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FEASIBILITY STUDY: ON-SITE DECONTAMINATION OF A DUTCH E&P SITE

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A B S T R A C T: During oil/gas production, Naturally Occurring Radionuclides (NOR's) from the ^{238}U and ^{232}Th series are occassionally co-produced and concentrated in deposits (e.g. scale, sludge) in production facilities. This enrichment may be to such an extent, that disposal of NOR-containing streams are subjected to regulatory limits. Once an oil/gas production site has been identified as one at which Naturally Occurring Radioactive Materials (NORM) have been shown to be present, an impact on the operability and high additional costs can be expected. Under the current Dutch Nuclear Energy Act, this is already being felt in the day-to-day operations of many E&P locations.

In order to investigate the scope for less restrictive operations and reduction of cost, a feasibility study into on-site decontamination of a NORM-contaminated E&P location is being carried out. The NORM contamination of the production facilities on the location have been scrutinised by means of an external radiation survey and a dedicated internal sampling and analysis programme. A laboratory study showed that on-site decontamination of these facilities with the aid of so-called "scale dissolvers" is feasible. However, on-site processing of NORM waste generated during gas/oil production operations is currently not approved as an allowed conduct of business by the competent authorities.

Any NORM waste produced during decontamination has to be disposed off at high costs by pre-treatment and storage at the only licensed Dutch nuclear waste site. An attractive option for the disposal of NORM waste is injection into subsurface strata, where long-term containment can be guaranteed. Downhole injection is a particularly attractive disposal option, since it ensures that the overall environmental and occupational hygiene impact of operations is minimised. Such an approach has a successful history to date, particularly in Alaska and in the Gulf of Mexico.

Subsurface injection is not a new technology for the E&P industry and is therefore a preferred disposal mechanism. However, given the nature of the waste streams, there exists some concern about the 'safeguarding' of the injection process with no chance of seepage of the waste to surface sediments and potable water sources, and that the integrity of the injection well is not compromised. Considerations for a successful injection programme will be elucidated.

On a location in North-East The Netherlands a production well was drilled in 1975 to a depth of some 3,000m and completed on the gas-bearing Zechstein carbonate formation. Commercial gas production started in 1976 via basic production facilities (Fig.1). Water production was first seen in 1978 and steadily increased to such an extent that commercial production from the well had to be suspended late 1983. In view of workover plans, investigations were carried out in 1985 to determine the extent of radiological contamination of the production facilities, a phenomenon which had at that time only recently been recognised as a potential problem area within E&P operations. While the presence of NOR's was identified in scales and sludges, removal was not permitted nor regulated and the site was closed. It remained out of use until late 1995/early 1996, when the decision was made to investigate its final abandonment. In the interim period, the industry amassed a wealth of knowledge and insight into the various aspects of Naturally Occurring Radionuclides associated with oil/gas production and processing activities. Identification of the geological origin, phase distribution and transport phenomena, standardised sampling and analysis methods are just a few of the aspects where expertise has been built up.

As a consequence, abandonment of the asset is in the process of undergoing the following preparation:

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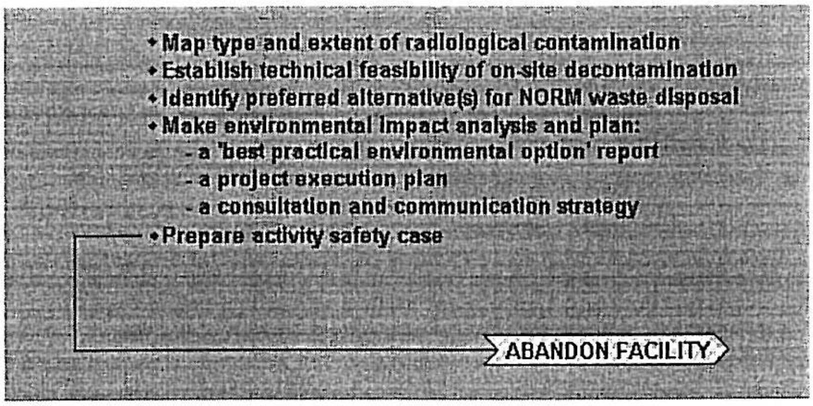
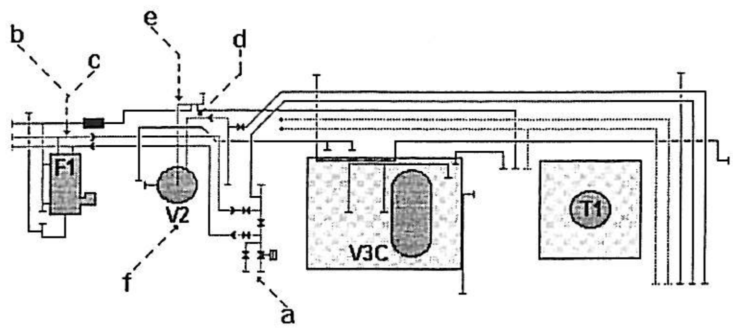


