NORM in the Oil/Gas Industry

NORM from
Cradle to
Grave

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OUTLINE

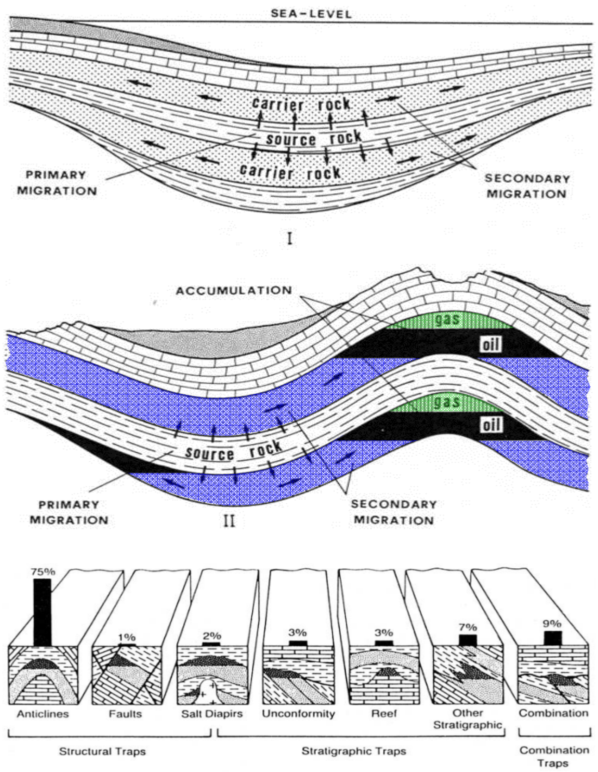
NORM in the **Oil/Gas Industry**

1. **Oil/Gas Reservoirs** and **Naturally Occurring Radionuclide's (NOR's)**
2. **Oil/Gas Production** and **NOR Appearances** (potential formation of **NORM**)
3. **NORM Formation in Oil/Gas Production Installations** (**NORM** Surveys)
4. **NORM Final Destination (Residue or Waste)** – NORM Family Album

1

Oil/Gas Reservoirs and **Naturally Occurring Radionuclide's (NOR's)**

Gas/Oil Formation – Geological Time Scale

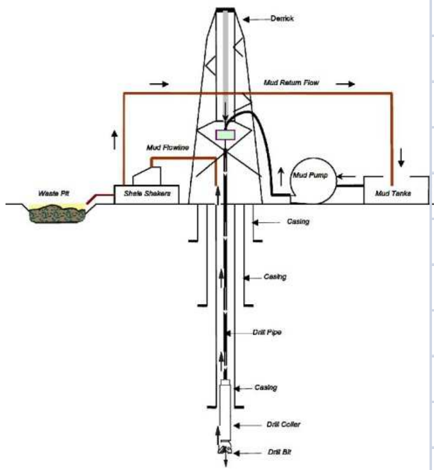


- hydrocarbon **source rocks** are sediments containing large amounts of organic matter (*e.g*. coal, organic rich shale)
- source rocks to have been buried to depths of at least 3 kilometers for a significant period of geological time (say up > **10^6 years**) before gas/oil is formed
- geological strata should be shaped in such a way that gas/oil escaping/seeping from source rock may be come **trapped** in a '***conventional***' reservoir
- most common **sandstone reservoir** with gas/oil/formation-water in the pores sealed by a dome-shaped salt (evaporite, shale) layer
- geological shale strata may contain gas/oil, that may be released by hydraulic fracturing ('***unconventional***' reservoir)

NOR's in Sedimentary Rocks (Gas/Oil Reservoirs)

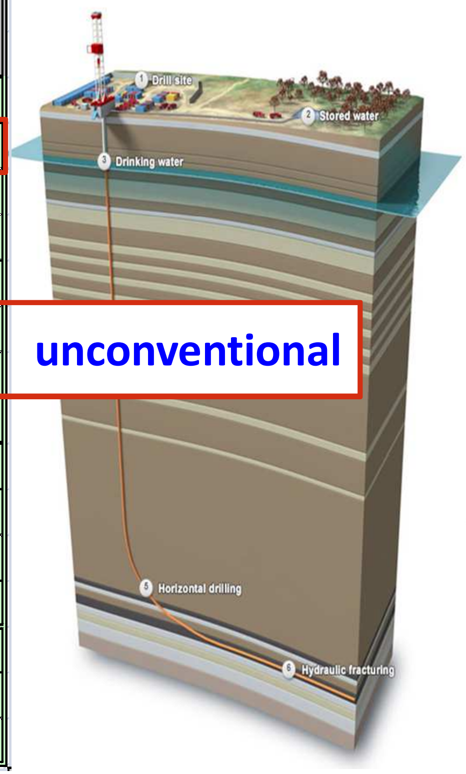
K, Th & U - Element and Activity Concentrations

