

PETRONAS TECHNICAL STANDARDS
HEALTH, SAFETY AND ENVIRONMENT

**DECOMMISSIONING, REMEDIATION AND
RECLAMATION OF ON-SHORE E & P SITES**
(GUIDELINE)

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AMENDMENTS RECORD SHEET

Chap No.	Sect No.	Description	Issue No.	Date	Rev No.	Date	App by: (initial)
All	All	PTS 60.198 Decommissioning Remediation & Reclamation	1	Sept 04	0	0	IGA

Chap No.	Sect No.	Description	Issue No.	Date	Rev No.	Date	App by: (initial)
All	All	PTS 60.3006 Decommissioning Remediation & Reclamation Of On-shore E & P Sites	1	June 05	0	0	IGA

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1 INTRODUCTION

1.1 SCOPE

These guidelines have been prepared for oil and gas and petrochemical companies to provide information on decommissioning, remediation and reclamation of on-shore oil and gas exploration and production and petrochemical sites. Decommissioning, remediation and reclamation programs should be prepared on a site-specific basis. The guidelines therefore promote flexibility in planning by recognising a range of environmental conditions, which could be encountered by oil and gas and petrochemical operations worldwide. These guidelines will have particular relevance in those countries where regulations concerning decommissioning, remediation and reclamation are not yet developed.

The following terms are defined for the purposes of these guidelines:

Decommissioning: facility closure followed by removal of process equipment, buildings and structures. This includes the plugging and abandonment of wells.

Remediation: the management of contaminated soil, surface water and groundwater to prevent, minimise or mitigate risks to public health and safety of the environment.

Reclamation: the actions required to return a site to a pre-determined land use that meets company, government and/or local needs.

Further definitions are provided in the *Glossary of Terms*.

1.2 PURPOSE OF THE GUIDELINES

The purpose of these guidelines is to provide information on the steps necessary to plan and implement decommissioning, remediation and reclamation programs. They are particularly relevant for exploration sites, small oil and gas production sites and petrochemical sites and have been developed for use by OPU/JV company field supervisors and regulatory agency personnel. The guidelines are not intended to provide a prescription for implementation of decommissioning, remediation and reclamation programs. This can be achieved through development of a detailed site or project decommissioning plan with assistance of advisors and in consultation with relevant regulatory agency and community representatives.

The specific objectives of these guidelines are:

- To outline a phased approach for developing and implementing a decommissioning, remediation, reclamation and monitoring plan for a given site.
- To provide decommissioning, remediation and reclamation guidelines for the types of operations and facilities relevant to the oil and gas and petrochemical industries including: access roads, camp sites, drill sites, seismic lines, well pads, oil and gas treatment and storage facilities, gathering lines, pipelines, gas

plants, petrochemical plants, waste disposal and/or treatment sites, pits, ponds and dumps.

1.3 STRUCTURE OF THE GUIDELINES

Experience has shown that a phased approach to decommissioning, remediation and reclamation is the most practical and cost effective. This phased approach allows the level of investigative and remediation effort to be tailored to the size and complexity of the problem. The required level of effort for decommissioning, remediation and reclamation is dependent on the type, size and age of the sites, historical waste management practices, the environmental and regulatory setting, and the proposed future use of the property. The guidelines are presented in sections that correspond to the phases of decommissioning, remediation and reclamation:

*** Planning (Section 2)**

This section describes land use, decommissioning, remediation and reclamation objectives and considerations relevant to program planning.

*** Evaluation (Section 3)**

This section outlines the steps for gathering information necessary to characterise a site for planning purposes. These steps include undertaking site information assessments, general site characterisations and detailed site characterisations.

*** Implementation (Section 4)**

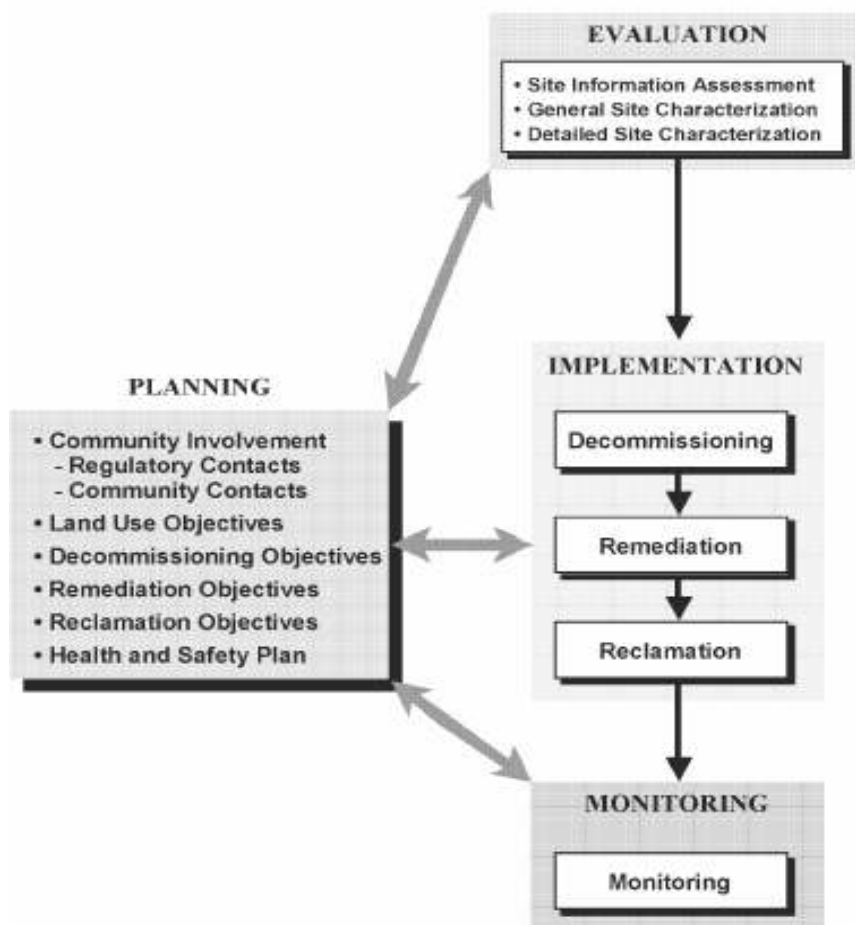
This section describes measures that may be used to implement decommissioning, remediation and reclamation programs.

*** Monitoring (Section 5)**

This section provides measures for confirmation of program success and considerations for post-remediation monitoring.

An overview of the decommissioning and reclamation process is given in Figure 1.

Figure 1 – Overview of Decommissioning, Remediation and Reclamation Process



2 PROGRAM PLANNING

It is essential to execute decommissioning, remediation and reclamation activities within the context of an overall plan. The main activities involved in developing this plan are:

- determining regulatory requirements;
- developing a community involvement strategy;
- establishing land use objectives;
- determining decommissioning objectives;
- determining remediation objectives;
- determining reclamation objectives; and
- developing a worker occupational health and safety plan.

2.1 REGULATORY CONTACTS

Regulations relating to decommissioning, remediation and reclamation typically address:

- planning and permitting;
- environmental protection; and
- health and safety issues.

