



**GeothermiX
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Monitoring protocol to assess the impact of natural radionuclides in geothermal energy production plants

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Introduction

Geothermal energy production was recently included among the industrial sectors involving NORM (Normally-Occurring Radioactive Materials) and leading **to exposure of workers or members of the public** which cannot be disregarded from a radiation protection point of view (art. 23 Directive 2013/59/EURATOM (EU-BSS) and art. 20 D.Lgs. 101/2020).

In the framework of a research project supported by INAIL - National Institute for Insurance against Accidents at Work (**INAIL BRIC ID30 2019**) a **radiological characterisation protocol** of high enthalpy geothermal energy production plants in Tuscany has been developed.

The **protocol** aimed at identifying **matrices** and **exposure scenarios of radiological concern**.



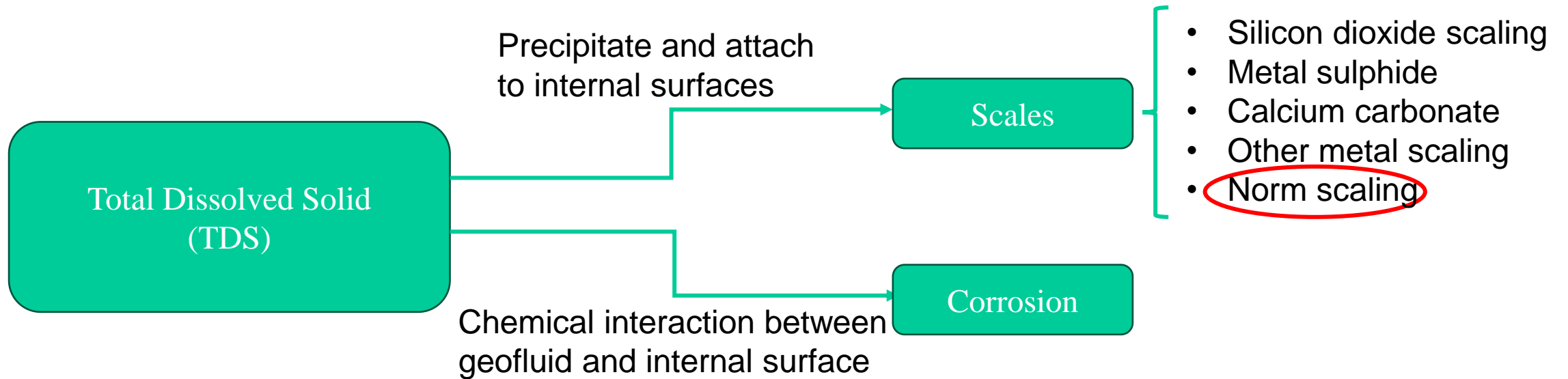
NOR materials in geothermal energy production

The use of superheated steam or saturated steam with a water content from deep wells can produce **scales deposits** and other **residues** in the plant **enriched in natural radionuclides** coming from rocks of the Earth's crust (mainly radionuclides from radioactive decay chains of U-238 and Th-232).

