Conclusion

Concerted efforts are needed to sensitize and create awareness among NARS scientists/scholars in building institutional repositories. Similar to Zonal Technology Management Units (ZTMU) and Institutes Technological Management Units (ITMU) in ICAR, which are working for securing patents and commercialization of the technological advances of ICAR institutes, other NARS institutions should also establish Research Assessment Metrics Cell (RAMC) to address the issues related to sharing of published research and copyrights. ICAR and Indian Agricultural Universities Association (IAUA) should make it mandatory to establish OARs in all the ICAR institutions and SAUs to deposit all the published research output, and then agricultural research knowledge would be freely available to all the stakeholders. The National Institute of Technology, Rourkela was the first to mandate OA in India and the only agriculture research institute to mandate OA for all its research publications is the International Crops Research Institute for Semi-Arid Tropics, Hyderabad (http://www.eprints.org/openaccess/policysignup) to share and disseminate wisely the results of its research and development activities. Similarly, NARS institutions should also make its OA mandates. In a recent study on the impact of the internet on institutions in the future by Janna Quitney Anderson of Elon University; the technology experts and stakeholders said that the internet would make government agencies more responsive and efficient by 2020 through innovative forms of online cooperation[8]. Are we ready to make most use of the internet for agriculture research and development? Or should we wait till the Indian government passes legislation for accessing publicly funded research?[6].

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Drill cuttings and fluids of fossil fuel exploration in north-eastern India: environmental concern and mitigation options

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Energy producing companies require drilling fluids and additive oils for drilling, gas and lubricants that are essential for modern civilization and industrialization. Biological wastewater is conventionally treated for the elimination of organic and inorganic pollutants. In the fossil fuel industry, drill cuttings and fluids are the piled up wastes and an environmental hazard. The high complexity of this hydrocarbon mixture (aromatic or napthenic nature) makes it highly resistant to biodegradability. Besides, the antibacterial agents, which are frequently used in the drilling operations, increase the difficulty of the biological treatment.

Several major oil and gas companies such as Oil and Natural Gas Corporation, Oil India Ltd, Canoro Resource Ltd, Geoenpro Petroleum Ltd, Jubilant Energy, Geopetrol International Inc. and Premier Oil, are involved in exploration activities in north-east India. The Ministry of Environment and Forests (MoEF), Government of India has accorded environmental clearance (EC) for drilling over 400 exploratory wells to ONGC and about 100 exploratory wells to the Oil India Limited. Also EC has been accorded to several private companies for carrying out exploratory activities in the north-eastern states of Assam, Arunachal Pradesh, Nagaland and Tripura. Since the implementation of Environment Impact Assessment Notification in 2006, handling of drilling cuttings and fluids of fossil fuel exploration has been a subject of environmental concern. The major EC stipulation with regard to management of drilling fluids (mud) and drilling cuttings includes only water-based mud (WBM). WBM is considered comparatively less hazardous than oil-based mud (OBM) and synthetic-based mud (SBM). OBMs are very effective but highly polluting, and environmental regulations insist on their restricted use in several countries. Exploratory companies are required to comply with guidelines for disposal of solid wastes, drill cuttings and drilling fluids for onshore drilling operation as per the notification vide GSR.546 (E) dated 30 August 2005. In order to reduce the mud toxicity, Hamed and Belhadri[1] developed a WBM system using two biopolymers, viz. xanthan gum and scleroglucan. It is generally accepted that these biopolymers exhibit high permeability for complex geometries such as horizontal wells.

In recent times, oil and gas industry has developed new drilling techniques for exploratory and extraction purposes. In order to increase productivity, drilling must reach rock (either horizontal or directional well). In these explorations, drilling mud requires specific properties. The literature reports that the most effective drilling fluids are oil, crude or synthetic based, but their impact on the environment is very important.

Drill cuttings originating from on-shore and separated from WBM should be properly washed and unusable drilling fluids are disposed off in a well-designed pit lined with impervious liner located off- or on-site. The disposal pit should be provided additionally with leachate collection system. No leachate collection system is provided by the major companies in this region as stipulated. Generally, the exploratory well depth in north-eastern India ranges from 2500 to 3500 m. The drill cuttings generated from an exploratory well ranges from 230 to 550 m^3. The approximate composition of drilling fluid constituents including the approximate quantities required for drilling an exploratory well are provided in Table 1.

