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34. Irrigation

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1. Scope

It is not just in arid climatic zones that irrigation and drainage are today increasingly coming to play an essential role in **agriculture**. Sprinkler systems or other types of irrigation schemes are also used in **rain-fed farming** to raise production and/or provide a safeguard against unfavourable weather conditions. Irrigation is the only way of permitting arable farming in some places at all; it has made it possible, for example, to reclaim what was once desert or steppe in countries such as Egypt, Israel, India and Mexico.

Apart from the demands of the market and the progressively more monetary nature of rural trade, it is above all rapid population growth that is making it necessary to introduce or improve (artificial) irrigation as one means of **raising production** on land which is in some cases in increasingly short supply. High growth rates are thus likely in this sector, which means that the **importance of providing a water supply** and the **quantity of water required** will both **increase dramatically**.

While in many places totally **unutilised water resources** are still to be found or existing resources are used on only a moderate scale, the **provision of a water supply** has already led elsewhere to immense and generally **irreversible ecological damage**.

Just as **wastewater disposal** plays a significant role in drinking-water or process-water supply systems (cf. environmental briefs Wastewater Disposal and Urban Water Supply), irrigation must always be accompanied by **drainage** measures. Although efficient drainage is often guaranteed simply by the natural structure of the terrain, planning of water conveyance systems frequently also has to address the question of drainage.

Failure to implement drainage programmes immediately after the introduction of all-year irrigation can lead to **irreversible damage** - primarily as a result of soil salinisation - and to a rise in the groundwater. Even small-scale irrigation projects have given rise in many countries to **salinisation problems** (= adverse influence on the soil's nutrient balance) in cases where no drainage system exists. Depending on soil type, between 10% and 20% of the irrigation water should be drained off in order to prevent long-term damage from salinisation.

In the light of the increasing demand for irrigation water and the related **water supply and conveyance costs**, there is a risk that drainage measures may be spread over a lengthy period of time or realised on as small a scale as possible. There is also a tendency for water-saving but more expensive conveyance systems to be over-hastily rejected on the grounds of cost in favour of open, unlined or overstrained low-tech systems. **Insufficient use has been made to date of "appropriate" solutions** which are not only inexpensive but also effective and thus help to conserve resources.

Irrigation covers the following **areas**:

- provision of a water supply through storage in small reservoirs, use of river water and tapping of groundwater
- conveyance and distribution of irrigation water by open channels and pipelines
- application systems of irrigation water by means of flooding, basins, border strips, rills, sprinkling, drop irrigation and subsurface
- drainage by means of open and concealed systems

This environmental brief is concerned only with small and medium-sized irrigation projects. It deliberately excludes large-scale dam projects and irrigation schemes for entire regions with measures involving entire river systems.

2. Environmental impacts and protective measures

Given that water resources are limited, water consumption is rising and irrigation and drainage systems are often inappropriate to their context, priority should be given to

- considering the question of water supply, as projects entailing large-scale utilisation of natural resources generally involve major environmental risks;
- making sure that irrigation and drainage measures are well matched;
- establishing whether the technology of the measures implemented is geared to the financial capacity of the country concerned and to other specific conditions (e.g. available technical know-how) and thus ensures that potential environmental hazards can be reduced or ruled out.

2.1 Impacts on components of the natural environment

2.1.1 Supply, conveyance and distribution of water

Depending on the activity involved, every aspect of the environment (soil, water, air/climate, species, biotopes/landscape) may be affected. Impacts on the **soil** vary in nature. The embankments of small reservoirs and open channels for conveying water can create **erosion risks**. All construction measures change (destroy) the soil structure, while irrigation itself alters the soil dynamics. The risk of erosion can be counteracted by stabilising embankments, for example with ground-covering plants having a dense root system.

A wide variety of impacts on **water** can be observed. Although small reservoirs improve the **availability of surface water**, they may also - depending on the subsoil - cause groundwater resources to become contaminated. In addition, small reservoirs too are liable to exhibit impairment of **surface-water quality** and the **nutrient balance** (particularly as a result of warming and eutrophication). It should be borne in mind that impounding measures in a particular area can reduce the available water supply in the lower reaches of the watercourse concerned. If rainfall is highly seasonal, however, the opposite effect is likely. If **river water** is used for irrigation the amount of available surface water will be reduced, while if the groundwater is tapped groundwater resources will be depleted. In the case of groundwater the quantity withdrawn depends not least on the **tapping method**. The easier (or in economic terms, the less expensive) it is to raise the water, the more wasteful the use of water resources may be.

The effect which **tapping of groundwater** has on the **dimensions of water resources** is of particular significance. This may apply even to small-scale schemes or micro-projects (e.g. where cropping areas are situated primarily on geological basement formations, often with few water reservoirs, or in wadi systems on the fringes of the Sahara). Tapping of **fossil groundwater** with no natural inflow will by definition exceed the available quantity. It thus constitutes **destructive exploitation** of a vital resource and should be permitted only in exceptional justified cases.

There is a **danger** that the groundwater may become **contaminated** if the **sites where water is raised are left unprotected** and/or if substances such as faecal matter or oil are discharged into the water.

In addition to having effects on the **microclimate, small reservoirs** also have an influence on the range of **species** found in the area. However, the precise nature of their impacts in the latter sphere is **not clear**. Certain species of flora and fauna may be destroyed or displaced, while the water and its surroundings may favour other species or indeed attract them. A (negligible) **reduction in dry biotopes** must be set against **the creation of new aquatic biotopes**. Wetlands may increase (above all around the edges of the reservoir) or decrease (as a result of reduced flow in the lower reaches of the watercourse). Increases and decreases in the presence of particular species may have **both positive and negative consequences** for man and nature. Particular attention must be paid to the effects of **fluctuations in the reservoir's water level**. It can be assumed that small reservoirs make for a more varied landscape.

Open water conveyance and distribution systems lead to **water losses** on account of **evaporation** and have a (slight) influence on the **microclimate**. Water conveyance systems in the form of earth cross-sections may have effects on flora and fauna; as is the case with small reservoirs, however, the precise nature of these effects is not clear. Depending on context, open water conveyance and distribution systems may enhance or mar the varied nature of the landscape.

Unless installed above ground, **enclosed systems** generally have only **minor impacts** on the natural environment.

2.1.2 Water application and drainage

Depending on the method used, water application - in other words the actual process of **irrigation** - can affect the **soil** to varying degrees. It is also likely to have impacts on **water, species** and the **microclimate**. The main problem encountered with many irrigation methods is that of **soil salinisation**, particularly if the system is poorly managed and there is no drainage. In simplified terms, salinisation can be defined as an **extreme nutrient imbalance** (excess of salts) and **damage to the soil structure** (puddling, crusting, compaction).

Traditional irrigation methods often involve **water dosage problems** (e.g. flood, basin, border-strip and furrow irrigation). The possibility of **erosion** cannot be ruled out where such techniques are used. Sprinkling and in particular drop irrigation may also lead to **salinisation** if not carried out properly.

Particular attention should be paid to methods in which **modern components** have been inappropriately **added** to **traditional techniques**. Water conveyance systems or application methods that gave rise to no problems in the past can cause **erosion or scouring** if the **introduction of power pumps** changes the way in which the water is supplied. It may be necessary for the entire system to be modified at considerable expense.

All irrigation methods can have adverse effects on the soil microflora and microfauna. When **geared to local conditions and properly managed**, however, irrigation can also **contribute to the nutrient balance** and **benefit microflora and microfauna**.

Drainage can do much to counteract the problem of salinisation. It thus **contributes to the**

nutrient balance and to **stabilising the soil structure**. Water application methods can be used to achieve at least partial desalinisation.

Drainage ditches in the form of earth cross-sections create a **risk of erosion**. Impacts affecting water are likely to take two forms. Traditional irrigation methods, sprinkling and open drainage systems cause **surface water to be lost** through **evaporation**. However, traditional methods and drainage ditches in the form of earth cross-sections can also induce **recharging of the groundwater**. Where over-irrigation recharges the groundwater, the crops may be adversely affected because the groundwater level is too high.

In arid regions, **seepage** represents a **waste of water** and can lead to over-exploitation of resources. Priority should therefore be given to **lining the water conveyance systems**. Evaporation losses in conveyance systems tend to be negligible (e.g. 1 - 2% in desert regions compared to seepage losses of up to 85% from unlined water conveyance systems in sandy terrain). Traditional irrigation methods, sprinkling and open drainage systems can all have an influence on the **microclimate**. Depending on local conditions, their effects may be **beneficial** (e.g. as regards oasis ecology) or **detrimental**.

All water application methods are likely to have an influence on **flora**. The natural balance of species will generally be disturbed, while the **number of species** may either **increase** or **decrease**.

As only relatively **small irrigated areas** are involved, there are still enough **refuges** available to the local **fauna** to prevent permanent changes in the balance and number of species. The fauna are more likely to be affected by the enlargement and use of the cropping area per se and by the type of crop growing practised (cf. environmental brief Plant Production).

Open drainage ditches in the form of earth cross-sections can have **influences on flora and fauna**. As is the case for water conveyance systems and small reservoirs, however, the **precise** nature of these impacts cannot be defined. The same applies to the potential influence of such drainage systems on the diversity of the landscape.

2.2 Impacts on the socio-economic environment resulting from water supply, conveyance, distribution and application as well as from drainage

2.2.1 Factor requirements, labour, income and distribution

General assertions regarding impacts on the socio-economic environment are bound to be fairly vague, if indeed they are possible at all. In order to reach any conclusions, it is essential to **analyse the circumstances of the particular case in question**.

Technically sophisticated systems generally not only call for a sizeable input of capital but may also require a great deal of **energy**. Attention must be drawn to the possibility of using small reservoirs and water conveyance systems in generating energy and of meeting energy requirements by using renewable energy sources. One way of reducing the amount of external energy required is to make use of the available **water power** in cases where irrigation water is obtained from rivers (water wheels with a lift ranging from 0.5 m to over 20 m).

The major problem encountered in **operating irrigation schemes** involving new technologies is generally that of meeting the considerable **training and management needs**. Introduction of irrigation systems is usually also accompanied by a move in the direction of technically more sophisticated and more intensive forms of agriculture, which are not automatically accepted everywhere. A great deal of **advice and encouragement is required** if this difficulty is to be overcome.

Women are often **excluded** from discussion, extension services and training measures, even though they may be responsible for certain areas of farm work or may be farmers in their own right. This factor is of particular significance when traditional **technologies** are to be **replaced** by new ones.

Construction and operation of irrigation systems necessitate a considerable amount of **extra work**, particularly when labour-intensive techniques are used, and in many societies it is primarily women who bear this additional workload. Income levels are satisfactory, however, especially in the case of capital-intensive methods. **Social disparities** may be increased.

The introduction of irrigation frequently brings **financial disadvantages for women**. It is often only the **men** who are registered as the **owners** of the land covered by irrigation schemes; in other cases, men may simply appropriate the irrigated land, which is considerably more valuable than that used for rain-fed farming.

Farmers may run into **serious economic problems** on account of the fact that **operating, maintenance and monitoring costs** and expenditure on **renewal of irrigation systems** are often inadequately calculated at the planning stage, or as a result of sudden changes in government support policy (cuts in extension services, equipment subsidies and even water subsidies). It should be established whether the technical design and dimensioning of irrigation systems allow the systems to be **used profitably** by the farmers even under **changed conditions**.

It can generally be assumed that irrigation makes for **more reliable yields and incomes.** This is not the case, however, where workers are paid only for work performed over a **limited period**, for example during system construction or for **seasonal work**, the volume of which varies considerably. If women participate in this seasonal work their **workload** may be **increased** at the expense of other activities (feeding the family etc.).

Irrigation is likely to influence the **distribution of income** (and not just the relative incomes of men and women). Capital-intensive methods can place less prosperous farmers at a disadvantage and cause income distribution to become **more unbalanced**. Women are often excluded where conversion of land to irrigation is carried out on the basis of a loan scheme. **Social distinctions** generally increase in proportion to the technical complexity and cost of an irrigation system. **Titles to land** should therefore be **distributed** as widely as possible or **upper limits** set for ownership of land within specified areas covered by irrigation schemes.

It is important to make sure that **women's traditional land-use rights** are taken into consideration, for example by making certain that women too are entered in the cadastral register as **land owners**.

2.2.2 Health

Irrigation schemes are likely to create a variety of **health risks**. The main problems are caused by **waterborne diseases**, particularly schistosomiasis and onchocercosis, whose foci may be located at different points within the irrigation system (stagnant/flowing water). By virtue of the way in which it is transmitted (via human excretion), schistosomiasis in particular may well occur in areas being irrigated for the first time. Irrigated farming can also **promote** the spread of hookworms (Ankylostoma duodenale) and eelworms (Ascaris lumbricoides).

Malaria, which often spreads in areas where large irrigation schemes are being realised, can also constitute a problem in small-scale projects using open reservoirs and water conveyance systems. The possibility of rheumatic ailments and accident risks must likewise be taken into account. Health risks are liable to arise in cases where irrigation systems are also used to provide a **drinking-water supply** (see environmental brief Rural Water Supply). It is particularly important to raise women's awareness of these risks by means of targeted **information and education measures**, as it is usually women who are responsible for providing the family's drinking-water supply. **Vector control** measures (using chemicals) in turn create environmental hazards.

2.2.3 Subsistence, housing and leisure

Unless the land is used exclusively for **growing non-food crops**, irrigation schemes generally **contribute to subsistence** in that land owners grow food **for their own consumption** or workers are **paid in kind**. Particular efforts must be made during crop planning to **ensure** that food crops are grown (cf. environmental brief Plant Production). Irrigation in arid regions generally increases the range of food crops that can be grown.

Irrigation can cause damage to the **fabric** of houses where construction materials such as lumps of clay, tamped earth, air-dried clay bricks or materials of plant origin have been used. Houses on irrigated land can be protected against rising damp by being built with stone **foundations**.

Irrigation projects may have effects on leisure if they considerably **increase** the workload of the land owners and their families. This applies in particular in areas where only rain-fed farming was practised previously. It is often the **women and children** who are called upon to perform the extra work. In extreme cases this may prevent the children attending school or force the women to abandon other important activities.

Irrigation systems should not unnecessarily ruin the **natural landscape** or disrupt **communications**. The population should not be obliged to make long detours on account of changes in the landscape (e.g. pipelines installed above ground on supports or in/on embankments, or wide open channels). Adequate **crossing facilities**, including routes for driving livestock, should be provided (e.g. routes passing underneath system components, bridges).