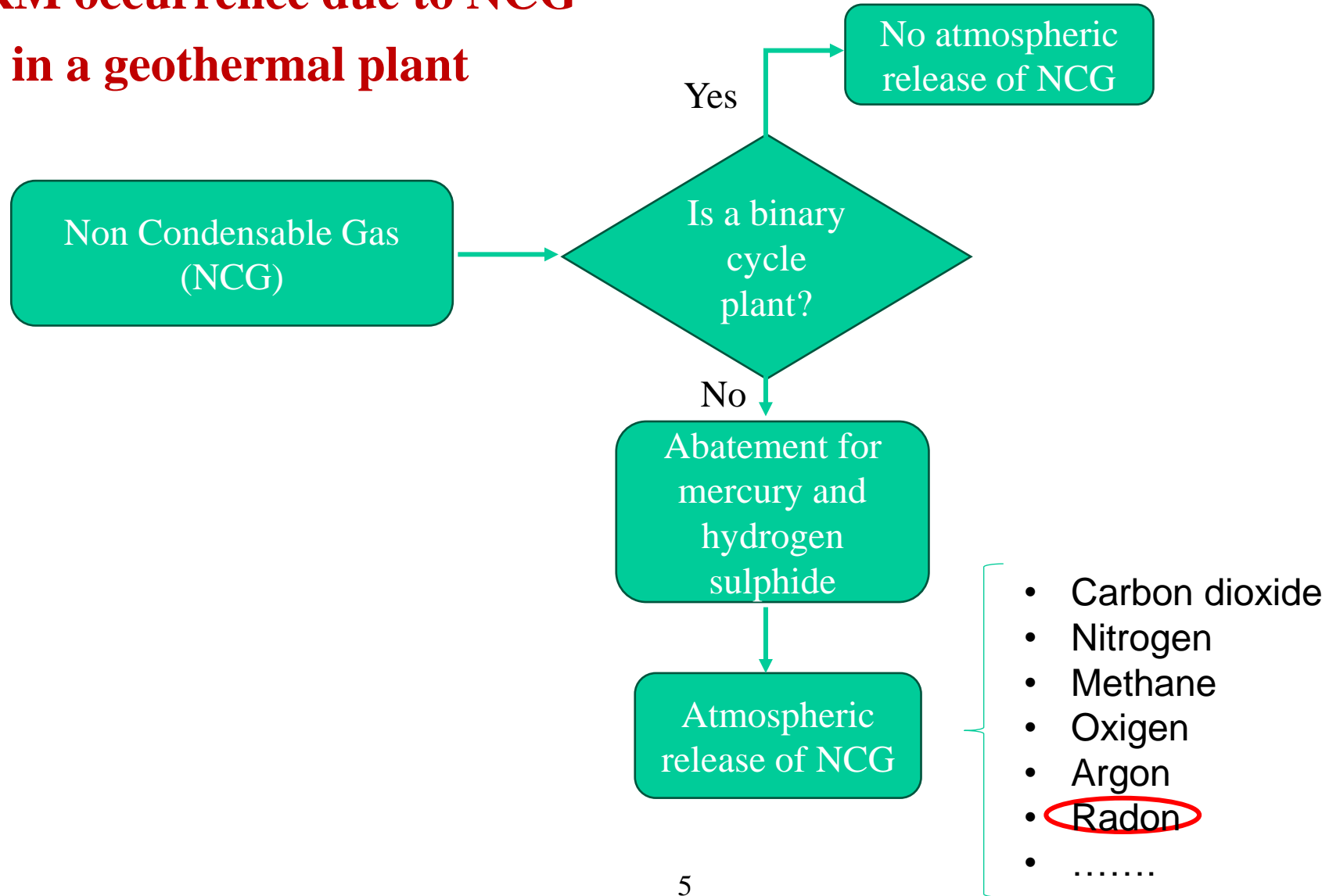
Total Dissolved Solids (TDS) and **Noncondensable Gases (NCG)** in geothermal fluid can potentially be **a source of NOR materials**.

Isotopes of radium (Ra-224, Ra-226 and Ra-228) and **lead** (Pb-210) are also present as TDS due to the leaching of primordial radionuclides (U-238 and Th-232) from the reservoir rock.

NORM occurrence due to TDS in a geothermal plant

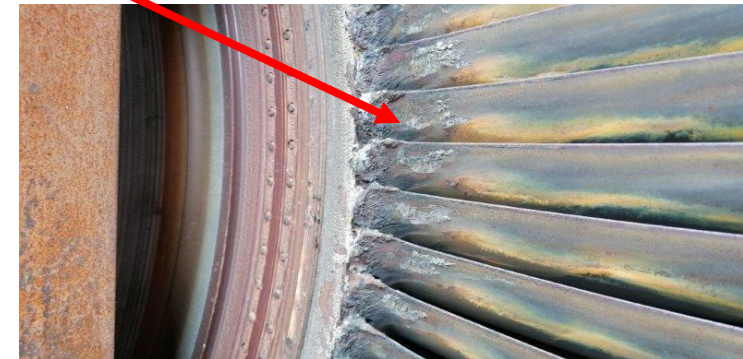


NORM occurrence due to NCG in a geothermal plant



Residues: SCALES

As the fluid rises from the well, the physical and chemical properties can change and lead to deposition of scales on the internal surfaces of production equipment (e.g. steam turbines, heat exchangers, valves, fluid handling equipment, etc.)