Involvement of regulatory agencies at appropriate times is essential to obtain the necessary consents and approvals. Typically the oil and gas and petrochemical regulatory agencies will have the guidelines or prescriptive regulations on abandonment of wells and other decommissioning activities. Thus the jurisdictional issues usually involve the agencies responsible for oil and gas and petrochemical regulation, environmental protection, water resources and public health and safety.

It is important to provide for sufficient lead time in the decommissioning, remediation and reclamation plan to ensure that approvals are obtained prior to implementation of the field programs. A local government agency may require information on the condition of the site, the remediation and reclamation program to be undertaken and measures proposed for the protection of public health and the environment. Regulatory agencies may be concerned with transportation and disposal of contaminated material off-site, materials and equipment used and workforce health and safety. Environmental protection legislation may require compliance with air and water quality standards, waste management regulations and remediation criteria.

Depending on the host countries regulatory requirement on the individual OPU/JV company internal requirement, an Environmental Impact Assessment may need to be prepared and approved prior to implementation.

2.2 COMMUNITY CONTACTS

The decommissioning, remediation and reclamation process encompasses social, economic and political issues. Community concerns normally include:

- environmental and human health risks (e.g. those posed by surface water, groundwater pollution, air emissions and transportation of contaminants);
- economic issues (e.g. local employment, effects on property values, impacts on local industry and the value of infrastructure);
- social issues (e.g. effects on community image, aesthetics, alternative and future land uses); and
- community issues (e.g. the vested interests of particular groups, responsibility for site management and local control).

In developing countries, community concerns may also focus on more particular issues, such as:

- access and use of scrap or waste materials from the site;
- reuse of buildings, structures, water supply systems and other similar facilities;
- land use and ownership rights (may be considered from an economic or social perspective); and
- maintenance of temporary access (e.g. tracks, bridges, ferries, etc.).

Community involvement should be tailored to the specific needs and concerns of the area and will be dependent on the scale of the project, the sensitivity of the site setting and the political and regulatory environment. Key elements of a community involvement strategy include:

- identifying the different interest groups (stakeholders) in the community;
- understanding legal or traditional land or water ownership and use rights;
- preparing a decommissioning, remediation and reclamation plan that permits full consideration of program alternatives and mitigation of negative impacts on the community;
- communicating as appropriate with local community representatives about the decommissioning, remediation and reclamation program objectives; and
- considering opportunities for positive impacts on the community (e.g., through

turning over roads, ponds, local employment, etc.).

2.3 LAND USE OBJECTIVES

Future land use alternatives should be discussed with regulatory agencies and other stakeholders as appropriate at an early stage in the planning process so that there is common agreement on decommissioning, remediation and reclamation goals.

Some of the more common end land use objectives are:

- agricultural production;
- commercial forest production;
- wildlife habitat;
- natural growth or parkland areas;
- recreation;
- industrial development; and
- residential development.

2.4 DECOMMISSIONING OBJECTIVES

The objectives of decommissioning planning are to:

- identify facilities/materials requiring removal (e.g. stored raw materials, chemicals and products, above or below ground piping, buildings, foundations, instrumentation, electrical and mechanical equipment, roads);
- identify facilities required for future operations or the anticipated land use;
- identify all wells that must be abandoned;
- identify health hazards and develop appropriate procedures to minimise exposure;
- identify operational and/or logistical constraints associated with decommissioning;
- develop a contaminated material (chemicals, scales, sludges) removal strategy;
- develop a planned sequence for equipment removal; and
- develop safety procedures.

Decommissioning alternatives that may be considered are facility mothballing, partial site decommissioning and complete decommissioning.

Facility mothballing applies where a facility is closed with the intention of future reactivation. Building structures and equipment should be maintained in a state where deterioration is minimised and reuse is possible. Access to the site should be controlled and site conditions monitored on a regular basis. Produced fluids and chemicals that could pose a hazard during the shutdown period should be removed. Any existing contamination may need to be treated or controlled to ensure compliance with applicable regulations and/or to prevent significant incremental contamination.

Partial decommissioning can be used for progressive decommissioning over a facility's life cycle. Progressive or phased decommissioning offers the following potential benefits:

- the opportunity to re-use structures and equipment while they may still have some useful service life;
- the incremental environmental degradation resulting from unremediated contamination can be minimised;
- remediated land areas can be made available for facility expansions that might otherwise occupy previously undisturbed lands;
- the cost effectiveness of various decommissioning, remediation and/or reclamation strategies can be evaluated on a site specific basis before a comparatively large scale, complete facility close out must be executed; and
- positive aesthetic impacts.

Alternatively partial decommissioning may simply involve leaving portions of the facility in place after shutdown when this is compatible with the anticipated future land use. For example, a land owner may prefer that most of a well site be decommissioned except for the access road. In any case, partial decommissioning should incorporate the same technical processes involved in complete decommissioning.

Progressive decommissioning and restoration of facilities in North-West Australia
Construction of a Shelf Gas Project located on the Burrup Peninsula, north-west Australia continued over a 10 year period. However all areas of the Peninsula temporarily disturbed by construction were decommissioned and reclaimed as soon as their interim use ceased. A work camp for 3,000 personnel was used for construction of two LNG trains. Facilities included the barracks, sewage treatment plant, water supply and tanks, roads and recreational areas. The work camp was located between rolling hills in an isolated site with no local population. The site was rocky, hot and arid with plant cover consisting of scrub grass and few trees. The objective was to return these areas to their previous environmental state. Areas reclaimed included laydown areas, borrow pits, roads and a construction camp. Topsoil was carefully recovered and stockpiled prior to construction activities commencing. After construction use, all man-made structures were removed and the area recontoured to conform with surrounding landforms. The conserved topsoil and vegetative material was then spread over the site and the area deep ripped following surveyed contour lines. Slight berms were created across the contour to collect runoff water in this arid environment. These became starting points for vegetation reestablishment. Semi-annual botanical surveys carried out over a 3 year period

confirmed the success of the decommissioning and reclamation program.

There are three basic options for the disposition of equipment, infrastructure and buildings:

- sale or donation of serviceable equipment and buildings;
- recycling of unserviceable equipment and clean demolition wastes as scrap; and
- disposal of unmarketable or contaminated material as waste.

The first two options are the most desirable given their potential for reducing overall decommissioning costs and for limiting environmental impacts.

2.5 REMEDIATION OBJECTIVES

The objectives for site remediation are to ensure that the site:

- adequately protects human health, safety and the environment;
- is suitable for the proposed land use; and
- is aesthetically acceptable.

Remediation objectives are strongly influenced by the land use objectives established for the site. For example, remediation requirements for agricultural land uses are typically more stringent than for industrial land uses.

Remediation criteria can be used to determine when a site is contaminated, when site remediation is necessary and when site remediation is performed to acceptable levels. Remediation criteria are generally categorised into two groups: 1) Generic Criteria; and 2) Site-specific Criteria. Some guidelines for selection of criteria are provided in Table 1.