2.2.4 Training and social relationships

Many irrigation methods or activities lend themselves to on-the-job **training**, although they often call for a high prior level of skill and know-how.

If activities can be organised and carried out on a **communal** basis, they can **encourage participation and social interaction**. Although irrigation can as a whole be seen as a communal task, it does not necessarily always help to consolidate social relationships. In many regions, irrigation establishes **unrestricted private ownership** of land **for the first time**, with the result that neighbourly cooperation is increasingly replaced by a system of hired labour.

It is **above all women who are affected** by the decline in communal activities (e.g. fetching water or washing clothes together, possibly also communal field work). In Islamic countries, for example, such activities give women an important opportunity for communication not afforded in any other way because of the restrictions imposed by social norms.

3. Notes on the analysis and evaluation of environmental impacts

General guidelines on **quantitative water management** exist in the Federal Republic of Germany. With the exception of technical guidelines for hydraulic engineering measures, however, there are **no standards** governing activities in connection with irrigation schemes. Standards could nevertheless be laid down to cover aspects such as

- permissible changes in the groundwater level resulting from tapping (lowering), seepage (rise) and drainage (lowering);
- **reduction of flow** where river water is used for irrigation purposes;
- **limits on use** of surface water, in order to prevent adverse effects on and/or destruction of aquatic organisms (defining minimum water quantity and depth etc.);
- the **quality of the irrigation water**, e.g. in order to prevent soil salinisation;
- the **degree of salinity** of flowing water where it receives discharges from drainage systems, etc.

The following could also serve as the **starting points** for standards governing measures affecting the water balance:

- The **quantity of groundwater used** must not exceed the medium-term recharge rate (often difficult to ascertain).
- **Fossil groundwater** may be **tapped** only in cases of extreme need.
- The **low-water flow** represents the **critical factor** for surface water quality when water is drawn off.

4. Interaction with other sectors

The environmental brief **Plant Production** should be additionally consulted in order to assess the impacts originating from crops grown on irrigated land.

The **individual areas involved in irrigation** also **interact** with other agricultural subsectors, including the following:

- **Plant protection**, in respect of the need to ensure that irrigation and drainage water is free of pollutants, for drainage water particularly in cases where it is discharged into surface water or groundwater
- **Livestock farming**
- **Fisheries and aquaculture**
- **Agricultural engineering**, e.g. in connection with use of organic manures and mineral fertilisers and their possible polluting effects

Use of water resources for irrigation purposes may **conflict** with other interests, above all in the light of the general demand for **conservation of natural resources**. Utilisation of artesian and/or fossil groundwater represents just one example of such a conflict. Other conflicts may arise with respect to the **wastewater and rainwater** subsector, leading to impacts on **health** in particular.

In certain cases there may also be links with

- **large-scale hydraulic engineering**, in connection with dams and weirs;
- **rural hydraulic engineering**, above all in connection with weirs (use of water for

irrigation), contour canals and small earth embankments forming part of water storage facilities;
- **wastewater disposal**, in connection with disposal of wastewater by means of discharge onto agricultural land or into receiving waters (surface waters).

5. Summary assessment of environmental relevance

Irrigation systems of **virtually every degree of technical complexity** can be planned and constructed with a minimum of environmental (and social) impacts provided that the scheme incorporates **measures appropriate** from the ecological, technological, economic and social viewpoints. Caution must be exercised during assessment, as financial constraints and other criteria often restrict essential measures to a minimum. The **technical practicality** of an irrigation system must be established, since it represents an important prerequisite for success. Although raising technical standards may have impacts on the natural environment, it is above all within the context of the socio-economic environment that problems are most likely to arise.

The **small-scale irrigation projects** discussed here are bound to have **fewer impacts** than measures which involve large-scale hydraulic engineering schemes or raising large quantities of groundwater. The potential **technological solutions** are often **interchangeable**; in other words, a number of different options may produce the same result, making it possible to choose the soundest alternative from the environmental viewpoint. It should be remembered that **traditional irrigation technologies** may well be geared to the natural environment, but can cause **environmental problems** if used **in combination** with "modern" technologies. Where appropriate combinations of old and new technologies are used, however, they can help to prevent negative impacts on both the natural and social environment.

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35. Reconnaissance, prospection and exploration of geological resources

Contents

1. Scope

This brief describes the environmental consequences and potential means of pollution control in connection with the reconnaissance, prospection and exploration of geological resources.

Geological resources in the present context comprise mainly **raw minerals** and **groundwater,** with attention to soil being restricted to the reconnaissance aspect. Reconnaissance, prospection and exploration are the terms used **for steps taken in preparation for the commercial extraction, i.e., utilization, of geological resources**. The environmental consequences of extracting, dressing, refining and distributing such resources are not dealt with in this brief. The entire petroleum/natural-gas exploration complex has also been excluded. Those areas and related sectors are investigated in separate briefs.

The purpose of **reconnaissance**, including stock taking and mapping of resources, is to obtain regional overviews and to identify and demarcate mineral prospects and/or pedological location factors.

Prospection aims to locate prospects and exploitation areas by way of geological, geophysical and geochemical methods of field investigation.

Exploration - the detailed study of prospective areas - uses the same methods as those employed for prospection, but also involves direct disturbance of the environment.

While there are various basic types of reconnaissance, prospection and exploration projects, their respective environmental impacts depend primarily on the individual activities involved.

Both **direct and indirect geoscientific methods** are employed in the reconnaissance, prospection and exploration of geological resources. As a rule, the **indirect** methods yield less accurate results but offer the capacity for covering large areas at low specific expense. More precise, and substantially more expensive, **direct** methods applied preferentially to prospective zones and already identified anomalies or deposits enable the refinement of data bases. The **raw minerals sector**, for example, employs the **following methods of investigation** (listed in the order of increasing exactitude):

- – interpretation of satellite photographs
- – interpretation of aerial photographs
- – interpretation of thematic geoscientific maps
- – interpretation of geophysical test data
- – interpretation of borings with the help of geochemistry and well logging; analysis of core samples
- – investigation of explored deposits via shafts and tunnels
- – interpretation of dressing tests

Groundwater prospection investigates the demand for water, its quantitative management, quality and protection, and the ecological consequences of its extraction (for details, cf. section 4). The protection-worthiness and sensitivity of the existing ecosystems, the volumetric and pollution-load capacities of the receiving waters, the effects of relevant road-building measures, and the social, sociocultural and ecological impacts of the anticipated settlement effects must be duly considered and assessed (for details, cf. section 4).

The **"soils"** subsector involves the evaluation and assessment of soils on the basis of soil surveys and the appraisal of soil utilization potentials. Moreover, measures designed to protect the soil from erosion, salinization and the effects of fertilizers and plant phytopharmaceutical products demand appropriate illumination.

2. Environmental impacts and protective measures

The environmental consequences of the subject sectoral measures are extensively limited, and the relevant protective measures are for the most part uncomplicated and inexpensive. Unavoidable damage of tolerable extent demands settlement by material compensation.

Reconnaissance, prospection and exploration activities can impose various hazards on the environment. The environmental consequences tend to increase as the activities progress from reconnaissance to prospection to exploration. In the first two cases, the impacts are usually modest and temporary. Exploratory measures are more elaborate and expensive, and the cost factor therefore helps retard their excessive implementation.

The main purpose of protective measures is to minimize the environmental consequences and to prevent environmental damage with respect to both time and space. The **avoidance of permanent damage** is especially important. Since geological resources are immobile, field investigations are usually limited to a **particular site**. Proper consideration of seasonal weather conditions can help avoid damage to the environment, e.g., by performing such work outside of the growing/breeding season.

Potential forms of environmental damage resulting from geological reconnaissance, prospection and exploration

Damage to the environment can be **extensively avoided**, or at least limited, by:

– careful execution of exploratory work - e.g., by avoiding the use of heavy (and accordingly expensive) equipment - inclusive of soil- and water-protection measures, stabilization measures, recultivation, etc.,
– choosing environmentally benign (micro-)sites for (prospecting) lanes in order to minimize the environmental burden, e.g., through dissection; the same applies to the choice of locations for camps and support facilities,
– taking measures to prevent environmental mishaps, e.g., by installing traps for oil and chemicals.

Environmental consequences can also be limited **by recovering and recycling materials and substances**. Recycling is preferable to (controlled) disposal. The ultimate goal is to restore the site as closely as possible to the state it was in prior to commencement of the work, or at least to preclude lasting detriment to the environment.

2.1 Access to work area

2.1.1 Access roads

It is frequently necessary to fell trees and move earth to make way for access roads. The damage resulting from such activities can by far exceed that caused by reconnaissance, prospection and exploration. Moreover, establishing **access to a previously inaccessible area** can lead to such social consequences as public unrest and land speculation. Controlling access to such roads can help prevent the subsequent uncontrolled generation of settlements.

2.1.2 Lanes

Geophysical investigations may require the cutting of narrow lanes as footpaths. This can cause temporary damage to the **vegetation** and expose the soil and subsoil to **erosion.**

In the tropics and subtropics, much more so than in semi-arid regions, the vegetation is normally able to close off such lanes within a year or two, so that **no permanent damage** remains. Protective measures are rarely necessary. The inadvertent provision of general access to the area in question must be avoided.

In areas characterized by a very fragile balance of nature (marginal locations, slopes) it may be necessary **to impose certain restrictions and to carefully accommodate the local situation**, e.g., by disturbing as small an area as possible and reducing the felling of trees to a minimum. If farmland is involved, the competent authorities and those affected must be consulted with regard to compensation.

2.2 Topographical and geological mapping

Unless **mapping activities** are **intensive** and require extensive **field checking**, little **impairment of flora and fauna** need be anticipated.

2.3 Camps and support facilities

In many cases, **permanent camps** comprising lodgings, workshops, field laboratories, storeyards, etc. can be required. The attendant land use, sealing of soil and general detriment to and disturbance of local flora and fauna are disadvantageous. Controlled disposal of liquid and solid wastes must be ensured.

2.4 Geophysics

2.4.1 Airborne techniques

The noise caused by **flyovers**, most notably in connection with helicopter-assisted methods of surveying, is **disturbing** to local animal populations.

2.4.2 Prospection seismics

The environmental consequences of prospection-seismic activities (blasting) on lanes can be extensively minimized by carefully **plugging** the blasting charges in the boreholes. Such activities cause no permanent damage to the environment.

2.4.3 Nonseismic geophysical investigations

All nonseismic geophysical investigative methods involve the use of **portable measuring instruments** at or slightly above ground level (1.5 m). The hauling and handling of the requisite equipment and the movements of personnel within the areas of interest can be expected to cause modest impairment of the local environment.

The **electricity** required for a camp and, possibly, for one or the other electric-powered piece of equipment may necessitate the use of a diesel- or gasoline-fueled generator. Environmental damage can result from improper or careless **handling and storage of fuels and lubricants**.

2.4.4 Well-shooting

Well-shooting is the term applied to measurements conducted in an **existing borehole** according to radiometric, electric, magnetic, acoustic, mechanical and thermal techniques to gain information on the immediate surroundings of the hole itself. Consequently, any **effects** on the environment are limited to the **immediate vicinity of the measuring point** - one exception to the rule being **radiometric measurements** performed with the aid of active radiation sources that require certain precautionary measures in connection with calibration and introduction of the probe - the loss of which must be avoided - into the borehole. Radioactive cores must be duly marked, and appropriate **protective measures** up to and including the services of a radiological safety officer must be taken in case of high-level radiation.

2.5 Hydrogeological investigations

2.5.1 Long-time pumping tests

The **sustainable yield** and/or groundwater permeability of wells and boreholes is determined by long-time pumping tests. **Lowering of the groundwater** level in the vicinity of the tested well can cause temporary detriment to other **wells situated nearby**.

2.5.2 Injection tests

Long-time injection tests serve in determining the sustainable injectivity of **drainage wells**. Such tests can **temporarily alter the groundwater regimen**. Care must be taken to ensure that the injected water is environmentally compatible.

2.5.3 Tracer tests

In karst areas, tracer tests are conducted to locate and determine **watercourses and groundwater retention times**. The methods employed rely on fluorescent dyes (1), radioactive substances (2), salts (3) and pollen (4). Tracers (1) and (4) have no

environmental consequences, although fluorescent dyes could be perceived as a visual infringement. The initial activity and concentration levels of tracers (2) and (3) must be kept low enough to avoid detrimental effects on the environment.

2.6 Exploratory work

Exploratory work serves to enable sampling activities. Depending on the depth of the planned sampling point and on the geological situation, different opening operations are appropriate:

2.6.1 Trial pits

The main environmental consequences of establishing a project result from **removal of the local vegetation** and soil. It is sometimes necessary to penetrate more deeply into the exposed rock, although such measures normally involve depths of a few meters at most. Cutting into a steep slope causes **erosion**. Upon completion of the exploratory work, the prospect must be refilled with the excavated material and separately stored topsoil to prevent aggravated erosion and accidents. Additional case-specific measures may be necessary to preclude erosion.

2.6.2 Shafts/tunnels

If boreholes and trial pits are insufficient for the envisioned scope of exploratory work, horizontal or slightly inclined tunnels and/or vertical shafts can be dug to enable **underground reconnaissance**, including sampling. Due consideration must be given to the fact that tunnels require appropriate entrances and that they tend to **collect groundwater**, possibly resulting in the **dewatering/drainage of overlying rock**. Special protective measures may be required in connection with the location and exploration of **uranium deposits**. In the absence of appropriate national directives, the radiation protection ordinance of the Federal Republic of Germany should be applied accordingly.

Major exploratory operations quickly equate to regular mining operations, the environmental consequences and relevant protective measures of which are dealt with in detail in the respective sections of this handbook.

Tunnel faces and shaft mouths must be **closed off** for safety reasons whenever the work is interrupted and following its completion.

Any shaft or tunnel that interrupts the flow of **groundwater** can simultaneously jeopardize its quality. Consequently, when the work is finished, all such **holes** should be completely **refilled**. As long as the work is ongoing, shafts must be secured to prevent unauthorized access and accidents. If regular measures are not possible, a sturdy cover must be installed.

Dug wells providing potable water in rural areas of dry-climate regions are especially important. If the exposed groundwater is not effectively protected against pollution, such wells can have negative qualitative effects on the environment. The same applies in essence to groundwater trial pits, while groundwater stemming from an adit is, as a rule, hygienically unobjectionable.