In vapour-dominated geothermal plants, water content in fluid is very low (a few percent at maximum). Consequently, the scaling processes are frequently poor.

Residues: **SLUDGE**

Sludge comes out from the counter flow cooling of the vapour phase and NCGs emission. Depending on the type of plant, the water content in sludge can be very different



Sludge is collected in the tank at the bottom of the wet cooling tower

Gaseous effluents

In direct cycle plants, **radon** is discharged in the atmosphere through the stacks of the cooling towers



Residues: adsorbent and filtering materials are employed in AMIS to trap mercury and hydrogen sulphide from gas

Sandblasting residues

During maintenance, parts of the geothermal plants can be disassembled and sandblasted. Sands of different grain sizes are used for the sandblasting.

Exhausted sand can be regenerated and employed more than once.

Exhausted sand and **dust** from the ventilation system's abatement filter of the sandblasting cabin are contaminated by radionuclides originating from the scales deposits.



The Italian transposition of Directive 2013/59/EURATOM: Leg.Decree 101/2020

The Decree 101/2020 requires the radiological characterisation of **all solid materials** involved in the practices, **including residues (art. 22)**.

PHASE 1: practices may be exempted from notification directly, on the basis of **compliance with exemption levels**, defined in terms of activity concentration

Radionuclides	Exemption levels (kBq/kg)	Clearance levels (*) (kBq/kg)
U-238 chain (Ra-226)	1	0,5
Po-210, Pb-210	5	2,5
Th-232 chain (Ra-228)	1	0,5
K-40	10	5

(*) levels for disposal in conventional landfills

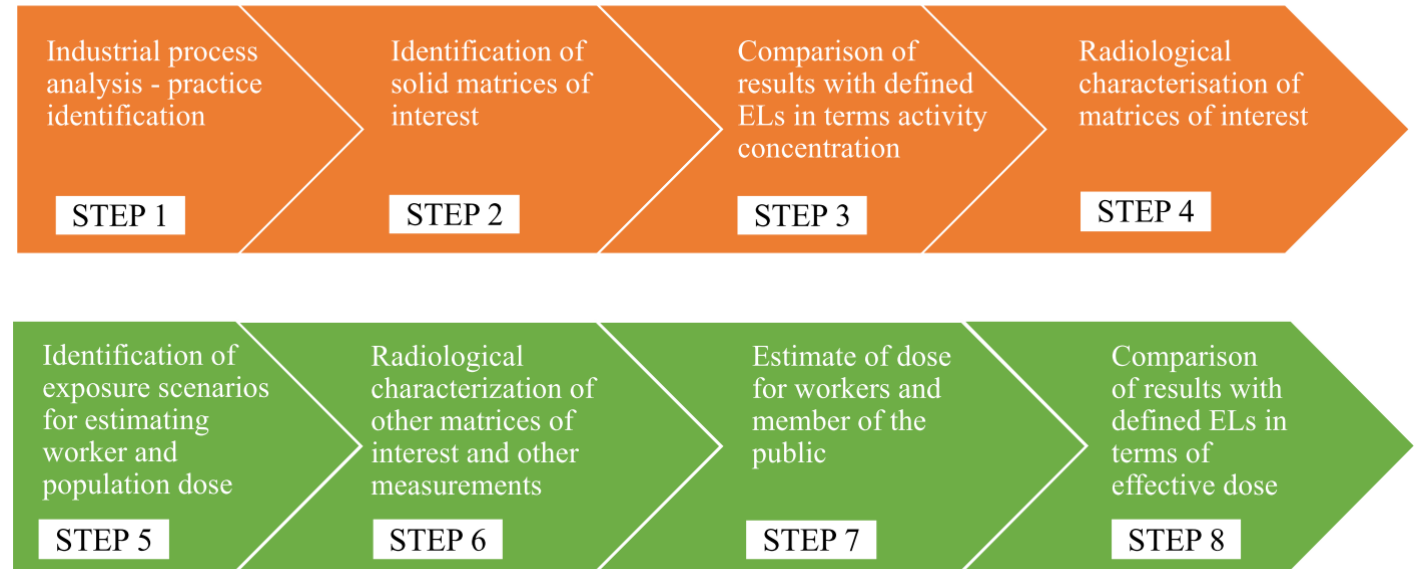
Italian legislation: Leg.Decree 101/2020