conventional



SEDIMENTARY ROCK CLASS	Potassium (K) %w	Potassium (K) Bq/g	Thorium (Th) ppm(w)	Thorium (Th) Bq/g	Uranium (U) ppm(w)	Uranium (U) Bq/g
DETRITAL	2,1	0,66	12,4	0,050	4,8	0,059
Sandstone & Conglomerates	1,2	0,37	9,7	0,039	4,1	0,050
Orthoquartzites	2,0	0,62	1,5	0,006	0,5	0,006
Arkoses	2,5	0,78	5,0	0,020	1,5	0,018
Shale						
Grey/Green	3,5	1,09	16,3	0,066	5,9	0,072
Black	3,0	0,94	13,0	0,053	3,0	0,037
Clay	0,6	0,19	8,6	0,035	4,0	0,049
CHEMICAL	0,6	0,19	14,9	0,060	3,6	0,044
Carbonates	0,3	0,09	1,8	0,007	2,0	0,025
Limestone	0,5	0,16	3,0	0,012	13,0	0,159
Evaporites					< 0.1	< 0.001
EARTH's CRUST	2,1	0,66	12,4	0,050	4,2	0,051
Top soil	1,5	0,47	9,0	0,037	8,0	0,098
Beach sands (unconsolidated)			6,0	0,024	3,0	0,037

unconventional



NOR's in Shale Drilling Cuttings

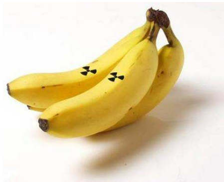
K, Th & U - Element and Activity Concentrations

Description	[K]	$\frac{Bq[^{40}K]}{g[sample]}$	ppm[Th]	$\frac{Bq[^{232}Th_{nat}]}{g[sample]}$	ppm[U]	$\frac{Bq[^{235}U_{nat}]}{g[sample]}$	$\frac{Bq[^{238}U_{nat}]}{g[sample]}$
Earth Crust	2,1%	0,63	12,4	0,050	4,2	0,0024	0,052
Shale	3,3%	1,00	14,6	0,059	4,5	0,0026	0,056
US Marcellus 1	1,8%	0,56	5,5	0,022	7,0	0,0041	0,087
US Marcellus 2	2,0%	0,60	9,6	0,039	7,8	0,0045	0,096
US Marcellus 3	1,8%	0,56	7,8	0,031	8,2	0,0048	0,102
US Marcellus 4	0,4%	0,13	1,8	0,007	1,8	0,0010	0,022
US Marcellus own	2,3%	0,69	8,5	0,034	3,7	0,0022	0,046
US Haynesville 1	1,8%	0,55	6,3	0,026	7,6	0,0044	0,094
US Haynesville 2	2,4%	0,71	6,5	0,026	7,8	0,0046	0,097
Field 1	1,7%	0,51	5,8	0,024	7,0	0,0041	0,087
Field 2	1,7%	0,50	5,6	0,023	8,1	0,0047	0,100
Field 3	1,9%	0,56	6,2	0,025	4,4	0,0025	0,054
Stacked Field 1a	2,4%	0,72	8,5	0,034	2,8	0,0016	0,035
Stacked Field 2a	2,8%	0,85	12,6	0,051	3,8	0,0022	0,047
Stacked Field 3a	2,0%	0,60	6,2	0,025	2,7	0,0016	0,034
Stacked Field 4a	2,2%	0,67	13,0	0,053	3,6	0,0021	0,044
Stacked Field 1b	2,7%	0,83	7,3	0,030	2,1	0,0012	0,026
Stacked Field 2b	2,6%	0,79	10,1	0,041	3,2	0,0019	0,039
Stacked Field 3b	2,0%	0,61	5,9	0,024	1,8	0,0010	0,022
Stacked Field 4b	2,4%	0,73	14,9	0,061	5,3	0,0031	0,066

Drilling Cuttings Natural Concentrations

of **K**, **Th** & **U**

NORM?



^{232}Th & ^{238}U Characteristics

Decay Series with Geochemically Relevant Terrestrial NOR's

Primordial NOR's ^{232}Th and ^{238}U are special
Heading a series of successive nuclear decays

^{232}Th	10^{10} y	
^{228}Ra	6 y	γ
^{228}Ac		
^{228}Th	2 y	(γ)
^{224}Ra	4 d	(γ)
^{220}Rn		
^{216}Po		
^{212}Pb		γ
^{212}Bi		γ
^{212}Po & ^{208}Tl		γ
^{208}Pb	stable	

<u>Relevant Gas/Oil Time Scales</u>

- Diagenesis > 10^6 y
- Reservoir Accumulation > 10^5 y
- Production ~ 50 y
- (Gas) Transport Time ~ days

Half-lives < "***1 week***" too short to develop chemistry of the element

^{238}U	10^9 y	
^{234}Th		(γ)
^{234m}Pa		
^{234}U		
^{230}Th		
^{226}Ra	1600 y	(γ)
^{222}Rn	4 d	
^{218}Po		
^{214}Pb		γ
^{214}Bi		γ
^{214}Po		
^{210}Pb	22 y	(γ)
^{210}Bi		
^{210}Po	138 d	
^{206}Pb	stable	

