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Construction of a naturally occurring radioactive material project in the BeAAT hazardous waste facilities

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Abstract–Naturally occurring radioactive material (NORM) is produced during exploration and production operations of subsidiaries of the Abu Dhabi National Oil Company (ADNOC) in the United Arab Emirates, and accumulates in drilling tubulars, plant equipment, and components. These NORM hazardous wastes need to be managed in such a way that they do not damage human health and the environment. The primary radionuclides of concern in the oil and gas industries are radium-226 and radium-228. These radioisotopes are the decay products of uranium and thorium isotopes that are present in subsurface formations from which hydrocarbons are produced. While uranium and thorium are largely immobile, radium is slightly more soluble and may become mobilised in the fluid phases of the formation (International Association of Oil & Gas Producers, 2008). In order to treat and dispose of NORM waste products safely, ADNOC's subsidiary 'TAKREER' is developing a new facility, on behalf of all ADNOC subsidiaries, within the existing Central Environmental Protection Facilities (BeAAT) in Ruwais city. The NORM plant is envisaged to treat, handle, and dispose of NORM waste in the forms of scale, sludge, and contaminated equipment. The NORM treatment facility will cover activities such as decontamination, volume reduction, NORM handling, and concrete immobilisation of NORM waste into packages for designated landfilling.

Keywords: NORM; Uranium; Thorium; BeAAT

1. UNITED ARAB EMIRATES REGULATIONS

1.1. The Federal Authority for Nuclear Regulation Established by Law 6 of 2009

Regulation No. 24 within Law 6 addresses basic safety standards for facilities and activities involving ionising radiation other than in nuclear facilities (it defines thresholds, licensing, etc.), and applies to the following:

- Ra-226 and Ra-228 activity threshold $>10\,\mathrm{Bq\,g^{-1}}$ and activity of $>1\times10^{5}$ Bq for radioactive material of <1 ton; and
- radioactive material in a bulk amount for which the activity concentration of each radionuclide in the U and Th decay series $>1\,\mathrm{Bq\,g^{-1}}$, or $>10\,\mathrm{Bq\,g^{-1}}$ for K-40.

There is exemption from licensing when:

- the effective dose does not exceed 1 mSV year^{-1}; or
- regulatory control of the planned exposure situation would provide no net benefit.

2. SELECTION OF ALTERNATIVES FOR TREATMENT AND DISPOSAL OF NORM

2.1. Disposal objectives

The guiding disposal objectives for selecting the best treatment and disposal (T&D) processes for use at BeAAT were determined to be (URS Corp, 2010):

- containment (from erosion, intrusion, dispersal);
- isolation (<0.3–1 mSv year^{-1} doses by blocking gamma, radon, and groundwater pathways);
- permanence (minimise maintenance and future liability);
- longevity (>200 years); and
- cost-effectiveness.

2.2. Method screening

T&D of NORM-impacted wastes includes segregation/volume reduction methods, treatment/solidification methods, and encapsulation/disposal methods. A variety of methods were identified and screened in terms of relative cost, effectiveness, and compatibility with each other, with the waste streams, and with the BeAAT environment. Three tiers (low, medium, and high) of each of the three parameters (cost, effectiveness, and compatibility) were used to rank each method. Scores from 1 to 3 were assigned for each parameter (with reverse order for costs), and added to estimate a ranking for each method.

2.2.1. Segregation/volume reduction

Twelve segregation and volume reduction methods used or proposed for use with oilfield NORM wastes were identified and ranked. Five of the methods separate NORM from equipment: hydrolysing, high-pressure washing, rattling, reaming, and chemical dissolution. Six other methods separate water and oils from solid NORM wastes: centrifuging, flocculating, solvent extraction, incineration, cyclone separation, and evaporation pond. One method is for volume reduction (compaction) and one method is for liquid phase separation (oil–water separation). The most useful methods for the waste streams at BeAAT were determined to be hydrolysing, high-pressure washing, incinerating, cyclonic separation, evaporation pond, and oil–water separation.

2.2.2. Treatment/solidification methods

Three solidification methods were assessed with the same ranking method. These included concrete cube solidification, grout solidification, and vitrification. The concrete cube and grout methods are similar, involving use of NORM-contaminated water to make concrete or grout, and incorporating oil-free NORM solids (from sludge and scale incineration) into the concrete or grout mix. Large (1 m^3) cubes currently made at BeAAT for hazardous wastes will use up to 40% high-NORM scale in the mix, along with gravel and sand aggregates to make low-permeability monoliths. Grout will use a similar low-permeability mix with lower-NORM sludge solids, targeting flow ability for use as backfill in and around equipment, and in making low-NORM monoliths that could be disposed of directly. Vitrification scored lowest because of its potentially lower suitability for NORM wastes and high energy, as well as handling costs for large waste volumes.