2.5.1 Generic Criteria

Generic criteria are non-site specific concentrations of contaminants in soil, sediments, surface water or groundwater that are intended to reflect acceptable levels of risk to human health or the environment. These generic criteria are applicable to a wide range of sites and are sometimes referred to as "absolute" because they are independent of site conditions. In most cases, these generic guidelines are based on conservative assumptions and professional judgement.

There are generic criteria available from many jurisdictions that may be considered for application (Appendix A). The various criteria demonstrate that there can be a wide range of values that have been judged to be acceptable for a given chemical of concern. The criteria values have generally been developed for a specific environmental, social and regulatory context. As a result, these criteria may have limited applicability outside the jurisdictions in which they were developed. An owner or operator choosing to use such criteria in other jurisdictions should have a

clear understanding of how they were derived and their suitability for use outside the jurisdictions where they were developed.

2.5.2 Site-Specific Criteria

The development of site-specific criteria often involves a risk assessment undertaken to quantify human health and environmental risks posed by a site. The site-specific criteria derived by this process may be referred to as "risk-based" criteria because they are related to the probability of adverse human health or environmental effects resulting from the presence of contaminants.

A risk assessment involves combining the contaminants' effects on humans and/or the environment (e.g., the toxicity of the contaminant to human, plant or animal life) with a measurement of the probability of exposure to the contaminant. This process includes consideration of the relevant aspects of current and future human habitation, soil and groundwater characteristics, the potential for contaminant migration from the location and the interactions of the residual contaminant with all the biological components of the ecosystem.

Table 1 - Guidelines for Selection of Remediation Criteria

Sites where remediation may not be necessary or can be deferred * There is no evidence of contamination, the concentration of any contaminants are not significantly elevated above background levels or contaminant concentrations are less than the absolute assessment criteria recognised by local regulatory authorities, or industrial / international standard. * Contamination is present, but has impacted modest material volumes and is permanently isolated from people and/or sensitive environments. * Situations involving jurisdictions that allow the responsible deferral of remedial action. * Situations where natural attenuation will reduce contaminant levels to acceptable concentrations within reasonable timeframes. * Situations where remediation (through access or disturbance) will generate greater health and/or environmental risks than leaving residual contamination in place. Sites where generic remediation criteria may be appropriate * Contaminated material volumes and remediation costs are not sufficient to justify the time and expense associated with the development of site-specific risk-based criteria. * Situations requiring quick remedial action. * Situations involving stakeholders that will not be receptive to owner/operator developed risk-based criteria. * Situations involving jurisdictions that accepts above background residual concentrations, which depend on land use. Sites where risk-based remediation criteria may be appropriate * Contaminated material volumes and remediation costs are high enough to justify the time and expense associated with the development of site-specific, risk-based criteria. * The time required to develop defensible risk based criteria does not result in significant incremental environmental degradation. * Situations involving stakeholders that will accept owner/operator developed risk based criteria. * Situations involving jurisdictions that do not recognise generic criteria or that will not accept generic criteria above background levels.

An adverse effect can only occur if the contaminant comes in contact with, and is absorbed by, a receptor (human, animal or plant). The main exposure pathways between life forms and a contaminant are:

- ingestion or plant uptake via soil, food or water;
- inhalation of vapours or contaminated dust; and
- direct contact of skin or plant surfaces with contaminated air, soil or water.

A wide variety of conceptual and mathematical models can be used to assess the pathways by which the contaminant can potentially influence human health and/or the environment. Each model has its own particular data requirements and limitations. This process assumes a knowledge of tolerable risk levels in a population for acute and chronic exposures to specific doses and an understanding of the doses which would result from exposure to soil, water or air containing a given concentration of contaminants.¹ In an assessment of human health risks, lifetime risks to individuals in a population are at issue. In ecological risk assessment, risks to larger scale population balances in the ecosystem are considered rather than risks to individual organisms.

Many risk assessment models have been derived for specific types of contaminants or for specific portions of the environment. For example, the American Society for Testing and Materials has developed a protocol entitled "Emergency Standard Guide for Risk-Based Corrective Action Applied at Petroleum Release Sites" (RBCA). It is a step-by-step approach, primarily to issues in the downstream sector of the petroleum industry, that assesses human health risk from petroleum residues (or associated chemicals) at specific sites². The tiered RBCA approach advocated is appropriate for analysing both simple or complex situations with the appropriate level of resources. This protocol currently has only a limited ecological component and is being adapted for E&P sites.

Use of Risk Assessment in Setting Remediation Goals

Two oily pit areas originating from the early 1900's had been abandoned by pushing in the sides of the pits. As an adjacent city grew, the sites came under regulatory screening. A site assessment and risk assessment were subsequently undertaken and a remediation plan developed in consultation with regulatory agencies. Approximately 20,000 m³ of soil was estimated to be contaminated with crude oil (greater than 3% TPH). The state had initially recommended a cleanup level of 1% TPH but accepted a 3% TPH cleanup level based on the findings of the risk assessment. This resulted in savings of about \$300,000 in remediation costs but still provided the required level of public protection.

It should be noted that it is **not always necessary or desirable to develop site specific criteria on the basis of detailed quantitative risk assessments**. Depending on contaminated material volumes and the anticipated costs of risk assessment, it may be advantageous to apply non-generic standards that are readily available or comparatively easy to assemble (e.g. background levels or standards demonstrated as acceptable in other similar ecosystems). In addition, depending on the scale of the problem and/or sensitivity of the local environment, relatively simple qualitative or semi-quantitative risk assessments may be acceptable alternatives to more elaborate and time consuming approaches.

2.6 RECLAMATION OBJECTIVES

The broad objective of reclamation is to return the site to a land capability equivalent to pre-disturbance conditions or to that of adjacent lands. The land capability is defined as the ability of the land to support a given land use based on characteristics such as topography, drainage, hydrology, soils and vegetation ³. This approach allows for flexibility in setting land use objectives in that the proposed future land use may be different from previous land uses or the adjacent land use, provided the land capability is unchanged. Specific reclamation objectives include the following:

- ensuring that the site is suitable for the proposed land use;
- ensuring that replaced soils (topsoil and subsoil) have a soil capability sufficient to meeting the land use objective;
- contouring the land surface to meet the land use objective and to ensure stability;
- protecting the land surface against wind or water erosion;
- providing for surface drainage;
- revegetating the land to meet the land use objective;
- re-establishing surface water resources to meet the land use objective; and
- ensuring that the site is aesthetically acceptable.

Although reclamation typically proceeds after decommissioning and remediation, reclamation planning should be incorporated as early as possible into the overall planning process. In addition, reclamation may be required at various times during a project's life-cycle, not jut after facility shut down. For example, construction activity typically disrupts considerably more land surface than is used during facility operations. This means that at least partial reclamation will be necessary many years before facility abandonment. These partial or phased reclamation requirements may also become evident as portions of a producing field are shut down for various operational reasons (e.g. high water cuts). These partial reclamation needs emphasise the requirement to undertake some planning comparatively early in a facility's life cycle. Indeed, some of this planning should proceed in concert with the development of a project Environmental Impact Assessment (EIA) and environmental management plan. Guidance for these early planning efforts can be found in (E&P Forum ⁵⁵).

