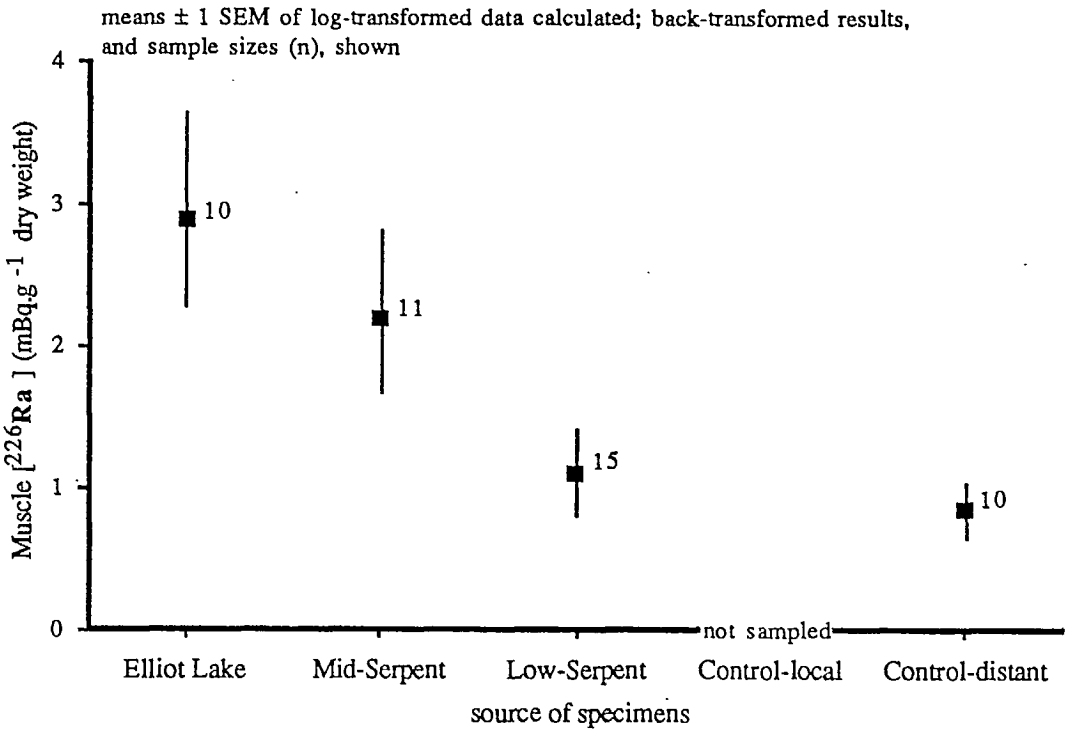

Fig. 4 - Levels of ^{226}Ra in muscle tissue of beaver from study and control areas (mean ±1 SEM of log-transformed data calculated; back-transformed result, and sample size (n) shown in each case).

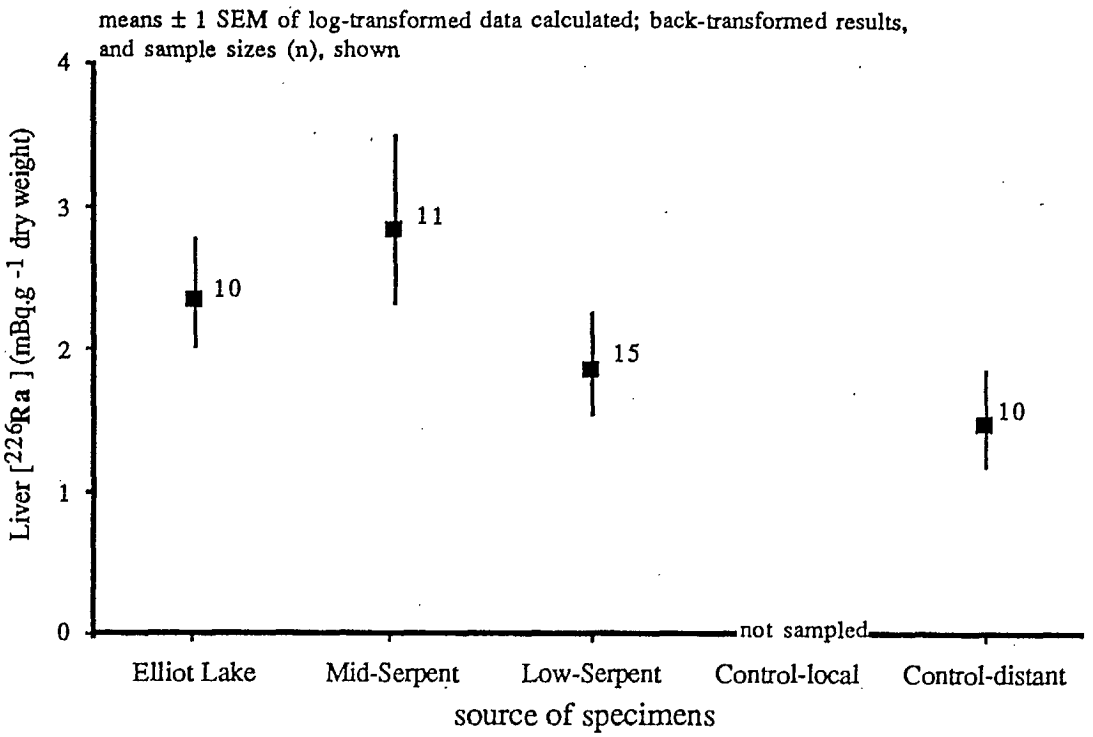

Fig. 5 - Levels of ^{226}Ra in liver tissue of beaver from study and control areas (mean ±1 SEM of log-transformed data calculated; back-transformed result, and sample size (n) shown in each case).

