AUTORIDAD REGULATORIA NUCLEAR

Norm survey in Argentina

Analia Canoba

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Autoridad Regulatoria Nuclear
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CONTENTS

- ✓ Some non nuclear industries concentrate in its processes natural radionuclides, that are present with other minerals.

- ✓ By-products, products, effluents flows and wastes from processes may enhance the exposure to workers and members of the public.

ARN carried out a project whose objective was the characterization and evaluation of NORM, in oil and gas industry, underground mine, tourist cavern and spas.

Oil and gas industry

- NORM are typically located in subsurface formations created in the Jurassic period.

- The techniques used in forcing the oil to the surface includes recirculation of produced water, which is extracted with the final products.

  - NORM are transported to the surface with this water.

  - Pressure and temperature decrease results in the sulfate and carbonate precipitation in pipelines and internal surfaces of the equipments.

- Similar chemical behavior between radium and barium → co-precipitating of both elements.

- It can also be found other products of the uranium and thorium decay chains.

- NORM: present in scales, in vessels with drained water or in sludges.

- Other radionuclides of interest (gas industry)
  - radon gas
  - ^{210}Pb: usually forms a thin cap in the internal surface of processing equipments

NORM IN OIL AND GAS PRODUCTION (IAEA Safety Report Series 34)

Type	Radionuclide	Characteristics	Occurrence
Ra scales	**^{226}Ra, ^{228}Ra, ^{224}Ra and progeny**	**Hard deposits of Ca, Sr, Ba carbonates and sulphates**	**Production installations**
Ra sludge	**^{226}Ra, ^{228}Ra, ^{224}Ra and progeny**	**Sand, clay, paraffin**	**Separators, skimmer tanks**
Pb deposits	**^{210}Pb and its progeny**	**Stable lead deposits**	**Gas production installations**
Pb films	**^{210}Pb and its progeny**	**Thin films**	**Oil and gas treatment and transport**
Po films	**^{210}Po**	**Thin films**	**Condensate treatment facilities**
Natural gas	**^{222}Rn, ^{210}Pb and ^{210}Po**	**Noble gas. Plated on surfaces**	**Gas treatment and transport systems**
Produced water	**^{226}Ra, ^{228}Ra, ^{224}Ra and ^{210}Pb**	**Large volumes in oil production**	**Each production facility**

•From the occupational point of view, the main aspects of radiological protection related with scales and sludges:

- External exposure by gamma irradiation (Ra-226, Bi-214, Tl-208)

- Internal contamination during maintenance and cleaning of equipments containing NORM
  - Radon gas inhalation
  - Aerosol inhalation
  - Ingestion
  - Skin

Underground mines and caverns

Radon gas may concentrate up to high levels. The exposure of workers by inhalation of ^{222}Rn may be significant.

Geothermal waters

- Waters with close contact with soil and rocks
- High mineral content as solubility increases with temperature.
- Radon can easily diffuse into the atmosphere
    - Sources of exposure: radon inhalation, exposure to ambient gamma-radiation and ingestion of thermal water

Installations surveyed

- ✓ 4 oil facilities and 3 gas facilities
- ✓ 1 underground mine
- ✓ 1 tourist cavern
- ✓ 10 thermal spas

Activities developed

- ✓ Selection of sampling points.
- ✓ Measurements both in normal and maintenance status.
- ✓ Background measurements.
- ✓ Dose rate measurements “on site”.
- ✓ Radon gas and progeny measurements.
- ✓ Sampling and analyses in ARN laboratories.
- ✓ Analysis of the worker exposure scenarios.
- ✓ Dose assessment and evaluation.
- ✓ Report of each survey.

- INTRODUCTION
- **INSTALLATION DESCRIPTIONS**
- MEASUREMENTS
- DISCUSSION
- CONCLUSIONS AND RECOMMENDATIONS

Installation descriptions

Oil facilities

Installation A

- Provides pumping systems for oil and gas extraction.
- Performs the assembling of equipments with new or recovered pieces.
  - equipments for recycling arrive to the Discharging sector.
  - from Discharging go to the Disassembling sector, where the components are washed, recovered and restored.
  - rejected components return to the Discharging sector to wait for a final destination:
    - to become a residue
    - to be sold as scrap.

