# S12-O3

## TENORM in geothermal applications in Iceland

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### Abstract

Sulphide scales in geothermal applications in Iceland are rare and mostly confined to a geothermal area in the Reykjanes peninsula in SW-Iceland. This paper reports the existence of technically enhanced levels of naturally occurring radioactive material, TENORM, in hard sulphide scales from two wells in this area. This is the first time that TENORM above the exemption limit of 1 Bq/g has been discovered in Iceland.

### Introduction

An exemption/clearance limit for naturally occurring radionuclides in solid materials in secular equilibrium with their progeny is 1 Bq/g, according to Table A, part 2 of the EU Basic Safety Standard (EU BSS) [1]. This applies to the U-238 decay chain of radionuclides which includes Ra-226, Rn-222, Po-210 and Pb-210 as members.

This paper reports that hard sulphide scales in geothermal surface pipes in the Reykjanes peninsula contain TENORM from the U-238 chain, above this exemption limit. This was not expected since levels of natural radioactivity are very low in Iceland.

### Natural radioactivity in Iceland

A very low level of natural radioactivity in Iceland is confirmed by various studies, including a recent nationwide survey of indoor radon which reports Radon Rn-222 concentrations with a mean of 13 Bq/m$^3$ and a median of 9 Bq/m$^3$. These values are among the lowest in the world [2]. Ambient gamma, terrestrial and cosmic radiation in Iceland is also low, around 50 nSv/h, verified for instance by measurements from four continuously monitoring radiation meters in the south-western, south-eastern, north-western and north-eastern corners of Iceland, available at the web-site of IRSA. The total radiation exposure in Iceland from natural sources has been estimated to be in the region of only 1 mSv/year [3].

Iceland has no oil and gas industry or other industries that typically produce TENORM as a by-product. The country has a number of geothermal plants that have been observed to produce TENORM in other countries, such as USA, associated with geothermal applications, i.e. in scales in pipes close to wells (boreholes). In Iceland, however, there is generally very little scaling in geothermal pipes and TENORM has not previously been detected.

### Reykjanes geothermal field

The Reykjanes geothermal system is located at the tip of the Reykjanes peninsula, 50 km southwest of the capital Reykjavík (Figure 1). Thirty-four wells have been drilled in the area which is mainly composed of hyaloclastite rocks interbedded with lava flows of tholeiitic composition and pillow basalts at a greater depth [4], [5].

