

MEMO

Title	Skejby NORM Measurements and Monitoring Plan
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This memo documents the NORM measurements that have and will be made across the Skejby geothermal system. NORM is the term used for Naturally Occurring Radioactive Material in minerals. So far for the Skejby geothermal system, NORM contamination is not observed on the hardware in the wells and geothermal plant.

NORM is precautionary measured in most geothermal developments as NORM contamination is a risk and often a slow process over years, which can negatively surprise if not monitored and pro-actively addressed. The root-cause for NORM contamination is linked to accumulation of minerals from the subsurface geology and fluids in form of scale. The minerals that could cause NORM contamination in the Skejby geothermal system are precipitation of lead (^{210}Pb) and Barium Sulphate scale with Strontium. NORM contamination from lead scale in the Skejby geothermal system is unlikely due to the low lead concentration in the Gassum formation water. Based on OLI scale software modelling, there is a low-to-medium risk of Barium Sulphate accumulating in the 1 μm filters. The 1 μm filters are monitored in SCADA and replaced and disposed frequently.

Innargi has a NORM Monitoring Plan, which ensures that NORM is measured whenever the geothermal loop is opened or well interventions are performed. Preventive cleaning or replacement takes place if NORM development is observed.

Background

Issues related to NORM is regulated by Sundhedsstyrelsen Strålebeskyttelse (SIS). SIS is the authority on all issues related to NORM and to radiation protection of people and the environment. Handling, storage and disposal of NORM contaminated waste requires approval by / information to Sundhedsstyrelsen.

Radioactive radiation is measured in Becquerel (Bq). Radioactive radiation is a measure of the number of nuclear transformations per second in a specific material (1 Bq = 1 nuclear disintegration/sec.) and an indirect measure of the radiation intensity. Derivative measures are:

- Specific activity: Bq/gram.
- Surface activity: Bq/cm².

Radiation activity is measured as CPS (Counts Per Second), which is converted to Bq/cm², see table below.

CPS	Bq/cm ²	CPS	Bq/cm ²	CPS	Bq/Cm ²	CPS	Bq/Cm ²
1	0.11	11	1.21	21	2.31	35	3.85
2	0.22	12	1.32	22	2.42	40	4.40
3	0.33	13	1.43	23	2.53	45	4.95
4	0.44	14	1.54	24	2.64	50	5.50
5	0.55	15	1.65	25	2.75	55	6.05
6	0.66	16	1.76	26	2.86	60	6.60
7	0.77	17	1.87	27	2.97	65	7.15
8	0.88	18	1.98	28	3.08	70	7.70
9	0.99	19	2.09	29	3.19	75	8.25
10	1.10	20	2.20	30	3.30	80	8.80

Radioactive dose rate is measured in Sievert, 1 Sv = 1 joule/kg. Radioactive dose rate is a measure of the absorbed radioactive radiation's influence on the human organism. Radioactive dose rate velocity is measured in $\mu\text{Sv}/\text{hour}$.

Materials and hardware are NORM contaminated if:

- Radioactive radiation $>2.7 \text{ Bq}/\text{cm}^2$
- Radioactive dose rate velocity $>2.5 \mu\text{Sv}/\text{hour}$

Legislation provides the limits of the maximum yearly radioactive dose rate velocity. The maximum limit for employees is 20 mSv/year. The Danish population is on average exposed to 3 mSv/year varying by 2 - 15 mSv/year from natural radiation sources.

At the Skejby site, Innargi has measured the background radioactive radiation at 0.68 CPS and radioactive dose rate velocity at 0.09 $\mu\text{Sv}/\text{hour}$, which translates to 0.08 Bq/cm² and 0.78 mSv/yr, respectively.

People can be exposed to NORM through external and internal sources. External radiation risk from process equipment is generally not a concern under normal operational circumstances for a closed-circuit system. Internal radiation exposure is possible when opening the geothermal circuit or retrieving downhole equipment from the wells.

NORM Measurements Made at Skejby Geothermal Plant and Wells

The natural occurring radiation from the Gassum geological formation and geothermal water are at background level and harmless to humans i.e. inline with ref. 1. Measurements were made during drilling operations, well testing and core evaluation.

The Gassum water composition is listed in Appendix 1. The lead content is low and according to ref. 2, formation of lead scale is unlikely over the operating life cycle for the geothermal system in Skejby. Formation of lead scale (being a galvanic process) is also improbable as the flow wetted materials in the wells and geothermal circuit are S13Cr, Glass Fiber Reinforced Epoxy (GRE), SS316 and titanium.