Installation B, C y D

- Performs cleaning, maintenance and inspection of tubing.
- Tubes are classified and stored before the washing process begins.
- Washing process:
  - mix of water and gasoline at 90°C, 10 to 15 minutes.
  - internal and external manual washing with pressured water.
  - the water is collected in vessels.
  - some facilities: mechanic equipment to remove scales.
  - solid wastes:
    - collected in containers both ends of pipes.
    - then wastes are carried to a big container:
      - ✓transitory storage.
      - ✓ finally removed by companies owner of piping.

Gas installations

Installation E

- Separates and fractions the heavy components of natural gas (ethane, propane, butane and gasoline).

Installation F and G

- These facilities

produce ethylene and polyethylene.

- Facility F is working since

1981 and facility G since 2001.

Underground mine

- ✓ Extraction of gold and silver.
- ✓ The installation was in the exploitation step.

Tourist cavern

- ✓ 1343 meters; sedimentation environments developed during Jurassic and Cretaceous periods.
- ✓ Wide calcite deposits, mainly of stalagmites and stalactites.
- ✓ 3 levels of main corridors. The third corridor is 20 m below the first one.

Thermal spas

- ✓ 10 thermal spas evaluated. One of volcanic origin.
- ✓ 9 spas: water coming from groundwater reservoirs.

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MEASUREMENTS

- ✓ Relevant industry sectors were identified in each case.
- ✓ The first priority was to focus on the type of operations identified from current knowledge and experience as being the most likely to require attention.
- ✓ In situ measurements, sampling and analyses were conducted to determine activity concentrations and radon gas measurements.

Measurements

Oil and gas installations

In situ measurements

- ✓ Dose rate measurements were carried out in previously agreed areas.
- ✓ Background measurements in the surroundings.
- ✓ Installations: dose rate measurements performed in points selected due to origin, function and also visual inspection. Detailed measurements performed in points above background.
- ✓ Some pieces were also evaluated in its internal surface.

Table 1: Dose rate measurements in contact at installations A, E, F and G.

Facility	Background measurement ($\mu Sv \cdot h^{-1}$)	Dose rate values ($\mu Sv \cdot h^{-1}$)	Number of points
A	0.20 ± 0.02	Background level	9
		< 2 $\mu Sv \cdot h^{-1}$	5
		2 - 10 $\mu Sv \cdot h^{-1}$	9
		10 - 20 $\mu Sv \cdot h^{-1}$	2
		> 20 (28.2 and 30 $\mu Sv \cdot h^{-1}$)	2
E	0.10 ± 0.02	Background level	7
		< 1 $\mu Sv \cdot h^{-1}$	6
F	0.15 ± 0.04	Background level	9
		< 2 $\mu Sv \cdot h^{-1}$	11
		2 - 10 $\mu Sv \cdot h^{-1}$	5
		> 10 $\mu Sv \cdot h^{-1}$ [a]	5
G	0.12 ± 0.03	Background level	19
		< 1 $\mu Sv \cdot h^{-1}$	11
		1 - 3 $\mu Sv \cdot h^{-1}$	16

Table 2. Values above 10 $\mu Sv \cdot h^{-1}$, at F installation.

Sampling points	Dose rate in contact ($\mu Sv \cdot h^{-1}$)	Dose rate at 1 meter ($\mu Sv \cdot h^{-1}$)	Dose rate at 3 meters ($\mu Sv \cdot h^{-1}$)
P5601 pump	400	20.0	2.0
P5601 suction pump	320	20.0	-
Pipes at 1 meter from P5601 pump	110	-	-
Pipes at 2 meters from P5601 pump	30	-	-
5601 pipe	22	5.5	-

Table 3. Dose rate measurements in contact in above background points at B, C and D installations.