It is against this background that this paper is presented. The objective is twofold: to initiate the provision of definite guidance for those E&P industries that encounter NORM on a regular basis; and to propose requirements for the control and disposal of NORM that will be acceptable to all regulatory agencies involved.

THE TYPE AND EXTENT OF ENCOUNTERED NORM

A variety of analytical techniques may be applied to establish the type and distribution of radionuclides in contaminated facilities. Utilising standardised sampling and interlaboratory validated analytical methods, the contamination was characterised by means of an external radiation survey and a dedicated internal sampling and analysis programme. Some pertinent results are depicted in Fig. 1.

FIG. 1. Production facility schematic and indication of NORM occurrence



—Natural Gas
—Feed Gas
—Produced Fluids
—Test Unit
—Hydrate Inhibitor
—Corrosion Inhibitor
—Water Injection Line
—Sump Line

F1 = Waterbath heater
V2 = High pressure separator
V3C = Water/condensate storage tank
T1 = Corrosion inhibitor storage tank

	Bq[^{226}Ra]/g	Bq[^{210}Pb]/g
a: Inlet Manifold	2883	900
b: Waterbath heater inlet	2030	197
c: Waterbath heater outlet	250	197
d: Separator inlet	3016	1561
e: Separator outlet	1327	784
f : Separator	12	9

Note that NORM is not uniformly distributed inside equipment (i.e. vessels, tubulars, etc.) but occurs at certain locations within the equipment.

Overall, the presence of NORM with a specific activity concentration of up to 3,300 Bq [^{226}Ra]/g and 1,800 Bq [^{210}Pb]/g was established. Also encountered were ^{228}Ra and ^{224}Ra, but their specific activity concentration was marginally small. Radium isotopes and progeny were encountered in the scales $Ba_{0.4\text{-}0.5}Sr_{0.6\text{-}0.5}SO_4$, whereas ^{210}Pb was encountered in deposits of metallic lead [Pb], galena [PbS] and hydrocerussite [$Pb_3(CO_3)_2(OH)_2$]. Fig. 2 shows the activity of [^{210}Pb] versus that of [^{226}Ra] for deposits originating from gas- and aqueous streams. The straight line depicts the activity ratio which would be expected from the natural rate of ingrowth of ^{210}Pb from ^{226}Ra (see Fig. 3). It is evident that the ^{210}Pb also derives from an independent deposition mechanism during the well's production history.