2.6.3 Drilling

Drilling serves as a means of **subterranean geological exploration**. It allows geological surveys, geophysical measurements and sampling. Pumping tests are conducted for hydrogeological purposes (cf. 2.5.1). Drilling can cause a substantial **noise nuisance**, with attendant disturbance of the local populace and animal life. Thus, all requisite active and passive means of noise control must be adopted, and the applicable work safety directives in particular must be followed.

Depending on the climatic zone, some extent of **land may have to be cleared** around the drilling site.

Wells and boreholes are **potential hazards for groundwater**. In the absence of protective measures, detrimental effects can result from cutting through confined groundwater (artesian, for example), from **interconnecting** different groundwater stories (possibly of divergent quality), and/or from **piercing** the bases of multiaquifer formations.

Bleeding artesian wells are a waste of groundwater reserves and can do damage to the borehole environs, e.g., by causing the soil to salt up. The hydraulic interconnection of different groundwater stories can detract from both the quantity and the quality of the entire resource. Intermediate groundwater stories can drain out to such an extent that **wells run dry** and the work of **fetching potable water** - mainly by women - for household purposes increases in relation to the distance to the next intact well.

Appropriate technical measures, however, can be taken for **drilling operations** (pressure regulating valves, special flushings, packers, clay seals) to prevent such damage. In areas with a relevant hazard potential, the geological and technical aspects of drilling must be carefully planned in all detail, with all the appropriate equipment provided and properly serviced. (For details, please refer to the environmental brief Petroleum and Natural Gas.)

In semi-arid regions, drill bits often encounter aquifers filled with fossil, nonrenewable groundwater. Thus, in any such case the **demand forecasts** and **proven reserves** must be carefully balanced in order to avoid both an unprofitable investment and consequential damage to the ecology.

Drilling operations can also have negative environmental consequences as a result of **drill cuttings, chemicals, process water and improper fuel storage procedures**. The incidental drill cuttings and flushings must be collected and properly clarified at the end of the drilling operations, so that only cleansed wastewater is returned to the environment. The drilling site must be cleaned up and restored as closely as possible to its original condition.

2.6.4 Solid waste/dumps

Solid waste can derive from laboratory work as well as from exploration and production operations. All scraps, e.g., worn drill rods, must be collected and either **properly disposed of or recycled**. The same applies to sludgy residues from flushing operations.

Trial pits, tunnels and shafts yield **excavated material** that requires temporary or permanent storage. The size of the requisite storage area depends both on how much material is excavated and on the local topography. Wind, precipitation and percolation can erode, leach, scour and elutriate excavation dumps and cause **water pollution** in the process. In particularly severe cases, the dump may **slump or slide**. The storage of any material with a high **hazard potential**, e.g., due to radioactivity, requires appropriate measures for:

- preventing washout and dust deflation,
- collecting wastewater/effluent (packing and possible percolation drainage) with

subsequent clarification, and
– monitoring its discharge.

Environmental detriment attributable to erosion can be extensively avoided - and the dump's stability enhanced - by **turfing, greenbelting or otherwise covering it**.

2.7 Sampling

2.7.1 Surface sampling

Sampling for analytical purposes often requires either the **removal** of near-surface strata or the extraction of material from special-purpose exposures. In some **rare cases**, sampling can impose a burden on the environment in the form of noise given off by jackhammers. As a rule, though, such problems are short-lived and

not particularly serious. By comparison, the work involved in establishing exposures is more likely to have negative environmental impacts, as described in section 2.6.

2.7.2 Marine sampling

Marine sampling operations can have environmental consequences for ecosystems in **shelf waters** as well as in the deep sea: alteration of the seafloor morphology, disruption of pediment, destruction of marine life, turbidity.

The following techniques and technology must therefore be employed for minimizing such effects:

- exploration of the seafloor via TV probes in order to confine and delimit the sampling area,
- selective sampling with TV-guided grabs,
- no large-scale clearance or scavenging of the seafloor,
- separating the sludge and fine slush from the liquid phase (undissociated suspensions can jeopardize marine fauna, especially if they get into the photic zone.),
- avoiding the local release (into the seawater) of acidic processing residues.

In some cases, in-situ analytical instruments use radioisotopes as a **source of excitation**, with a possible attendant (normally harmless) increase in radioactivity.

2.8 Laboratory testing

2.8.1 Laboratory analysis

Activities in connection with chemical and physical laboratory testing and analysis can yield substantial amounts of **solid, liquid and gaseous wastes**, some of which may contain **toxic reagents**. Exhaust air and exhaust gases may require filtration or scrubbing, while **liquid wastes and effluents** can be neutralized, precipitated, clarified, separated, etc. Organic solvents must be collected and the escape of noxious fumes and vapors to the atmosphere prevented.

Additionally, appropriate

measures must be adopted to ensure either the orderly disposal (incineration, dumping, ultimate storage) or recycling of liquid and solid waste products. The environmental brief Analysis, Diagnosis and Testing contains pertinent information in detail.

2.8.2 Dressing tests

Deposit exploration projects sometimes necessarily include dressing tests. The incidental **wastewater** must be collected in settling tanks and appropriately treated to the extent that it contains substances capable of polluting the recipient body or groundwater; cf. environmental brief Minerals Handling and Processing.

3. Notes on the analysis and evaluation of environmental impacts

Distinction must be drawn between the environmental consequences dealt with in section 2 and those which may result from **follow-up measures**. Any study, expert opinion or commentary prepared in connection with such projects should include references to the potential **environmental impacts** of subsequent project **implementation**. Even at the initial reconnaissance and exploration stage, such consequential effects should be appraised. If necessary, pertinent studies must be conducted in parallel with the prospecting activities. Such preliminary studies should focus on the **data requirements** of the subsequent environmental impact assessment. Section 4 and other environmental briefs offer further-reaching information on the scope, evaluation and possible countermeasures.

4. Interaction with other sectors

The following other environmental briefs are also of relevance:

- Spatial and Regional Planning
- Water Framework Planning
- Urban Water Supply
- Rural Water Supply
- Road Building and Maintenance, Building of Rural Roads
- Rural Hydraulic Engineering
- Large-scale Hydraulic Engineering
- Surface Mining
- Underground Mining
- Petroleum and Natural Gas - Exploration, Production, Handling, Storage
- Minerals - Handling and Processing
- Cement and Lime, Gypsum

– Glass.

The **groundwater domain** is a focal point of interest in that connection. Regional planning, in particular for rural development, is heavily dependent on access to properly protected groundwater, and timely evaluation of the potential environmental consequences of project measures is therefore of major significance. Diverse cross-links also exist between the groundwater domain and the mineral resources and mining sector, since potential environmental impacts often become apparent at the feasibility-study stage.

5. Summary assessment of environmental relevance

The **project goals** encompass preparations for the environmentally appropriate satisfaction of basic needs (e.g., access to potable water), the protective use of resources (such as water), appropriate use of soils, self-sufficiency in the environmentally sound exploitation of mineral and fuel resources and, as a result, improved employment perspectives in conjunction with the extraction and exportation of resources. Two of the most important project objectives are the transfer of know-how and the enhancement of environmental awareness.

As long as the project is carefully planned and executed with due regard for the described consequences and protective measures, activities in connection with the reconnaissance, prospection and exploration of geological resources can be expected to have only **limited**

impacts on the environment.

Appropriate and available **means of controlling or remedying environmental damage** can be implemented **with relatively modest inputs**.

The subject studies and investigations also serve to supply the environmentally relevant **data and information** needed to achieve sustainable utilization of soil and groundwater and the protective extraction of nonrenewable mineral resources.

In connection with the implementation of protective measures, the interested and concerned parties must be made aware of environmental concerns. The analysis and evaluation of potential environmental impacts must be considered an **integral part** of the project appraisal phase.

Pertinent directives serve to ensure that:

- intervention in the environment is limited to the smallest possible, essential scope;
- unavoidable encroachments are accommodated to the natural situation;
- resultant damage is remedied or, if that is not possible, at least controlled;
- permanent damage is avoided to the greatest possible extent.

The necessary measures and corresponding responsibilities must be defined and established during the project planning phase.

Controls aimed at ensuring the success of the protective measures should be **conducted during and at the end of the project**.

Attention must be drawn to potential environmental consequences resulting from the continuation or expansion of a project.

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36. Surface mining

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1. Scope

Surface mining is the term used to describe diverse forms of **raw-material extraction from near-surface deposits**. It involves the complete removal of nonbearing surface strata (overburden) in order to gain access to the resource. Depending on the physical characteristics of the raw material and on the site-specific situation, **various surface-mining techniques** are applied:

Dry extraction of loose or solid raw materials: In hardrock mining, the product must first be "worked" (loosened). Then, it can be loaded, hauled and processed by mechanical means similar to those employed in loose-rock mining. Accordingly, dry surface mines require appropriate dewatering.

In **wet-extraction**, or dredging, operations, loose raw materials are mechanically or hydraulically extracted and transferred to a processing facility. The entire extraction equipment is normally located on/in the water, often floating on a river or artificial lake.

Offshore, or shelf, mining is the term used to describe the extraction of loose material from nearshore deposits (marine beach placers). Like in wet extraction, the material is excavated and conveyed by mechanical or hydraulic means.

Deep sea mining is a - future - form of mining in which raw materials are extracted from ocean beds; not to be dealt with in the present context.

The various surface mining techniques are applied to different types of raw material reservoirs.

Table 1 - **Forms of surface mining and major raw-material products**

Hardrock mining		**Loose-rock mining**			
dry extraction		**dry extraction**		**wet extraction**	
				terrestrial	**offshore**
building stones diamonds gems feldspar gypsum limestone/ raw materials for cement	metalliferous ores (copper, iron, silver, tin) oil shale hard coal uranium ore	brown coal diamonds gold kaolin/ china clay phosphates sand, gravel	heavy minerals (ilmenite, rutile, RE-minerals1), zircon) clay tin ore	diamonds gold heavy minerals tin ore sand, gravel	diamonds heavy minerals (ilmenite, rutile, zircon, monazite) tin ore

1) RE-minerals = rare-earth minerals

Surface mines vary in size according to the nature of the deposit and the employed techniques of extraction. Among terrestrial workings, one encounters mines ranging in size from small

one-man operations to huge strip mines measuring several kilometers in diameter. Due to the elaborate, expensive technology required, marine workings always strive toward minimum dimensions.

Since mining amounts to a site-bound activity, new and expanding operations often have to compete with other potential users of the premises in question, and the infrastructure required for surface mining operations may still have to be established. As regards the demarcation of surface mining activities, it is inherently difficult to separate them from the required mineral dressing facilities, because such processing normally takes place directly at the place of extraction.

2. Environmental impacts and protective measures

The environmental consequences of surface mining operations are strongly dependent on the project type. Consequently, this section distinguishes between impacts and control measures.

2.1 Potential environmental consequences of surface mining

Common to all surface mining activities is that their environmental impacts are both size-dependent and location-dependent, particularly with regard to climatic, regional and infrastructural contexts. For the sake of simplicity, the potential environmental impacts of

surface mining operations are categorized in the following sections according to the employed type of raw-material extraction.

***Table 2* - Forms of surface mining and their main environmental impacts**

	dry extraction	**wet extraction**	**nearshore extraction**	**deep-sea mining**
earth's surface	areal devastation; altered morphology: danger of falling rocks at the faces; destruction of cultural assets	areal devastation; altered morphology and river course; formation of large dumps	altered ocean-floor morphology; coastal erosion	
air	noise; percussions from blasting; dust formation due to traffic, blasting, wind; smoke and fumes from self-ignited dumps; blast damp,	noise due to power generation, extraction, processing and conveying;	noise, exhaust gases	noise; exhaust gases

	noxious gases; vibrations	exhaust gases		
surface water	altered nutrient levels (potential eutrophication); pollution by contaminated wastewater; pollution by aggravated erosion	denitrification; burdening of recipient with large quantities of muddy wastewater; pollution by contaminated wastewater	turbidity; oxygen consumption; wastewater pollution	turbidity; oxygen consumption wastewater pollution
groundwater	recession of groundwater; deterioration of groundwater quality	altered groundwater level; altered groundwater quality		
soil	denudation in the extraction area; loss of (agric.) yield, dryout, ground sag, danger of swamping	denudation in the worked	altered seafloor; deterioration of seafloor	deterioration of seafloor nutrient

	due to local groundwater recovery, soil erosion	area	nutrient content	content
flora	destruction in worked area; partial destruction/alteration in surrounding area due to altered groundwater level	destruction in the worked area		
fauna	expulsion of fauna	expulsion of fauna	destruction of stationary marine life (corals)	destruction of stationary marine life (corals)
humans	land-use conflicts; induced settlement, destruction of recreation areas	land-use conflicts; social conflicts in boom times; induced settlement	impaired fishing (destruction of spawning grounds)	impaired fishing (destruction of spawning grounds)
structures	water damage due to groundwater recovery			

mis-cella-neous	potential modification of microclimate	modification of microclimate; growth of pathogens in still-water areas		

2.1.1 Dry extraction

Differentiation is made between loose-rock and hardrock mines. Wherever necessary, the following sections include reference to specific influences. The environmental consequences are broken down according to physical, biological and social effects.

Physical environmental impacts of dry surface mining

In essence, the foremost environmental impact of surface mining is the extraction of nonrenewable resources. The processes and activities involved in the extraction of a raw mineral can involve mining losses, free-standing ore pillars, presently uneconomical sections of deposit, overcutting, etc., with resultant destruction of sections to the extent of their becoming inaccessible for future extraction. The strip mining of carbonizable or combustible raw materials such as coal or peat can lead to the destruction of resources by fire (seam fires).

The space requirements of surface mining operations can be quite substantial, comprising the quarry itself and dumps for overburden, which can be very sizable for deep hardrock mines (e.g., open-cast ore mines), tailings heaps, which also can become very large for low-grade ore, and room for infrastructural facilities (miners' lodgings, power supply, transportation, workshops, administration building, processing equipment, etc.). Since surface mining operations are inherently bed-bound, their size and location are determined by the given geological conditions of the bedding and associated strata. And since major disruption of the earth's surface is unavoidable in connection with surface mining operations, the question of tolerability under the prevailing conditions must be given due consideration prior to commencing with any extractive processes.

In and around the mine and its dumps, some of the soil has to be removed, and some gets covered over. Nearly all industrialized countries have regulations governing the treatment of cultivable soil (topsoil). As a rule, its removal and temporary storage prior to the beginning of direct mining activities is mandatory. In addition, subsequent replacement of the topsoil and recultivation of backfilled ground may also be prescribed.