PHASE 2: if activity concentration in solid materials exceeds ELs, the procedure requires **dose assessment** for **workers and population** to demonstrate the respect of the limit of the effective dose of:

- 1 mSv/y for workers
- 0,3 mSv/y for a member of the public

The aim is to identify the most **critical exposure scenarios** and verify the **compliance of exposure levels** for workers and members of the public to the relevant ELs.

The graded methodology for the monitoring protocol



The monitoring protocol for geothermal energy production plants

**Phase 1: Radiological characterisation of
the solid matrices of interest**

**Phase 2: Identification of exposure scenarios
to estimate worker and population dose**

Phase 1: Radiological characterisation of the solid matrices of interest

Type of materials	Materials to be sampled	Description of the samples	Most critical radionuclides
Residues	Scales deposits	Scales from tubes, vessels, turbines, etc.	Ra-226+, Ra-228+, Pb-210 and Po-210
	Sludge	Sludge of the collection tank of the cooling tower	Ra-226+, Ra-228+
	Exhausted adsorbent and filtering material	Sorbent and catalyst	Ra-226+, Ra-228+, Pb-210 and Po-210
	Other exhausted materials	Sandblasting sand, Dust from ventilation of the sandblasting cabin	Ra-226+, Ra-228+, Pb-210

- Ra-226+, Ra-228+ are chain segments in which the Ra isotopes are in secular equilibrium with shorter-lived daughter nuclides
- Ra-226+, Ra-228+ and Pb-210 are measured by gamma spectrometry
- Po-210 is measured by alpha spectrometry

Phase 2: Identification of exposure scenarios to estimate worker dose

Exposure scenarios	Exposure scenarios defined in RP docs(*)	Types of matrices	Materials	Exposure pathways
from removing residues	Removal of scales RP 107	Residues	Scales, sludge	Ex, In, Ig, Rn
from process vessels and pipes	RP 107	Raw material Residues	Geothermal fluid Scales	Ex
to stockpiles of materials	RP 122 part II	Residues	Scales Sludge Filtering materials	Ex, In, Ig, Rn
transport of materials (loading/unloading)	RP 122 part II	Residues	Scales Sludge Filtering materials Sandblasting Sands and Dust	Ex, In, Ig

Ex=external exposure, In=inhalation, Ig=ingestion, Rn=radon

(*) RP docs=Radiation Protection documents

Phase 2: Identification of exposure scenarios to estimate population dose

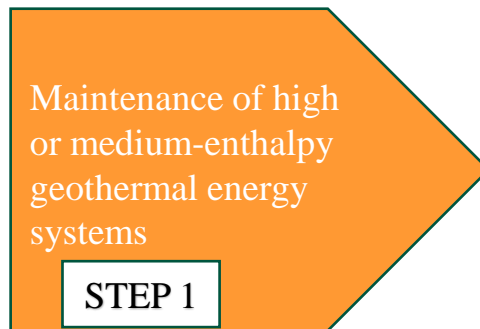
Exposure scenarios	Exposure scenarios defined in RP docs(*)	Types of matrices	Materials	Exposure pathways
radon discharge	Not defined	Effluents	Geothermal fluid	Rn
reuse or landfilling of residues	Landfill RP 122 part II	Residues	Scales Sludge Filtering materials Sandblasting Sands and Dust	Ex, In, Ig