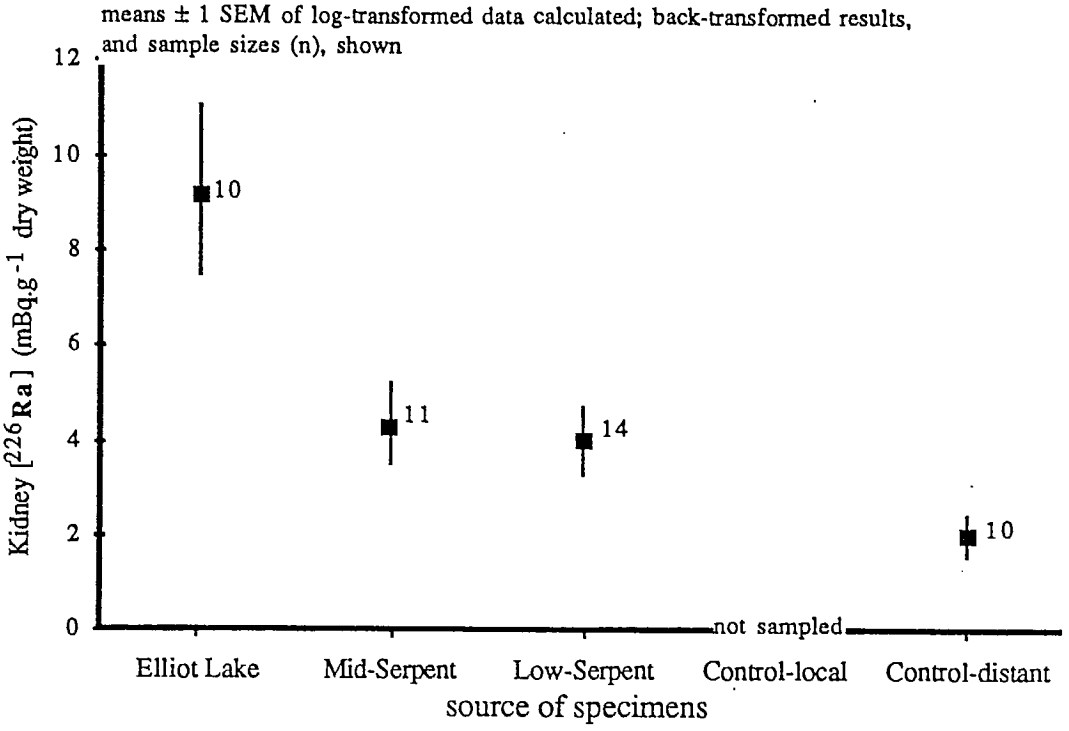

Fig. 6 - Levels of ^{226}Ra in kidney tissue of beaver from study and control areas (mean ±1 SEM of log-transformed data calculated; back-transformed result, and sample size (n) shown in each case).

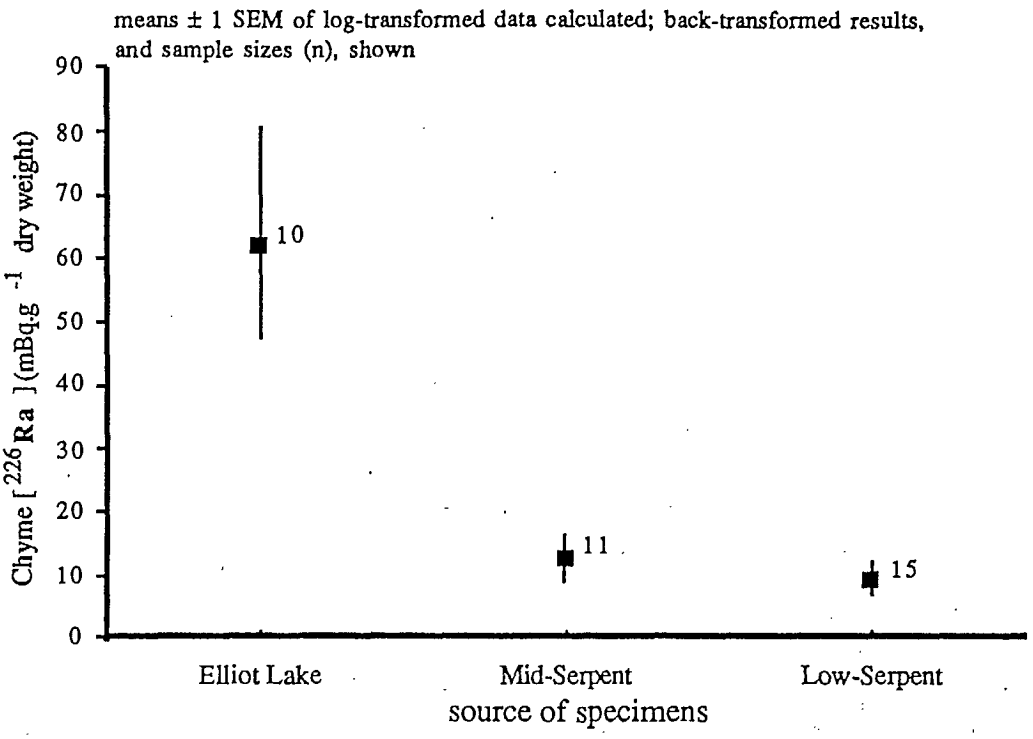

Fig. 7 - Levels of ^{226}Ra in chyme of beaver from study areas (mean ±1 SEM of log-transformed data calculated; back-transformed result, and sample size (n) shown in each case).