Failure to incorporate reclamation into decommissioning planning ultimately leads to site degradation.

Exploration drill sites were located in mixed dipterocarp forest in Brunei. The drill sites of approximately 4 to 5 ha were cleared of forest vegetation, levelled and paved with laterite at the site of the drill rig. Storage pits were excavated to hold water and drilling mud. Upon abandonment, after up to 18 months of drilling activity, the paving was removed and the

storage pits infilled. No attempt was made to revegetate the abandoned sites. The result was that 14 years after site abandonment over half the cleared area was still bare ground with extensive erosion. The remainder of the site was covered with the coarse grass *Imperata cylindrica*. Natural revegetation of the abandoned drill sites by forest had not occurred⁴.

2.7 DEVELOPMENT OF WORKER OCCUPATIONAL HEALTH AND SAFETY PLAN

Prior to implementation of any field program, appropriate health and safety protocols should be put in place to adequately manage the risks of incident from physical, biological and chemical hazards to workers. This typically includes development of a worker occupational health and safety plan as a part of the overall planning process.

The main components of a typical plan include:

- a site characterisation describing the study location, project scope and duration;
- a hazard analysis describing potential chemical, physical, pathological and safety hazards that are anticipated on the site;
- a description of the key personnel involved with the project, their responsibilities with regard to health and safety (including designation of a project health and safety coordinator and a site safety advisor) and a reporting structure;
- requirements for personnel protection equipment (PPE);
- procedures for equipment and materials handling;
- site access protocols;
- requirements for controlling and monitoring personnel exposures and for handling/storing chemicals, fuels and contaminated materials;
- a site safety protocol incorporating recommendations for personal conduct (e.g. use of the "buddy system") and personal safety measures (e.g. security arrangements during in-country travel and at living quarters).
- an emergency contingency plan describing the location of hospitals and clinics, first aid procedures, emergency response procedures and an evacuation plan.

A summary of the issues to be considered in the development of a health and safety plan are provided in Table 2.

Table 2 - Issues to be considered in development of a Worker Occupational Health and Safety Plan

Hazard	Issue	Worker Safety Plan Requirements
Electrical	Underground and above ground power cables.	Determine location of power cables prior to drill programs or excavation of pits; Safety protocols and training.
Physical	Unstable slopes; dangerous debris; heavy machinery; surface water; confined spaces; trenches, excavators.	PPE (hard hats, flotation devices); pit/trench supports; safety protocol and training; barriers and access controls (marking/maps).
Noise	Aesthetic impact and ear damage.	PPE (ear muffs); safety protocols and training.
Temperature	Stress and heat exhaustion; hypothermia.	Safety protocols and training; clothing.
Radiation	Exposure to radiation from NORM, LSA scale.	Dosimeters to monitor exposure; dust suppression; respirators; safety protocols and training.
Pathological	Disease, infections and parasites.	Inoculation; medical examination; PPE (e.g. respirators, insect repellents).
Chemical	Explosion; fires; skin and eye contact/irritants; inhalation and ingestion (e.g., heavy metals, acids, caustics, herbicides, volatile organics, PCB's, other chlorinated hydrocarbons, asbestos, H ₂ S).	Determine locations of underground pipelines prior to drill programs or excavation of pits; decontamination equipment and clothing; vessel entry procedures; control of ignition sources; PPE (e.g. latex or neoprene gloves, Tyvex suits, safety glasses, etc.); dust suppression; respirators; medical examination; prohibition of eating, drinking and smoking on-site; safety protocols and training.
Gas	Underground public utility or oil field pipelines.	Identification; demarcation; worker instruction.
Transportation	Helicopter, air and road travel.	Equipment selection; safety protocols and training.

3 EVALUATION

The purpose of the evaluation phase is to gather information on facilities for decommissioning, remediation and reclamation planning and implementation. Evaluation may encompass up to three levels of investigation: site information assessment, general site characterisation and detailed site characterisation (Figure 2). Evaluation of a given site may stop at the completion of any of the three levels of investigation if sufficient information has been obtained to assess risks and reclamation and decommissioning needs. An owner or operator can then proceed directly with implementation.

3.1 SITE INFORMATION ASSESSMENT

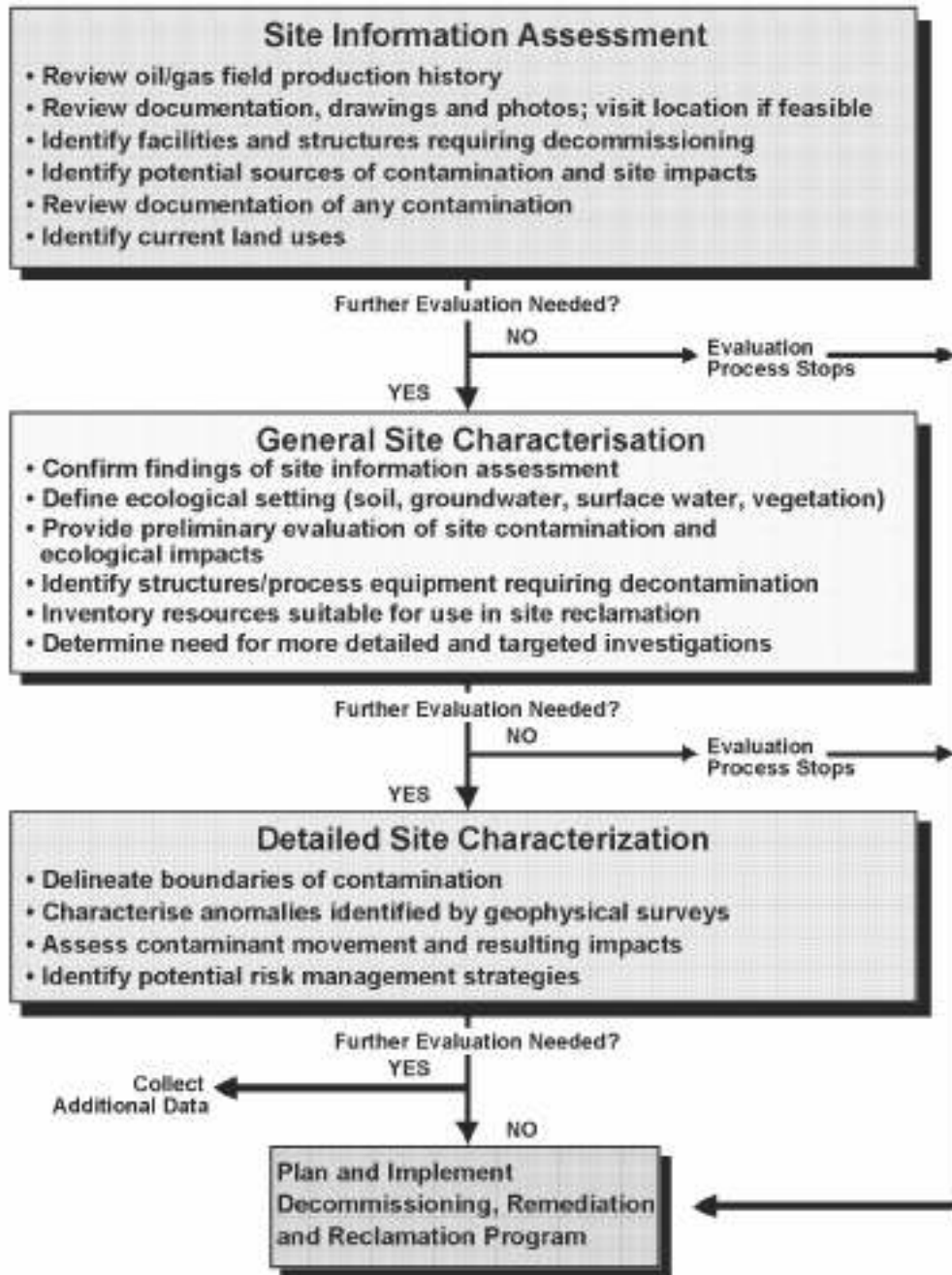
The objectives of the site information assessment are to identify wells, facilities and structures requiring decommissioning, to identify known or potential sources of contamination and to identify reclamation requirements for the proposed land use. The site information assessment identifies and defines environmental concerns associated with a facility primarily through a desk study and a brief visual inspection. Information (if available) should be reviewed back to the first property use (i.e., prior to development) that may have affected site environmental conditions. The effective identification and utilisation of existing knowledge is far more economical than obtaining the knowledge from field programs and provides an historic context that cannot be obtained by other means.