Facility	Background measurement (μSv·h^{-1})	Points above background	Dose rate values in contact (μSv·h^{-1})
B	0.09 ± 0.01	1	2.2
C	0.11 ± 0.01	0	-
D Store area	0.13 ± 0.01	1	2.8
D Washing area [a]		3	1-10
		1	10-20

[a] See table IV for details

Table 4. Measurements in washing area, D installation.

Sampling points	Dose rate values in contact ($\mu Sv \cdot h^{-1}$)	Dose rate values at 1 meter ($\mu Sv \cdot h^{-1}$)	Dose rate values at 3 meters ($\mu Sv \cdot h^{-1}$)
Washing container	1.0	-	-
Big container	10.0 – 18.5	3.0	0.90
Waste container 1	1.0 – 2.8	-	-
Waste container 2	3.8	0.80	-
API vessel	0.10 – 0.13	-	-

Tourist cavern

12 different sampling points measured: all the results below 0.1 μSv/h.

Thermal spas

Dose rate measurements performed: background measurements in the surroundings of the spas were within natural radiation levels (0.1 – 0.2 μSv/h).

ARN laboratory measurements

Oil installations

Table 5. Maximum and minimum radium isotopes and natural uranium concentration values in samples from installations A, B, C and D

Facility	Uranium		^{226}Ra		^{228}Ra	
	Minimum value	Maximum value	Minimum value (Bq·g^{-1})	Maximum value (Bq·g^{-1})	Minimum value (Bq·g^{-1})	Maximum value (Bq·g^{-1})
A	< 0.4 μg·g^{-1}	1.9 ± 0.8μg·g^{-1}	< 0.1	1270 ± 130	115 ± 11	1670 ± 17
B	< 10.0 μg·l^{-1}	33.0±9,8μg·l^{-1}	< 1.7 E-3	26.8 ± 2.7	< 1.1 E-3	9.6 ± 0.9
C	< 10.0 μg·l^{-1}	1.5 ± 0.7μg·g^{-1}	< 1.4 E-3	0.07 ± 0.01	< 9.6 E-4	0.1 ± 0.01
D	< 0.4 μg·g^{-1}	< 0.7μg·g^{-1}	1.9E-3 ± 4E-4	18.7 ± 1.8	2.1E-3 ± 4E-4	65.4 ± 6.5

- ✓ Samples from scales, sludges and washing effluents.
- ✓ Gamma spectrometry: Canberra GeHp detectors.
- ✓ Ra-226 analyses by radiochemical method: coprecipitation of radium with $BaSO_4$ and measurement of radon gas by liquid scintillation.
- ✓ Uranium concentration by fluorimetry Jarrel Ash equipment.

ARN laboratory measurements

E, F and G Gas installations

Radon gas measurements by Lucas method.

- Samples in cells coated with SZn(Ag).
- Measuring in alpha counters.

Table 7. Radon gas concentrations in the different gas streams

Facility	Radon gas concentration ($Bq \cdot m^{-3}$)	Sampling points
E	1841 ± 300	Ethane + CO_2
F	337773 ± 30000	Tower top (propane 18% - propylene 75%)
G	62572 ± 5000	Tower top (propane 18% - propylene 75%)

UNDERGROUND GOLD MINE

Radon gas concentrations performed with activated charcoal adsorption and liquid scintillation measurements

Table 8: Radon gas concentrations in air

Sampling points	Radon gas concentration ($Bq\ m^{-3}$)
1	1840
2	3460
3	8200
4	1280
5	180
6	8200
7	6240
8	12900
9	145
10	150

*Uncertainty: 10% with K=2

Tourist cavern

Firstly measured by activated charcoal as screening and then by time-integrated detectors, CR-39 and Makrofol track detectors.