NOR Geochemistry
Reservoir Conditions

element	^{232}Th-series	^{238}U-series	chemical behaviour	Diagenesis/ Accumulation
U uranium		^{238}U, ^{234}U	reducing environment: U^{4+} insoluble, no UO_2^{2+}	remains inside or at surface of reservoir grains
Th thorium	^{232}Th, ^{228}Th	^{234}Th, ^{230}Th	reducing environment: Th^{4+} very insoluble	
Ra radium	^{228}Ra, ^{224}Ra	^{226}Ra	alkaline-earth (Mg, Ca, Sr, Ba)$^{2+}_{aq}$ carrier for Ra^{2+} ions	preference for and geo-chemically transported by aqueous phase
Rn radon	^{220}Rn	^{222}Rn	noble gas, very polarisible atoms	water/oil/gas phase partitioning
Pb lead		^{210}Pb	stable Pb^{2+}_{aq} carrier for $^{210}Pb^{2+}$ ions	preference for and geo-chemically transported by aqueous phase

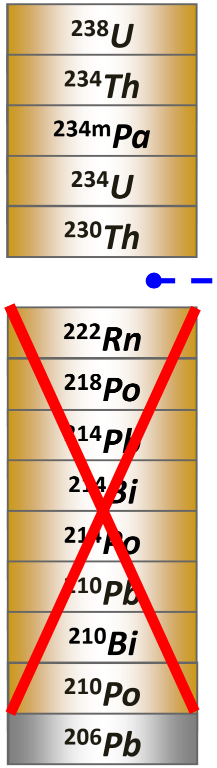
2

Oil/Gas Production and **NOR (re)Appearance**

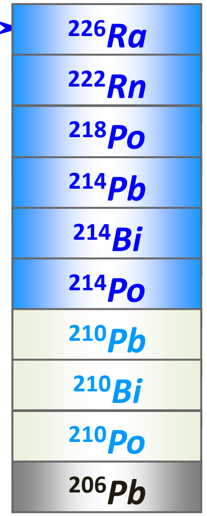
(potential formation of **NORM**)