2.2.3. Encapsulation/disposal methods

Nine encapsulation or disposal methods were evaluated. These included concrete vaults, high-integrity containers, bitumen membranes, bitumen volumetric fill, polymerised plastics, grouting (tubing and equipment), containment in equipment, landfill cover/liner systems, and well injection with hydrofracture. The most useful in this category were identified as concrete vaults, routing equipment cavities, and landfill burial. Bitumen surface coatings were also considered for deflecting any infiltrating water from concrete/grout monoliths, primarily for their low costs. Injection well disposal also ranked highly, but this was not considered to be feasible because there are no known opportunities to use it in the BeAAT area.

2.3. Optimum treatment and disposal processes for BeAAT

The combinations of the most promising processes were examined to develop a T&D strategy best suited to the ADNOC wastes and the BeAAT environment. The prime disposal option for meeting the disposal objectives and using the BeAAT site was determined to be landfill disposal. While the dry Ruwais environment is ideal for landfill disposal, the relatively shallow water table could be problematic. Secondary containment in low-permeability concrete canisters was therefore considered to be important in meeting the longevity and isolation objectives. Conversion of the wastes into low-permeability waste forms, such as concrete cubes and grout ingots, was chosen as an additional measure to reduce risks from leaching of radium into the groundwater. Incineration of both sludge and scale wastes appears to be the simplest and least-expensive means of removing hydrocarbons sufficiently from the raw waste streams to render the solid residuals suitable as ingredients for concrete and grout. For NORM-contaminated equipment, a combination of hydrolasing for pipes and tubing, and high-pressure washing for tanks and other vessels offers the most efficient moisture removal with good containment of the removed NORM. Water associated with equipment and facility cleanout, and the incinerator scrubber will be filtered and recycled as much as possible, but will use an evaporation pond to accommodate excess volumes that cannot be used in concrete and grout mixes.

2.3.1. High-NORM treatment and disposal

The combination of processes for the highest-NORM scale wastes include hydrolasing to remove them from pipes and tubing, supplemented by high-pressure washing of scale in separators and other non-tubular equipment. A hydrocyclone separator and filter will remove most scale from the wash water, allowing much of it to be re-used for equipment cleaning. Excess water will be drained to an evaporation pond after removal of solids, and an incinerator will be used to burn off residual hydrocarbons from the drained scale solids. The incinerator scrubber will use NORM-contaminated water from the evaporation pond. Dried scale solids will be moistened with evaporation pond water for safe transfer from the incinerator to the concrete batch plant, where they will be mixed with clean aggregate, evaporation pond water, cement, and pozzolans to form low-permeability concrete. The concrete will be cast and cured in 1-m^3 cubes, similar to those used at present for hazardous wastes at BeAAT. The cubes will be loaded into concrete canisters, grouted to fill residual void spaces. Closed and sealed canisters will be placed in the Class 1 landfill, where their top and side surfaces will be coated with a bitumen moisture barrier to deflect any infiltrating water. Canisters will be covered periodically by flowable fill. The covered canisters will finally be isolated by an engineered cover system for closure of the landfill.

2.3.2. Low-NORM treatment and disposal

A similar combination of processes will be used for low-NORM sludge wastes. These are generally removed from equipment, where necessary, by high-pressure washing. An oil–water separator will be used to separate excess oil from the wash water before it is drained to the evaporation pond. Sludge solids will be burned in the incinerator and treated in the same way as the scale solids, except that the sludge solids will primarily be used to prepare low-permeability, flowable grout. The grout will be used to fill voids in equipment being disposed, concrete canisters, and to seal canister lids. Excess grout material will be cast into cubic or ingot monoliths for disposal in the landfill outside the concrete canisters. The ingots will be coated with a bitumen moisture barrier before burial in the landfill.

2.4. Injection well disposal

Based on the US experience, it may be more cost-effective by reducing waste handling and processing it for deep well injection. This technology requires different treatment equipment such as tanks and pumps to support injection, hydro-fracture, and monitoring. However, at present, no available or suitable deep-disposal formations have been identified in the BeAAT vicinity that could potentially have satisfied the containment, isolation, permanence, and longevity criteria for NORM wastes.