FIG. 2. Distribution of NORM

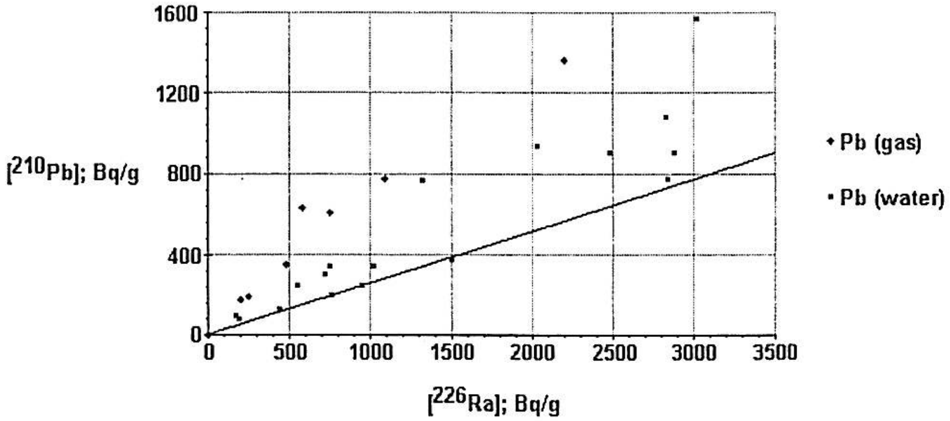
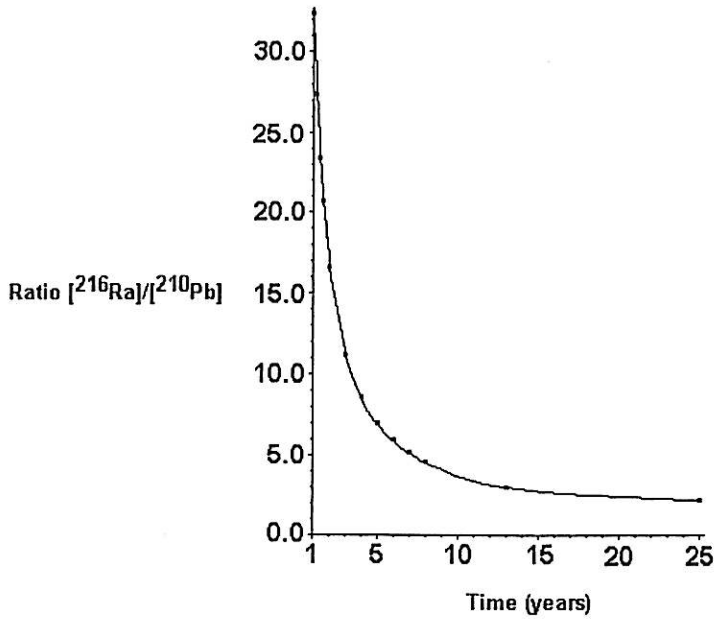


FIG. 3. Production of ^{210}Pb from ^{226}Ra



TECHNICAL FEASIBILITY OF ON-SITE DECONTAMINATION

Utilising the contaminated waterbath heater as test equipment, laboratory trials were carried out to determine whether decontamination to below legally prescribed limits is possible using dissolution of the scale matrix. This was done by firstly circulating an aqueous solution of a commercially available sulphate scale dissolver through the unit. Such scale dissolvers, which are widely used within E&P operations in those instances where the formation of calcium, barium and strontium sulphate scales impairs oil and gas production, are commonly based on chelating chemistry. This process led to the rapid and complete removal of sulphate and hydrocerussite scales. However, approximately 40% of the initial ^{210}Pb activity remained in the waterbath heater, leaving a calculated surface contamination of 20 Bq[^{210}Pb]/cm^2. After use, the scale dissolver solution was found to contain a specific activity of 3.4 Bq[^{226}Ra]/g and 1.1 Bq[^{210}Pb]/g.

A second scale dissolver solution, specifically formulated to remove metallic lead, was then circulated through the water bath heater. The solution's chemical composition cannot be disclosed at this time because of patent registration. After its use, the residual surface contamination remaining in the waterbath heater was below 0.2 Bq/cm^2 and thus below the threshold level for material classified by the Dutch Nuclear Energy Act as radioactively contaminated; this threshold level (wipeable contamination) is 4 Bq/cm^2 for β-/γ-emitting nuclides and 0.4 Bq/cm^2 for α-emitting nuclides. As a result the waterbath heater could be scrapped via conventional means. After use, the scale dissolver solution was found to contain a specific activity of 0.15 Bq[^{210}Pb]/g. Rinse water used in between treatments to preclude vigorous chemical interactions between the two scale dissolver solutions contained 0.06 Bq[^{226}Ra]/g and progeny and 0.15 Bq[^{210}Pb]/g.