3.1.1 Scope

The site information assessment typically involves compiling and reviewing the following information:

- site and facility description;
- well location and history;
- construction practices;
- development and operational history;
- location and history of fuel and chemical storage;
- waste production and disposal history;
- spill and leak history;
- environmental protection practices;
- environmental setting; and
- environmental monitoring records.

Figure 2 - Key Components of the Evaluation Phase



The assessment scope will be dependent on the age and nature of the facility to be decommissioned. For example, the available operational history will normally be more extensive for petrochemical and gas processing plants than for a well site. If neighbouring properties may affect, or be affected by the property they should be included in the site information assessment. Where possible, an orientation visit to the site should be made, or current photographs of the site examined, to provide an indication of the physical layout of the site and to confirm the accuracy of available site and facility description information.

3.1.2 Sources of Information

Information on the ecological setting and operational history of the facilities or individual well site can be obtained from a number of sources including owner or operator records, government agency records, maps and reports (Table B1, Appendix B). The assessor should document each source of information that is examined, even if a source provided no findings or no response was received. In many countries, some types of information (e.g., spill records, waste management records, as built drawings) will be unavailable or unreliable. Current and historical aerial photographs and satellite imagery can be used to identify physical features of the site, site infrastructure and access, potential contaminant sources and current and historic impacts.

Interviews with current and former employees with knowledge of the facility and regulatory agency personnel are often one of the best sources of information. Questionnaires in the local language can be provided to the relevant personnel prior to any interviews. These should include requests for records, maps and site plans and should cover the topics listed in Section 3.1.1.

3.2 GENERAL SITE CHARACTERISATION

The objectives of the general site characterisation are to confirm the findings of the site information assessment and to provide site-specific inputs for decommissioning, remediation and reclamation planning and implementation (Figure 2). Typically a phased approach is used when undertaking field assessments to characterise facilities. A general site characterisation (which is usually a visual inspection with limited media sampling and analysis) may be followed by a detailed characterisation which incorporates a more comprehensive sampling and analysis program (Figure 2).

For many small oil and gas production sites (e.g. a well site or battery) a general site characterisation may adequately establish environmental conditions and provide sufficient information for decommissioning, remediation and reclamation purposes. However, on larger or more complex sites, a more detailed sampling and analysis program may be necessary.

3.2.1 Investigative Techniques

General site characterisations usually involve the use of simple techniques to describe site conditions augmented with limited soil, surface water and groundwater sampling and analyses.

3.2.1.1 Site Inspection

Standard field assessment data sheets should be prepared prior to the site inspection. These can be completed at each site and will provide for consistent evaluations of conditions. An example checklist for a general site characterisation is given in Appendix C. A description of how the information recorded can be used is outlined in Table 3.

3.2.1.2 Geophysical Surveys

Geophysical survey methods that may have application for general site characterisations are given in Table 4. These surveys can sometimes be helpful in identifying general stratigraphic conditions, subsurface inorganic contamination (e.g., groundwater contamination resulting from saline produced water), buried metal structures (e.g., pipelines, underground storage tanks, buried drums, etc.) and landfills. Geophysical methods can be used to reduce requirements for soil and/or groundwater sampling and analysis.⁵ However, these techniques are subject to interferences from various natural and/or man-made phenomena that limit their usefulness in some situations (e.g. variations in stratigraphy, adjacent metallic structures and equipment). Local conditions should be evaluated carefully before undertaking geophysical investigations.

3.2.1.3 Portable Instrumentation

Portable instrumentation can be used for preliminary characterisations of soil and water conditions, particularly at remote sites (Table 5). Data from these preliminary analyses should be compared with visual observations (soil staining, patches of bare vegetation, hand auger logs) to describe the potential scale and mobility of contamination. These instruments will provide an indication of the relative severity of contamination at a given site but analyses for individual parameters of concern will still be necessary to compare contaminant levels to remediation criteria (see Section 2.5).

In some oil and gas fields, naturally occurring radioactive materials (NORMs) may be present in the form of scale and sludge in production tubing, heater treaters and salt water tanks⁶. Where the presence of NORM is suspected, a sodium iodide scintillation detector can be used to survey the exterior of production equipment at selected sites using appropriate survey techniques^{7, 8}.

Table 3 - Utilisation of Typical General Site Characterisation Information

Type of Information	Use
Site infrastructure (plants, wellheads, injector wells, pits, lagoons, tanks, buildings, and access roads).	Structures or process equipment which require decontamination prior to removal and disposal; potential sources of contamination; structures that must be removed or altered to allow natural drainage across the site; access requirements.
Topography and surface drainage pattern.	Pathways for spread of contamination; length and steepness of slopes determine need for recontouring prior to revegetation.
Extent of surface disturbance and natural recovery.	Areas requiring reclamation; gravelled or compacted road surfaces that require removal or physical treatment prior to revegetation.
Adjacent land use and vegetation cover.	Proximity to residents and other potential receptors; determining land capability and land use objectives; remediation objectives; surface water and groundwater use in the area; plant materials for use in revegetation.
Hydrogeological Conditions	Information on water table and aquifer depths, subsurface stratigraphy and natural groundwater quality is necessary to assess the risks that contamination might pose to both groundwater and surface water resources.
Location of surface water bodies and shore lines.	May need to evaluate impacts of site discharges on benthic communities and sediment/water quality.
Surface erosion, soil stability.	Need for recontouring, erosion control measures.
Fuels, chemicals and wastes present on site.	Types, locations, quantities and condition requiring removal or treatment.
Contents of electrical equipment and hot oil systems.	Estimate volumes of PCB containing materials and the potential for PCB contamination of soils and waters.
Storage tank/process equipment contaminant inventory.	Types, locations, quantities and condition requiring cleaning and/or removal. Determine number of underground storage tanks and evaluate the associated potential for leakage.
Spill and stain characterisation.	Preliminary estimate of volumes of contaminated soil from leaks and spills.
Pit inventory.	Types, locations, condition and contents of pits that may require remediation.
Soil resources present.	Quantity and quality of suitable surface soil (or organic amendments) available on or near site for use in remediation and/or

	reclamation of disturbed surfaces.
Surface water, spring and seepage (leachate) characterisation.	Local surface water and groundwater quality.
Location map of samples collected and borehole/test hole logs.	Estimate of area and volume of contaminated soil; rate of contaminant movement.
Photographic log and site sketch. Historic and current aerial photos if available.	Location of significant spills or other soil staining; general layout of site infrastructure; historic impacts on vegetation.