During drilling operations, large amount of drilling mud is lost into the geological formation. In this case, normal mud circulation is no longer possible and the fluid level of the borehole drops drastically creating a dangerous situation. A variety of mixtures are used in different situations; many of the formulations are well guarded secrets and are known by trade names only. The major wastes generated during exploratory activities include drilling fluids, drilling cuttings, sludge from wastewater treatment plant and treated wastewater. Therefore, the WBM from drilling wastes may contain free oil, dissolved aromatic hydrocarbons, heavy metals (Figure 1 *a*–*d*) (chromium, copper, nickel, lead, zinc, barium, mercury, cadmium, etc.), radionucleides (minerals such as barite and bentonite and some drilling chemicals may contain minute amount of radium), biocides and other additives. Some additives used as defoamers, descalers, thinners, viscosifiers, lubricants, stabilizers, surfactants and corrosion inhibitors are reported to have effects on aquatic organisms ranging from minor physiological changes to reduced fertility, lower feeding rates and higher mortality depending on the concentrations.

Drilling for fossil fuel exploration generates a large amount of waste material which gets eroded and re-transported to the surface. This will cause soil degradation and the waste materials thus generated are often very unstable and become sources of pollution. The direct effects are loss of cultivated land, forest or grazing land, and the overall loss of production[2]. The indirect effects include oil and water pollution and siltation of rivers and ravines. These eventually lead to the loss of biological diversity and economic wealth[3]. Bioremediation of such sites can fulfil the objectives of stabilization, pollution control, visual improvement and removal of threat.

There has been a continuous increase in publication of articles on bioremediation of drill cuttings (Figure 2). Bioremediation of the disposal site would help avoiding construction of hundreds of concrete structures in the region and will save the exchequer millions of rupees that would be required for creation of landfill sites with leachate collection systems in this region. The available biodegradation and clean-up technologies are based on bioremediation principles and using physico-chemical treatment by

Table 1. Approximate composition of drill cuttings and fluids of fossil fuel exploration

Chemical	Purpose	Quantity (approx.)
Barite	Weighting additive	> 500 tonnes
Bentonite	Viscosifier	> 25 tonnes
Caustic soda KOH	pH control	> 8.0 tonnes
Potassium sulphate K_2SO_4	Hole stabilization	> 175.0 tonnes
Sodium bicarbonate	pH control	> 2.0 tonnes
Calcium carbonate	LCM	> 30.0 tonnes
Citric acid	pH control	> 1.0 tonnes
Biocides	Bacterial control	> 300 gallons
Soda ash	Calcium control	> 1.5 tonnes
Kwikseal	LCM (Lost circulation material)	16.0 tonnes
Nut plug	LCM	> 7.0 tonnes
Poly sal/PAC	Filtrate control	> 40.0 tonnes
Mica/starch	Filtrate control	> 4.0 tonnes
Douvis	Rheology control	> 4.0 tonnes
EO lube	Lubricant	> 1000.0 gallons
Glycol	Cloud point	> 2700.0 gallons

Figure 1. ***a***, Drill cutting fluid due to exploration of fossil fuels. ***b***, Stored in valley with high density poly ethylene lining. ***c***, Leachate through hill crevice. ***d***, Concrete leachate collection and treatment system facility at Masimpur, Cachar, Assam.