Production Breaks Secular Equilibrium within Decay Series

Production Time Scale: Days

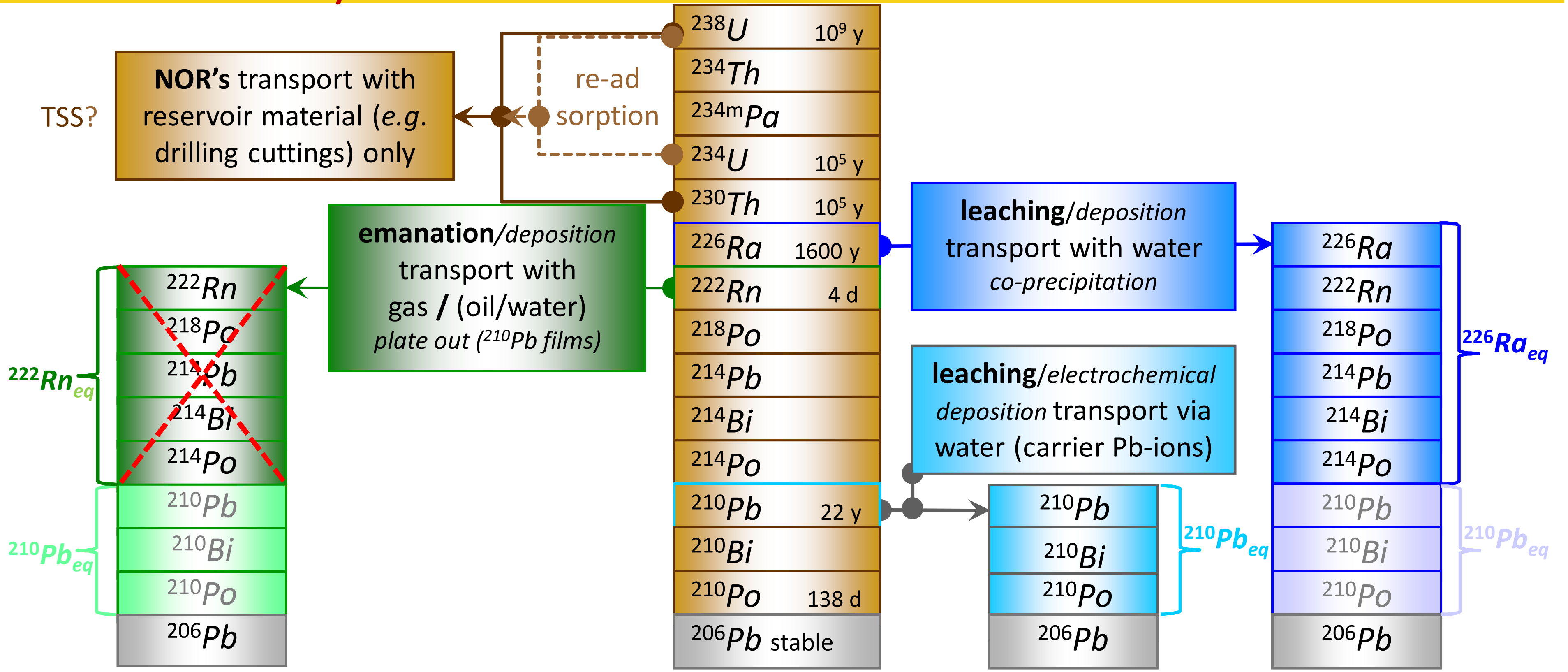


- ✓ If a "system" is not closed to radionuclide migration the secular equilibrium will become disturbed. The migrated *daughter* nuclide will start a decay series for its own, so-called ***sub-series*** will be formed.
- ✓ For example: a ^{226}Ra "system" consists of a formation with entrapped formation pore water. As waters start to move, dissolved radium-ions (Ra^{2+}) may be transported to somewhere far from the originating formation, *i.e.* far from its parent ^{238}U. Consequently, no ingrowth of ^{226}Ra anymore by nuclear decay > ***unsupported***.
- ✓ **^{226}Ra** will form a new secular equilibrium with its short-lived daughters > ***^{226}Ra or $^{226}Ra_{eq}$ sub-series***.



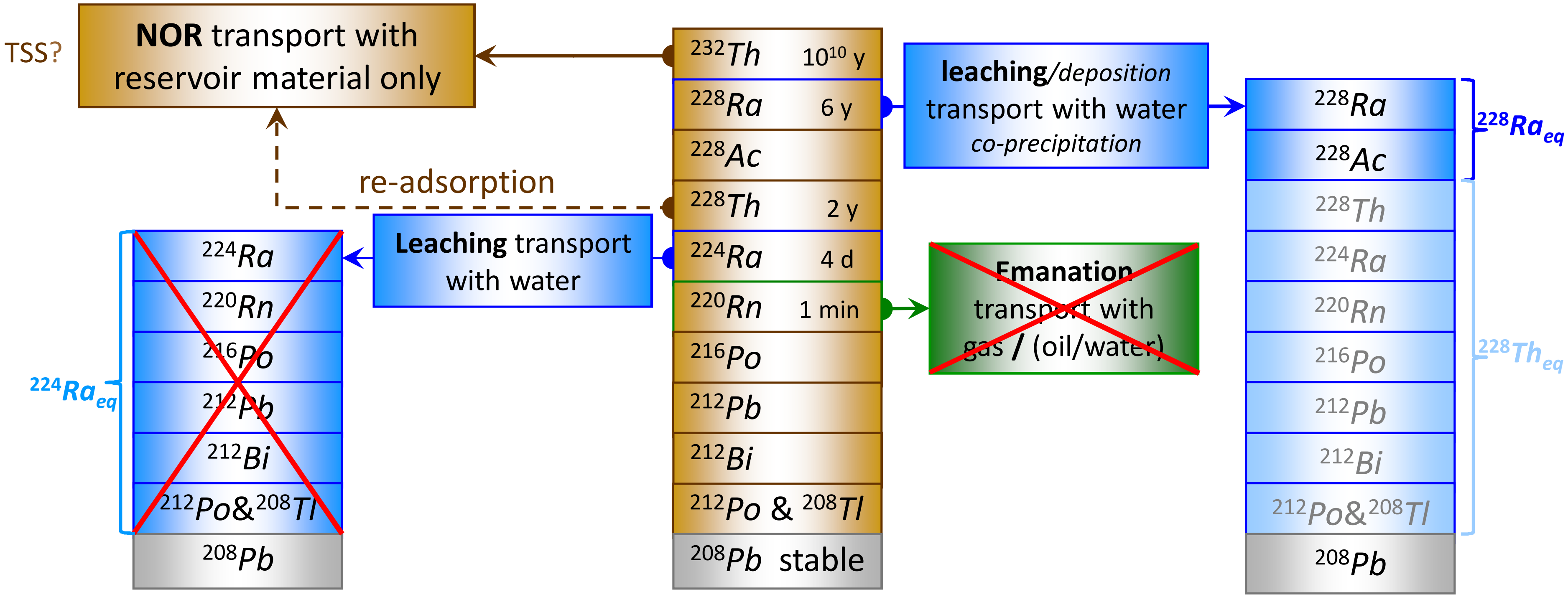
NOR Characteristics – Well Fluids

^{238}U Decay Series overview



NOR Characteristics – Well Fluids

^{232}Th Decay Series **overview**



NOR Appearances

Activity Concentration Range – Waste Streams

Naturally Occurring Radionuclide *(NOR)*	Drilling Cuttings	Production Water	Scale & Sludge		
			(hard)	*(medium)*	*soft*
	Bq[NOR]/g	*Bq[NOR]/L*	*Bq[NOR]/g*	*Bq[NOR]/g*	*Bq[NOR]/g*
^{238}U	0.02 <> 0.10 secular equilibrium	0.000 3 <> 0.1	0.001 <> 0.5	0.001 <> 0.5	0.005 <> 0.01
^{226}Ra		**0.002 <> 1,200**	**0.1 <> 15,000**	**0.8 <> 400**	**0.05 <> 800**
^{226}Ra *(shale)*		10 <> 650	0.1 <> 2		
^{210}Pb		**0.05 <> 190**	**0.02 <> 75**	**0.05 <> 2,000**	**0.1 <> 1,300**
^{210}Pb *(shale)*		0.5 <> 20	0.1 <> 20		
^{232}Th	0.01 <> 0.06 secular equilibrium	0.000 3 <> 0.001	0.001 <> 0.002	0.001 <> 0.01	0.002 <> 0.01
^{228}Ra		**0.3 <> 180**	**0.05 <> 2,800**	**0.05 <> 300**	**0.5 <> 50**
^{228}Ra *(shale)*		20 <> 100	0.1 <> 1		

NORM?