Table 9: Radon gas concentrations in air of the tourist cavern surveyed

Sampling Points	Activated charcoal (Bq/m^3)	Track etched detectors* (Bq/m^3)
A	2831 ± 258	2297
B	963 ± 88	761
C	1222 ± 111	1494
D	1184 ± 108	903
E	---	1317
F	1062 ± 97	1168
G	1256 ± 115	1084
H	---	1126
I	427 ± 39	424
J	923 ± 84	1017
K	405 ± 37	792
L	409 ± 37	707
LL	250 ± 23	482
M	219 ± 20	435
N (Entry)	116 ± 11	321

The equilibrium factor measured was between 0.3 and 0.6 /*Uncertainty: 20% with K=2

Thermal spas

Waters: two samples were collected at each sampling point, one for dissolved radon and one for natural uranium, Ra-226 and Pb-210

[Rn-222] (Bq/m^3) in geothermal waters used for medical purposes at Thermal spas

Thermal spa	Description	Minimum value	Maximum value
1	Water at spring	3300 ± 1100	15600 ± 2700
2	Water at spring	< 1000	-
3	Water at spring	< 1000	-
4	Water at spring	2168± 461	5230 ± 1094
5	Water at spring	2036 ± 435	2132 ± 461
6	Water at spring	< 1000	2563 ± 549
7	Water at spring	1835 ± 391	2625 ± 560
8	Water at spring	5249± 1094	5957 ± 1246
9	Water at spring	2273 ± 489	3388 ± 712
10	Water at spring	2869 ± 609	3113± 655

Thermal spas (cont.)

[Uranium], [Ra-226] and [Pb-210] in geothermal waters

Uranium		Ra-226		Pb-210	
Samples below LD	Values above LD (µg/L)	Samples below LD	Values above LD (Bq/L)	Samples below LD	Values above LD (Bq/L)
22 (LD: 0.1 µg/L) n = 41	Minimum 0.14 ± 0.01 Maximum 28.4 ± 2.8	29 (LD: 0.01 Bq/L) n = 46	Minimum 0.02 ± 0.03 Maximum 1.13 ± 0.10	41 (LD: 0.06 Bq/L) n = 43	Minimum 0.07 ± 0.02 Maximum 0.17 ± 0.03

LD: detection limit

Thermal spas (cont.)

- Radon levels in air: detectors at different locations of each thermal spa.
- Thermal spa 1 in a fumarole area.

Sampling points	[Rn-222] (Bq/m^3) Activated charcoal	[Rn-222] (Bq/m^3) Time integrated detectors
Health office	140 ± 15	120 ± 25
Bath A	1543 ± 170	1100 ± 200
Office bath A	490 ± 50	373 ± 70
Corridor bath B	300 ± 30	68 ± 15
Bath C	205 ± 20	414 ± 80
Corridor bath C	305 ± 30	254 ± 50
Bath D	770 ± 80	*
Bath D, sulphurous water	861± 90	877 ± 160
Corridor bath D	177 ± 20	113 ± 20
Bath E	854 ± 90	1755 ± 340
Corridor bath F	600 ± 60	459 ± 90

*Detectors lost

Thermal spas (cont.)

[Rn-222] in air (Bq/m^3) at thermal spas 2 to 10, with CR-39 detectors

Thermal spa	Sampling location	[Rn-222] (Bq/m^3)*
2	Jacuzzi	199
	Emergency room	84
	Indoor swimming pool	87
3	Emergency room	35
	Indoor swimming pool	72
4	Women's locker room	45
	Medical office	21
5	Jacuzzi	29
6	Women's locker room	179
	Indoor/outdoor swimming pool	114
7	Outdoor swimming pool	107
	Dinning room	91
8	Men's locker room	82
	Indoor swimming pool	89
	Men's locker room	175
9	Jacuzzi	45
10	Emergency room	69

