URANIUM, THORIUM, AND POTASSIUM IN SOILS ALONG THE SHORE OF LAKE ISSYK-KYOL IN THE KYRGHYZ REPUBLIC

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Running Head: Natural Radioactivity in Lake Issyk-Kyol Shoreline Soils

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ABSTRACT

The Kyrghyz Republic, located in the southeastern region of the former Soviet Union, maintains a population of more than one-half-million persons and is heavily dependent on Lake Issyk-Kyol, both to draw tourists to the area and for its utilization by some as a food and recreation source. Historical surveys, conducted primarily for geological exploration, have indicated that localized areas of shoreline on Lake Issyk-Kyol have relative radiation levels in excess of ambient background by as much as a factor of ten. Uranium mining operations in the mountains bordering the lake to the south may have resulted in the contamination of a number of areas on the lake's southern shore. Concentrations of naturally occurring uranium, thorium, and potassium are present in these soils in elevated quantities. This paper presents the results of an investigation of soil concentrations along the shoreline of Lake Issyk-Kyol relative to previously discovered areas of high exposure rate.

INTRODUCTION

Lake Issyk-Kyol is situated in the northeast region of Kyrghyzstan, one of the independent republics of the former Soviet Union and bordered by China to the south and east, Kazakstan to the north, and Uzbekistan and Tajikistan to the west (Figure 1). The lake is one of the largest in Central Asia, having a surface area of 6,240 km^2 and a depth of 668 m. It lies in the valley between the Terskei mountains to the north and the Kungei mountains to the south, at a surface elevation of 1,550 m (CAGC, 1987). The briny lake, fed by mountain runoff which flows through about 80 small rivers and creeks, has no discharge streams. Lake Issyk-Kyol is used for swimming, boating and fishing, but because of its salt content, it is not a direct source of drinking water. During the Soviet era, hotels along the central northern shore of Lake Issyk-Kyol were well known vacation spots for the Soviet elite, but otherwise it remained in virtual isolation from the outside world until the early 1990's. Today, the lake attracts tourists from all over Central Asia.

A government commission in Kyrghyzstan was established from 1994 to 1996 to assess the radiation situation at Lake Issyk-Kyol and determine whether radioactivity in areas with elevated radiation levels was natural or man-made. An investigation of radiation levels along the shoreline of Lake Issyk-Kyol was conducted previously by Kyrghyz scientists (SCSC 1990) and more recently by Hamby and Tynybekov (1999). The SCSC (1990) survey included about 400 measurements and our survey consisted of over 2,200 measurements taken along the circumference of the lake. The most recent measurements indicate that sampling locations near Genish, Kadji-Sai, Bokonbaevo, and Cholpon-Ata have radiation exposure rates in excess of ten times ambient levels (Hamby and Tynybekov, 1999). To corroborate earlier data and to determine the source of the increased radiation fields, a radiological assessment of the shoreline of Lake Issyk-Kyol was executed, including analyses of nearly 300 soil samples.

We have measured concentrations of thorium, uranium, and potassium in the shoreline soils. Each of these naturally-occurring elements has isotopes that are radioactive and may increase the amount of exposure received by the populations living in the vicinity of the lake. These exposures can result in individuals receiving radiation dose in the form of external gamma radiation or internal alpha and beta emissions. Additionally, radon is a decay progeny of thorium and uranium and may result in increased radiation dose via the inhalation exposure pathway. The present study reports on the results of our soil analyses at Lake Issyk-Kyol.

METHODS

Sample collection. In early 1999, several hundred soil samples were obtained from ninety-nine locations around the shoreline of lake Issyk-Kyol. The selection of these sampling locations was driven by results from previous assessments of external exposure rates in the region (Hamby and Tynybekov, 1999), so as to include representative areas of both high and low gamma exposure. Samples were collected at locations near the mouths of streams emptying into Lake Issyk-Kyol, along the shoreline of the lake, and at specific locations with elevated radiation levels. Precise positional data were recorded using a portable GPS receiver.

Soil samples were collected by first recording location and relative exposure rate at 1 m from the undisturbed surface, directly over the area to be sampled. An area of 30 x 30 cm was marked and cleared of debris. Three, thirty-to-forty gram samples (wet weight) of surface soil, to a depth of 1-2 cm, were collected at random within the marked, 900 cm^2 area. The three samples were then combined into one, sifted, mixed thoroughly, and dried for 4 hours in a 100° C oven. Water fractions averaged 8.9%, ranging from less than 1% to as much as 37%. Dry weights of combined samples were consequently 83.6 ± 12.1 grams.

Dried samples were sealed in 250 mL polyurethane bottles and set aside for a minimum of 30 days to allow the in-growth of uranium and thorium decay products (Myrick *et al.,* 1983; Murith *et al.,* 1986).

Sample counting. Prepared soil samples in radiological equilibrium were counted in their sealed bottles on a high-purity germanium (HPGe) detector with 70% efficiency, relative to a 3x3" NaI. Following a 30-minute counting time, count rates were recorded for five gamma energies: 0.239 MeV (^{212}Pb, with a 44.6% gamma yield); 0.352 MeV (^{214}Pb, 37.1%); 0.609 MeV (^{214}Bi, 46.1%); 0.911 MeV (^{228}Ac, 27.7%); and 1.461 MeV (^{40}K, 10.7%). Concentrations of ^{232}Th were determined from the average concentrations of ^{212}Pb and ^{228}Ac in the samples, and ^{238}U was determined from the average of the ^{214}Pb and ^{214}Bi concentrations. Radiological concentrations of ^{232}Th, ^{238}U, and ^{40}K were then converted to total elemental concentrations of thorium, uranium, and potassium in surface soils, as described below. Total thorium and uranium concentrations are reported in units of ppm, while concentrations of potassium are reported in units of percent.

Calculation of elemental concentrations. Radiological concentrations in soils collected from the Issyk-Kyol shoreline are determined from measurements of the gamma rays emitted by specific radionuclides in the decay of uranium, thorium, and potassium. These concentrations, while specific only to particular radioisotopes, are used to estimate elemental concentrations in the soil samples. Since the decay progeny of ^{232}Th and ^{238}U are measured, we must rely on the establishment of secular equilibrium in the samples in order to provide an accurate measurement of total thorium and uranium, hence the 30-day in-growth time. A true measure of potassium is taking place since we are measuring ^{40}K directly.

Elemental concentrations are calculated from measured radiological concentrations in the soil samples. First, the radiological concentration of nuclide i, $C_{S,i}$, in units of Bq per gram of soil, is calculated using,

$$C_{S,i} = \frac{\dot{C}_i}{Y_i \cdot \varepsilon_i \cdot M_x}$$

where $\dot{C}_i$ is the measured count rate [cts/sec], Y_i is the yield of gamma rays per disintegration, ε_i is the efficiency [cts/gamma] of the detector at the energy of the nuclide i gamma ray, and M_x is the dry mass of the soil sample being analyzed. The fraction of the element in the soil sample, F_E, in units of % or ppm, is then calculated by,

$$F_{E,j} = \frac{C_{S,i} \cdot M_{A,j}}{\lambda_i \cdot N_A \cdot f_{A,i}} \cdot K$$

where $M_{A,j}$ is the atomic mass [g/mol] of element j; λ_i is the decay constant [s^{-1}] of the radioisotope being counting; N_A is Avogadro's number [6.023×10^{23} atom/mol]; $f_{A,i}$ is the fractional atomic abundance of ^{232}Th, ^{238}U, or ^{40}K; and the constant, K (with a value of 100 or 1,000,000), converts the ratio of the element's mass to soil mass into a percentage or ppm.

RESULTS AND CONCLUSIONS

Concentrations of total thorium, uranium, and potassium are plotted in Figure 2 for our ninety-nine sampling locations around the perimeter of Lake Issyk-Kyol. Measured concentrations over all sampling sites are 53 ± 110 ppm, 21 ± 64 ppm, and 5.7 ± 1.3 % for thorium, uranium, and potassium, respectively. For comparison, Myrick *et al.* (1983) have determined arithmetic mean concentrations and standard deviations of thorium and uranium in surface soils in more than 300 samples obtained from locations around the United States to be 8.9 ± 4.2 ppm and 3.0 ± 2.5 ppm, respectively. Also, Chang *et al*. (1974) report the concentrations of thorium, uranium and potassium in earthen building materials of Taiwan to range from 14 to 16 ppm, 1.2 to 4.3 ppm, and 0.15 to 12.8 %, respectively. Potassium concentrations in a wide variety of rock types are estimated to range from approximately 0.1 to 3.5 % (Kohman and Saito, 1954).

For thorium at Lake Issyk-Kyol, if the two high concentrations at locations 37 and 38 (Figure 2) are removed from the analysis, the concentration over the remaining soil samples is 37 ± 20 ppm, about a factor of two-to-four greater than the averages of Myrick *et al.* (1983) and Chang *et al.* (1974). Likewise, removing the four high concentrations at locations 87, 90, 95, and 96, the concentration of uranium is 10 ± 5 ppm, a factor of about three greater.

An analysis of concentrations of potassium in Lake Issyk-Kyol shoreline soils shows less variability among samples, with two comparatively low values being recorded for locations 28 and 38. If these values are removed from the analysis, the concentration of potassium in the Issyk-Kyol shoreline is 5.8 ± 1.1 %, in the range of the data of Chang *et al*. (1974), but about 65% higher than Kohman and Saito's (1954) high value.

Several representative sampling points, plotted relative to the lake's shoreline, are shown in Figure 3. These particular locations are plotted to highlight areas found to have elevated radiation exposure rates (Hamby and Tynybekov, 1999) and areas of relatively high uranium, thorium, and potassium concentrations. As expected, locations with high soil concentrations of these radionuclides (locations 37, 38, 87, 90, 95, and 96) are consistently located near areas of the lake previously determined to have high exposure-rate measurements (SCSC, 1990; Karpachov, 1996; Hamby and Tynybekov, 1999).

Measurements by our international team of scientists have confirmed the existence of areas with elevated levels of radiation exposure and high concentrations of naturally occurring radionuclides on the southern shore of Lake Issyk-Kyol, in the Kyrghyz Republic. Thorium, uranium, and potassium concentrations in specific areas near the lake are somewhat higher than average concentrations around the world. Visual inspection of Lake Issyk-Kyol's white, sandy beaches near the towns of Bokonbaevo and Kadji-Sai show a distinctive mixture of black sands in very localized areas. Monazite is an insoluble rare-earth mineral that is known to appear with the mineral ilmenite in sands at other locations in the world (Eisenbud, 1987). Monazite contains primarily radionuclides from the ^{232}Th series, but also contains radionuclides in the ^{238}U series. The sands on the Lake Issyk-Kyol beaches very likely contain monazite and ilmenite. These mineral outcroppings are the source of radioactivity along the shoreline of Lake Issyk-Kyol. Historical evidence provides insight into possible other sources of radioactivity in this area of the world, however, our results suggest that shoreline radioactivity is of natural origins.

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FIGURE CAPTIONS

Fig. 1. Location in Central Asia of the Kyrghyz Republic and Lake Issyk-Kyol.

Fig. 2. Thorium, uranium, and potassium concentrations in soils on the shore of Lake Issyk-Kyol.

Fig. 3. Relative radiation levels and areas of relatively high thorium, uranium, and potassium concentrations at specific locations on the shoreline of Lake Issyk-Kyol.