	Elliot Lake 1987 - all	Mid-Serpent	Low-Serpent	Control-distant
Mean [^{226}Ra] mBq.g^{-1} =	2.9	2.2	1.1	0.9

(back-transformed means presented, those sharing same underline are not significantly different , $P \geq 0.05$)

Levels of ^{226}Ra in liver tissue of beaver taken from each area are indicated in Figure 5. As analysis of variance of the log-transformed data failed to indicate any significant difference among the groups ($F_{3,42} = 1.88$, $P \geq 0.05$), no further analysis was carried out.

Levels of ^{226}Ra in kidney tissue of beaver taken from each area are indicated in Figure 6. One-way ANOVA indicated significant difference(s) among the groups ($F_{3,41} = 8.61$, $P < 0.005$). Fisher's PLSD test, when applied to the log-transformed values, indicated the following:

	Elliot Lake 1987 - all	Mid-Serpent	Low-Serpent	Control-distant
Mean [^{226}Ra] mBq.g^{-1} =	9.2	4.3	4.0	2.0

(back-transformed means presented, those sharing same underline are not significantly different , $P \geq 0.05$)

Levels of ^{226}Ra in chyme of beaver taken from each area are indicated in Figure 7. One-way ANOVA indicated significant difference(s) among the groups ($F_{2,23} = 11.65$, $P < 0.005$). Fisher's PLSD test, when applied to log-transformed values, indicated the following:

	Elliot Lake 1987 - all	Mid-Serpent	Low-Serpent
Mean [^{226}Ra] mBq.g^{-1} =	61.9	12.5	9.3

(back-transformed means presented, those sharing same underline are not significantly different , $P \geq 0.05$)

Significant variation in ^{226}Ra levels in beaver bone, muscle and kidney

is attributable to site. Bone of beaver collected in 1986, from Elliot Lake sites with historically high levels of ^{226}Ra in associated water bodies, and in 1987, had higher levels than local control animals and those from down-stream. Animals from sites in the Elliot Lake area with medium and low historical radionuclide levels, even though taken a short distance from others with significantly higher levels, and those from Mid-Serpent did not differ from local controls. Bone from Elliot Lake-Low, Mid- and Low-Serpent did not differ in their levels of ^{226}Ra, and Mid- and Low-Serpent did not differ from distant controls.

Levels of ^{226}Ra in muscle were higher in Elliot Lake and Mid-Serpent beaver than in distant controls; Low-Serpent animals did not differ from distant controls. The Elliot Lake mean value (2.9 $mBq.g^{-1}$ dry tissue) is in the middle of the range reported by MacLaren (1978) for four beaver taken in the same area: 2.6 to 3.3 $mBq.g^{-1}$. Variation in liver concentrations was not related to area or site of capture of the animals. Kidney levels of the radionuclide were higher in beaver taken at Elliot Lake than in those trapped down-stream; all study populations had significantly higher mean radionuclide levels in kidney tissue than was seen in distant controls.

The variation seen in chyme values parallels closely the decrease in vegetation levels with increasing distance down-stream and away from Elliot Lake (see below).

Ra-226 IN PLANT TISSUES

Levels of ^{226}Ra measured in woody plant samples are seen in Table 2. The ^{226}Ra levels in trembling aspen and white birch, sampled from the vicinity of tailings in the Elliot Lake area, agree with data reported previously on samples taken from the tailings themselves: Dave et al. (1985a), reported trembling aspen from the tailings with 33 $\pm$ 7 to 126 $\pm$ 11 $mBq.g^{-1}$ dry weight in leaves and 70 $\pm$ 11 to 148 $\pm$ 15 $mBq.g^{-1}$ dry weight in

stems, and white birch with 222 ± 19 to 1,021 ± 37 and 130 ± 7 to 633 ± 37 $mBq.g^{-1}$ dry weight of leaves and stems, respectively. Kalin (1988) found mean ^{226}Ra values of 96.2 and 92.5 $mBq.g^{-1}$ in trembling aspen stems and leaves from several sites on the tailings, and 321.9 and 325.6 $mBq.g^{-1}$ in white birch stems and leaves. Levels in stems of the same species from the Control-distant area generally agree with control values of Dave et al. (<4 $mBq.g^{-1}$ dry weight); the higher value seen in white birch leaves from the control area is attributed to the small sample weight, and is not considered further.

Twigs of white birch (moose browse) collected by MacLaren (1987) some distance from the river at a level corresponding to the Mid-Serpent section of the current study, had ^{226}Ra levels, recalculated as dry weight basis values from ash weight data presented, ranging from 7.4 to 23.4 $mBq.g^{-1}$ (mean 14.1 ± 3.45, n = 4). This value is similar to the level reported here for samples taken close to the river.