These findings demonstrate the technical feasibility of on-site decontamination, not only in the event of site abandonment but also for reconditioning of critical pathway equipment in turnaround (e.g. maintenance) operations. For the facilities in question, on-site decontamination utilising scale dissolver solutions is estimated to cost Nfl. 350 thousand (excluding disposal of used dissolver solutions). Were abandonment to be pursued via conventional means (viz. dismanteling, transportation to a licensed cleaning contractor's site for decontamination, etc.), the involved costs would be approx. Nfl. 1.25 million. Hence, in this case on-site decontamination offers a potential cost saving of some 70%. Overall, application of this technology has, of course, a much larger impact on the operational expenditure incurred by the deposition of NORM in E&P facilities. However, the issue remains of what to do with the used scale dissolver solutions and rinse fluids. The current position of the Dutch authorities is that the obtained solutions must be viewed as radioactive substances, irrespective of the total specific activity concentration of these solutions. This current position potentially nullifies any economic, environmental and occupational hygiene benefits which may be gained from on-site decontamination since a potentially much larger volume of "contaminated" material must be disposed. Nevertheless, the competent authorities invite the E&P industry to propose alternative disposal options for consideration and possible approval. Once approved, the authorities will generally be eager to monitor the actual disposal process, particularly if specific E&P skills are applied.

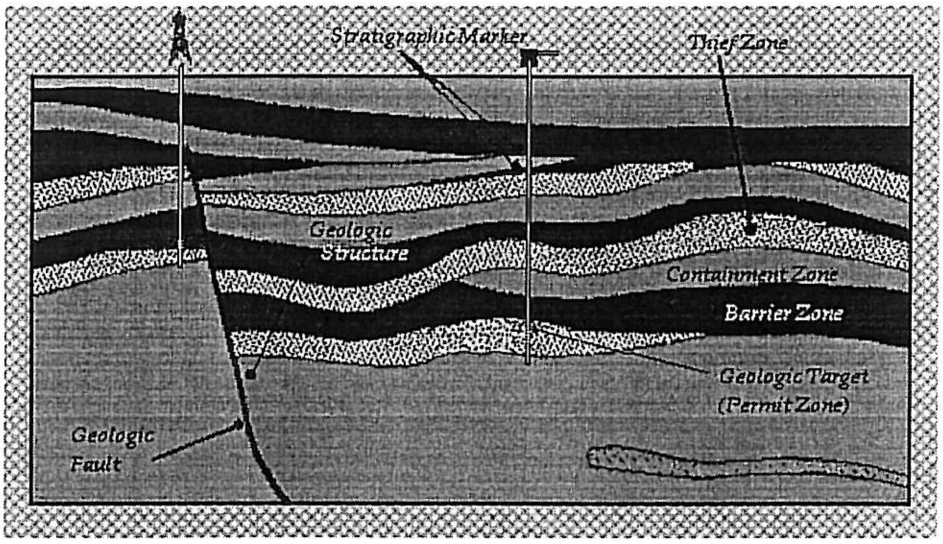
PREFERRED APPROACH TO NORM WASTE DISPOSAL

Solid and semi-liquid NORM wastes generated in the process of producing hydrocarbons are typically transported to a licensed storage site. In most instances this "disposal" mechanism of this low activity waste is viewed to be adequate (albeit expensive), although the medium- and long-term environmental issues of such storage can be subject of debate. The emergence of more stringent legislation and concomitant increase in waste volumes (such as resulting from on-site decontamination) severely limit the environmental as well as economic viability of licensed storage. An alternative option being developed for the disposal of NORM wastes is their injection into sub-surface rock strata where long-term containment is assured. This approach has had a successful history to date, particularly in Alaska and the Gulf of Mexico. Within the European sphere of operations, downhole injection of NORM wastes has only recently received attention as a disposal mechanism. It is particularly attractive because it combines minimisation of the overall environmental impact, energy utilisation and costs with maximal confidence of containment. Since the longest lived nuclide in E&P NORM (^{226}Ra) possesses a half-life of 1602 years, storage for the duration of ten half lives or more in suitable sub-surface strata is both feasible and likely. Given the nature of the waste stream, it is essential to ensure that disposal is complete with no chance of break-out to potable water sources. In addition, the integrity of injection well(s) must not be compromised. Fortunately, sub-surface injection is a well-developed and understood technology for the E&P industry and can therefore be modelled and the key consequences predicted. Considerations for a successful and thus for regulatory authorities acceptable injection programme are:

a) ***Injection site summary***: an overview of the proposed injection site should be given in order to establish the context within which the injection is programmed. Both surface and sub-surface constraints need to be evaluated as a precursor to the decision to inject, as does the proximity to environmentally sensitive areas. The location of other wells in the area, either planned or existing, should be considered and the associated legislative requirements identified.
b) ***NORM waste identification***: having described the injection site, it is important to consider the processes by which NORM wastes are generated. In some cases deposition will occur at the same site at which injection will take place, but there will also be instances where trans-shipment of NORM wastes from a particular location to the targetted injection site is the preferred option. In the latter case, the practicability and safety of the method of transportation need to be clearly established. This option should be discussed in detail with the regulatory authorities since its acceptability may be dependent on their interpretation of certain national and international conventions.
c) ***Injection zones***: having determined the types and volumes of NORM wastes that are suitable for injection (e.g. spent scale dissolver solutions), it becomes necessary to identify the geological horizon which will accept these wastes on a permanent basis. A proposed sub-surface injection model is depicted in Fig. 4. Reference can be made to the Glossary of Terms at the end of this paper for an explanation of specific E&P terms used in its explanation below.

   The permit zone into which injection may take place, under either non-fracturing or fracturing conditions, is an horizon of low modulus, high porosity and low cementation fully enclosed by over- and underlying impermeable (shale) barriers. These barriers are defined as "zones of uncertainty" in that the demonstration of waste fluid and/or fracture containment within the permit injection zone is to some extent uncertain (i.e. limited by the - proven - reliability of available predictive tools). These zones of uncertainty are in turn enclosed by containment zones in which waste fluid flow and/or fracture growth is, in principle, not permitted. As a further safety margin, the containment zones may be over- and underlain by enclosed thief zones of sufficient permeability and voidage to contain injected waste fluids which may inadvertently enter these zones. Depleted oil/gas reservoirs will generally conform to these criteria.

FIG. 4. Sub-surface NORM waste injection model



For NORM waste injection to be successful, all risks associated with the injection programme need to be identified and addressed. Reliable containment of the waste being injected under

For NORM waste injection to be successful, all risks associated with the injection programme need to be identified and addressed. Reliable containment of the waste being injected under either non-fracturing or fracturing conditions should be demonstrated up front, providing confidence beyond reasonable doubt to regulatory authorities that the operation will be under control. Thus:

- The formation with respect to future NORM waste injection is characterised before applying for a permit to inject. The effects of increases in injection pressure, increases or decreases in the in-situ stresses etc. must all have been modelled.
- It is demonstrated that the injected NORM wastes cannot penetrate to surface or to any other protected horizon (e.g. fresh water aquifers).
- It is also demonstrated that the injected NORM wastes will not pose a serious threat to any existing well or to any future drilling operations.
- The volume of waste that can be safely injected in the permit zone has been estimated.

d) ***Well integrity***: the integrity of the well or annulus is critical to the injection process and is one of the prime areas of consideration. It must be assured that the implications of the injection programme on the integrity of the injection well and the potential failure points have been identified and fully evaluated.

e) ***Surface equipment and waste conditioning***: once the sub-surface requirements have been established, it is necessary to validate the design of the surface equipment required to process and inject the NORM wastes. Fluid properties, compatibility with the target zone formation and any fluids contained therein, and hence any waste pretreatment requirements, can be determined through analysis. Required injection pressures can be established through modelling. Thus the type, capacity and output of surface equipment can be accurately specified.

f) ***Monitoring and reporting***: the extent to which regulatory authorities require monitoring and reporting will vary considerably and will normally be included as a specific stipulation of the injection permit. The monitoring programme will be designed to ensure that the injection programme is proceeding as planned. It will contain those elements that will allow the reliability of predictions to be compared against actual injection performance. The monitoring programme will be able to identify failures in the injection process and will form the basis of a data set for promulgation of the lessons learnt from the operation.

g) ***Contingency planning***: failures can occur with even the best planned operation. Potential failure modes should therefore be evaluated at the planning stage and the method by which the failure(s) can be identified established as an integral part of the monitoring programme. In each case the remedial steps to be taken must be identified beforehand.

h) ***Injection zone abandonment***: an injection zone will be considered permanently abandoned when the well has reached the end of its useful life and is itself abandoned in conformance with the applicable regulatory requirements. At the completion of the NORM waste injection programme, the well or annulus has to be stabilised. Trapped pressure - resulting from the injection - will bleed off. However, the rate at which this occurs will be a function of leak-off and the waste fluid itself. The method of injection zone abandonment will therefore vary depending on the residual pressure and the immediacy of the need to complete well abandonment. It will in any case be such that future inadvertent intrusion will not be possible.