Ex=external exposure, In=inhalation, Ig=ingestion, Rn=radon

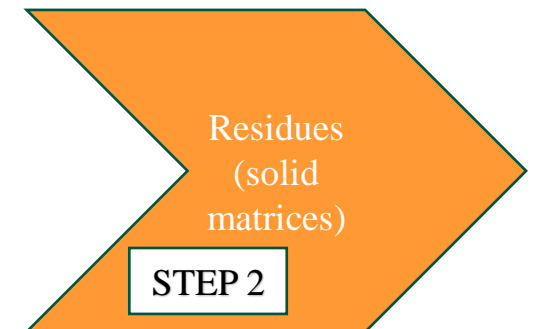
(*) RP docs=Radiation Protection documents

Application of the graded methodology to geothermal energy production plants in Tuscany

Step 1: the Decree 101/2020 specifies as critical exposure situation the
Maintenance of high or medium-enthalpy geothermal energy systems



Step 2: the Decree 101/2020 requires the characterisation of
only **solid matrices** to verify the compliance with ELs in terms
of activity concentrations.
Since the raw material is the geothermal fluid, **only residues**
are to be characterised



Application of the graded methodology to geothermal energy production plants in Tuscany

Step 3:
Radiological characterisation of residues



Two labs are involved:

ARPAT and L. B. Servizi S.r.l., commissioned by ENEL

Both laboratories are accredited to **UNI EN ISO 17025**

During **maintenance** from **5 to 20 samples** for **each plant** (depending on scales depositing) were collected.

About **50 samples** from **4 different plants**, representing the two areas Larderello and Mount Amiata, were analysed by both laboratories **in 2021**.

The results of the two laboratories **matched within the uncertainty**

Application of the graded methodology to geothermal energy production plants in Tuscany

IN MAINTENANCE RESIDUES: scales, sludges, filtering and sandblasting materials

Maximum values of activity concentration does not exceed the concentration ELs

STEP 4

Plants		Number of samples	U-238 chain (Bq/kg)	Pb-210 (Bq/kg)	Po-210 (Bq/kg)	Th-232 chain (Bq/kg)	K-40 (Bq/kg)
Larderello Area	ARPAT	17	1 – 50	10 - 1900	-	1 – 42	10 – 390
	ENEL GP	49	3 – 60	63 – 590	9 - 2070	3 – 47	23 – 640
Amiata Area	ARPAT	11	1 – 24	5 – 134	-	1 – 26	5 – 450
	ENEL GP	11	1 – 25	80	315	8 – 27	30 – 410
Sandblasting plant	ARPAT	12	20 – 360	-	-	20 – 370	30 – 370
	ENEL GP	2	58 – 270	3 – 98	24 – 225	80 – 290	1 – 47

The graded methodology for the monitoring protocol in geothermal energy in Tuscany



According to the graded approach, on the basis of the first data collected, no further investigation regarding dose assessment for workers and population should be required

However, measurements are **still in progress** while the maintenance programme of all geothermal plants is being completed



Following a precautionary approach, **dose assessment for workers and population** has been carried on by Enel GP Radioprotection Expert

Conclusions

The **graded methodological approach** developed to manage legislative requirements for NORM involving industries was fitted to the geothermal industrial sector, which is in the indicative list of NORM involving industrial sectors in the EU-BSS.

The most critical matrices and exposure scenarios from the radiological point of view have been identified by means a **radiological characterisation protocol** of geothermal energy production plants.

About **50 samples of residues** from different geothermal plants in both areas in Tuscany (Larderello and Mount Amiata) were collected during the programme of plants maintenance in **2021**.

As far as results so far are concerned, **data** from residues measurements **comply with the activity concentration exemption levels** set in the Decree 101/2020, the Italian transposition of Directive 2013/59/EURATOM.

Conclusions

The radiological characterisation program is still going on with a **systematic application to in maintenance plants.**

The radioactivity content of materials and residues can vary, also accounting for the geothermal fluid and other working parameters of each plant (e.g. the nature and the quantity of the tower sludge depend on the working parameters of the plant)

Therefore, following a precautionary approach, **dose assessment for workers and population** has been carried on by Enel GP Radioprotection Expert

This work has been developed in the framework of a research project supported by the National Institute for Insurance against Accidents at Work (INAIL): *Protocols and computational methods to support stakeholders of NORM-related industrial sectors in Italy.*



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Thank you for your attention