High values observed in white birch from Low-Serpent may reflect contamination of the trees or their habitat by silt from the river. Trees were sampled within 5 m of the river, from a low-lying area subject to flooding from time to time when the river overflows its banks during spring run-off, or at other times of high water. Serpent River sediments are rich in radionuclides (Hart and McKee 1985) and some of these particulates are probably resuspended during turbulence when the river is in spate. Levels seen in the speckled alder, black ash, sweet gale, and wine berry, all bush-sized plants growing in an area on the river bank subject to periodic flooding and all of which showed beaver clips, may have been similarly affected. Woody plant data generally agree with previously published values and show a general decrease down-stream and in the control area.

Ra-226 IN WATER

Levels of ^{226}Ra measured in water samples are seen in Table 3. Total ^{226}Ra concentrations reported here for water taken from the Serpent River, and the lakes through which it passes, are higher than in moose drinking water sampled in the region and at a control site (range 5 to 60 $mBq.L^{-1}$, MacLaren 1987). However, samples in that study were collected some distance from the Serpent River. Control-distant values are close to the limits of sensitivity of the analytic method employed and differences between total and filtered concentrations, and between our results and those for controls in studies in this area (5 $mBq.L^{-1}$, MacLaren 1987) and elsewhere (20 $mBq.L^{-1}$, Swanson 1985) are not considered important.

Total ^{226}Ra concentrations reported in Table 3 generally agree with others found in the Elliot Lake region. Most fall within the ranges reported by MOE for equivalent sites (Table 4). The Elliot Lake sample, with 558.7 $mBq.L^{-1}$ corresponds to the MOE site 014 which had a range of 80-610 $mBq.L^{-1}$ in the period from 1984 to 1987. The Mid-Serpent water, showing 192.0 $mBq.L^{-1}$, corresponds to MOE site 035 sampled once in 1984 and again in 1985 with a total ^{226}Ra concentration of 60 $mBq.L^{-1}$ found each time. However, water entering Whiskey Lake is the outflow of Quirke Lake with a range of 20-970 $mBq.l^{-1}$ from 1984 to 1987 as measured at MOE site 049. The Low-Serpent values of 232.0 and 358.7 $mBq.L^{-1}$ fall within the range for MOE site 001 of 30-600 $mBq.L^{-1}$.

Consonance of these data with others from the area, their general agreement with expectations for the area, and the decrease in ^{226}Ra concentrations with distance down-stream from tailings, leads to confidence in the reported values.

The relationship between water and beaver bone ^{226}Ra levels is seen in Figure 8. Although the slope of the regression line is significant (ANOVA,

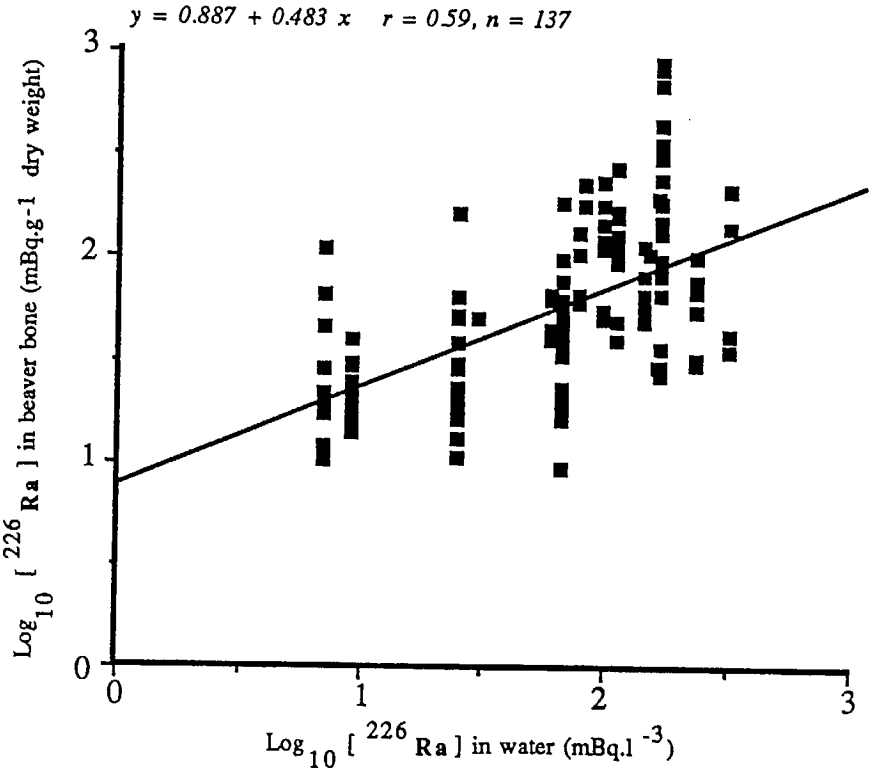

Fig. 8 - Relationship between levels of ^{226}Ra in 137 beaver and water levels at their kill sites.

$F_{1,136}$ = 73.50, P <0001), the low value of r (0.59) indicates the variability between bone and environmental ^{226}Ra levels is too great for the animal to be used as a bioindicator.

OTHER RADIONUCLIDES

Levels of other radionuclides, as reported by AECL and MONENCO, in tissues of two beaver are seen in Table 5; CANMET ^{226}Ra data have also been included for comparison. Beaver muscle levels of ^{238}U indicated here (<0.1 and 0.3 $\mu g.g^{-1}$ dry weight) compare to values previously reported in four beaver sampled in the same area (<0.05, <0.05, 0.07 and 0.08 $\mu g.g^{-1}$ dry weight) (MacLaren 1978). Levels of ^{232}Th, ^{230}Th and ^{210}Pb in beaver muscle were below detection limits in the same four beaver, and in the two reported on here.