Surface mining operations also alter the morphological makeup of the mine site as a (temporary) result of shaping the quarry and its dumps and heaps. Once an abandoned mine has been recultivated, some such changes remain behind in the form of permanent, residual (submorphic) hollows, the size of which depends on how much material has been extracted from the mine. Morphological changes can be particularly pronounced in hardrock mines, which tend to have very steep slopes and for which little material is left for refilling (e.g., in

stone quarries).

By comparison, the morphological changes occurring in loose-rock mines consist primarily of the overburden dumps established at the time of opening the mine, and ground subsidence caused by dewatering.

Surface mining activities also interfere with the surface water regimen. Relevant intentional intervention aims to keep surface water and groundwater out of the workings by collecting and channelling the water from around the perimeter as well as from the mine proper. Riverbeds are bypassed around the mine, and runoff water from precipitation and drained slopes is collected in ponds and discharged into the natural hydrographic network. Increased sedimentation and altered chemism resulting from such measures can cause qualitative degradation of the recipient water body.

Loose-rock surface mining can also interfere with the groundwater regimen, with resultant loss of groundwater quality due to the infiltration of contaminated wastewater and in washout and leaching of dumps, heaps and the mine itself. If the groundwater level is not lowered in time, groundwater will flow into the pit. Consequently, all around and within the mine, wells are sunk to below the lowest pit bottom in order to enable dry extraction while enhancing the stability of both the slopes and the floor by relieving the effective hydraulic pressure. The well water is generally unpolluted and can be fed directly into the natural river system. Lowering the groundwater level has major consequences for the surrounding area, e.g.:

- **drying up of nearby wells,**
- **settlement/subsidence,**
- **disturbance of the vegetation due to altered groundwater supply.**

When the mine is closed down, hollows resulting from extraction of the resource and removal of overburden during the opening phase remain behind. The hollows eventually form groundwater-fed ponds and lakes reflecting the return of the groundwater level, which may proceed very slowly, depending on the depth of the erstwhile mine and on the given hydrogeological situation. Indeed, it may take more than 50 years for a new state of equilibrium to be achieved. If the zone of contact between the water and the soil contains soluble substances, power-plant ash and/or industrial residues, the water quality may suffer. The most well-known problem in that connection is an excessively low pH in the lakewater. A lack of affluxes and effluxes aggravates the problem, promoting eutrophication, particularly if the surrounding areas are intensively farmed.

The extraction activities impose a noise nuisance on their surroundings, with major noise sources including the machines and devices required for getting, loading, hauling, reloading, etc. In hardrock mines, drilling and blasting constitute two additional sources of noise. In addition to the sound of the explosion, the attendant vibrations and reverberations amount to an additional dynamic burden on the environment that not only annoys the neighbors, but can also cause damage to structures.

Finally, dry surface mining activities also lead to air pollution, the causes and effects of which

are multifarious:

– Blasting in hardrock causes dust pollution in that rock dust becomes entrained in the blast damp. The wind can stir up any and all exposed materials, especially during loading, reloading and dumping operations, all of which adds to the dust nuisance;
– Air pollution in the form of gases results from the exhaust of vehicles and engines, which tend to be diesel-driven, as well as from the escape of blast damp. Open-pit coal mines are susceptible to still other, deposit-specific hazards: the extraction of deep-lying coal can give rise to the escape of methane, and spontaneous combustion can release other noxious gases.

Hot, dry weather poses a considerable fire hazard - by spontaneous combustion - for exposed coal at the bottom of the pit and at the loading and unloading points.

Additionally, self-ignition can cause hard-to-extinguish smoldering fires in overburden dumps and feigh heaps containing small amounts of coal. Such fires can pollute the environment with odors and noxious gases for years or even decades.

– Radiation exposure can occur in special cases, i.e., in connection with the mining of uranium ore or rare-earth pegmatites.

Interference with the biological environment by dry surface mining

The surface extraction of raw materials necessitates areal exposure of the deposit. Removal of the soil in and around the mine itself, the surrounding dumps and the requisite infrastructure destroys the local flora.

In turn, fauna is driven out of the area by the destruction of its natural habitat.

Aquatic ecosystems can be disrupted by qualitative and quantitative changes in surface water conditions, while wetlands can be emburdened by an altered groundwater level, e.g., its lowering or recovery with subsequent lake/swamp formation. Fragile ecosystems in extreme locations are particularly susceptible to permanent damage or destruction.

Terrestrial ecosystems are also affected by mining-induced situational changes (in connection with the groundwater level, for example). Even after the mine has been abandoned and recultivated, the residual changes in soil physics and chemistry, available water resources, etc. can lead to the appearance of different plant and animal associations constituting an irreversible alteration stemming from the original disruption.

Effects of dry surface mining on the social environment

The areal nature and deposit dependence of surface mining activities engender the presumably most serious effects on human living conditions. Frequent consequences include:

- **the necessity of resettling the inhabitants of the area to be mined. Surface mining**

operations demand the relocation of settlements as well as traffic routes and communication infrastructure. The consequences range from economic loss to sociological and cultural disruption. The latter will be all the more serious, where the local population feels strongly attached to a limited natural environment, cultural or religious localities, established tribal structures, territorial sovereignties, etc.;
– land-use conflicts when the area to be mined is being used for agricultural or forestry purposes or contains significant cultural monuments, recreation areas/facilities or the like that stand to be destroyed or negatively affected by the mining operations.

If, due either to the large area to be affected by a surface mining operation and/or to attendant damage to the local flora and fauna, farmland and, hence, income potentials are lost, or even the relocation of entire settlements necessitated, those responsible and those affected must investigate in advance which special consequences and impacts the project can be expected to have for existing groups - women in particular. Likewise, the extent to which women will be able to partake of the economic advantages the region stands to gain from the mining operation must be duly investigated.

Moreover, the environmental effects of mining operations can affect the health of both the miners themselves and the people living in the surrounding area.

Finally, the establishment of mining infrastructure can inadvertently induce the uncontrolled generation of settlements in areas which otherwise may have remained undisturbed.

2.1.2 Wet extraction

With regard to the environmental consequences of wet surface mining, the previous subdivision according to physical, biological and social impacts is maintained. In case of identical consequences, the reader is referred to section 2.1.1.

Physical environmental impacts of wet surface mining

Since the wet extraction of raw materials is a function of site- and mineral-specific factors such as a low degree of consolidation, certain particle-size spectra, well-balanced, shallow topography and adequate quantities of water, the number of potential locations and, hence, the scope of environmental consequences are more limited than for dry extraction.

The differences begin with the space requirement. Wet extraction normally involves a very limited extraction area. Precious-metal and tin dredgers, for example, rarely require more than one hectare, unless overburden has to be removed in advance. On the other hand, the extraction area wanders more or less rapidly over the entire explorated field, which eventually becomes completely modified: when dry land is being worked, the soil is removed, but when a river is being worked, the entire riverbed is altered, and the entire course of the river is likewise affected. Cutting and winning leaves behind rubble containing large amounts of classified material that is extensively lacking in fine and superfine contents. Consequently, pedogenisis, or soil formation, as an essential prerequisite for recolonization by plant associations, is seriously impeded. Meanwhile, the fine and superfine fractions emburden the

river with large quantities of muddy wastewater. Such wet-extraction sludge plumes sometimes develop into water pollution loads that remain clearly visible over hundreds of kilometers before the clay fraction finally settles out of suspension. The situation can be additionally aggravated by contaminated wastewater. The escape of mercury from gold-placer processing activities, for example, or the uncontrolled disposal of used oil, constitute serious pollution potentials.

With regard to resources, noise and air, the reader is referred to the hazards discussed in item 2.1.1.

Effects of wet surface mining on the biological environment

Like dry extraction, wet extraction also destroys flora and drives away fauna. Also and in particular, however, wet extraction disturbs the aquatic ecosystem. The aforementioned mining-induced sludge contamination of affected rivers degrades the water quality, alters the river bed by depositing fine and superfine material, and disrupts the nutrient balance of the rivers, with consequential effects on river fauna and flora. Frequently, such pollution leads to lower fish populations due to dying and migration away from the affected sections of the river.

In tropical areas, wet extraction of mineral resources poses an additional serious environmental hazard in that resultant still waters can serve as breeding places for pathogenic agents such as malaria-carrying mosquitos. Indeed, it can happen that regionally eradicated tropical diseases flare up anew.

Effects of wet surface mining on the social environment

In otherwise infertile areas, the loss of fertile flood plains or easily irrigated areas to wet surface mines can lead to bitter land-use conflicts. Even if the areas in question are recultivated afterwards, irreversible damage may remain behind on a location- and situation-specific basis. The impairment of fish-farming activities by the aforementioned sludge pollution of rivers counts more as a temporary effect. By contrast, health impairment resulting from the contamination of rivers with mercury, for example, counts as irreversible, permanent damage.

Social conflicts in connection with wet mining activities become particularly serious when boom times (a local gold rush, for example) draw large numbers of small miners (diggers, garimpieros, pirquineros) into a particular area. Many such newcomers lack legal mining titles and either breed or intensify diverse problems (crime, speculation, exploding prices, disease, social tension among the native population, etc.). As the originally rich deposits become harder to work and eventually depleted, such problems tend to intensify.

2.1.3 Nearshore marine mining

In dealing with the environmental consequences of marine mining, deep-sea mining is not gone into separately, because it does not yet actually contribute to the production of raw materials. The environmental effects of deep-sea mining are comparable to those of nearshore marine mining, with the latter limited by definition to the use of bucket chain (scoop) and suction dredgers in waters with a maximum depth of about 50 meters.

Physical environmental effects of marine mining

The most serious effect of extracting minerals from the ocean is that such activities alter the ocean floor. The ground is removed by mechanical or hydraulic means in order to separate it from its ore in an on-board processing facility. Altering the morphology and composition of the ocean bed amounts to its total restructuring, since natural classifying processes take place when the oversize, tailings and perhaps overburden is re-deposited - assuming, of course, that the raw material in question contains low-grade ore (e.g., heavy mineral sand) and that processing leaves behind large quantities of nonbearing materials. When a large percentage of the material being extracted is commercially valuable (sand, gravel), its removal in large volumes also modifies the seafloor morphology, possibly resulting in intensified coastal erosion and accumulation of sediments, since the "new" ocean floor is less compact and lacking in fine and superfine particles.

The fine and superfine fractions that are left over from ore processing and which swirl up from the ocean floor remain in suspension for a long time, causing turbidity that can be carried off by ocean currents to pollute areas as far as 10 km away from the source.

If the water flows slowly, the fine and superfine particles settle out, covering the ocean floor with a layer of clay.

Moreover, by way of analogy to dry mineral extraction, the mining equipment, machines and apparatus generate noise and pollute the air and water.

Effects of marine mining on the biological environment

The altered seafloor interferes with the natural ocean-bottom nutrient balance, both within the mined area and in the emburdened vicinity. The effects are particularly devastating for immobile marine organisms such as corals, which can be partly or completely destroyed by the combination of high turbidity and fine-particle sedimentation.

The clouds of turbidity also impair marine life in the water itself, e.g., by reducing insolation, lowering the available oxygen level due to oxidation of stirred-up particles, obstructing the respiratory passages of marine organisms, and possibly even poisoning them with trace metals.

Mobile marine fauna can evade the polluted environment by moving off, but are nonetheless unable to prevent the destruction of their spawning grounds.

Effects of marine mining on the social environment

Since marine mining has no direct impact on the human environment, its social effects are limited to usufructuary conflicts, most notably with fish farmers, whose livelihood can be prejudiced by such mining, and with the operators of recreation facilities that can be adversely affected by mining-induced pollution.

2.2 Measures for limiting the environmental consequences of surface mining activities

A selection of technical options for use in limiting the pertinent environmental impacts prior to, during and subsequent to surface mining activities are pointed out below. Naturally, the limitation of environmental consequences (= pollution control) entails a suitable institutional basis and the existence, adherence to and monitoring of appropriate directives.

2.2.1 Measures prior to commencement of mining activities

The most important precommencement measure is to ascertain the momentary condition of the environment as a basis for evaluating subsequent environmental impacts. The relevant studies should give due consideration to cultural and historical monuments, soil conditions, groundwater and surface water qualities and quantities, as well as flora, fauna, land use, etc.

In the case of marine placers, the marine flora and fauna, prevailing currents, seafloor gradients, etc. also should be determined in advance.

Careful planning of operational sequences enables significant limitation of environmental consequences even before mining activities begin. For example, a suitable time schedule with provisions for the archiving and conservation of archeological finds, the harvesting of standing timber in the area to be worked, and/or keeping the mine open only as long as necessary is extremely useful. Likewise, careful separation and separate storage of humus and the upper soil horizons of the overburden ensure that suitable material will be available for subsequent recultivation. Selective dewatering according to a time scale and the use of modern drainage techniques and/or sealing methods can help minimize the problems arising from groundwater

recession.

With a view to precluding potential social tensions, all relevant planning must - in order to protect their interests - involve the groups of persons who will be affected either directly, e.g., by having to resettle, or indirectly, e.g., by impaired fishing conditions. It is particularly important that all parties concerned and affected, as well as the local authorities, be allowed to appropriately participate in the planning and execution of relocating measures, compensation and possible resettlement.

Finally, both the decision makers and the miners must be instructed and sensitized in and toward the environmental and health aspects of surface mining activities prior to their commencement.

2.2.2 Measures in the course of mining activities

In order to avoid excessive land consumption, inside dumps should be established, i.e., the overburden should be stored within the open spaces of the mine.

The noise nuisance must be limited by appropriate soundproofing of individual pieces of equipment. Whole units of equipment can be encapsulated or equipped with special exhaust systems (mufflers). Additionally, the miners must be required to wear personal noise-protection gear, e.g., ear protectors. Finally, time limits can be imposed on noise emissions, e.g., by limiting blasting operations to once a day. Moreover, the propagation of acoustic

waves in the near vicinity of noise emitters can be reduced by such measures as noise-control embankments.

In hardrock mines, optimized blasting methods can substantially reduce noise and dust emissions. By optimally matching the explosive quantities to the drilling pattern and by stemming the holes, the overall quantity of explosives and, hence, the magnitude of the explosion (vibrations), the incidence of microfine dust, and the intensity of the blasting noise can be substantially reduced.

Dust control measures in surface workings can encompass such individual measures as sprinkling water on the roads and other conveying routes, washing down transport equipment (trucks, etc.), irrigating and turfing dumps and exposed areas, and applying dust bonding agents as necessary. Also, individual pieces of equipment such as crushers over belt feeders can be encapsulated and surrounded with trees or hedges that filter out dust and reduce the overall drift (deflation). Drills and boring tackle can be fitted with wet or dry dust precipitators.

Wastewater can be cleansed of suspended solids, neutralized and clarified in wastewater treatment facilities to meet minimum quality standards for release into a recipient body. For each and every solution or suspension, there are appropriate liquid/liquid and solid/liquid separation processes for use in purifying contaminated water. For metal-polluted acid mine drains (a.m.d), electrolysis is indicated, while an ion-exchange technique is more suitable for radioactive wastewater. In general, all means of countering the causes of pollution should be exploited. For example, the use of bypass microfilters in engine lubrication systems can reduce

the incidence of used oil by up to 90 % by prolonging its useful life.

The dredges used for working nearshore marine placers should be equipped with long rubbish chutes for use in covering the tailings/trash and oversize with overlay shelf in order to restore a close-to-natural particle-size spectrum to the seafloor.

Wet extraction from an artificial lake is preferable to working directly in a river, because it involves much less of a sludge load for the latter. Wells and other large boreholes that are no longer needed but could disturb groundwater barriers (aquitards) should be sealed.

Particularly for fragile working faces, the angle of slope around the perimeter of the mine must be designed to preclude major flank movements (slides and falling rocks).

In dry coal mines, care must be taken at the planning stage to protect coal-bearing dumps from spontaneous ignition by appropriate surface compaction and air-exclusion measures. The same applies to coal pillars and abandoned working faces, which also require sealing to prevent smoldering fires.

Such special measures as the posting of trespassing notices, installation of fences and blocking of roads can help protect and preserve adjacent ecosystems.

Persons likely to be affected can and must be afforded appropriate protection through, say, the appointment of environmental affairs and/or safety officers and occupational physicians.

Since damage to the environment cannot be limited exclusively to the mining area, the right to medical services should also be extended to persons living in the general vicinity.

Continuous monitoring of all important factors must accompany all surface mining activities and attendant pollution-control measures. Such factors include exhaust gases, noise levels, vibrations, water pollution, particulate emissions, slope movement/stability, ground subsidence and groundwater levels.

2.2.3 Measures following termination of mining activities

As soon as any section of a deposit has been fully exploited and refilled with waste from new operations, appropriate rehabilitation measures can and must be taken. Since surface mining operations tend to be quite expansive, ongoing mining operations in one area can be accompanied by rehabilitative measures in another. The same is true of wet mining operations outside of riverbeds. To rehabilitate means to immediately transform the areas concerned into as natural a landscape as possible.

Following wet extraction, particularly in tropical locations, all worked-out areas must be drained and graded to eliminate all open bodies of water that could serve as breeding grounds for pathogenic vectors like malaria-transmitting mosquitos. On the other hand, bodies of water created by surface mining activities can, on a case-by-case basis, also be utilized as dry-season water reservoirs or for such commercial purposes as fish-farming.

Dumps, open-pit perimeters, outside dumps and erstwhile extraction areas require immediate greenbelting or planting with indigenous vegetation in order to limit or prevent erosion, especially in humid, tropical climates, and deflation in arid climates. Special erosion control methods such as drainage and consolidation must be employed in particularly vulnerable areas.

The ultimate aim must be to fully recultivate the worked out areas to enable appropriate and corresponding use, or to renature them for another purpose. To reclaim the land, it must be graded, compacted and covered with soil and humus to allow immediate oversowing and subsequent soil management. It should be borne in mind, however, that recultivation is not the only means of limiting environmental detriment. Recultivation is very time-consuming, and the ultimate success is usually uncertain. Especially recultivation in tropical areas has not yet been adequately researched and developed with regard to planting sequences, site-appropriate species, etc. Moreover, successful recultivation entails extensively natural soil physics (permeability, granularity/type of soil) and soil chemistry (pH, nutrients, absence of pollutants). Otherwise, the soil would not be able to fulfill its diverse functions as a water reservoir, a biotope for plants and animals, and a basis of agricultural production.

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3. Notes on the analysis and evaluation of environmental impacts

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The principal regulations governing mining activities and pertinent environmental protection in Germany are the *Bundesberggesetz* BBergG [Federal mining law] dated August 13, 1980, and the *UVP-VBergbau* (ordinance on the environmental impact assessment of mining projects) dated July 13, 1990, the *TA-Luft* (Technical Instructions on Air Quality Control), the *TA-Lrm* (Technical Instructions on Noise Abatement), the *BImSchG* (Federal Immission Control Act) and its various implementing provisions, as well as the respective mining regulations of the various states and their laws governing landscape, preservation of nature and excavation. In addition, the *Verein Deutscher Ingenieure* (Association of German Engineers) has issued a number of guidelines dealing primarily with the relevant mechanical equipment.

Other industrialized countries like the USA, Canada and Great Britain have similar, in part more stringent, laws and regulations - including, for example, the U.S. "Clean Water Act" (1977) and the "Surface Mining Control and Reclamation Act" (public law 95/87, 1977), with supplementary provisions drawn up by the Office of Surface Mining Reclamation and Enforcement (OSM) and by the Environmental Protection Agency (EPA).

A precommencement status quo study with thorough investigation of all matters relevant to the physical, biological and social environment provides a crucial basis for evaluating the environmental consequences of surface mines and planning recultivation measures; cf.

environmental brief Reconnaissance, Prospection and Exploration of Geological Resources.

Growing awareness of the environment and the will to protect it is emerging in many parts of the world. To some extent, however, that new awareness has not yet found its expression in appropriate national laws. But even where laws protecting the environment already are in place, their enforcement is frequently neglected for a lack of control and monitoring options. The absence of an appropriate legal basis and/or of its proper implementation has serious large-scale and small-scale consequences for the environment, whereas mining regulations could be adopted with which to hold mine operators responsible for the consequences of their own mining activities. For small mines that are difficult to monitor, a pertinent recommendation was proposed at the UN-sponsored International Round Table on Mining and the Environment Congress in Berlin: recultivation guarantee funds can be set up, e.g., included in the concession fee. If the mine operator fails to rectify substantial environmental damage when he leaves his concession, financial reserves will be available to pay for recultivation. Otherwise, the withheld funds could be returned to the mine operator following satisfactory inspection of the properly recultivated areas.

Illegal mining is the biggest problem with regard to environmental destruction and recultivation. When large numbers of gem seekers and gold diggers intrude into and begin working an area in a completely uncontrolled manner - especially in developing countries - their activities are bound to cause areal destruction, often accompanied by pollution of the soil and rivers (with mercury and cyanide in the case of gold diggers). Legal measures have proven totally inadequate as a means of control, because the form of mining involved requires very

little equipment, thus promoting a high level of mobility and, hence, good chances of evading control. Moreover, supervision becomes nearly impossible when large numbers of such people converge on an area and are willing to use force in defense of their interests. Consequently, damage to the physical and biological environment is accompanied by pronounced social tensions between the various interest groups.

4. Interaction with other sectors

In sparsely populated and undeveloped regions, mining tends to serve as a pacemaker for infrastructural development. Frequently, mining projects have to carry the major share of the relevant cost of building access roads and establishing rail links to deposits for hauling away the mineral products and of building homes for the miners and their families, including all the requisite supply and disposal facilities. The new infrastructure can act as a catalyst for extensively uncontrolled settlement and economic development of the area in question.

Ore mines in particular tend to include an initial processing stage for local first-step product enrichment. Frequently, the purchaser and the mine operator agree to share the storage and supply facilities. In many brown-coal and hard-coal strip mines, the raw (possibly upgraded) coal is used directly for fueling thermal power plants. Accordingly, power generating facilities and distribution systems tend to be installed near such mines. Storage grounds for disposing of residues can be established in worked-out parts of the mine for some future use. Fly ash from

power plants, for example, is often used for consolidating mine roads.

Land-use conflicts can quickly arise due to the space requirements of surface mining. The various interests must be reconciled within the context of appropriate regional planning.

While land-use problems occur less frequently in sparsely populated countries, legal problems nonetheless may arise. Property rights, for example, may not have been duly registered, and the boundaries may have been inaccurately mapped. Such problems intensify when those concerned happen to be groups of people with no lobby and a life-style and social status that afford them few options for preserving their traditional habitat. The very existence of such groups can be threatened. What is needed is a form of regional and development planning that duly accounts for ecological and ethnic concerns alongside of economic interests.

The following sectors, the environmental consequences of which are described in other environmental briefs, can be affected by surface mining activities and therefore require consideration:

- **Spatial and Regional Planning**
- **Planning of Locations for Trade and Industry**
- **Overall Energy Planning**
- **Water Framework Planning**
- **Wastewater Disposal**
- **Transport Planning and Traffic**

- **Reconnaissance, Prospection and Exploration of Geological Resources**
- **Underground Mining**
- **Minerals - Handling and Processing**
- **Thermal Power Stations.**

5. Summary assessment of environmental relevance

Surface mining of mineral resources involves different methods: wet and dry, marine and terrestrial. Common to all, however, is that they have serious environmental consequences.

Although most mining activities are temporary by nature (approx. 20 - 50 years), they often cause permanent damage to the environment through irreversible disruption. The earth's surface and the groundwater and surface-water regimens tend to sustain the most serious direct damage. Mineral extraction by surface mining methods also causes air pollution, noise nuisance, alteration of the soil, flora and fauna, and social problems arising from land-use conflicts, resettlement, etc. Such impacts are invariably dependent on the area involved, the location and the climate. Additionally, points of law and control options play major roles in determining the extent of environmental damage caused by surface mining activities and/or its limitation by such means as recultivation or renaturation. Recultivation, however, always amounts to substituting a new ecosystem for the original one in the affected area. Moreover, the ultimate success of such measures can rarely be guaranteed, especially in locations for

which no relevant empirical data is available.

The extent of damage can be limited through careful planning, preparation and implementation of the mining activities. A thorough analysis of the actual situation in the region is an indispensable prerequisite and basis for planning with due consideration of the mining activities' anticipated effects in the form of environmental impacts and structural modification of the subject region. This must include the regulation of compensation and the planning of resettlement measures as well as the elaboration of recultivation plans.

As a flanking measure, concerned organizations, institutions and individuals must be sensitized and informed to prepare the way for the ecologically oriented implementation of the project.

The need to minimize costs must not be allowed to induce the promotors and others responsible for the project into cutting back on expenditures for environmental protection. Consequently, project desk officers should see to it at the project appraisal and authorization stage that the project encompasses adequate landscape and environmental protection measures, including the optimal use of resources, and that a sustainable structure with the appropriate control and regulatory functions is in place.

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37. Underground mining

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[5. Summary assessment of environmental relevance]

[6. References]

1. Scope

Mining is defined as the extraction of mineral resources from the earth. Underground mining is the extraction of raw materials below the earth's surface (deep mining) and their conveyance to the surface. Access to the vein or lode is by shafts and tunnels with links to the surface. (The subsequent stages of raw material processing are dealt with in a separate brief: Minerals - Handling and Processing.) The present brief examines only the underground extraction of solid mineral resources.

There are some 70 individual types of useful minerals that occur in minable concentrations either alone or in combination with other minerals, frequently as natural mixtures (aggregates).

Underground mining includes all work involved in the winning of raw materials by people using technical contrivances. Apart from the actual extraction and conveyance processes, the term underground mining also covers development of the deposit and provision of the requisite infrastructure (transportation/handling, storage facilities, surface plant, e.g.,

administration building, workshops, etc.) and all measures devoted to ensuring the safety of the miners. This includes:

working	conveyance	ventilation
loading	drainage	support

Small-scale mining activities in many countries frequently include a transitional form of extraction referred to as trench mining, or burrowing.

In special cases, the mineral can be made transportable and hauled off from its natural surroundings with no need of exploratory work (brine mining, in-situ leaching and in-situ gasification of coal).

Deep mining creates underground spaces in which people work. Their working conditions with regard to air temperature and humidity, presence of harmful or explosive gases or radiation, as well as moisture, dust and noise, can be specific to the mined mineral and/or the surrounding rock, the depth of the mine, and the type of machinery in use.

The locations of deep mines are dictated by the presence of potentially profitable raw materials. Underground extraction is practiced in all climate zones, in remote areas as well as under large cities, on the ocean floor and in alpine regions. The size, or output, of such mines ranges from less than 1 to more than 15 000 tons a day, and the depth at which extraction

takes place ranges from a few meters to more than 4 kilometers.

2. Environmental impacts and protective measures

Deep mining impacts the environment in three different areas: in the deposit itself and the surrounding rock, in the underground spaces created by and for the mine, and aboveground. Optimal exploitation of the resource with attendant limitation of environmental effects is dependent on detailed planning of the sequence of operations and on the mining methods and technology to be employed.

2.1 Environmental impacts on the deposit and the surrounding rock

2.1.1 Exploitation of resources

The most important environmental consequence of underground mining is that it involves the exploitation of a nonrenewable resource. The process of extracting the raw material necessarily also involves mining losses and impairment of other parts of the deposit. The best way to counter the latter effects is to carefully plan the extraction operations, stowing measures, etc.

Some raw materials (coal and several sulfidic ores) can under certain circumstances ignite

spontaneously and cause mine fires.

2.1.2 Disruption of rock structure

The opening up of underground workings creates cavities and leads to stress and motion in the surrounding rocks. The effects of mining on the rock structure can include:

- **subsidence due to cave-ins in the cavities. The resultant settling can propagate to the surface, possibly causing damage to structures and facilities (subsidence damage; cf. section 2.3.3 for protective measures);**
- **destruction of hanging parts of the deposit (most likely as a result of inadequate extraction planning).**

2.1.3 Disruption of groundwater flow

The opening up of underground workings modifies the formerly stable water balance of the rock structure by creating new water conduits. Water drainage, for example, can cause significant recession of the groundwater level with substantial attendant detriment to vegetation within the affected area (cf. section 2.3.2).

2.1.4 Alteration of groundwater quality

Mining activities can pollute groundwater in several ways: mine waters (cf. item 2.2.4), for example, can enter the groundwater system, and various alkaline and other solutions used in

in-situ dressing processes, as well as leakage losses of refrigerants used in the sinking of shafts, all can contaminate the groundwater, just as the leaching of dumps produces percolating water that can alter the character of groundwater. Effective preventive measures include the sealing off of soils, shafts and worked-out parts of the deposit, drainage and/or canalization.

2.2 Underground environmental impacts

Man, machine, rock and climate all interact underground, whereas man is impacted most significantly. Matters concerning the health and safety of miners are therefore given priority consideration.

2.2.1 Air / climate

The underground climate is influenced by the elevated temperature of deep rock and by the gases and liquids it contains.

Table 1 **- Factors influencing the atmosphere in underground mines**

Potential hazard /	**caused by ...**	**danger of ...**	**Preventive measures**
Reference values			
Oxygen deficiency	displacement by irrespirable (black)	fatigue, asphyxia	ventilation

(O_2) --------- 19 % min.	damps and firedamps, respiration, open mining lamps, mine fires		
Radiation	radioactive rock compo-nents, measuring probes	radiation affection	limited exposure time with dosimetric control
Radon	gas evolution from surrounding rock	radiation affection	ventilation, limited exposure time
Methane (CH_4) --------- 5 - 14 % = explosive	gas evolution from coal	explosion	gas extraction, ventilation, flameproof equipment
Coal dust	mining, handling of coal	explosion	dust precipitation, flameproofing
Carbon monoxide (CO) ---------	exhaust, gas evolution in abandoned hard-coal	poisoning	ventilation

> 50 ppm	mines		
Carbon dioxide (CO_2) --------- > 1 %	gas eruption in salt, exhaust, gas evolution from thermal waters	asphyxia	ventilation
Hydrogen sulfide (H_2S) --------- > 20 ppm	gas evolution from mine and thermal waters	poisoning	ventilation
Oxydes of nitrogen (NOx) and blast damp	blasting	poisoning	ventilation, specification of blasting times
Exhaust gases	engine exhaust	poisoning	ventilation
Low-temperature carboni-zation gases, smoke	mine fires	poisoning	extinguishment, damming off, precautionary measures
Aerosols of oil	pneumatic equipment	poisoning	oil precipitation
Heat	elevated rock	fatigue	ventilation, air

	temperatures, off-heat from engines		cooling

2.2.2 Noise

In underground workings, noise is generated by drilling and blasting, by internal-combustion engines and pneumatic and hydraulic motors, and by various means of conveyance (conveyor belts, trains, vehicles) and fans.

Machine-generated noise can be reduced by various design measures, and ear protectors are mandatory beginning at certain sound intensity levels.

2.2.3 Dust

Exposure to dust (stone dust in coal mines, for example) must be limited to minimize the incidence of related diseases, the most dangerous of which is silicosis resulting from the inhalation of silica particles. Dust forms when rock is destroyed by mechanical means (drilling, blasting, crushing, handling, etc.).

Dust consisting of the following mineral substances poses a hazard to human health: asbestos, beryllium, fluorspar, nickel ores, quartz, mercury, cinnabar, titanium dioxide, manganese oxide, uranium compounds and tin ores. Pulverized asbestos and respirable dust containing nickel ore and/or beryllium, as well as soot from diesel engines, are carcinogenic. Coal dust can cause dust explosions.

Countermeasures against dust pollution include its consolidation during drilling and conveying, either by spraying it with water or by saturating the face through appropriately arranged boreholes prior to extraction. Gas masks prevent the inhalation of dust, and filters on engines bond soot particles.

2.2.4 Mine waters

Mining activities alter the characteristics of mine waters.

Appropriate safety clothing protects miners against aggressive mine waters, and appropriately resistant materials prevent corrosion of material goods.

***Table 2* - Pollution of mine and surface waters**

Type of pollution	**Typical polluting substances**	**Preventive Measures**
Altered pH		neutralization
Soluble inorganic substances	heavy metals, salts, sulfur	precipitation
Insoluble inorganic suspended solids	mud	agglomeration and settling
Organic substances	oil, grease,	precipitation in

	lubricants, emulsifying agents	settling tanks
Heat		cooling, mixing

2.3 Aboveground environmental impacts

The aboveground environmental consequences derive from communication between the mine and the surface in the form of ventilation, mine pumping and conveyance of the product, in combination with establishment of the requisite aboveground mining infrastructure. Vibrations caused by blasting and ground movement are also perceptible aboveground.

2.3.1 Air / climate

The harmful effects of air pollution, particularly on nearby vegetation can be alleviated by filtering the outgoing air from the shafts and tunnel faces. Dumping and wind-induced erosion of dumps can cause substantial air pollution, most notably in the form of dust.

Dust evolution can be controlled by appropriate sprinkling in connection with dumping and by immediate greenbelting, oversowing and protective dams. In arid regions where land planting is hardly possible, preventive measures must be taken in the form of restricted use in the prevailing wind direction.

Coal mining releases large quantities of methane (CH_4), one of the most notorious

"greenhouse gases". The best way to control methane is to "drill and extract" (with subsequent utilization). Particulate solids in the vitiated air from underground mines can be extensively eliminated by filtration.

2.3.2 Water

The pH of mine waters, particularly in the presence of sulfidic ores, can range below 5.5 (acidic). Adherence to the limits prescribed for sulfates, chlorides and metals is essential.

If the groundwater is being used as drinking water and ore is being discharged into a body of surface water, the relevant values must be monitored. It is important to know which anions and cations can occur in mine water and which of them constitute potential hazards on the basis of their concentration or toxicity.

It is also important to mention that heaps of material extracted from an underground mine are liable to contain high concentrations of chlorides and sulfates and that, in a humid climate, such salts can be leached out by precipitation.

Whenever minewater is discharged into a body of surface water, care must be taken to avoid damaging any sensitive ecosystems and to ensure that no long-term accumulation of pollutants occurs in the sediment and that overall use of the water in question, e.g., for fishing purposes, is not impaired.

Marine pollution and alteration of the ocean floor or fishing/spawning grounds can result from the conveyance of polluted water through rivers leading to the coast.

Finally, underground mining consumes water for such activities as drilling, gobbing/stowing, hydro-mining, etc.

The measures described in section 2.2.4 (table 2) should be adopted to prevent pollution of surface and groundwater by mine waters.

2.3.3 Subsidence

For the day surface, the most frequent danger resulting from underground mining activities is subsidence, or settling. Subsidence-induced tilt, curvature, thrust, stretch and compression of the day surface can cause damage to buildings and infrastructural facilities as well as to the natural environment. Watercourses such as canals and rivers - and rice paddies, for example - react very sensitively to the slightest change in ground inclination.

Protective measures begin with early regional planning with due consideration of the potential mining-induced consequences of ground subsidence.

Settling can also be avoided or at least reduced by properly lining the mine with support material and backfilling the face workings with rejects and/or the use of certain suitable extraction techniques. Well-planned and controlled extraction allows slow areal settling that is

unlikely to damage buildings or public utility lines and facilities.

2.3.4 Dumps, land consumption, landscape

Underground mining activities are usually accompanied by the appearance of large rubbish heaps within the immediate vicinity of the mine, where rejects and other useless material are dumped. The residual metal contents of such material should be ascertained, even though the metal burdens emanating from dressing heaps can be expected to be higher. Frequently, rubbish dumps are difficult to recultivate, and appropriate measures therefore should be included in the working plans.

Underground mines require a certain extent of surface area for the requisite infrastructure (hoists, buildings, workshops, storage areas, power generating equipment, access road, etc.). The aboveground facilities can impair the appearance of the landscape, and relevant architectural measures have limited effects. The establishment of any such industrial complex is bound to alter the landscape in the vicinity of the mining facilities. To the extent that resettlement is necessary, the affected parties must receive appropriate compensation.

Lowering the groundwater level can have detrimental effects on the local vegetation, including the drying out of ponds, streams, etc. Moreover, the local fauna and human population can be adversely affected by a diminishing supply of drinking water as a result of the altered water regimen.

Adequate protection of wetlands against such negative impacts may require the artificial recharge of groundwater, particularly since receding groundwater tends to cause settling, with damage to structures as one likely result.

Finally, vibrations caused by blasting and ground movement are also perceptible aboveground.

2.4 Other consequences of underground mining

Establishing mining operations in remote areas can have the inadvertent effect of opening the area up to uncontrolled settlement and land use. Appropriate planning-stage backup measures are therefore called for.

The intensive use of wood for timbering mines can trigger the large-scale felling of trees and, hence, erosion of the exposed soil. Orderly silvicultural activities in the area around the mine can help prevent such problems, especially if fast-growing species of trees are planted. Nonetheless, long-term effects on the ecosystem remain unavoidable. The use of anchoring techniques and steel supports in underground mines can extensively reduce wood consumption.

The world over, underground mining provides employment almost exclusively for men, because cultural and traditional conceptions forbid women to work underground. If at all, jobs for women are to be found in the areas of mineral processing, marketing and attendant services. Children should never be allowed to work in underground mines. Other social

problems can arise in connection with mining if the housing for the miners and their families is either inadequate or not accompanied by the appropriate infrastructure (water, markets, schools, etc.) and if the miners are not covered by social insurance.

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3. Notes on the analysis and evaluation of environmental impacts

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3.1 Air / climate

The gas contents of air in underground mines is regulated in Germany by pertinent laws such as the mining ordinances *(Bergbauverordnung)* BVOSt and BVOE of the North Rhine-Westphalian mining inspectorate *(Landesoberbergamt LOBA)* and its pertinent and specific directives.

For methane (CH_4), the following limits apply to free airflow:

more than 0.3 % : tram shutdown

more than 0.5 % : recorded monitoring
more than 1.0 % : electrical equipment shutdown
more than 2.0 % : monitoring equipment shutdown

Gas extraction equipment is subject to measures in accordance with the relevant gas extraction directives.

Carbon monoxide (CO) in concentrations of 50 ppm and higher calls for special rescue, recovery and security measures according to a life-saving plan (Hauptstelle fr das Grubenrettungswesen der Bergbau-Forschung GmbH, 1982).

Mines must be evacuated if the carbon dioxide (CO_2) level reaches 1.0 % or higher.

Nitrous gas levels of 300 ppm NOx, including 30 ppm NO_2, allow a maximum exposure time of 5 minutes. A level of 100 ppm NOx (including not more than 10 ppm NO_2) extends the maximum exposure time to 15 minutes per shift.

The oxygen content must amount to at least 19 %.

The hydrogen sulfide (H_2S) concentration must not exceed 20 ppm.

All gas measurements must be performed using calibrated commercial-type instruments.

The airflow velocity should amount to at least 0.1 m/s in large spaces and at least 1.0 m/s in fast-line sections. The air velocity in levels used for travel (tram levels) should not exceed 6.0 m/s.

Minimum air volumes amount to 6 m^3/min per person, plus 3 - 6 m^3/min per diesel horsepower for CO levels ranging from 0.06 % to 0.12 %.

Airflow velocities are measured with anemometers, and the airflow volumes are calculated by multiplying the velocity by the cross-sectional area.

The regulations governing gas contents, air volumes and airflow velocities differ from country to country (hard-coal mines in India, mines in Chile, the People's Republic of China, etc.).

3.2 Noise

Underground noise limits can be drawn up along the lines of rules issued by the North Rhine-Westphalian Mines Inspectorate (LOBA) in Dortmund.

The sound intensity level of noise generated by drills should not exceed 106 dB (A) at a distance of 1 m (LOBA *Rundverfgung*).

Transgression of a certain reference intensity calls for the use of ear protectors. The 1988 EC directive on noise in mining came into force in Germany in 1992. Noise measuring

specifications have been developed by the Westphalian miners' union fund *Westflische Berggewerkschaftskasse* in Bochum, and the appropriate measuring instruments are commercially available.

3.3 Dust

In the Federal Republic of Germany, the German Research Foundation *(DFG - Deutsche Forschungsgemeinschaft)* publishes yearly dust emission limits/standards in the form of occupational exposure limits (*MAK-Werte*), technical exposure limits (TRK) and biological tolerance values for working materials (BAT). To the extent that the limit values in question are directly relevant to human health, the above or comparable guidelines, e.g., from the World Bank or other international organizations, should be adhered to.

The most important occupational exposure limit, or MAK-value, is that pertaining to fine silica dust, which amounts to 0.15 mg/m^3. The corresponding value for siliceous fine dust is 4 mg/m^3. In hard-coal mining, the limits for fine silica and siliceous dust presently (as of this writing) amount to 0.60 mg/m^3 and 12 mg/m^3, respectively, and were scheduled for reduction in 1992. Fine dust is referred to as siliceous if it contains more than 1 % quartz.

The maximum personal dust exposure, measured in mg/m^3 x number of shifts worked in five years, shall not exceed 2500. All underground work is classified according to different dust-exposure categories.

Workers suffering from incipient pneumonoconiosis (or anthracosis) may not be exposed to more than 1500 (mg/m^3 x number of shifts worked) in the span of five years. In North Rhine-Westphalia, the German *land* with the largest number of mines, the mining ordinance for hard-coal mines *Bergbauverordnung fr Steinkohlebergwerke*, section 44 - 48, version dating from February 19, 1979) governs the measurements and interpretation.

***Table 3* - Miscellaneous dust limits (MAK-values) with mining relevance**

	Fibers/m	**mg/m**
Asbestos, crocidolite	0.5 x 106*	0.025*
All other types of asbestos-laden fine dust	1 x 106* --	0.05* 2.0*
Beryllium	carcinogenic	
Iron-oxide powder	--	6
Fluorspar	--	2.5
Nickel-ore dust (sulfid.)	carcinogenic	
Mercury		0.1
Cinnabar		0.01
Titanium dioxide		6

Manganese oxide		1
Uranium compounds		0.25
Determined by means of atomic absorption analysis and X-ray fluorescence analysis. Application to projects in developing countries in accommodation of local measuring techniques and analytical methods (cf. references) is recommended. * technical exposure limit (TRK)		

3.4 Water

The discharge of industrial process water and mining effluent is strictly regulated in Europe. The EC Council Directive 80/778 relating to the quality of water intended for human consumption, dated July 16, 1975, supplemented July 15, 1980, lists three water categories requiring less extensive (category A1) or more extensive (categories A2 and A3) treatment. The guideline values (G) and imperative values (I) for the third category are listed in the following table along with the threshold values (TV) and limit values (LV) stipulated by the North-Rhine Westphalian State Agency for Water and Waste (*Landesamt fr Wasser und Abfall Nordrhein-Westfalen*) in the draft ordinance on potable water *Trinkwasserverordnung* (TVO) dated July 26, 1994, selected on the basis of relevance to deep-mine waters.

Table 4 - **Potable water obtainment guidelines**

Element	EC-values		NRW (North-Rhine/ Westphalia)		Element	EC-values		NRW	
[g/l]	G	I	TV	LV	[mg/l]	G	I	TV	LV
Fe	-	0.2	-	0.2	Cr	-	0.05	0.03	0.05
Mn	-	0.1	-	0.1	Pb	-	0.05	0.01	0.04
Cu	1	-	0.03	-	Se	-	0.01	-	-
Zn	1	-	0.1	2.0	Hg	0.0005	0.001	-	-
B	1	-	-	-	Ba	-	1	-	-
Mg	-	-	25	50	NO_3	25	50	5	11
Na	-	-	50	150	SO_4	150	250	120	240
K	-	-	5	12	Cl	200	-	25	-
Ni	-	0.05	0.03	0.05	F	0.7/1.7	1	-	-
As	-	0.1	0.006	0.04					
Cd	-	5	2	5	pH	5.5-9			6.5-8

3.5 Soil

Oversown dumps are rarely used for agricultural purposes. In the event that such a use is envisioned, the applicable heavy-metal tolerance values for soils are to be found in the guidelines and directives issued by the Darmstadt-based *Verband Deutscher Landwirtschaftlicher Untersuchungs- und Forschungsanstalten* (German association of agricultural research and analysis stations) and by the Biologische *Bundesanstalt fr Land- und Forstwirtschaft* (Federal Biological Research Centre for Agriculture and Forestry) in Berlin. It is generally necessary to determine the constituents of the dump and any leaching behavior that could impose limits on the available soil utilization options.

4. Interaction with other sectors

With regard to environmental consequences, underground mining is closely linked to a number of other sectors, including in particular:

– prospection and exploration of deposits in preparation for the actual underground extraction activities;
– processing of the raw materials to obtain marketable products, with such

processing normally taking place in centralized plants situated directly at or near the mine;

– conversion into electricity in thermal power stations, many of which are located in the near vicinity of brown-coal mining operations;

– building construction and civil engineering as sectors pertinent to establishment of the requisite mining infrastructure and means of transportation to the market. (Mines tend to be found in isolated locations, accordingly intensive construction activities are required.);

– waste disposal, e.g., for thickener sludge, hydraulic oil, spent oil and the like, and problems concerning ultimate disposal;

– water management, since natural water is quantitatively and qualitatively altered by the discharge of mine water into surface waters or groundwater as well as by the extraction of water for use as process water;

– forestry as a bulk provider of timbering wood;

– and, finally, regional development, which consistently derives strong impetus from mining activities.

5. Summary assessment of environmental relevance

In sum, underground mining can be referred to as an activity with substantial impact on the environment. The consequences can be very detrimental to the environment, especially

through the extraction of resources, alteration of the rock structure and groundwater regimen, pollution of the air, the effects of noise and dust, pollution of surface water and alteration and disruption of the landscape. Compared to surface mining, underground mining has modest surface area requirements, both for the winning of raw materials and for other industries. With the exception of leftover rubbish dumps, the area in question is only needed for as long as the deep mine remains in operation.

Among the most significant environmental effects of underground mining is its impact on the miners themselves, whose health and safety are quickly and seriously jeopardized, if the protective rules, regulations and measures are not systematically adhered to.

Finally, underground mining has social consequences, especially in connection with speculative forms of mining, e.g., for precious metals or gems.

Many environmental consequences can be moderated but not prevented. Extensive data is needed as a basis for assessing the environmental impacts and designing protective measures; the uncertainty levels are accordingly high. Even the preparatory activities (reconnaissance, prospection and exploration) necessitate good coordination between the relevant environmental impact assessments and their data requirements.

The stipulation, enforcement, monitoring and control of limit values and underground mining operations has, to a certain extent, evolved to exemplary levels. Direct application of limit-value enforcement and monitoring to other countries is only conditionally possible, since the

basic prerequisites usually differ. Nevertheless, every attempt should be made to apply and meet standards designed to preclude detrimental effects on man and the environment. Probably the biggest problem from an environmental standpoint are the uncounted "informal" small-scale mining activities employing uncontrolled, inadequate, unsafe methods that also tend to be hazardous to the environment.

Proper and orderly mining operations require stringent supervision (routine measurements, data collection and monitored adherence to essential limit values). That, in turn, calls for competent executing agencies.

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38. Minerals-handling and processing

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5. Summary assessment of environmental relevance

6. References

1. Scope

Processing constitutes the technological link between the extraction, or mining, of raw minerals and their conversion into industrially useful working materials. The techniques applied are designed to separate the valuable from the barren material while upgrading, or concentrating, the former. The large variety of raw materials and the many different types of deposits in which they are found naturally necessitate an accordingly broad array of processing routes, from the simple classification and washing of sand and gravel to the more elaborate methods of processing hard coal, and on to the material beneficiation of disseminated metal ores. Ores processing (dressing) does not, however, include the various stages of metallurgical processing described in the brief dealing with the production of nonferrous metals.

In many cases, the environmental relevance of a given stage of processing increases in relation to its scope and/or degree of difficulty. The present brief therefore focuses on the environmental aspects of ore processing facilities as the source of most damage potentials.

It must be noted in that connection that no account is made of special cases such as uranium

ore processing, which is already subject to special statutory regulations around the world. Likewise, no processes are dealt with that serve in the reclamation or reprocessing of spent merchandise such as worn-out batteries, scrap glass, etc.

2. Environmental impacts and protective measures

2.1 Handling

The loading and unloading of trucks and railroad cars can generate large amounts of dust. During transportation, fine dust is lost to relative (head) wind, while trucks emit pollutant-laden exhaust gases, and both trucks and trains are noisy. Transportation by truck or rail entails the consumption of land area for roads and railways. The construction and use of traffic routes can have detrimental effects on nature and residential quality; cf. briefs dealing with transport and traffic planning, provision and rehabilitation of housing, and road traffic.

In the interest of environmental protection, the mineral processing plant should be located either directly on or in the immediate vicinity of the mine premises. That way, the ore can be moved from the mine to the processing facility by conveyor belt instead of by truck or rail. If transportation by truck is unavoidable, the haul roads should be provided with a course of bituminous road-building material or concrete and kept clean at all times. A wheel-washing stand and/or routine washing of the vehicles helps reduce dust emissions. Low-emission,

noise-abated trucks are designed to help reduce overall emissions of carbon monoxide, hydrocarbons, oxides of nitrogen, soot and noise. Other in-transit protective measures include moistening the load with water, tarping it over, or using closed containers. Dust extraction and control devices are required for loading and unloading operations, i.e., on loading equipment such as downcomers, and on unloading equipment such as dumping chutes. When filling closed containers with dust-generating products, the displaced air must be dedusted. The required degree of dust extraction depends on the hazardousness of the dust in question. Cyclone separators and fabric filters are inherently suitable.

Conveyor belts should be encapsulated as a pollution-prevention measure (not for maintenance purposes), i.e., as a means of restricting dust and noise emissions. The conveyor drives at the corners (diversion points) emit sound intensity levels reaching as high as 120 dB (A). Any sound insulation employed should be harmonized with that used for other noise sources within the processing plant. The use of noise locks on bunkers also helps reduce noise emissions, since the size of the opening is decisive for the amount of sound radiated during unloading.

2.2 Crushing, screening, milling, classifying

The rock material is preferably rough crushed in jaw crushers and subsequently screened, with the oversize being returned for recrushing. The normal fractions are collected in a surge bin. A conveyor transfers the material from there to the fine crusher. Classification to standard sizes involves continuous feedback of the oversize and interim storage of the standard-size fractions.

Additional classification and particle-size reduction can be effected in rod or ball mills, with separation of the desired size fractions and raw materials.

All of the above processing steps involve dust and noise emissions that can emburden both the workplace and the environment.

There are no generally applicable values for the dust quantities encountered, because they depend on the crystalline structure of the minerals and of their geological association, requisite extent of crushing and various engineering factors. However, in view of now-common ore throughputs of up to 50 000 t/d, even minimal proportional dust emissions can put pressure on the soil and vegetation around ore processing facilities. In particular, the attendant deposition of heavy metals can jeopardize human health by way of the food chain, and the presence of fibrogenic dust at the workplace can cause silicosis or asbestosis.

In order to minimize dust pollution, the machinery should be encapsulated. Wherever that would be unfeasible for technical reasons, the dust-laden exhaust air should be collected and put through a dust precipitator. The type of filter to be used depends on the composition and particle-size distribution of the dust. Generally, cyclone filters are used for coarse filtering, while fabric filters serve to remove fine dust particles. Such equipment can achieve residual dust contents (clean gas dust loads) of less than 10 mg/m^3. Equipment operators at dusty workstations must be required to wear dust masks (particle respirators). Masks designed for use in very warm climates should have appropriately large filtering surface areas.

In the interest of noise control, such facilities must have enclosures with a minimal number of openings. Since processing plants operate around the clock, suitable noise control measures in the form of safety distances, embankments, shielding walls and the like must be planned in at an early stage to preclude excessive prejudice to adjacent residential areas.

The only real options for limiting the workplace noise nuisance is to automate and install control centers. The operators of noisy equipment generating high acoustic intensities must be provided with ear protectors and made aware of their importance for preventing noise-induced deafness.

2.3 Separation, flotation

Ore processing facilities use water for separating buoyant and nonbuoyant, i.e. floating and nonfloating, materials: in cyclones and screen classifiers for grading by gravimetric separation or for pulp preparation, where water serves as a working medium for separating the useless material by gravimetric means and for eliminating suspended solids from the concentrate. The overall water requirement varies widely, depending on the type of raw material, the nature of the deposit, and the processes employed.

Dense-medium techniques are used exclusively for the coarse-size range, with medium solids consisting of magnetite, lead glance (galena), ferrosilicon and, occasionally, heavy spar (barium sulfate). Between 0.3 and 1 g of sodium hexametaphosphate can be added per liter of pulp to reduce its consistency. The water used in heavy media separation processes should be

recirculated. Accordingly, the entrained solids have to be separated out in settling tanks, irrigated electrostatic precipitators or hydrocyclones. Even if the water from pulp regeneration is recirculated, the fresh water requirement can still amount to 0.5 - 1.5 m^3/ton of crudes.

Concentration by flotation is achieved with the aid of flotation agents. Special chemicals induce physicochemical surface reactions that are useful for separating and separately concentrating mixed and disseminated ores that have been sufficiently comminuted to eliminate most intergrowth between the constituents of interest. Consequently, the solid contents of flotation slimes in part occupy the microfine to colloidal size range. Since such slimes sediment out very slowly, part of the process water can be recovered more quickly by dewatering the flotation products in thickeners. The still-wet mining wastes (tailings) are then pumped into settling tanks and given ample time - perhaps a week - for extensive sedimentation of solids. The liquid phase can be recaptured as gravitation water.

Among the various flotation agents, distinction is made between collectors, frothers and modifiers. Collectors, or collecting agents, are surface-active substances that make the surface of the ore water-repellent. Organic compounds serving as collectors are selectively employed according to the type of ore. In the flotation of sulfide ore, for example, between 10 and 500 g of xanthate is needed per ton of ore, while anywhere from 100 to 1000 g of sulfonates or unsaturated fatty acids are consumed per ton of nonsulfide ores.

Frothers, or frothing agents, which influence the size of air bubbles and help stabilize the froth in the flotation apparatus, include terpenes, cresols, methyl isobutyl carbinol, and monomethyl esters of various propylene glycols. Consumption levels run between 5 and 50 g/t for flotating crude sulfide ores.

The modifiers, or modifying agents, include chemicals for regulating the pH: lime, soda and caustic soda for adjusting the alkalinity, and predominantly sulfuric acid for acidification. Passifiers and actifiers, which are used to intensify the differences between the water-repelling properties of the ores to be separated, include copper sulfate and zinc sulfate. Alkali cyanides serve in the selective flotation of sulfide ores. Cyanides can only be added to an alkaline pulp; otherwise, hydrogen cyanide could evolve and be released to the atmosphere. The amounts required range from 1 to 10 g/t ore. Sodium sulfide, dichromate, water glass and complexing agents also belong to the group of selective flotation agents.

Many flotation agents and other chemical additives constitute a hazard to water. Consequently, carefully monitored dosing apparatus is required to preclude overdosing, and special safety requirements must be met by plant and equipment used for storing, decanting, handling and using such hazardous-to-water flotation agents. The facilities must be designed to safely preclude contamination of surface water and groundwater to an extent reflecting both the pollutive potential of the substances in question and the protection requirements of the relevant locations, e.g., potable water protection areas. Impervious, chemical-resistant, drainless collection and holding vessels must be provided to the extent

necessary for intercepting in a controlled manner any media that may escape as a result of leakage, overfilling or accidents. The retention volume must suffice to hold back the escaped

substances until such time as appropriate countermeasures can be brought to bear. Additional safety precautions include double-walled storage tanks, overflow prevention devices and leakage sensors.

All requisite measures and precautions for avoiding hazards due to potential water pollutants in the form of flotation agents should be stipulated and communicated via appropriate handbooks. Plans pertaining to monitoring, repair and alarm response to malfunctions should also be compiled in handbook form. In addition, occupational safety measures must be instituted and monitored in connection with the handling of potentially dangerous flotation agents.

Sensitization and training measures are of essential importance, because the inexpert handling, storage and transportation of working agents are frequent sources of environmental pollution.

Along with the depleted material, small amounts of flotation agents, leaching chemicals and/or heavy medium can get into the tailings ponds. The gravitation water collecting in the drains should be tested for the presence of flotation agents and chemicals prior to its return to the process water circuit. Most of the agents and chemicals remain in the floated concentrate. When the concentrate is dewatered, the agents and chemicals are washed out and re-injected into the fine-grinding cycle.

Once the concentrate has been thickened, filtered and dewatered, its residual moisture

content will amount to roughly 8 %. Thus, the freshwater requirement for such processing facilities can amount to about one third of the overall process water consumption rate of about 5 m^3/ton of ore. The water consumption of a given concentration plant must be carefully attuned to the existing original water budget, i.e., to the available volumes of groundwater and surface waters, in order to avoid both detrimental effects on the environment and problems with the supply of drinking water.

The process water should be appropriately treated and recirculated. Processes in which the water is discharged into a recipient body on a once-through basis can cause silting and contamination of the receiving water due to high sediment contents and residual chemical additives.

The disposal of barren rock and tailings is also problematic in that it consumes land area. As the percentage of valuable material diminishes, the throughput quantities increase, and the long-term areal requirement rises proportionately. An ore processing facility with a throughput of approximately 45000 tons/d, for example, requires a settling basin measuring some 400 to 500 hectares in area and 300 to 350 million m^3 in volume for 20 years of operation. In some cases, the tailing ponds can be kept somewhat smaller by extracting dried material for use in refilling underground mines. Due to the altered material properties, however, this option is only conditionally appropriate and would never be able to fully replace tailings ponds and rubbish dumps.

Large settling basins should never be constructed prior to painstaking pertinent investigation including precise specification of the physical and chemical compositions of the tailings as well as of the geological and, above all else, the hydrological set-up. The permeability of soil strata, for example, and natural drainage systems are very important with regard to groundwater protection. Since many tailings ponds stay in service for decades on end, building up all the while, the relevant accident analysis must consider a possible dam failure due to excessive surface runoff.

Rubbish dumps must be established with due attention to the fact that precipitation can induce leaching processes with attendant pollution of surface and gravitation water. Any mining waste containing large amounts of water-soluble substances or heavy metals can jeopardize the groundwater, unless the soil under the dump is sufficiently impermeable. Thus, the essential protective measures include an adequately dense subgrade, minimal sprinkling and the collection of runoff water. Before the first load of material is dumped, observation wells should be sunk for monitoring the groundwater.

It would be impossible to preclude all dust generation in connection with dump operations, but it can be minimized by keeping the discharge heights of dry tailings as low as possible and by encapsulating the transfer points. Wind erosion can be limited by compacting the surface, sprinkling the pile, applying suitable, environmentally benign binders to the surface, or planting the windward side of the heap. The equipment required for dump operation (pumps, dump trucks, conveyor belts, bulldozers, ...) can be quite noisy. Noise control measures in the form of quiet tools and vehicles, acoustical barriers, etc. are called for whenever sensitive

legitimate residential areas are located nearby.

The surface and gravitation water (percolation) from rubbish dumps should be collected by way of an impermeable peripheral trench and tested before being released to a recipient body. Moreover, before the water is discharged, its settleable solids content must have been ascertained as appropriate to the outlet channel's own sensitivity and intended use. Depending on the material composition of the tailings in the pond and/or of the rubbish in the dumps, additional testing for the presence of environmentally relevant pollutants such as heavy metals and processing chemicals may be necessary. The treatment required for the impounded water may consist merely of settling in an appropriate basin or, depending on the entrained substances, of physicochemical processes (precipitation, flocculation, chemical oxidation, evaporation, ...).

Long-term, if not permanent, monitoring of the surface runoff and gravitation water is called for, because the nature and extent of discharge can change over time due to weathering (surface disintegration).

In addition to flotation, leaching and amalgamation also serve as separation processes. In gold mining, for example, the gold is extracted from the gravity-separated concentrate by making it react with metallic mercury to form amalgam. The concentrated residue is then leached with a cyanide solution. Both processes have negative environmental impacts that are very difficult to control. The mercury content of the effluent is particularly problematic, if the wastewater is discharged to the outlet channel without having been treated. It is still an open question as to

whether or not the new ion-exchanger resins will, in the long run, be able to bind enough mercury to meet the residual concentration requirements. Leaching involves the use of numerous different chemicals. In gold processing, for example, these include cyanide, lime, lead nitrate, sulfuric acid and zinc sulfate. The processes themselves also jeopardize the air, water and soil. All measures and precautions that would apply to the concerns of environmental protection and occupational safety in connection with an industrial-scale inorganic chemical process must be allowed for at the planning stage. This would include, for example, capturing the exhaust vapors from the reaction tanks and vessels and installing vapor scrubbing equipment (vapor stacks) to prevent harmful emissions. The aqueous solutions emerging from filter presses should be recirculated, and the waste sludge from suction filters must be tested for disposability and treated as necessary. The wastewater from amalgamation and leaching processes requires periodical monitoring.

2.4 Roasting

The processing of sulfide ores includes roasting. The roasting gases contain large amounts of sulfur dioxide and therefore require gravitational separation (inertial impaction) and electrostatic precipitation. Further processing of the incidental sulfur dioxide should be obligatory, because release of the unprocessed roasting gases would unavoidably destroy most of the vegetation around the roasting plant. It is particularly important that the feed and discharge devices on the roasting furnace be airtight. Fabric filters mounted on the roasted-ore silo can extensively preclude dust emissions. To the extent that the blowers give off too much noise, their encapsulation is recommended. A chlorinating roasting process may involve the

formation of polychlorinated dibenzodioxins and furans in the exhaust gas, the roasting residue and/or the slag, depending on the operating conditions and on the nature and extent of organic substances. Whenever the formation of any such harmful substance is detected in connection with a chlorinating roasting process, the operating conditions must be altered such as to minimize the level of emissions.

2.5 Storage and handling of concentrate; recultivation

If concentrates are stored outdoors and unprotected, wind- and precipitation-induced erosion can pollute the air, the soil and the waters.

The ground in the storage area should be sealed to prevent contamination of the topsoil. Continuous maintenance of adequate surface moisture and/or covering the ground with mats does not always suffice to prevent all wind erosion. Consequently, the concentrate storage area should be roofed over and enclosed, and appropriate measures, e.g., low dumping heights, should be taken to minimize dust generation during loading and unloading.

The measures to be taken in connection with hauling correspond to those described in section 2.1.

The extent to which planned heaps and sedimentation facilities would occupy the former life space, i.e., the habitats, of local flora and fauna must be ascertained on a case-by-case basis. The possibility of promptly recultivating slopes should also be examined as a means of

preventing wind- and water-induced erosion while achieving a certain degree of ecological compensation. The nature and extent of early recultivation must be discussed and coordinated with those responsible for regional/landscape planning and defined in a catalogue of measures. If the area in question is to be used for agricultural or horticultural purposes, the anthropogenic pollutive burdens in the stored material and their mobility (pollutant transfer factors) must be accounted for by appropriate measures such as sealing or compacting of the subsoil to interrupt the paths of emission. Even at the planning stage, information should be gathered on the availability of cultivable materials fit for land restoration.

3. Notes on the analysis and evaluation of environmental impacts

The processing, handling and transportation of raw minerals can cause substantial environmental pollution by dust evolution. The most effective available means of dust collection and precipitation must be applied to dust containing cadmium, mercury, thallium, arsenic, cobalt, nickel, selenium, tellurium or lead. Quartzose dust (silica dust) can cause silicosis and therefore must be allowed for as an occupational safety consideration. Depending on the mass flow, the material must be analyzed for the presence of the aforementioned heavy metals, and clean-gas limits need to be defined, whereas those for cadmium, mercury and thallium should be lower than those pertaining to the other heavy metals. The workplace dust concentrations must be monitored as a basis for controlling the silicosis hazard. Industrial medical care must be provided for the workers.

The local vegetation is liable to be destroyed by the caustic effects of mineral constituents dissolved by rain. Also, a thick layer of dust can so strongly impede the plants' natural assimilation process that they die off. The soil around processing facilities for ores containing heavy metals can eventually become contaminated. The geogenic contents of the soil should be determined prior to erection of any such facility.

Well-proven dust collecting and precipitating devices are available for use in controlling dust emissions. Their adequate separation efficiency in continuous operation must be monitored. The nature and extent of inspections, preventive maintenance and repair of precipitators should be specified in a service manual.

Under certain unfavorable conditions, an accumulation of heat, an overheated bearing or a spark can trigger the ignition or fulmination of fine dust. Good ventilation, possibly in combination with inertization, pressure-surge-proof encapsulation and/or the use of pneumatic drives, can substantially reduce the hazard.

Substances constituting a hazard to water in connection with ore dressing processes can lead to soil and water pollution due to leakage, carelessness, accidents, etc. Consequently, all facilities required for storing, decanting, handling and using potentially water-polluting substances must be designed and operated such as to avoid contamination of the soil and water. Appropriate precautionary measures also must be taken for the transportation and disposal of the chemicals, and pertinent occupational safety measures must be specified for handling them. The potential environmental hazards emanating from the chemicals (cyanides,

mercury, etc.) and from the acidic roasting gases involved in separation and concentration processes based on leaching, amalgamation and roasting can be particularly severe. Thus, appropriate measures must be taken to hold back the mercury, cleanse the roasting gases, control the leaching process, and otherwise contribute toward the minimization of emissions.

Tailings ponds, settling basins and rubbish dumps for the residues of dressing processes all have substantial space requirements. Knowledge of the subsoil structure is important for properly assessing the effects of harmful emissions. With a view to ensuring the long-term protection of groundwater and surface waters, relevant special studies and analyses must be conducted at the planning stage. There are as yet no official limit values for acceptable levels of ground contamination by mill slurries from the processing of raw minerals. Consequently, planners of new facilities have to rely on experiential values gleaned from settling basins for similar dressing plants. In the case of coal mud heaps, good compaction is required to prevent spontaneous combustion.

To the extent that farmland and, hence, income potential must be sacrificed for processing activities, the consequences for the affected subpopulation, women in particular, must be investigated and suitable alternatives developed as necessary. Early involvement of the local populace in the dissemination of information and decision-making processes is an effective means of avoiding or alleviating conflicts in advance.

The effluent from mineral processing activities and the gravitation water emerging from tailings ponds and rubbish dumps may contain heavy metals or potentially water-polluting chemicals

that pose a hazard to surface water, groundwater and the soil. Special attention must be given to the possible jeopardization of potable water supplies. In case of excessive sediment contents, the river bed is liable to silt up and accumulate harmful substances. The wastewater from ore processing plants therefore has to be continuously monitored. Depending on the nature and extent of settleable solids, heavy metals or chemicals posing a hazard to water, the effluent will require appropriate treatment.

Properly sized equipment enclosures with adequate acoustic insulation properties are very important for reducing the amount of noise emitted by processing plants. Appropriate safety clearances should also be planned in for between the plant and neighboring residential areas. Suitable noise control measures also should be applied to the operation of tailings ponds and rubbish dumps located in the near vicinity of residential areas.

Permissible noise emission levels are specified in Germany's *TA-Lrm* (Technical Instructions on Noise Abatement). The site surroundings - e.g., an industrial zone, commercial area or residential district - are decisive for the maximum allowable noise intensity level.

As in Germany, ore processing plants should have immission-control, water-pollution-control and waste-management officers, whose positions should be independent of the production division. A safety officer and an occupational physician should be available for matters concerning occupational safety.

4. Interaction with other sectors

As a rule, mineral processing plants are attached directly to the relevant mining operations. The environmental briefs pertaining to mining therefore apply.

The large area required for a processing plant necessitates its coordination with present and planned regional land use. As such, the environmental briefs Spatial and Regional Planning, Planning of Locations for Trade and Industry should also be consulted.

If the processing plant cannot be installed directly at the mine, appropriate roadbuilding measures become necessary, in which case important details can be found in the briefs Road Building and Maintenance, Building of Rural Roads.

In arid regions, the water neeeded for operating the processing equipment is a very important resource, and its judicious use must be incorporated into Water Framework Planning.

5. Summary assessment of environmental relevance

If the planned site of a processing plant is located in a thinly populated area, it must be brought in line with the goals of regional development planning. In selecting the site, importance should be attached to choosing a location with a relatively low level of ecological

sensitivity and which is not crucial to the vitality of the regional natural household.

Most processing plants emit large amounts of material- and process-generated dust and noise. Within the plant premises, such nuisances/pollution can be reduced to tolerable levels by the use of suitable enclosures and dust retention devices. Dust emissions from dry heaps and dumps, however, is more difficult to control, particularly when finely comminuted material is exposed to wind and weather. Such material must be kept moist and/or covered, and the surface should be consolidated or sown over.

Large volumes of low-grade material accumulate at processing plants and have to be pumped into tailings ponds for sedimenting. Before any such settling basin is established, its long-term environmental impacts must be carefully analyzed, because it could well remain in operation for several decades, becoming larger and larger all the while. The analysis must cover important aspects of protection for the soil and groundwater, stability (e.g., in case of flooding) and subsequent recultivation, including definition of appropriate measures.

Prior to establishing and operating rubbish dumps, the site-specific hazard potentials for the subsoil, groundwater and surface waters must be carefully investigated. The subgrade must be sealed and a means of collecting all surface runoff and gravitational water provided.

Old tailings ponds and dumps should be given close-to-natural shapes prior to their recultivation in order to fit them into the landscape in a manner appropriate to their planned future use.

Process effluent and gravitational water from processing plants, tailings ponds and rubbish dumps must be put through wastewater treatment facilities, the nature and extent of which depend on the sensitivity and manner of utilization of the recipient body. Silting should be avoided, of course, and pollution by mercury and other heavy metals should be minimized. Observation wells should be sunk to allow monitoring of the groundwater.

Bulk transportation by road or rail can have negative impacts on the environment: through construction of the required hauling routes (and attendant erosion potential) and in the form of airborne dust and noise. Dust emissions can be avoided by hauling the material in closed containers. Quiet, low-emission trucks should be given preference. Fine-grained material should not be stored in the open air for any length of time. Otherwise, wind- and precipitation-induced erosion could cause pollution of the soil and water. Frequently, the cost of relevant environmental protection measures is more than offset by resultant reductions in the loss of resources.

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39. Petroleum and natural gas - Exploration, production, handling, storage

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Contents

1. Scope

In the year 2000, petroleum and natural gas together will cover between 50 % and 70 % of the global energy requirement, and the energy-coverage ratio between the two will be about 2 : 1 to 1.5 in favor of petroleum. Obviously, in view of the corresponding scale of petroleum and

natural-gas production, countries with major resources and corresponding development projects in the mining sector will have continued exposure to consequential environmental impacts. Due to the immobility of deposits and to the technical processes required to obtain the crude product, petroleum and natural-gas mining activities have their own specific environmental consequences. According to prevailing international definitions, a typical petroleum/natural-gas development project comprises the following three phases:

- **exploration, on- and offshore, mainly by geophysical methods and exploration drilling, including a test phase following any discovery;**
- **production, beginning with field development drilling as a precondition for actual production, in the course of which certain phases are run through, up to and including basic conditioning of the raw material. The production of crude oil and natural gas requires a certain infrastructure;**
- **handling and storage directly following the production stage, i.e., prior to the further processing of crude oil and natural gas into energy-market products. These activities utilize part of the overall infrastructure.**

2. Environmental impacts and protective measures

2.1 Exploration

Exploration is the term used to define the scientific prospecting and reconnaissance of raw material deposits by means of

- **mapping/charting**
- **geophysics**
- **exploratory drilling.**

Exploration for petroleum and natural-gas is based on a large-scale, onshore-specific aerial mosaic (photomap). In many regions of the world, superficial analysis of such maps can suffice to detect promising areas. Exploration then continues according to geophysical and geochemical methods of prospection. Finally, the superficial geological, geophysical and geochemical reconnaissance of promising structures requires confirmation by way of exploratory drilling, incl. well shooting, and the interpretation of drill cuttings and cores.

The environmental consequences of exploration are relatively minor on the whole, though the attendant drilling has a substantially higher disruptive hazard potential; cf. environmental brief Reconnaissance, