RATIONALE for the MEASUREMENT of RADON-222
in the DEEP LAYERS of LAKE NYOS, CAMEROON

The use of radon-222 ($T½$= 3,82 days) as a method to locate a resurgence or a spring of water on a river bed lies in the sharp contrast of radon concentration between groundwater and surface waters. Radon concentrations of the former depend on the geological, geochemical and lithological characteristics of the aquifer, and particularly on its radium-226 content, the parent radionuclide of radon-222. The following Table provides orders of magnitude of the radon content of typical ground waters (the radon is always unsupported by dissolved radium, by a factor of 10^2 to 10^4).

AQUIFER	^{222}Rn (Bq.l^{-1})
Granitic	500
Metamorphic	150
Basaltic	15
Sandy	10
Calcareous	1

The ^{222}Rn content of thermal waters in France[1] ranges consistently from 10 to 1500 Bq.l^{-1}. Values in the US fall within the 0.6 to 818 Bq.l^{-1} range, for limestone and granite, respectively[2].

On the other hand, radon-222 concentration in river waters, at some distance from the spring, and generally in all surface waters, is close to its equilibrium value with atmosphere, *i.e.*, between 3×10^{-4} and 9×10^{-4} Bq/l^{-1} @15°C to 20°C. For a normally aerated river, radon concentration is halved every 350 m downstream, before reaching the equilibrium value with dissolved radium (negligible) and with the input from the bedrock and alluvial deposits. Generally, radon concentration of surface waters is 100 to 10000 times lower than radon concentration in the aquifers that feed them. Therefore, radon is a good candidate for quantifying exchanges between surface and underground water tables.

Spring water entering a lake from under its bed would be readily detected by a radon anomaly in the lake water: this feature was capitalised upon for uranium prospecting, e.g., in numerous lakes of Canada (see Figure). Note that radium is rapidly fixed in the lake bed deposits either by inorganic precipitation, by absorption or complexing with organic matter[3].

In the case of lake Nyos, where convection is hindered by density stratification, the contrast will be even more conspicuous. Indeed, the diffusion length of radon being of the order of 2 cm in water, an input of radon-rich water will not be concealed by the radon emanating from the lake bed. In order to locate the still hypothetical soda spring(s) beneath lake Nyos, the "radon method" is much more powerful than other methods based on thermal or chemical measurements since the temperature and CO_2 content of the spring may be very close to the temperature and CO_2 content of the lake bottom water.

[1] Rémy, M.L. and Lemaître, N., 1990. Eaux minérales et radioactivité. *Hydrogéologie*, 4: 267-278.
[2] Cothern, C.R and Smith, J.E., *Editors*, 1987. Environmental Radon. Plenum Press, New-York, 363 pp.
[3] Smith, A.Y., Barretto, P.M.C. and Pournis, S., 1976. Radon methods in uranium exploration. *In*: Proceedings of a Symposium on Exploration of Uranium Ore Deposits, IAEA & OECD/AEN, Vienna, 185-211.

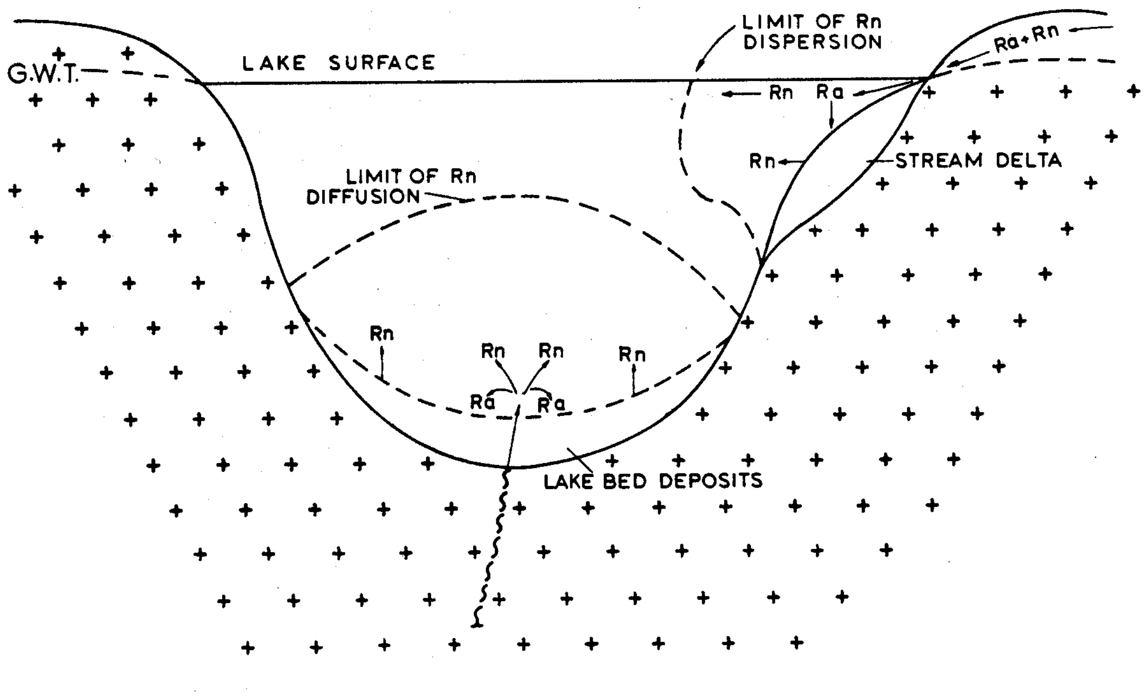

FIG. 6. Idealized lake water system.

After: Smith, A.Y., Barretto, P.M.C. and Pournis, S., 1976. Radon methods in uranium exploration. *In*: Proceedings of a Symposium on Exploration of Uranium Ore Deposits, IAEA & OECD/AEN, Vienna, 185-211.

In 1993, the dissolved CO_2 content of the -206 m water layer of lake Nyos, as measured at one point[4], was 322 mmole.kg^{-1}. If one assumes a low 15 Bq.l^{-1} in the soda water feeding the deep layers of lake Nyos, and a CO_2 content equal to the CO_2 concentration of the lake bottom water, the radon-222 will be analysed, after gas/water separation at the surface, as 15 Bq in 7 litres of carbon dioxide, *i.e.*, above 2000 Bq.m^{-3} of gas — a concentration easily accessible to measurement, even after dilution by radon-free water. The portable radon monitor chosen (PYLON AB-5), with a 270 ml Lucas cell, has a lower limit of detection of 11 Bq.m^{-3}, allowing integration times of the order of a few minutes. Deep water will be driven upwards through a 10 mm diameter pipe, according to the gas-lift method we designed for gas profile measurements[5].

The radon survey will be the first horizontal profile of lake Nyos physiography; indeed, all previous surveys focussed on vertical profiles, assuming a perfectly horizontal stratification. The radon survey will thus shed light on the recharge mechanism of lake Nyos, and on its double (heat and CO_2) diffusion regime, both vertically and horizontally. It will also clarify the potential for an intrinsic instability of the lake, the "eruption" of which being possibly triggered by a local saturation of its deep layers.

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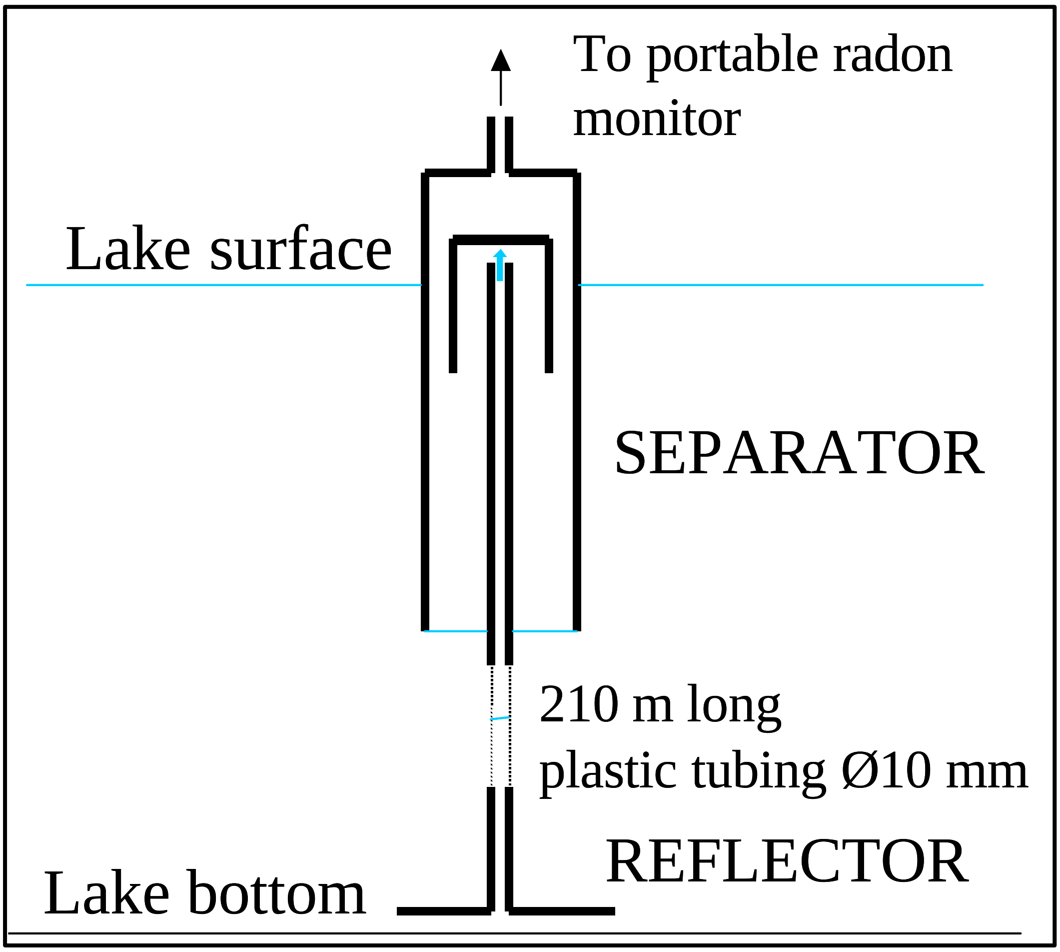
[4] Kusakabe, M., Tanyileke, G.Z., McCord, S.A. and Schladow, S.G., 2000. Recent pH and CO_2 profiles at lakes Nyos and Monoun, Cameroon: implications for the degassing strategy and its numerical simulation. *J. Volcanol. Geotherm. Res.*, 97: 241-260.

[5] Sabroux, J.C., 1993. A very simple method to diagnose hazardous gas content in crater lakes. World Organization of Volcano Observatories, *Newsletter*, 3:10-11.

It is of particular importance that this survey could be carried out before the onset of the degassing project : since water can move more freely along layers of constant density than it can across it, degassing pipes will tamper with the pristine horizontal distribution of carbon dioxide and heat. Knowing this distribution *ex ante* will allow to optimise the setting of the degassing pipes across the lake.



The separator uses the gas-lift method, as described elsewhere (see Footnote 5). Transition between one-phase and two-phase flow occurs at *ca.* 130 m deep in lake Nyos. The gas backpressure is adjusted by the depth at which the 1 meter long separator is plunged into the water. A *ca.* 3.5 $l.min^{-1}$ flow rate of water is expected with a 10 mm diameter plastic tubing: since the radon monitor needs typically no more than 1 $l.min^{-1}$ as airflow rate to operate, extra gas will be allowed to bubble at the bottom of the separator. Gas will be dried prior flowing through the Lucas cell of the radon monitor. Counting rate will be slightly lowered in pure carbon dioxide, as compared with nominal counting rate in air. The reflector will be used to locate precisely the pipe inlet by means of a depth sounder fitted with GPS and operated from the surveying boat.

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