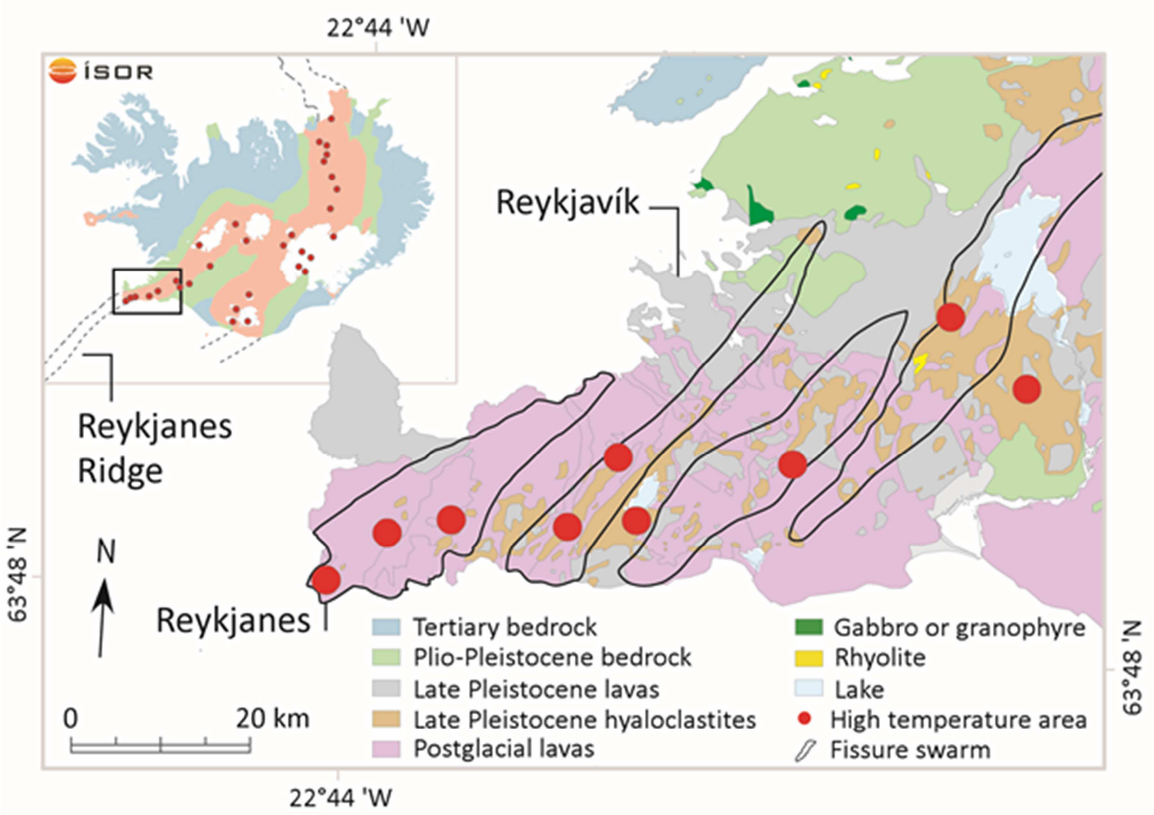


*Figure 1*. Geology map of Reykjanes Peninsula. Iceland is in the insert with the location of the Reykjanes Peninsula outlined. The high-temperature area, Reykjanes, is furthest to the west [6].

The Reykjanes reservoir fluid, with seawater salinity, has reacted with the basaltic host rock at elevated temperatures between 270-340°C. The concentrations of metals and trace elements in the reservoir fluid collected at 1350–1500 m depth are; Cu ~15 mg/kg, Zn 5-25 mg/kg, Fe 10-140 mg/kg, Mn ~2.5 mg/kg, Pb 100-300 µg/kg, Ag 30-100 µg/kg and Au 1-6 µg/kg [7]. The chemical properties of the reservoir fluid have long been studied for the purpose of producing salt and valuable minerals. Commercial attempts at doing that have however been unsuccessful while electrical power production has proved to be viable. The geothermal fluid has been utilized since 2006 by HS Orka in a 100 MW electricity power plant, Reykjanesvirkjun.

*Figure 2.* Scale precipitated in a pipe from well RN-22. The scale is formed in one year from 2006-2007. An orange has been placed for size comparison [6].

As the fluid ascends from a well it starts to boil due to pressure decrease resulting in precipitations of mainly sphalerite ((Zn,Fe)S) up the well from about -1200 m depth. At surface downstream of an orifice plate, a sudden decrease in pressure from ~37 bar to 22 bar causes rapid boiling (flashing) which results in abundant precipitation of sulphides as shown in Figure 2. In order to better understand the build-up of scales and the resulting decrease in fluid-flow in the surface pipeline, a detailed geochemical and mineralogy study has been done on the scales by Hardardottir [6], and her co-workers [8]. The scales are primarily composed of sphalerite, with some chalcopyrite ($CuFeS_2$), small amounts of galena (PbS) and traces of other sulphides (mainly Cu-sulphides like bornite ($Cu_5FeS_4$) and digenite ($Cu_9S_5$) [6].

## TENORM in scales

The scales emit beta radiation which can be detected with hand held meters. Some alpha radiation can also be detected. Only very weak gamma radiation is present but it does however enable identification of Pb-210 and Po-210 nuclides through gamma-spectrometry in a laboratory as can be seen in Figure 3.