CONCENTRATION RATIOS

In the study of ^{226}Ra movement in the Elliot Lake site ecosystem, concentration ratios were calculated between 'diet' items and tissue compartments of beaver taken from the site (Table 6). Vegetation items and gut contents were taken as indicators of 'diet' levels; water was considered a component of diet.

The range in concentration ratios (vegetation to beaver tissues) can be restricted by calculating a single value for the ^{226}Ra content of beaver diet. Assuming a beaver eats equal parts of trembling aspen, largetooth aspen, white birch, and willow (alder being excluded as it is not a favoured species), and assuming that the amount of food material (biomass) from each plant is obtained in the ratio of 1:4 from the leaf and branch sections, then a weighted average concentration can be calculated taking into account the contributions of each species and component of that species. The value for ^{226}Ra in plant material calculated in this way is 51.6 $mBq.g^{-1}$ wet weight (the unweighted value is 44.6 $mBq.g^{-1}$ wet weight). The beaver chyme might be

expected to have a level of radionuclide approximating the amount in the vegetation being eaten. The observed value was 12.9 $mBq.g^{-1}$ (n = 10), which is only about 25% of that value. Part of the explanation for this difference may be the higher moisture content of chyme compared to that of vegetation: chyme is saturated with water and secretions and has a consistently high moisture content averaging 79.2 with a range from 75.7 to 82.32% of fresh weight.

The desirability of working with values calculated on a dry weight basis is illustrated by the following: if values are calculated as in the last paragraph, but on a dry weight basis, then the average vegetation ^{226}Ra values are: unweighted 110.1 and weighted 110.2 $mBq.g^{-1}$ dry weight. The concentration of ^{226}Ra in the chyme is calculated on the same basis is 61.9 $mBq.g^{-1}$ dry weight, which is closer than the agreement between wet weight based values.

Using the calculated vegetation value of 51.6 $mBq.g^{-1}$ wet weight, and the mean tissue levels in the table, then the concentration ratios are as follows:

Bone/vegetation	67.5/51.6	=	1.31
Muscle/vegetation	0.8/51.6	=	0.02
Liver/vegetation	0.7/51.6	=	0.01
Kidney/vegetation	2.3/51.6	=	0.04

Using dry-weight based values for stomach contents and beaver tissues concentration ratios are as follows:

Bone/chyme	107.2/61.9	=	1.73
Muscle/chyme	2.2/61.9	=	0.04
Liver/chyme	2.38/61.9	=	0.04
Kidney/chyme	9.2/61.9	=	0.15

Ra-226 concentration ratios from diet to bone are higher than those to

other tissues; this probably reflects the radionuclide being incorporated in the bone matrix in the same way as its analog Ca (Friedlander and Kennedy 1962; Lloyd et al. 1976; Raabe et al. 1983). Concentrations in soft tissue (Mahon 1983; Schlenker et al. 1982; Swanson 1983; Ruttenber et al. 1984) does occur, but to a lesser extent than in bone. Bound in calcium hydroxyapatite bone crystals, ^{226}Ra may cause tissue damage, possibly resulting in osteosarcoma, as it is an internal emitter of alpha and beta radiation (Van Dilla et al. 1958; Mays et al. 1975; Schlenker et al. 1982; Raabe et al. 1983).

The concentration ratios reported here are lower than those (1.94 to 3.99) calculated from diet (cattails) to bones of muskrats taken at Elliot Lake in waters with historically high contamination levels (Mirka et al., in preparation). In moose, reported CRs from vegetation (95% confidence intervals) are: to bone 1.30-7.04; to muscle 0.027-0.048; to liver 0.054-0.091 (MacLaren 1987). The concentration ratios for beaver tissues calculated herein overlap those of the moose study with the exception that liver values are less than a quarter of the moose values.

ESTIMATES OF ANNUAL INTAKES

Although consumption of beaver is not as common now as it was in the past, trappers and residents of the area report beaver (along with grouse, muskrat, rabbit and hare) are roasted or stewed with onions and tomatoes before eating. Stewing exposes game to mild acidity, due to the presence of tomatoes, which may elute some ^{226}Ra and Ca from the bones of the carcass. Levels of such liberation is unknown.

Estimates of annual consumption involve assumptions regarding quantities of tissue consumed per year. Goldfarb (1977) reported local hunters consume 46 kg of game per family per year. This consumption supplements or replaces dietary animal material from other sources. According

to Health and Welfare Canada (HWC 1975) average annual consumption of all meats by Canadian males 20 to 29 y old is 71 kg. To make a very conservative assessment, it is assumed here that a resident of Serpent River basin might obtain all his animal material from wild sources and that muscle tissue, liver tissue and bone particles are consumed in the (arbitrary) ratio of 100:10:1. These assumptions lead to an estimated daily consumption of about 175 g of muscle, 17.5 g of liver and 1.8 g of bone.

The above tissue consumption rates, used in conjunction with the tissue radionuclide values of Table 5, permitted estimation of annual intakes of radionuclides from each species. Detection limit values were used in those cases in which a radionuclide was not measurable in a tissue sample from one animal, but was measurable in the same tissue in the second representative examined. Values converted to $mBq.g^{-1}$ wet weight using mean water contents of tissues, measured during ^{226}Ra estimations (n = 10 in all cases): bone 36.6%, muscle 72.5%, liver 69.4% and kidney 74.2%. For levels of ^{226}Ra in bone, both the CANMET and MONENCO values were included in the calculations; CANMET values were used for ^{226}Ra in muscle and liver.