OTHER NORM WASTE DISPOSAL TECHNIQUES

A review of possible disposal routes has been given in a previous paper[Ref. [1]] as well as in a recent publication prepared by the Western Canadian NORM Committee[Ref. [2]]. The indicated disposal options, many of which are based on current or proposed Canadian and/or US states legislation, have been screened on possible applicability within The Netherlands. In addition to the preferred disposal route, namely injection into depleted oil/gas reservoirs or other suitable sub-surface formation, other routes include:

- Mix with non-reclaimable drilling fluids and/or cuttings, and inject as slurry in a suitable sub-surface formation.

  Mixing the NORM waste (e.g. spent scale dissolver solutions) with sludges, non-reclaimable drilling fluids, cuttings, aqueous chalk suspensions, etc. is carried out to obtain sufficient dilution. The resulting slurry is then injected into a deep permeable sub-surface formation with no fresh water or mineral value.

- Store in plugged and abandoned oil/gas production wells.
  Plugged and abandoned wells can be used for the disposal of accumulated NORM waste, where it will remain nearly completely inaccessible from surface intrusion. For liquid and semi-liquid NORM wastes, some form of volume reduction technique will need to be employed in view of the limited available storage volume in such wells.

- Mix with cement for setting downhole plugs.
  Using liquid NORM waste to make up cement slurries for setting downhole plugs serves to immobilise the NORM waste. Inherently, the waste is isolated from the surrounding environment but can be retrieved at a later date, if required, by drilling out the set plugs. Here also, limited storage volumes exist.

- Mix with cement for setting casings.
  This disposal option is only applicable in those instances where casing is set in formations below underground sources of potable water which are confined by impermeable layers that are likely to remain intact. In this case the NORM-waste-containing cement would not be retrievable. This option also entails limitation of storage volumes.

- Store at a licensed storage site.
  NORM containing waste will need to be reduced in volume before it can be offered for storage at the single capacity-restricted Dutch nuclear waste site.

Each of these disposal alternatives share engineering considerations, environmental, occupational hygiene and transportation risks, all of which impact adversely on economic feasibility and obtaining the necessary approvals may prove to be politically difficult. On balance these risks outweigh those of disposal by injection in well-chosen deep formations and their pursuit should be discouraged.

CONCLUSIONS

The on-site decontamination of E&P production facilities contaminated with NORM to below legislative threshold levels can be achieved through the application of scale dissolver technology. This results in significant cost savings and additionally provides possible pathways towards the prevention of NORM deposition. However, the disposal of the generated (secondary) waste streams, currently viewed by Dutch authorities as a LSA waste irrespective of total activity concentration levels, needs to be addressed before this technology can be applied. Injection into deep permeable sub-surface formations with no fresh water or mineral value is proposed as a viable and responsible disposal route. Considerations for a successful and safe injection programme focus on providing confidence beyond reasonable doubt that the operation is well understood and under control.

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GLOSSARY OF TERMS

Annulus: space between tubing through which is injected and well casing (metal pipe cemented against the rock formation while drilling the injection well to prevent hole collapse).
Cementation: the degree to which rock grains are bonded together.
Cuttings: rock debris resulting from drilling a well.
Depleted: oil or gas reservoir from which all recoverable hydrocarbons have been removed.
Fracturing: rupturing of the rock which makes up de zone into which is being injected under influence of (high) pressure.
Modulus: parameter used to characterise rock strength.
Permeability: the ability of rock to conduct fluid flow.
Plugged well: a well in which a cement column has been placed to prevent inadvertent pressure communication between sub-surface formation(s) and surface.
Porosity: parameter used to express the void (pore) space in a rock relative to the total rock volume.

Voidage: the total volume of pores in a rock.

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