*Uncertainty: 20% with K=2

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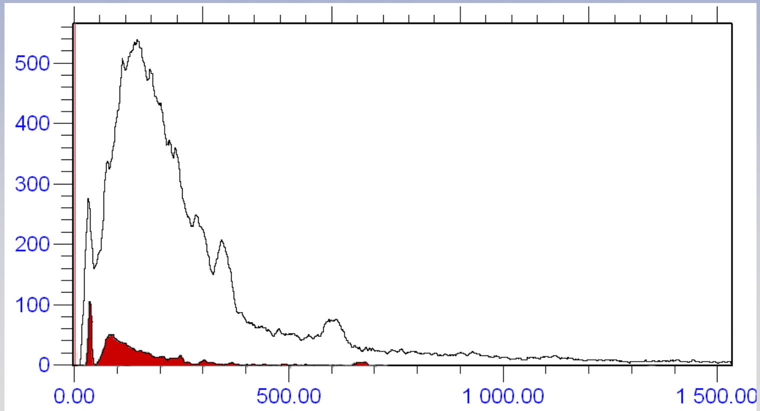
External exposure



- Of 100 % evaluated points:
  - 57 % in the background order
  - 19 % below 2 $\mu Sv \cdot h^{-1}$
  - 15 % in the range of 2 -10 $\mu Sv \cdot h^{-1}$
  - 9% was above 10 $\mu Sv \cdot h^{-1}$.

- Values above background in tubing with scales, isolated pieces, containers from washing and maintenance processes and in ethane and propane flows.

- Conservative scenarios to assess the maximum occupational doses received by a worker.

- Occupational factors on the basis of the information given by the facilities staff.

- An homogeneous whole body irradiation was assumed.

Table 14. Results of external exposure assessments in oil and gas facilities

Facility	Pieces above background	Maximum value (µSv/h)	Occupational factor (hours/y)	Annual effective doses (mSv/y)
A	Isolate pieces, pipes	30	20 (5 minutes per day - 240 days in a y ear)	0.6
B	Pipes	2.2	25 (5 minutes per day - 300 days in a year)	0.05
C	Not detected	-	-	-
D[a]	Pipes	2.8	25 (5 minutes per day - 300 days in a year)	0.07
	Container with scales	0.8[b]	320	0.26
	Big container	18.5[c]	25 (5 minutes per day - 300 days in a year) in contact	0.45
		3[b]	50 (10 minutes per day - 300 days in a year) at 1 meter	0.15
E	Depropanized pump	0.9	20 (5 minutes per day - 240 days in a year	0.02
F	Pump 5601	400	4	1.6
G	Pump P93	3.0	4	0.01

[a] In the case of D facility it is assumed that a worker may be exposed to all the scenarios, being the total annual effective dose 0.93 mSv /y

[b] Dose rate at 1 meter.

[c] Dose rate in contact.

Oil and gas installations

Radon gas concentration

- Radon gas is concentrated in ethane and propane flows and follows them in the cracking process.

Sample analyses in laboratories

- Uranium is not concentrated in scales: uranium does not mobilize in the oil extraction processes.

- Radionuclides involved from natural origin, from the decay chains of U-238 and Th-232. Mainly Ra-226 and Ra-228.

- Some radium concentrations in scales samples were above exemption values IAEA N° RS-G-1.7 (1 $Bq \cdot g^{-1}$ for uranium and thorium series radionuclides, irrespective of the quantity of material).

The exclusion values were derived on the basis of the concept of exclusion, i.e non-amenability to control, and were selected by considering the upper end of the worldwide distribution of activity concentrations in soil.

Underground mine

- Sampling points 1, 2, 3, 4, 6, 7 and 8, values resulted above the corresponding internationally agreed reference level value established for workplaces 1000 Bq/m^3 (12800 Bq/m^3)

Tourist cavern

- Sampling points A, C, E, F, G, H and J, the values above the corresponding reference level value established for workplaces (2300 Bq/m^3)

Thermal spas

- Spa 1: Similar radon gas results obtained with both types of detectors.
- Maximum worker dose assessment: highest value 1755 Bq/m^3. Although this value is above the corresponding reference level value, as the spent time of workers is well known, the annual effective dose was calculated with a spent time of 1000 hours: annual effective dose 6 mSv/y.
- The individual dose criteria established for deriving reference radon levels, both for members of the public and for workers is 10 mSv/y The maximum annual effective dose calculated resulted below this reference dose criterion.

Thermal spas

- Water characterization: almost all values were below the corresponding guidance levels recommended by WHO for drinking waters: 100.000 Bq/m^3 for Rn-222, 0.1 Bq/L for Pb-210 and 1 Bq/L for Ra-226 .
- 2 values above guidelines values: one value of Pb-210 of 0.17 Bq/L and one value of Ra-226 of 1.13 Bq/L.
- Although these waters are not used as drinking waters, the annual effective dose by ingestion was calculated in a conservative way, an annual ingestion of 730 liters and each corresponding dosimetric factors .
- For Pb-210, the annual effective dose calculated was 0.08 mSv/a, and 0.23 mSv/a for Ra-226. Both values are well below the dose limit for members of the public, 1 mSv/a.

Thermal spas

- Natural uranium: in order to calculate the maximum result obtained (28.4 µg/L) in terms of activity concentration for U-238, the corresponding specific activity and abundance for U-238 in natural uranium were used (NPL 2008). The result was 0.34 Bq/L of U-238, well below the corresponding WHO guideline value (10 Bq/L).

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- INSTALLATION DESCRIPTIONS
- MEASUREMENTS
- DISCUSSION
- **CONCLUSIONS AND RECOMMENDATIONS**

CONCLUSIONS AND RECOMMENDATIONS
Oil and gas installations

- *Dose rate measurements*:

✓ Oil facilities: points above background in tubing, washing and maintenance area.

✓ Gas facilities: points above background in the ethane and propane flows.

✓ Higher values measured in older installation due to higher natural radionuclides accumulation.

- *Annual effective dose:*

- *O*il facilities
  - ✓in tubing: 0.6 mSv. y^{-1}.
  - ✓assuming duties in store area and in washing area: 0.93 mSv. y^{-1}.
- Gas facilities
  - ✓1.6 mSv. y^{-1}.

- It was suggested to optimize the time spent in these areas: presence of workers justified and situation properly informed to the personnel.

CONCLUSIONS AND RECOMMENDATIONS

- Although annual effective doses calculated were below 2 mSv/y, clear and open procedures for optimization of protection for the management of NORM are advisable. (guides)

- Scale and sludge samples: radium isotopes were well above exemption values. But, the scenarios analyzed implied that the calculated doses were well below the dose limits. In this sense protective strategies would be implemented in relation with the characteristics and magnitudes of the exposure situations.

- Radon gas measurements in gas facilities: it was confirmed that radon concentrates in ethane and propane flows. The possibility of gas inhalation should be taken into account during inspection, repair or maintenance activities, as in normal operation the gas is confined in the pipes and vessels with no risk to workers.

CONCLUSIONS AND RECOMMENDATIONS

- Locations of mine and cavern surveyed where radon measurements resulted above reference level for workplaces, actions were recommended not only to reduce radon concentration values below reference level but also to assure that protection has been optimized.
- Mine: it was recommended to improve all the ventilation system.
- Cavern: it recommended to optimize spent time of tourist guides.
- Both exposure situations have to be kept under review.
- Spas: maximum annual effective dose from radon inhalation resulted below the reference dose criteria. Water below the corresponding guidance levels recommended by WHO for drinking waters.

CONCLUSIONS AND RECOMMENDATIONS

- The management of NORM situations has to be subjected to a graded approach consistent with the optimization principle (ICRP 104).

- A graded approach to regulation: is particularly relevant to NORM, because the exposures are generally moderate, and with no extreme radiological consequences from accidents.

CONCLUSIONS AND RECOMMENDATIONS

- Regulatory requirements: take into account the large variety of processes, materials and activity concentrations, even within a same industry. A case by case analysis is recommended. The costs and benefits of introducing regulatory requirements also need to be considered and compared with other options that would achieve the same objective.

- Engagement of stakeholders is clue in the appropriate management of NORM.

Thank you for your attention

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