When does **production water/scale/sludge** classify as **NORM?**

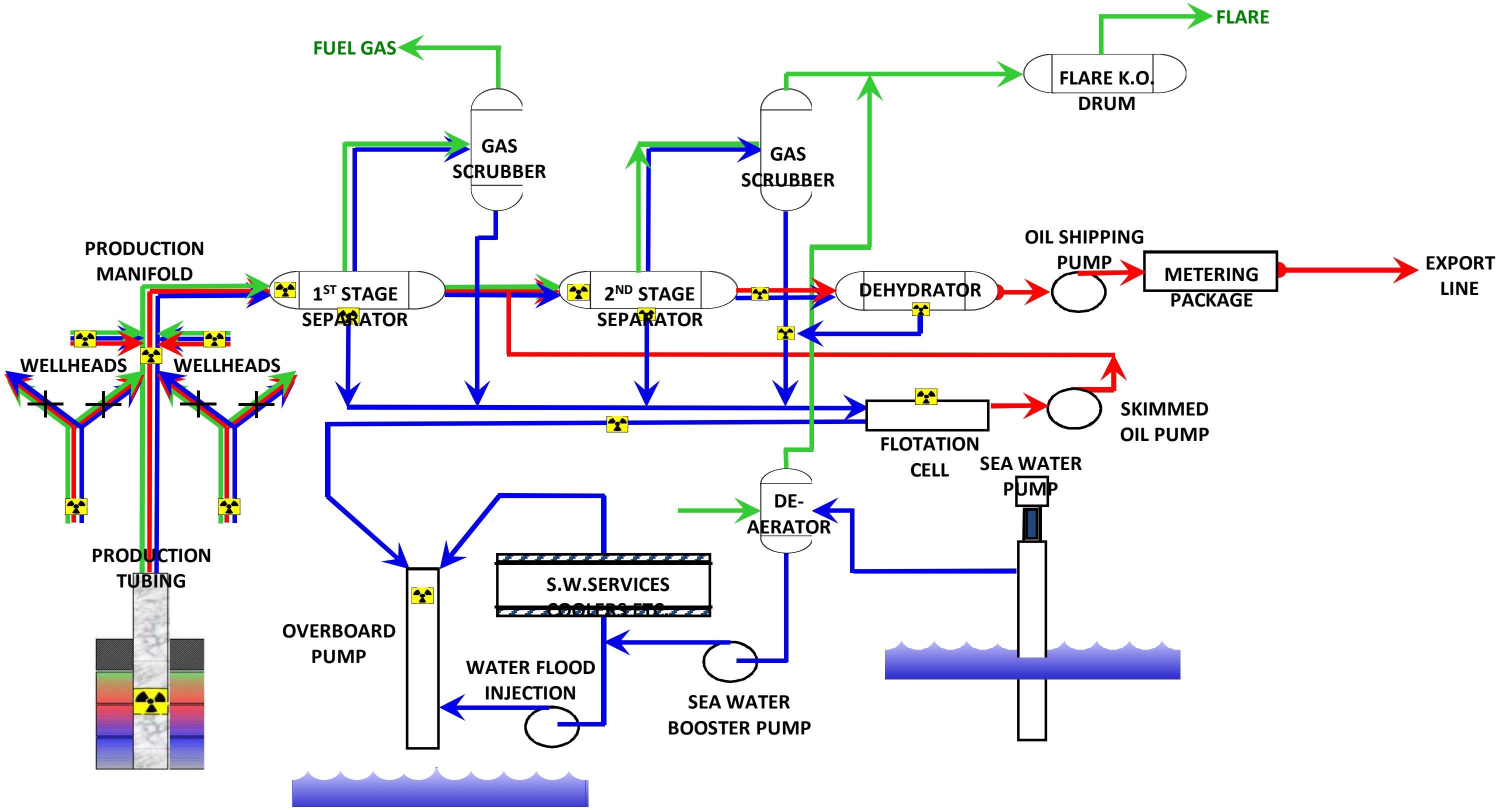
3

NORM Formation in Oil/Gas Production Installations

(**NORM** Surveys)

NORM Surveys

Exploit all *a priori* Knowledge



NORM Surveys Operating Conditions

γ-radiation (Dose Rate) Survey

- all α-particles will be stopped will be stopped in metal
- all β-particles will be stopped will be stopped in metal
- only high energy γ-photons will pass through wall and may contribute to an external dose rate around the facilities,
  20 mm wall: $T_{200\ keV} \approx 10\%$ & $T_{500\ keV} \approx 30\%$

NOR	sub-series	appears in	γ-yield/Bq[sub-series]	
			E_γ > 200 keV	E_γ > 500 keV
^{232}Th	^{232}Th	not in E&P NORM	-	-
$^{228}Ra_{eq}$	^{228}Ra & ^{228}Ac	water, scale, sludge	90%	60%
$^{228}Th_{eq}$	^{228}Th <> $^{212}Po/^{208}Tl$	water, scale, sludge	190%	130%
$^{238}U_{eq}$	^{238}U <> ^{230}Th	not in E&P NORM	1%	1%
$^{226}Ra_{eq}$	^{226}Ra <> ^{214}Po	water, scale, sludge	175%	115%
$^{210}Pb_{eq}$	^{210}Pb <> ^{210}Po	water, scale, sludge	5% 47 keV	-

NORM Surveys — Operating Conditions

γ-radiation Survey (μSv/h)

explosion proof (intrinsically safe) is a must for oil/gas industry

- ❑ no? specific instruments for Oil/Gas industry
- ❑ different instruments for different applications
- ❑ no single instrument type will do everything
- ❑ instruments used to detect:
  - ➢ external γ-radiation from bulk quantities of NORM $^{226}Ra/^{228}Ra$ (but no ^{210}Pb) accumulations
  - ➢ low dose rate range is an advantage

NORM Surveys — Maintenance Conditions

β: Potentially Detectable (Oil-film Covered) Surface Contamination

NOR	sub-series	appears in	β-yield/Bq[sub-series]	
			E_{β}^{max} > 200 keV	E_{β}^{max} > 500 keV
^{232}Th	^{232}Th	not in E&P NORM	-	-
$^{228}Ra_{eq}$	^{228}Ra & ^{228}Ac	water, scale, sludge	80%	65%
$^{228}Th_{eq}$	^{228}Th <> $^{212}Po/^{208}Tl$	water, scale, sludge	255%	175%
$^{238}U_{eq}$	^{238}U <> ^{230}Th	not in E&P NORM	100%	100%
$^{226}Ra_{eq}$	^{226}Ra <> ^{214}Po	water, scale, sludge	195%	190%
$^{222}Rn_{eq}$	^{222}Rn <> ^{214}Po	NG, NGL & LNG facilities	195%	190%
$^{210}Pb_{eq}$	^{210}Pb <> ^{210}Po	water, scale, sludge	100%	100%

α/β/γ Surface Contamination Monitors (c/s)

- α measurements very sensitive to self-absorption
  - usually not useful
- β measurements recommended for NORM, but self-absorption within source material can be high
- γ sensitivity depends on stopping power detector
- activity surface contamination (Bq/cm^2)
- sensitivity relates to detector surface area
- cylindrical detectors useful for inside tubulars
- explosion proof contamination monitors: a must for the Oil/Gas industry

4

NORM Final Destination (Residue or Waste)

NORM Family Album

NORM Variety

Black Dust is the waste that occurs after pigging of gas pipes. Composition: **FeS** most often with **^{210}Pb** and **Hg**. Black dust is pyrophoric and therefore has to be stabilised prior to disposal. Chemical stabilisation: oxidation of Fe and S Immobilisation: use of *e.g.* geopolymer

NORM Intermediate Storage

NORM Disposal Options
(derived concentration limits and costs/drum [1997 US data])

		$Bq[^{226}Ra]/g$
Landspreading	$ 5	4
Landspreading with Dilution	$ 15	10
Burial with Unrestricted Site Reuse		75
Non-Retrieval of Surface Pipe		500
NORM Disposal Facility		750
Burial in Surface Mine	$ 500	
Commercial Oil Industrial Waste Facility		1000
Commercial Low Level Waste Disposal Site		2000
Well Injection	$ 1200	4000
Plugged and Abandoned Well	$ 2000	4000
Hydraulic Fracturing		4000
Salt Dome Disposal		4000

NORM DISPOSAL OPTIONS
Landspreading

trenches filled with sludge

sludge farming (only in hot, arid climate at remote locations)