The Barium, Strontium and Sulphate concentrations are low, yet, with high flow rates and years of operations, BaSO₄ scale with Strontium will form slowly in the process. A 3rd party scale study using OLI software has concluded that BaSO₄ will drop out in the 1 μm filters. Formation of BaSO₄ scale is

initiated as the temperature of the geothermal water is lowered in the heat exchangers. BaSO₄ scale will not form in the heaters due to long induction time. BaSO₄ scale cannot be dissolved with chemicals (only very slow reacting solutions exist). BaSO₄ scale can only be removed mechanically, or the affected hardware is replaced 1-to-1.

NORM measurements have been made for all activities at the Skejby geothermal system, which are:

- Well Aarhus-01. Rig based well test with ESP, April 2024. Performed measurements on ESP before installation and after retrieval, there was no change in NORM, which was at background level. Reported in daily rig operations reports and submitted to DEA (Danish Energy Authorities).
- Well Aarhus-03. Stand-alone well test with coiled tubing nitrogen lift, September 2024. Performed measurements on the coiled tubing bottom hole assembly before and after the well test. Both measurements were equal to NORM background level.
- Well Aarhus-01. ESP installation, June 2025. Performed measurement on retrieved tubulars. NORM measurements were equal to background level.
- Well Aarhus-01. ESP performance test, 26th June 2025. Performed measurement on geothermal water sample. NORM measurement was equal to background level.
- Flushing geothermal circuit, 6th August 2025. NORM measurement was equal to background level.
- Commissioning of Skejby geothermal circuit from August and still ongoing. NORM measurements were made on replaced 5 µm filters on the 11th September 2025 and 8th October 2025 and equal to background level.

No harmful NORM levels have been measured in any of the above activities.

Monitoring Plan: Safeguards to Avoid Development of NORM Contamination

The instituted safeguards against developing NORM contamination in the Skejby geothermal system are:

1. Low insitu concentration of Lead, Barium, Strontium and Sulphate in the Gassum formation water at the Skejby location.
2. The wells and geothermal circuit will be operated above bubble point at all times. The water chemistry is thereby not altered and scale formation is unlikely.
3. Monitor daily for increases in pressure drop across the hydro-cyclones, 5 µm filter, preheaters, intermediate heaters and 1 µm filters with dp alarms implemented in SCADA.
4. Measure for NORM when opening the geothermal circuit and performing well interventions. The measurements are logged in Innargi's NORM register. See figure 1 for the apparatus that Innargi uses.
5. If upwards trending NORM or above back-ground level measurements are recorded, then:
 - A sample of 5 grams of the deposit is taken. The sample shall have a transport label marked with: Date, Place of sampling and Address. The sample is sent to 3rd party laboratory for detailed analysis.
 - The hardware / equipment is taken out of service immediately and is cleaned or replaced with a new 1-to-1.
 - All NORM contaminated equipment, material and waste will be handled in compliance with Danish NORM legislation. The criteria for NORM waste disposal is:

Activity	Disposal
< 0.5 Bq/gram	Disposed as normal oil waste.
> 0.5 Bq/gram	Disposed at 3 rd party designated NORM waste disposal site.



Figure 1: NORM monitors used by Innargi at Skejby site.

References

1. Source and occurrence of radionuclides in geothermal water. GEUS. 2018/41.
2. Lead deposition in geothermal installations. TNO. 2014. R11416.

Appendix 1 – Gassum Formation Water Composition

Two downhole water samples from Aarhus Gassum formation have been obtained and analysed.

Parameter	Unit	Result
Anions (CFA)		
Chloride as Cl (EN-ISO 15682)	mg/l	140,000
Anions (Conform ISO 15923-1)		
Sulfate as SO ₄	mg/l	110
Acidity/Alkalinity [Conform WAC/III/A/006]		
Alkalinity up to pH 4.5	mmol/l	2.2
Alkalinity up to pH 8.3	mmol/l	<0.050
Bicarbonate as HCO ₃	mg/l	140
Carbonate as CO ₃	mg/l	<1.5
Hydroxyl content as OH ⁻	mg/l	<0.85
Dry Residue (Conform WAC/III/A/001)		
Dry residue	mg/l	220,000
Hardness [Calculated] (A)		
Hardness	mg CaCO ₃ /l	23,196
Metals [Conform NEN 6961/NEN 6966/C1 (EN-ISO 11885)] (A)		
Barium	µg/l	11,000
Cadmium	µg/l	4.5
Calcium	µg/l	7,600,000
Chrome	µg/l	50
Copper	µg/l	240
Iron	µg/l	62,000
Lead	µg/l	110
Magnesium	µg/l	1,000,000
Nickel	µg/l	650
Potassium	µg/l	460,000
Natrium	µg/l	71,000,000
Strontium	µg/l	390,000
Zink	µg/l	410
Density [Gravimetric]		
Density	kg/l	1.15
pH [Conform ISO 10523]		
pH at 20°C	-	5.5