Table 4 - Typical Geophysical Survey Methods

Survey Method	Applications	Advantages and Disadvantages
Magnetometers (including vertical gradiometers)	Location of buried steel pipelines, vessels and casing heads.	Magnetic surveys are easy to perform with minimal training; depth limitation for small objects.
Ground conductivity meters	Mapping the extent of leaks or leaching from pits, ponds and landfills; produced water leaks from pipelines; and aquifer contamination from produced water.	Fast surveys are easily performed by one person; depth of investigation ranges from under 1 m up to about 30 m; metal conductors interfere with readings; little or no data processing is required for single frequency systems.
Ground penetrating radar	Can be used to locate oil leaks, old pits, trenches, large pipes and other structures.	Only effective when sufficient oil is present to appreciably alter the dielectric permittivity of soil or groundwater; even a small quantity of clay in the soil will severely limit the depth of penetration.

Source: (Young ⁹).

Table 5 - Onsite Methods used to analyse Soil or Water

Method	Applicability
Total organic vapour analyser	Provides a gross measure of total volatile hydrocarbons; various analysers (using flame ionisation or photo ionisation detection) are available; measurement of soil vapour concentrations can be used to delineate extent of contamination where volatile hydrocarbons are present.
Portable Gas Chromatography/Mass Spectrometry (GC/MS) Equipment	Provides on-site quantification of volatile organic compounds.
Indicator (Drager) tubes	Indicator tubes are available for specific substances (e.g., benzene, mercury vapour); some other chemical substances may interfere with results.
Scintillometer	Measures gamma radiation levels; can be used to detect presence of NORM.
Conductivity meters	Measures specific conductance of soil/water suspension or water samples; indication of total soluble salts.
pH meters	Measures acidity or alkalinity of soil/water suspension or water samples.
Specific ion electrode	Can be used to measure specific ions (e.g. chloride) which may indicate produced water contamination; other chemicals may interfere with results.
Enzyme immunoassay (e.g. ENSYS Penta RISC System) and other (e.g. HNU-Hanby alkylation reaction) test kits	Quantitative or semi-quantitative methods to indicate the presence of contaminants above specified threshold limits; kits are available for PCBs, BTEX, PAH, total petroleum hydrocarbons and various pesticides. These kits can be helpful for large scale site screening where time constraints are factor or in areas where laboratory capabilities are unavailable or unreliable. Detection limits are generally higher than laboratory methods and these kits will therefore have limited application where detection limits exceed remediation standards.

3.2.2 Suitability of Soil and Plant Materials for Use in Reclamation

The end land use may require reclamation and revegetation of the site following decommissioning and remediation. The capability of surface soils to support the appropriate vegetation cover should be assessed during the general site characterisation. This is particularly important where the end land use is agricultural. Soil from undisturbed areas on the site should be examined to determine horizon sequence and the thickness and depth of topsoil. The volume of topsoil in storage piles should be estimated so that the availability for respreading over disturbed areas can be calculated. Samples from the major soil horizons

should be collected and analysed to determine the suitability and/or limitations of in place soils for use in reclamation. Some of the key physical and chemical properties that should be assessed and their desirable ranges are given in Table 6.

Plant materials such as seedlings, cuttings or leaf litter (which may contain seeds of indigenous plant species) should also be assessed for their potential use in revegetation efforts.

3.2.3 Preliminary Sampling and Analysis

A plan describing sample locations, equipment needs, sampling methods and quality assurance/quality control (QA/QC) procedures should be developed before sampling begins. However, the sampling plan should be sufficiently flexible to permit adjustments during field activities. Problems such as restricted access, equipment failure or unavailability, unanticipated subsurface conditions or adverse weather conditions may necessitate program changes. An overview of sampling procedures for soils, sludges, surface waters and groundwaters is given in Appendix D.

For a general site characterisation, screening or indicator parameters can be used to determine if contaminants are present. These should be selected to be relevant to the location and situation at hand. Some indicator parameters suitable for general assessments of the facilities are given in Table 7. Some non-routine screening parameters such as extractable organic halides (EOX), polynuclear aromatic hydrocarbons (PAHs) or polychlorinated biphenyls (PCBs) may be included where the site information assessment has indicated that they may be present. The significance of these parameters as indicators of contamination is given below:

- pH - provides an indication of acidity or alkalinity when produced water, acid or caustic spills are suspected.
- Electrical conductivity - provides evidence of salt contamination from produced fluid spills.
- Chloride - provides evidence of salt contamination from produced fluid spills.
- ICP metals scan - provides evidence of contamination by metals (e.g., chromium, barium in some drilling muds, lead in pipe dope).
- Hg - provides evidence of mercury leakage from process instrumentation and equipment flowline.
- Total petroleum hydrocarbons - assesses total purgeable and extractable hydrocarbon levels to provide for preliminary evaluations of the toxicity and mobility of hydrocarbon contamination.
- Extractable organic halides - provides evidence of contamination by halogenated compounds that may be associated with some herbicides or solvents.

- PAH scan - provides evidence of contamination by toxic and persistent compounds (polynuclear aromatic hydrocarbons) sometimes associated with flare pit sediments and process sludges.
- PCBs - provides evidence of contamination by toxic and persistent compounds sometimes present in electrical transformers and capacitors.

Table 6 - Parameters useful for Soil Reclamation Assessment

Soil Parameters	Significance	Desirable Range ^a
Texture	Related to soil moisture and nutrient holding capacity; susceptibility to erosion.	20 to 80% sand; <50% clay; <50% coarse fragment content.
Consistency	Related to soil workability (ploughing); susceptibility to erosion and compaction; water infiltration and plant root penetration.	Very friable to firm (when moist).
Reaction (pH)	Influences availability of nutrients to plants, solubility of metals.	pH 6-9.
Salinity and Solidity	Related to salt toxicity to plants; plant moisture availability; soil structure.	Electrical conductivity (EC) <4 dS/m ^b
Sodium adsorption ratio (SAR) <8-12 ^c		
Organic Matter	Related to soil moisture and nutrient holding capacity; soil structure.	1-10%.
Nutrients	Macronutrient (N, P, K, S) and micronutrient deficiencies may limit plant growth.	Dependent on plant species.
Total Petroleum Hydrocarbons (TPH)	Related to plant growth and soil moisture	<1%.