NORM DISPOSAL OPTIONS

Burial with Unrestricted Site Reuse/Non-retrieval of Surface Pipe

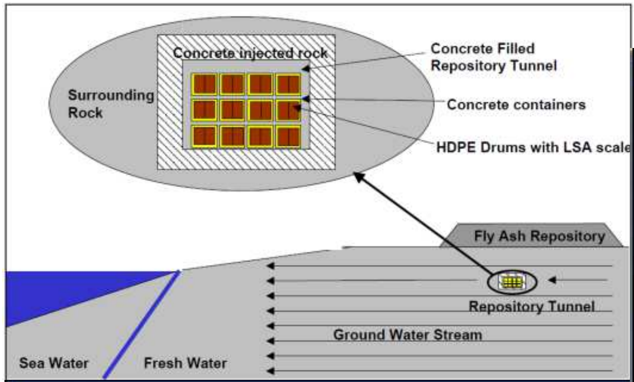
Burial with Unrestricted? Site Reuse

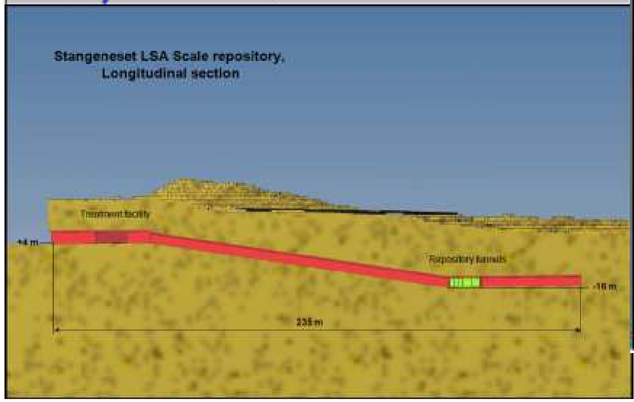
Non?-retrieval of Surface Pipe

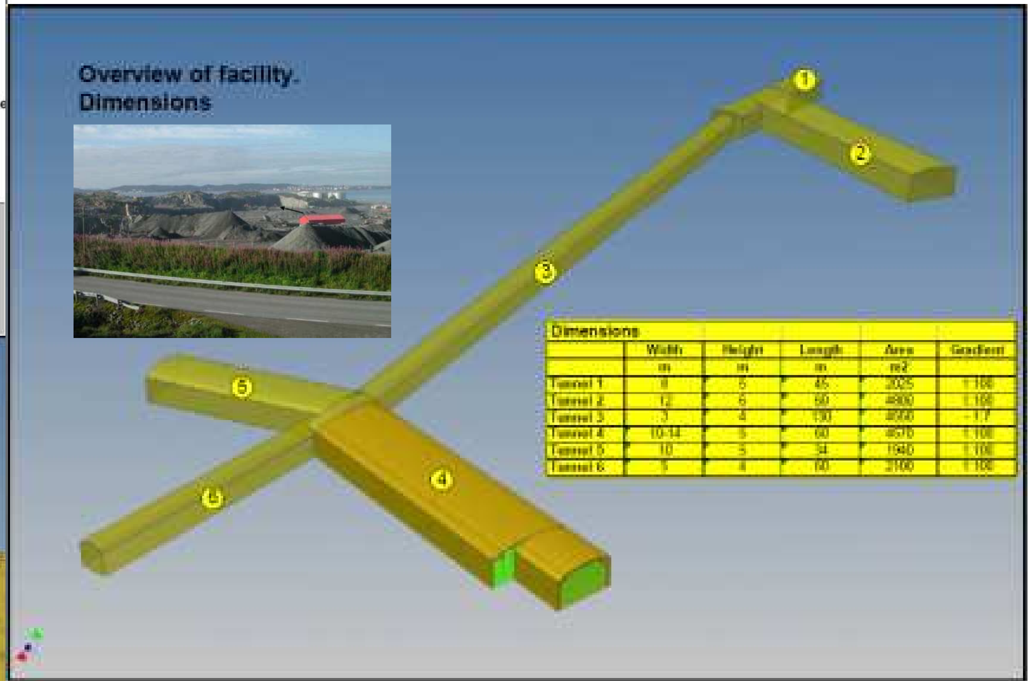
NORM Decontamination

NORM Disposal Options

NORM Disposal Facility/Burial in Surface Mine (Quarry 1)







NORM Disposal Options
NORM Disposal Facility/Burial in Surface Mine (Quarry 2)

NORM Treatment & Disposal Options
Oily Sludge (Mixed Waste 1) Transportation to Processing Site

NORM Treatment Options

Oily Sludge (Mixed Waste 2) Vacuum Thermal Distillation

Contaminated rest materials like sludge's

NORM sludge in drum before processing

Crude Mercury - *refined to marketable product*

Dust Filter contaminated with NOR's

Residue of Oily Sludge contaminated with NOR's & Hg after Processing

no more C_xH_y
no Mercury
no H_2S

NORM Disposal Options
Oily Sludge (Mixed Waste 3) Chemical Waste Landfill

Landfill Maasvlakte (VBM)

NORM materials

Sludges/scales (offshore)
- Dried mineral scales
- **Residues of vacuumdestillation (mercury recovery)**

Slag wool
- Older type of insulation of thermal process industry, such as refineries or power plants

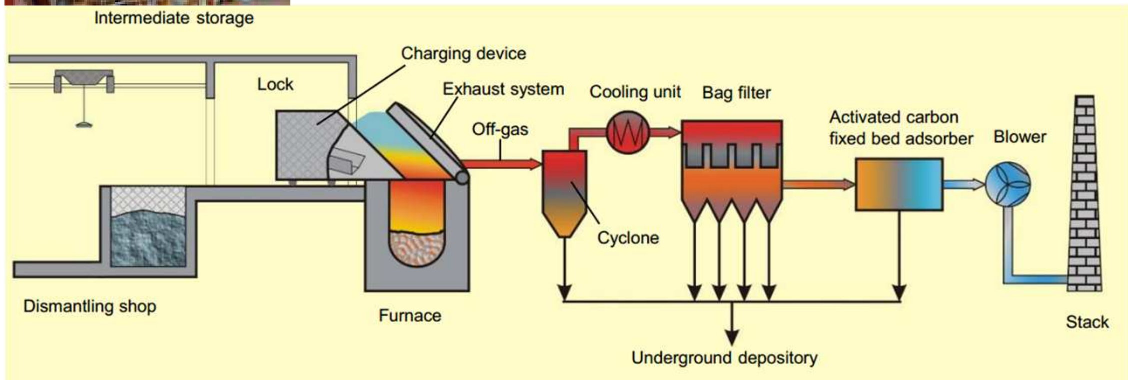
NORM Disposal Options
Scrap Melting

by melting of NOR surface contaminated objects, the NOR's

- ➢ reappear in the slag
- ➢ or in the bag filters (^{210}Pb, ^{210}Po)
- ➢ but not in the metal produced

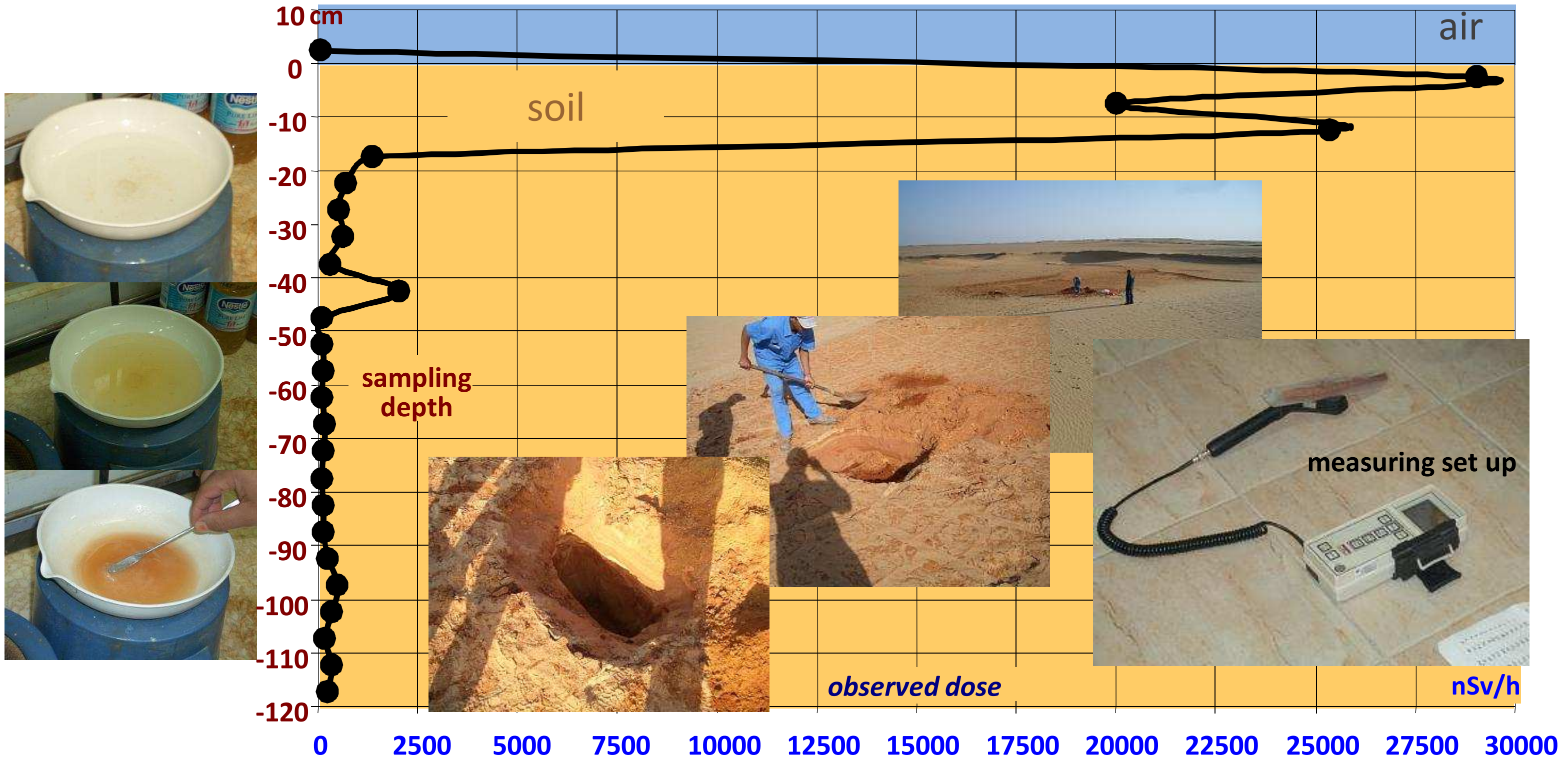
but smelters dedicated to melting NOR surface contaminated metal objects from the oil/gas industry are required:

- ➢ Siempelkamp, Germany
- ➢ Studsvik, Sweden



Case Study: Unlined Evaporation Pond (1)

Depth Profiling



5th European IRPA Congress
4 - 8 June 2018
The Hague, The Netherlands

Encouraging Sustainability in Radiation Protection

5th European IRPA Congress

The Dutch Society for Radiation Protection (NVS) is pleased to host the 5th European IRPA Congress, scheduled to take place from 4th to 8th June, 2018 in the historical city of The Hague, The Netherlands.

With the theme "Encouraging Sustainability in Radiation Protection", the congress will focus on aspects needed to make sure that we have, and will continue to have, adequate equipment, staff and resources to protect human health and our environment against the adverse effects of ionising and non-ionising radiation.

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Thank You

Q&A

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