2.5. Chemicals

No liquid chemicals are used for NORM removal, and no spent-chemical wastes are generated. Solid products used for concrete and grout include cement powder, pozzolans, and water reducers. Solid bitumen is melted as necessary for coating concrete and grout surfaces, and small quantities of solvent may be required for bitumen equipment clean-up. Rags and rubbish contaminated with bitumen and solvent will be incinerated with the sludge waste stream.

Welding/cutting gases will be required to support equipment cutting operations. Dust-suppressing agglomeration chemicals may be used as necessary to reduce dust resuspension from NORM-contaminated materials.

2.6. Support facilities

The NORM T&D facility at BeAAT will require a variety of supporting equipment. This includes fork-lifts, crane and rigging, front-loaders, and excavation/construction equipment for handling and moving materials, supplies, equipment, and waste cubes/ingots, as well as for excavation and preparation of landfills. Pumps, filters, cyclone separators, and tubing will be required to support the pressure washing equipment, incinerator scrubber, concrete plant, and evaporation pond. Gamma scintillation meters and beta/gamma meters will be needed for equipment surveys and assessing surface contamination, respectively. Air sampling/monitoring equipment will be required in the equipment cleanout, incinerator, and concrete mixing areas, supported by water sprayers and antidusting additives as needed. Cutting/welding equipment will be needed to open equipment such as separators for internal decontamination. Drainable concrete pads will be needed for equipment staging, cleaning, and supply storage.

2.7. Treatment capacity

The NORM T&D operation is sized to accommodate quantities currently stored as historical waste and the wastes produced in the first year. The T&D operation would handle approximately 370 m^3 of contaminated equipment (plus contingency), 450 m^3 of sludge, and 50 m^3 of scale solids. Disposal capacity allows for disposal of 300 m^3 of contaminated equipment, 130 m^3 of high-NORM concrete, and 520 m^3 of low-NORM grout in 50 15-m^3 concrete vaults. An additional 610 m^3 of low-NORM grout ingots would be disposed of in landfill outside of the concrete vaults. The landfill dimensions are estimated at 30 m x 30 m x 3 m, and the evaporation pond dimensions are estimated at 35 m x 35 m x 2 m. The concrete batch plant accommodates 5-m^3 batches, and the incinerator accommodates approximately 10 m^3 per batch.

3. SAFE NORM HANDLING AND TRANSPORTATION

3.1. NORM handling

Safe handling of NORM-impacted materials requires training and awareness, worker protection, and contamination control. Graded training requirements include NORM awareness training for all BeAAT workers, technical training for workers who clean equipment and handle NORM, and supervisory training for NORM T&D managers and radiation safety officers. Worker protection includes continuing training and safety meetings, isolation of operating areas, and restriction of operating areas to essential personnel. Contamination control includes published waste acceptance criteria, advance notification/scheduling of waste shipments, clear labelling/signage for equipment and operating areas, dust control guards and moist-handling of NORM solids, operation only with trained personnel with proper equipment and personal protective equipment, monitoring for landfill leachate and evaporation pond leakage, and secure transportation of NORM wastes to the site and within the site.

3.2. NORM transportation

Shipments of NORM-impacted wastes to the site should be, as per international standards (IAEA, 2005), regarded as low-specific activity (LSA)-1 or surface study contaminated object (SCO)-1 materials, unless they are determined to be below the 100 Bq g^{-1} Ra-226 or Ra-228 threshold, which is the case for ADNOC's waste. These categories allow minimal packaging provided that:

- there is no escape of radioactivity under routine transport conditions;
- material is transported in exclusive-use vehicles; and
- exclusive-use vehicles are not required for SCO-1 materials with minimal surface contamination.

Other important transportation considerations include advance notification and planning; provision of emergency contingency plans to the vehicle operator; use of appropriate placards and signage; records of shipment description, contents, waste form, volume, and quantity of NORM; and use of strong, tight transportation drums, boxes, and bulk containers. Wastes may not contain free water or liquids that could drain, should the containment leak or become damaged. Contaminated equipment may be shipped without packaging provided that all openings to the contamination are secured by threaded caps or other durable tight closures to prevent leakage.

4. CONCLUSIONS

By developing, designing, and implementing this NORM T&D project, ADNOC was able to solve a historical dilemma in dealing with NORM waste. This solution is a transferable example for adaptation by oil and gas operating companies in the Middle East.

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