- ^a These are general ranges, the owner or operator should determine their applicability to a particular site and regulatory environment.
- ^b If EC >4 dS/m is caused by ions other than sodium, soil structure may not be negatively affected.
- ^c SAR values above 8 indicate permeability problems in clay - textured soils, higher SAR values may be needed to affect soils that contain less clay and more sand.

Sources: (API 10, 11), (Sims et. al. 12).

Table 7 - Typical Analytical Parameters for Oil and Gas Production and Petrochemical Sites

Soil/Sediment Samples	
Routine:	Salinity (EC, Na, K, Ca, Mg, SO ₄ , Cl) pH Total Petroleum Hydrocarbons (TPH) Metal Scan (including Ba, Pb, Cd, Hg, As, Se, hexavelant Cr)
Non-Routine:	Cation Exchange Capacity (CEC) Exchangeable Sodium Percentage (ESP) Elemental Sulphur Polynuclear Aromatic Hydrocarbons (PAHs) Benzene, Toluene, Ethylbenzene and Xylenes (BTEX) Polychlorinated Biphenyls (PCBs) Halogenated Volatile Organic Compounds (VOCs) Extractable Organic Halides (EOX) Radioactivity Glycols and Amines Sterilant Scan
Water Samples	
Routine (Field):	Temperature pH Dissolved Oxygen Conductivity
Routine (Laboratory)	Total Alkalinity Total Hardness Total Dissolved Solids Dissolved Cations, Anions Total Petroleum Hydrocarbons (TPH) Total Phenols Total Nitrogen Total Phosphorus Total Organic Carbon (TOC) Dissolved Organic Carbon (DOC) Chemical Oxygen Demand (COD)
Non-Routine:	Metal Scan (including Ba, Pb, Cd, Hg, As, Se, hexavelant Cr) Benzene, Toluene, Ethylbenzene and Xylenes (BTEX) Polychlorinated Biphenyls (PCBs) Halogenated VOCs Absorbable Organic Halides (AOX) Polynuclear Aromatic Hydrocarbons (PAHs)

(a) Parameters should be selected on a site specific basis.

3.2.4 Data Evaluation

Completion of the general site characterisation is a decision point determining subsequent actions. If contamination on the site does not represent a significant risk to public health and/or the environment (e.g. soil contamination is not severe or widespread; surface water or groundwater resources are not in jeopardy) and sufficient information is available on site structures, equipment and reclamation resources, it is possible to proceed directly to development of a decommissioning, remediation and reclamation plan (Figure 2).

If further information is required on the extent of contamination, hydrogeological conditions and/or exposure pathways before remediation options or risk management strategies can be determined, a detailed site characterisation may be necessary.

3.3 DETAILED SITE CHARACTERISATION

The objectives of the detailed site characterisation are to delineate the boundaries of contamination, assess contaminant pathways and to identify potential decommissioning and remediation strategies (Figure 2).

The sampling strategy for a detailed site characterisation program should be based on a working hypothesis (conceptual model) that identifies the major issues that need to be addressed. Activities usually focus on areas of concern identified in the general site characterisation. In contrast to the general site characterisation, sample analyses typically focus on target chemical parameters. This is needed to provide information on site contamination that can be evaluated against specific remediation guidelines or for risk assessment activities. Target parameters used for assessing contamination at oil and gas production or petrochemical sites are given in Table 7.

A detailed site characterisation may also be required to provide further information necessary for decommissioning planning. These additional studies may include:

- equipment interior inspections;
- evaluating equipment suitability for reuse or recycling; and
- sampling and analysis of scales, sludges, catalysts, transformer oils and process fluids from vessels, tanks and piping.

Where necessary, detailed site characterisation should also include more comprehensive evaluations of soil types and properties, hydrogeological conditions, surface water and groundwater quality, local plant life and revegetation resources (see Appendix D). In situations where significant reclamation activity is anticipated, heavy equipment access requirements should be assessed and the impacts on local environments and publics resulting from reclamation activity evaluated.

Detailed site characterisation may also incorporate reclamation field trials. These trials might take the form of test plots or studies designed to evaluate:

- different methods of erosion control or slope stabilisation;
- different techniques for surface scarification;
- various recontouring angles; and
- different vegetation types, planting techniques or fertiliser mixtures.

Comparative data from test plots in areas where erosion, rapid vegetation or soil fertility are concerns can help optimise reclamation programs and avoid expensive rework and environmental damage. Test plots should be considered when activities are being carried out on small areas adjacent to drilling, construction or production operations before larger scale decommissioning and reclamation activities begin.

More comprehensive information relating to the execution of detailed site characterisation programs can be found in (CCME 5, 46), (USEPA 43, 44) and (Department of the Environment 45). The Malaysian EQA may be used in countries where there are no guidelines available.

4 PROGRAM IMPLEMENTATION

The implementation component of the decommissioning, remediation and reclamation process involves integrating the objectives established during program planning with data from the evaluation phase into a detailed action plan for the site (Figure 1). It is important to note that planning, evaluation and implementation should not necessarily proceed in a linear fashion. The most likely approaches and technological options available for implementation should be considered throughout the program and thereby incorporated into the approved planning and evaluation processes.

4.1 DECOMMISSIONING

Facility decommissioning refers to the decontamination of process equipment and facility structures and the dismantling and removal of structures. Decommissioning is implemented after a facility has been shut down and vessels, piping and equipment have been depressurised. The major tasks for decommissioning are:

- down hole abandonment of wells;
- cleaning and purging of process equipment and piping of fluids and sludges;
- treatment and/or disposal of process fluids and sludges;
- removal of wastes and/or chemicals for disposal or reuse;
- dismantling of wellheads, piping and plant facilities with reusable items placed in laydown areas;
- removal and cutting (if necessary for size reduction) of equipment and materials tagged for sale as scrap;
- removal and cutting or sealing of contaminated equipment, tagged for disposal;
- removal of transformers, instrumentation and electrical systems for reuse or disposal;
- removal of structures, pads and foundations not destined for reuse;
- isolation of underground piping, tanks and structures which are left in place;
- removal of bridges, drainage culverts, roads and other civil works not needed for future access or erosion control; and
- installation of access controls for remaining structures.

Decommissioning strategies for various facilities are summarised in Table 8. As discussed in the Table, plans for future uses of roads and camp sites should be discussed with local authorities and communities to determine whether such infrastructure can be productively reused and maintained. Consideration should be

given to whether abandonment in place may result in undesired impacts such as immigration into sensitive areas, establishment of squatter communities, and potential failure of structures or bridges due to misuse or poor maintenance. In such cases complete removal of buildings and structures, removal of bridges, culverts and boat landings, break-up of roadbeds or aircraft landing areas and blocking or screening of access tracks should be included in the decommissioning process.

Table 8 - Decommissioning of Facilities

Exploration, appraisal, injection, production, water and observation wells.	Leave potable water wells as agreed with local authorities; isolate production interval to prevent communication between aquifers of different nature or salinity; isolate from the surface; plug and abandon down hole according to applicable guidelines ¹⁵ ; place surface cement plug below the cellar to allow removal of surface components; backfill to surface.
Production, processing and utility facilities including production manifolds, separators, heaters, dehydration/storage tanks, pumps, compressors, generators including all piping, instrument and electric cables/tubing and fencing.	Purge and clean to remove lubricants, residues, etc.; reuse, recycle or scrap redundant equipment such as generators, compressors, etc.; landfill remaining equipment.
Flowlines and pipelines.	Purge and flush with water to remove residues; cut above ground lines and sell for scrap; remove or plug and abandon below grade lines.
Redundant buried structures, foundations and cables.	Purge and clean to remove residues; abandon in place or remove completely according to proposed end land use.
Concrete and steel structures including concrete foundations, wellhead cellars, skid foundations and telecom masts, gratings, buildings (including workshops, offices, houses, etc.) and bridges.	Remove steel structures for reuse or recycling; remove wellhead cellar to 1 m below soil surface; remove concrete foundations and slabs down to soil level (unless abandoned in place for future use); break up concrete slabs at ground level into 1 m ² to allow vegetation to regrow through the fissures or remove completely according to proposed end land use; remove buildings or leave in place for reuse; provide access controls for physical structures remaining on-site, that are unsafe or hazardous to humans or animals.
Earthworks such as roads, airstrips, quarries, asphalt covered areas and berm walls.	Reach agreement with local authorities for use of usable assets such as roads, airstrips, quarries; remove asphalt for remediation and/or land filling; level mounds and dispose of waste rock; remove and recycle or reuse gravel (if clean); decompacted subsoils and re-establish vegetation.

Source: (Shell Gabon ¹⁶).

4.1.1 Well Abandonment

In many oil and gas producing jurisdictions, systematic procedures for well abandonment have been developed and published. This guidance, which normally takes the form of regulations or local industry practice, should be consulted wherever it is available.

4.1.1.1 Down Hole Abandonment

The basic objectives for a down hole abandonment program should be to abandon each completed formation separately and to cover the base of groundwater protection. Options for meeting these objectives include ⁵⁴:

- setting a bridge plug within about 15 metres of the perforations or open-hole section, pressure testing and capping with cement;
- setting a cement retainer above the perforations or open-hole section and cement squeezing the perforations or open-hole section, pressure testing the retainer and capping with cement;
- setting a plug in a permanent packer, pressure testing the plug and packer and capping with cement; and
- setting a cement plug across the perforations or open-hole section, with a minimum 15 metres of cement above and below the completed interval.

Non-perforated wells should have the existing casing string pressure tested. After the completed interval is abandoned, the well bore should be circulated to a corrosion-inhibited fluid. Weighted inhibitors may be used if the well does not have tubing. Alternatively, the well bore may be circulated to inhibited fluid prior to conducting abandonment work.

Other issues requiring consideration during down hole abandonment include:

- the need to confirm that groundwater resources are adequately protected, particularly if surface casing does not extend below the deepest available aquifer; and
- the need to ensure that risks associated with vent flows and gas migration are adequately managed.

4.1.1.2 Surface Abandonment

Surface abandonment activities should be undertaken shortly after down hole operations have been completed and typically include ⁵⁴:

- cutting the casing strings off a minimum of 1 metre below the final contour elevation;
- plugging production or intermediate casing at surface with a cement slurry on top of a wiper plug or a steel plate welded across the production or intermediate casing; and

- welding a steel plate across the surface casing.

In some situations, it may be desirable to cut the casing strings lower than the minimum 1 metre level below final contour elevation. These include:

- areas with special farming practices, such as deep tillage, drainage works and peat lands; and
- areas in close proximity to urban development (e.g. wells within 15 kilometres of a city should have casing strings cut 2 metres below final contour elevation).

4.1.2 Removal and Disposal of Contaminated Materials and Residues

Fluids and sludges should be recovered from process vessels (separation/dehydration vessels, etc.) and tanks. Flow lines, fuel gas lines and pipelines should be purged of fluids and the fluids recovered. Particular emphasis should be given to the removal of mercury, PCB and other hazardous materials prior to disposal. Sludge materials and decontamination residues should be dewatered where possible to reduce bulk and disposal costs. Treatment and disposal options for various materials and residues that may result from decommissioning of facilities are given in (E & P Forum ¹³).

All friable asbestos insulation, gaskets, packing or other such applications should be removed and placed in marked containers or bags, or encapsulated/encased where removal is not a viable option. PCB containing materials should be shipped to a licensed disposal facility or sealed in drums for secure storage prior to ultimate disposal. Lubricating oil should be recovered from rotating equipment (pumps, compressors, etc.).

Spent iron sponge from gas processing operations will contain iron sulphides prone to spontaneous oxidation. Combustion hazards should be controlled by keeping the sponge wet, by limiting the thickness of sponge to prevent heat build-up and by periodically raking the sponge to maximise exposure to air. The sponge is safely oxidised when it has changed from a black colour to one varying from deep red to red-brown to grey-red ⁵³.

If process equipment exhibits NORM contamination above regulatory action levels, it should be labelled as NORM contaminated, segregated and stored in an area with controlled access. This equipment should not be transferred to another owner for reuse or sold as scrap. Disposal options for NORM contaminated equipment are described in (E & P Forum ⁸) and (API ¹⁴).

4.1.3 Equipment Removal and Disposal

A site layout drawing should be prepared showing topographic contours and physical features, underground utilities and equipment and buildings slated for disposition. If buildings are contaminated, the surfaces and associated sumps and duct work should be cleaned using appropriate techniques. Equipment associated

with typical oil well and separation facilities can be reused, recycled, scraped or landfilled.

Equipment disposition activities will include:

- removal of components such as valves, pumps, motors and instruments which can be reconditioned and readily used;
- removal of vessels and dismantling of tanks and other large components which may be sold or reused;
- dismantling of other piping, structures and equipment which may be sold as scrap, placed in a recovery yard or landfilled; and
- removal or demolition of remaining structures, buildings and foundations.

As discussed in Table 8, removal plans for buildings, foundations, structural steel and paved pad areas should be compatible with reclamation plans for recontouring and erosion control and anticipated future land uses. As a general guideline, all physical facilities should be removed to ground level or to a sufficient depth to allow soil cover for the desired revegetation to occur. In areas where future land use may include agriculture, residential or other such uses where surface cultivation may occur, then facilities should also be removed to 1 meter below the final ground surface.

4.1.4 Pipeline Abandonment

Underground pipelines can generally be plugged and left in-situ without significant impacts on the environment. However, all surface components should be removed. Factors which need to be considered when abandoning pipelines include ensuring that:

- the pipeline is not a potential source of contamination;
- the pipeline does not act as a conduit to surface water;
- the pipeline is not a physical barrier (e.g. to deep ploughing and excavation); and
- the pipeline will not be exposed by streambed scour and surface erosion.

Disadvantages of full or partial pipeline removal include:

- the technical impracticalities of removal in some circumstances;
- the extent of surface disturbance resulting from removal;
- the need to dispose of the pipe; and
- the potential for ground subsidence with its attendant hazards for livestock,