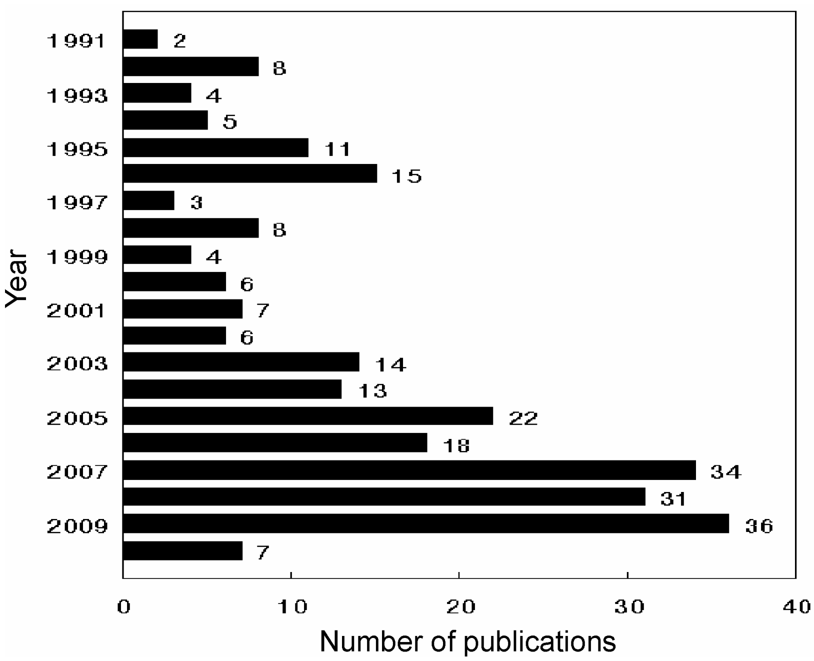

Figure 2. Continuous increase in publications featuring the use of bioremediation of drill cuttings (source: www.sciencedirect.com; search parameters used = (drilling fluids AND bioremediation). A total of 254 articles have been indexed in ISI web of science starting with only 2 in 1991.

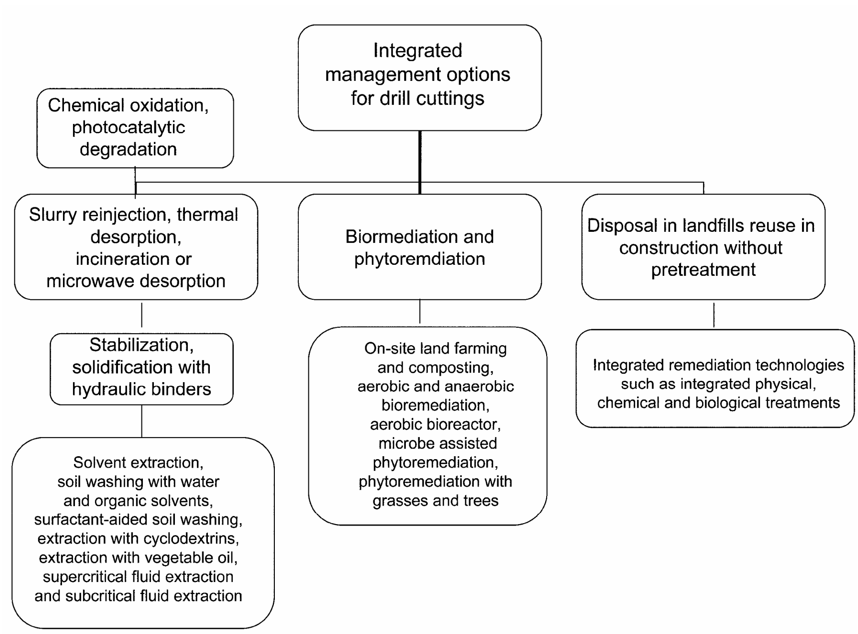

Figure 3. Integrated remediation technologies for drill cutting and fluids of fossil fuel exploration fluids. For details see refs 10–25.

washing the contaminants[4]. There has been a growing interest in bioremediation applications in environmental remediation[5–7], for e.g. biosurfactants. The mechanism behind surfactant-enhanced removal of oil from soil has been proposed to occur in two steps: mobilization and solubilization[8]. Biosurfactants are produced by many microbes in response to their growth in petroleum hydrocarbons. These compounds offer greater potential than chemical surfactants in bioremediation of petroleum hydrocarbons (PHCs) as they exhibit lower toxicity, greater biodegradability and environmental compatibility. Plant-assisted bioremediation is the actual degradation process that is performed by microorganisms in the rhizosphere. Plants promote microbial growth and activity in their rhizosphere (rhizosphere effect) by positively altering or regulating the soil environment (e.g. pH, moisture). Due to root penetration, soil aggregates are loosened and oxygen, which is needed for oxidation of contaminants, can enter even deep soil layers along root channels. Tropical pasture grass, for e.g. *Brachiaria brizantha* is reported to enhance the rhizosphere microflora, viz. bacteria, fungi and degraders of alkanes, aromatics, cycloalkanes and crude oil in petroleum hydrocarbon contaminated soil (sludge amended soil)[9]. Oil sludge degradation under the influence of *B. brizantha* is due to microbial activity[10]. Other factors like oxygen availability, plant enzymes and synergistic degradation by microbial consortia are also known to play a key role. Fungi play a significant role in degradation of oil sludge, since they tolerate lower pH than bacteria. Native species found in the region are the best candidates to cover a range of physiology and root morphology. Studies on thousands of abandoned disposal sites in the northeast region should be undertaken to assess their actual hazardous potential. So far, there is no single management option for drill cuttings. Integrated remediation technologies are being followed for effective management of drill cuttings and fluids of fossil fuel exploration (Figure 3).

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