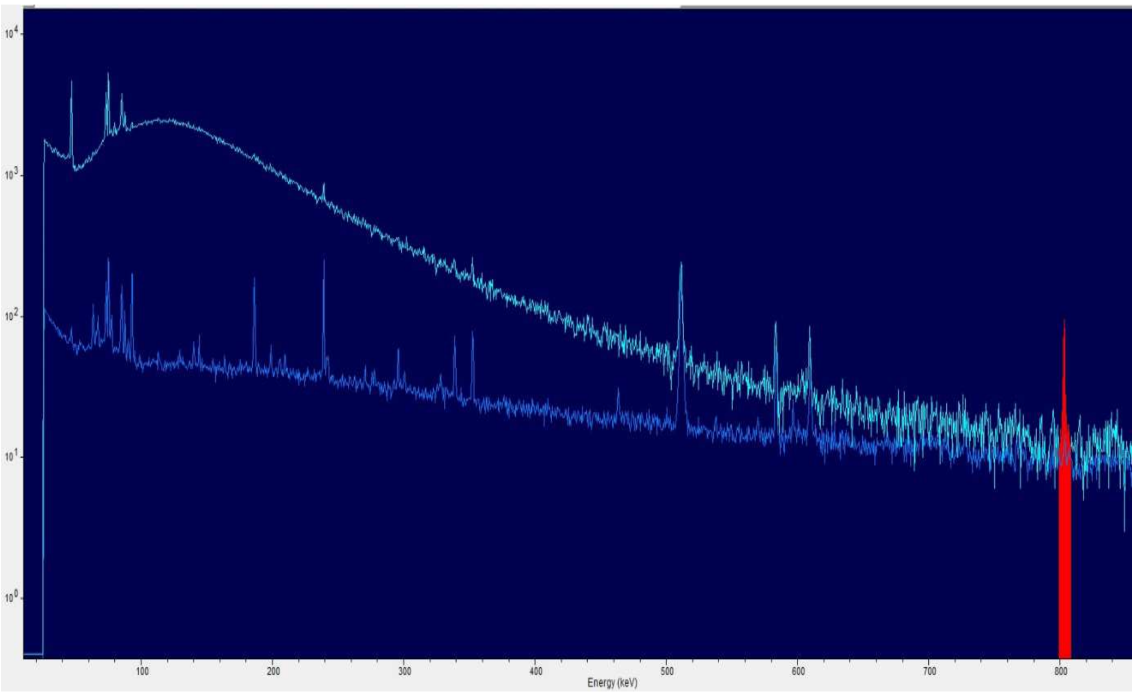


*Figure 3*. A gamma-spectrum emitted by the scaling. A peak for Po-210 is highlighted in red. A low voltage peak at 47 keV due to Pb-210 is also visible. A background spectrum without these peaks is shown for comparison.

Analyses of gamma-spectra as in Figure 3 show the presence of nuclides from the natural U-238 chain (Figure 4).