Calculated annual intakes of radionuclides from beaver are as follows:

	bone	muscle	liver	total	% of derived limit on annual intake
^{238}U (mg)	<1	4	<1	<6	<0.09
^{232}Th (mg)	nm	nm	nm	-	-
^{232}Th (Bq)	nm	nm	nm	-	-
^{230}Th (Bq)	nm	nm	nm	-	-
^{228}Th (Bq)	5	nm	nm	5	0.01
^{210}Po (Bq)	52	849	110	1,011	10.11
^{210}Pb (Bq)	63	nm	nm	63	1.58
^{226}Ra (Bq)	51	68	5	124	0.62

nm = not measurable in tissue of either specimen

These estimated values are extreme which assume high consumption levels and no loss of radionuclides during cooking. Detection limit values, which

probably overestimate concentrations, are used in some cases. Furthermore, data came from only two specimens and these were selected because their tissue burdens of ^{226}Ra were high relative to others. A diet with a mixture of sources would probably contain less radionuclides.

To indicate the magnitude of radionuclide intakes, values are compared to one tenth of the values of Annual Limits on Intake for occupational workers given by the ICRP (1979a,b). These values, which may be considered as maximum yearly radionuclide intake, are as follows: ^{210}Pb - 4000 Bq, ^{210}Po - 10,000 Bq, ^{226}Ra - 20,000 Bq, ^{228}Th - 50,000 Bq, ^{230}Th - 40,000 Bq, ^{232}Th 7,000 Bq (1,550 mg), ^{238}U - 80,000 Bq (6,500 mg). These levels approximate the Canadian regulatory dose limits for the members of the public. Clearly, estimated values of annual radionuclide intakes from consumption of beaver or grouse are considerably less than the limits on yearly intake.

As indicated, these are extreme estimates based on 'worst-case' assumptions concerning consumption rates and use values from only two animals, from the most contaminated areas, which had been selected for their high levels of ^{226}Ra. It is considered unlikely that consumers would take in their diet even one tenth of the amount used in these calculations: trappers in the vicinity of Elliot Lake rarely, if ever, eat any of the beaver that they catch. Although members of the Serpent River Band, located in the Low-Serpent area, probably consume more game in their diet, this is likely to be substantially lower in radionuclides than that consumed by Elliot Lake inhabitants (if radionuclides occur in the same proportion to ^{226}Ra): mean ^{226}Ra levels in bone and muscle of beaver from Low-Serpent are 20% and 30% respectively of values obtained at Elliot Lake. Beaver liver contains ^{226}Ra levels not significantly higher than in samples taken from undisturbed control areas. Assuming the more realistic consumption level of 7.1 $kg.y^{-1}$ then aggregate annual intake from beaver would be only 1.24% of the limit on annual

intake.

QUALITY ASSURANCE

Duplicate estimates were performed on six bone samples: two low-level beaver bones (from the Control-distant site) were analyzed twice in the CANMET laboratory; two high-level beaver from the experimental areas were analyzed at CANMET and also at the MONENCO laboratory. The latter analysis was performed blind. Results of the duplicate estimations are contained in Table 7.

Samples of cow shank bone spiked with ^{226}Ra and ^{133}Ba, were run through the analytical procedure and showed recovery rates of 98 $\pm$ 10%. Standard samples from CANMET, similarly processed, gave results within 10% of the known values. The agreement of the duplicate analyses at in both low and high level samples is good and indicates that confidence may be put in the experimental results.

CONCLUSIONS

Findings indicate that radionuclide contamination of beaver is localized. Only animals taken in the immediate vicinity of U operations in the Elliot Lake area show high ^{226}Ra levels; those taken from water with mean ^{226}Ra concentrations $\geq$148 mBq.L^{-1} in the period 1984-1988, have bone ^{226}Ra levels higher than animals taken from local control areas. However, levels of ^{226}Ra in bone of beaver taken in Elliot Lake waters with lower mean ^{226}Ra concentrations ($\leq$147 mBq.L^{-1}) even though trapped close to U operations, do not differ from those of specimens from local undisturbed control areas; those taken down-stream in the Serpent River do not differ from distant controls. Levels of ^{226}Ra in beaver muscle decline with site of capture, and animals from the Low-Serpent area are not distinguishable from distant controls. Levels in kidney of beaver taken in the study area were all significantly higher than those of distant controls. Levels in beaver liver showed no

significant elevation associated with site. Levels of ^{226}Ra in diet and tissues of beaver are similar to those reported in other studies of animals and plants in the study area.

Concentration ratios of ^{226}Ra between diets and beaver tissues are comparable to those reported for other animals in the area. Radionuclides other than ^{226}Ra are present in beaver tissues at low levels. Radionuclide intake by humans consuming even substantial amounts of beaver taken in the Serpent River drainage basin, are calculated as less than annual limits set by Canadian regulatory authorities.

Poor correlation between bone and environmental levels of ^{226}Ra effectively bars the beaver from further consideration as a bioindicator species for environmental contamination by the radionuclide.

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Table 1 - Numbers of beaver specimens from study and control areas.

	beaver collected		
	1986[a]	1987	total
SITES			
Elliot Lake	-	10	**10**(10 bmlks)[b]
-high	34	-	**34**(34 b)
-medium	29	-	**29**(29 b)
-low	57	-	**57**(57 b)
Mid Serpent	-	11	**11**(11 bmlks)
Low Serpent	-	15	**15**(15 bmlks)
Control - local	20	-	**20**(9 b)
Control - distant	18	-	**18**(18 b, 10 mlk)
			Total: 194

[a] includes four specimens taken in 1985

[b] in parentheses, figures indicate specimens processed; letters indicate tissues analysed (as available). Key: b = bone, m = muscle, l = liver, k = kidney, s = chyme (stomach contents).

- samples not taken

Table 2 - Ra-226 in woody plants from study and control areas

	[Ra-226] mBq.g^{-1} dry weight of tissue							
	collection sites							
	Elliot Lake		Mid-Serpent		Low-Serpent		Control-dist.	
species	Leaves w(u)	Stems w(u)	Leaves w(u)	Stems w(u)	Leaves	Stems	Leaves	Stems
Trembling aspen *Populus tremuloides*	41.8(38.9)	68.9(55.6)	14.2(12.4)	11.0(9.0)	13.9	8.3	14.9	3.4
Largetooth aspen *Populus grandidentata*	52.7	98.7	-	-	3.7	4.7	-	-
Balsam poplar *Populus balsamifera*	34.8	32.0	-	-	-	-	-	-
White birch *Betula papyrifera*	252.2(268.0)	222.7(217.9)	16.2(12.3)	9.7(11.8)	76.8	29.0	46.0[a]	3.9
Willow *Salix sp.*	93.1	50.7	-	-	-	-	5.6	3.4
Speckled alder *Alnus rugusa*	99.7	135.7	[38.0]		-	-	-	-
Black ash *Fraxinus nigra*	-	-	39.1	35.2	130.3	89.8	-	-
Sweet gale *Myrica gale*	-	-	[12.3]		[99.3]		-	-
Wine berry *Ilex verticillata*	-	-	-	-	[171.6]		-	-

[a] sample small (<0.5g d.w.)
w washed, (u) unwashed
[ ] sample not partitioned
- samples not taken or processed

Table 3 - Levels of ^{226}Ra in water samples from study and control areas

	[Ra-226] mBq.l^{-1} water[a]				
collection sites:	Elliot Lake	Mid-Serpent	Low-Serpent		Control-distant
			Hwy 17 bridge	Drive-In theatre	
dissolved	118.1	122.4	95.1	80.1	12.1
total	558.7	192.0	232.0	358.7	9.0

[a] Average of two samples, each with duplicate subsamples

Table 4 - Levels of ^{226}Ra in water sampled at locations in the Serpent River basin (after M.O.E. reports).

M.O.E. Site	location	latitude (° ' " N)	longitude (° ' " W)	n	mean total [^{226}Ra] 1984-87 ($mBq.l^{-1}$)
#001	Old Hwy 17, E of Hwys 108 & 17	46 12 40.9	82 30 43.92	20	75.6
#002	At lake Depot	46 20 7.52	82 32 22.78	20	21.6
#003	At Pecors Lake	46 22 26.74	82 26 16.91	11	85.3
#004	At Pecors Lake	46 23 36.85	82 29 54.14	13	165.0
#006	Crotch Lake	46 25 4.8	82 35 19.79	15	65.6
#007	Buckles Creek at Hwy 108	46 22 25.61	82 35 50.27	20	163.9
#009	Sheriff Creek at Hwy 108	46 24 9.12	82 39 49.8	20	72.5
#010	Rochester Creek Near Inlet to Quirke lake	46 29 57.97	82 31 24.36	7	54.3
#011	Serpent River near inlet to Quirke Lake	46 30 39.11	82 36 32.87	21	149.0
#012	Creek near road to Stanrock townsite	46 28 17.81	82 33 4.73	4	285.0
#014	Serpent R. at Panel Mine side rd	46 30 11.54	82 38 28.89	19	158.0
#017	Stollery L. at Denison dam	46 29 8.68	82 38 6.36	18	978.0
#019	Dunlop L. outlet	46 28 51.78	82 38 55.1	19	29.7
#020	Serpent R. Trib., Moose L. outlet	46 27 44.66	82 30 59.54	8	36.3
#023	Pronto Effluent at Hwy 17	46 12 6.4	82 41 52.59	19	87.0
#026	Serp. R. Trib. Panel Mine Tr plant out	46 30 27.99	82 32 21.51	23	314.0
#027	Elliot Lake Municipal Pumphouse	46 23 22.09	82 39 53.05	19	25.0
#030	Dunlop L. in Bay A	46 29 4.37	82 39 21.27	2	8.0
#031	Quirke L. SW of Stanrock Mine	46 28 6.32	82 34 14.73	3	77.0
#032	Quirke L. NE of CanMet Mine	46 29 13.97	82 31 44.24	2	80.0
#033	Quirke L. SE corner	46 28 20.44	82 31 49.77	2	75.0
#034	Quirke L. E of Denison Dam	46 29 10.87	82 35 31.64	2	75.0
#035	Whiskey L. S end Near Rum Point	46 24 27.28	82 20 56.9	2	60.0
#036	McCabe L., center of Lake	46 25 22.23	82 33 50.11	1	290.0
#037	Camp L., at S end	46 14 6.0	82 26 29.49	3	63.0
#038	Serpent Harbour, near Hospital Point	46 11 55.43	82 40 32.93	1	60.0
#039	McCarthy L., at W end	46 19 45.02	82 29 5.71	1	30.0
#040	McCarthy L., at S end	46 18 29.74	82 26 55.11	1	60.0
#041	Hough L., centre of lake	46 24 32.22	82 29 32.24	2	110.0
#044	Westner L. at ski club rd.	46 22 59.8	82 37 33.09	11	141.0
#045	Williams L. Creek, at Denison Mine rd.	46 29 44.31	82 38 7.43	12	163.0
#046	Pronto Ditch, below Pronto Treat. plant	46 12 15.39	82 42 41.86	4	75.0
#049	Serpent R., at Quirke L. outlet	46 29 14.25	82 29 20.01	20	132.0
#051	Quirke Mine Tailings	46 30 30.32	82 39 14.5	19	178.0
#054	May L., S end of lake	46 25 38.35	82 28 51.88	1	220.0
#055	May L., N end of lake	46 26 42.52	82 29 40.48	1	120.0
#056	Panel Creek at Quirke L.	46 30 11.16	82 33 7.95	4	135.0
#067	Esten L., central part of lake	46 21 4.28	82 41 50.51	1	7.0
#070	Orient L. outlet	46 27 30.74	82 31 10.88	14	70.0
#071	Panel Mine Tailings Effluent	46 31 8.36	82 32 30.86	13	230.0
#072	Gravel Pit outlet	46 31 7.57	82 41 5.92	16	13.0
#073	Evans L. outlet	46 29 37.89	82 39 55.13	19	18.0
#074	Esten L. outlet	46 20 39.4	82 36 55.01	19	50.0
Intermediate locations					
Stations					
051 & 011				40	162.7
009 & 044				31	96.8
007 & 074				39	108.6
014 & 011				40	153.4
067 & 074				20	48.3

Table 5 - Radionuclides in tissues of beaver from Elliot Lake

	[radionuclide] in dry tissues								
	AECL		MONENCO						CANMET
	^{238}U	^{232}Th	^{232}Th	^{230}Th	^{228}Th	$^{210}Po^{a}$	^{210}Pb	^{226}Ra	^{226}Ra
	----- $\mu g.g^{-1}$ ----		---------- $mBq.g^{-1}$ ----------						
beaver:									
DSC 2									
bone	0.3	<1.0	<5.0	<5.0	10.0±5.0	70.0±10.0	90.0±30.0	90.0±10.0	123.0
muscle	<0.1	<1.0	<5.0	<5.0	<5.0	75.0±10.0	<50.0	-	2.1
liver	0.4	<1.0	<5.0	<5.0	<5.0	65.0±10.0	<50.0	-	2.6
DSC 8									
bone	0.1	<1.0	<5.0	<5.0	15.0±5.0	160.0±20.0	190±50.0	120±10.0	124.8
muscle	0.3	<1.0	<5.0	<5.0	<5.0	11.0±5.0	<50.0	-	4.9
liver	<0.1	<1.0	<5.0	<5.0	<5.0	35.0±5.0	<50.0	-	2.8

[a] measured 4th May 1988
- samples not taken or processed

Table 6 - Concentration ratios to tissue compartments of beaver from Elliot Lake

COMPARTMENT		X_e = [Ra] (mBq.g^{-1}) dw	moisture %[b]	X_e = [Ra] (mBq.g^{-1}) ww	$f_{le} = X_l/X_e$ (concentration ratios) bone	muscle	liver	kidney
					^{226}Ra concentration (mBq.g^{-1})[a]			
					X_l = 67.5	0.8	0.7	2.3
trembling aspen	leaf	41.8	70.0	12.5	5.38	0.06	0.06	0.19
	stem	68.9	47.1	36.4	1.85	0.02	0.02	0.06
largetooth aspen	leaf	52.7	70.0	15.8	4.27	0.05	0.05	0.15
	stem	98.7	49.7	49.6	1.36	0.02	0.01	0.05
white birch	leaf	252.2	70.0	75.7	0.89	0.01	0.01	0.03
	stem	222.7	47.1	117.8	0.57	0.01	0.01	0.02
willow	leaf	93.1	70.0	27.9	2.42	0.03	0.03	0.08
	stem	50.7	58.2	21.2	3.19	0.04	0.03	0.11
alder	leaf	99.7	70.0	29.9	2.26	0.03	0.02	0.08
	stem	135.7	49.7	68.3	0.99	0.01	0.01	0.03
chyme				12.9	5.25	0.06	0.05	0.18
water				0.12[c]	572.05	6.73	6.15	19.88

[a] wet-weight basis, calculated on log-transformed values, back-transformed mean values presented

[b] see text

[c] mBq.g^{-1} ≈ mBq.mL^{-3}

Table 7 - Levels of ^{226}Ra ($mBq.g^{-1}$ dry weight) in beaver bone: repeated measures.

	[Ra-226] $mBq.g^{-1}$ dry weight of tissue	
sample	first measure	second measure
BO102 (beaver, Control-distant)	11.12[c]	4.5[c]
BO103 (beaver, Control-distant)	20.21[c]	8.1[c]
DSC 2 (beaver, Elliot Lake)	90.0 ± 10[m]	119.6[c]
DSC 8 (beaver, Elliot Lake)	120.0 ± 10[m]	124.8[c]

[c] measured at CANMET laboratory, Elliot Lake.
[m] measured at MONENCO laboratory, Calgary.