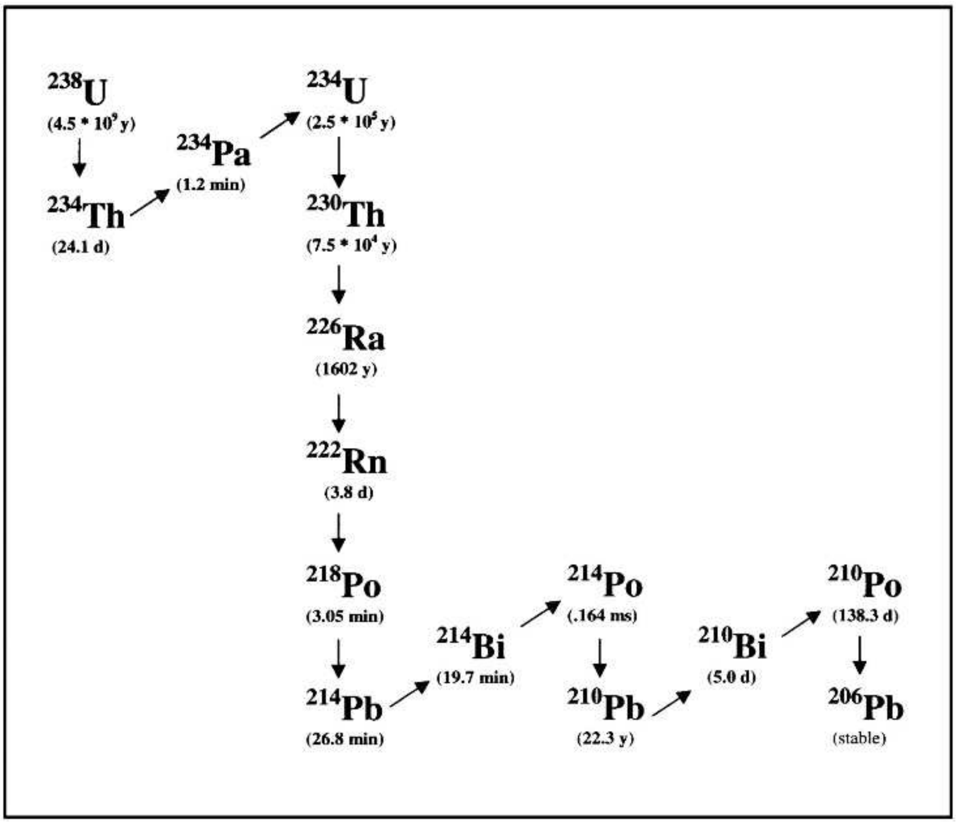


*Figure 4.* The U-238 decay chain. The radionuclides Pb-210 and Po-210 originate from radium (through radon). The half-life of each nuclide is in parentheses.

Samples from scales originating in surface pipes from two wells (boreholes) were obtained in June 2015 for accredited analysis at STUK Environmental Radiation

Surveillance and Emergency Preparedness, an accredited testing laboratory. A report was prepared, dated 31st July (see Appendix). These wells are currently the most productive wells of the power plant Reykjanesvirkjun in terms of electricity and in amount of scaling. The analysis showed the following results for these samples:

*Table 1*: Activity in scales from two wells when measured on 14$^{th}$ and 15$^{th}$ July 2015. The uncertainty of results (2 sigma) indicates that the results are, with a 95% confidence interval, within the given limit values.

| Radio-nuclide | Well RN-12 Bq/g | Well RN-11 Bq/g |
|---|---|---|
| Ra-226 | < 0.002 | < 0.002 |
| Pb-210 | 33.7 ± 4.1 | 51.5 ± 9.3 |
| Po-210 | 123.0 ± 20.0 | 214.0 ± 30.0 |

## Discussion

The existence of TENORM in Iceland has now been confirmed for the first time. The volume of geothermal scales produced each year through cleaning of the geothermal pipes is estimated by the operator in 2015 to be a few metric tons and less than one cubic meter. In 2007, it was estimated to be 4 tons [6]. Values for comparison from geothermal plants in other countries are few in number and therefore this paper presents the following information on the more common oil and gas facilities. A report from IAEA on radiation protection and management of TENORM in the oil and gas industry [9] states that a "production facility may generate quantities of scales and sludge ranging from less than 1 t/a to more than 10 t/a, depending on its size" (page 69). In the IAEA report (page 56) the following table is presented (see Table 2):

Table 2: Concentrations of naturally occurring radioactive material in oil, gas and by-products. This table is given in reference [9] as Table no. III.

| Radio-nuclide | Crude oil Bq/g | Natural gas Bq/m$^3$ | Produced water Bq/L | Hard scale Bq/g | Sludge Bq/g |
|---|---|---|---|---|---|
| U-238 | 0.000 000 1–0.01 | | 0.0003–0.1 | 0.001–0.5 | 0.005–0.01 |
| Ra-226 | 0.0001–0.04 | | 0.002–1200 | 0.1–15 000 | 0.05–800 |
| Po-210 | 0–0.01 | 0.002–0.08 | | 0.02–1.5 | 0.004–160 |
| Pb-210 | | 0.005–0.02 | 0.05–190 | 0.02–75 | 0.1–1300 |
| Rn-222 | | 5–200 000 | | | |
| Th-232 | 0.000 03–0.002 | | 0.0003–0.001 | 0.001–0.002 | 0.002–0.01 |
| Ra-228 | | | 0.3–180 | 0.05–2800 | 0.5–50 |
| Ra-224 | | | 0.5–40 | | |

The values for the Reykjanes scales seem to be higher than those in the oil and gas industry with regard to the activity of Po-210. These atypical values and the absence of Ra-226 make the processes that made these scales very interesting from a scientific point of view.

NORM and TENORM is included in the Icelandic Act on Radiation Protection and any potential radiation protection issues associated with TENORM in geothermal applications will be addressed as needed by the Icelandic Radiation Safety Authority.

The author expresses his gratitude to the recently deceased Seppo Klemola at STUK who first provided him with an estimate of a Po-210 activity above 10 Bq/g in a scaling sample from Reykjanes. This paper is dedicated to his memory.

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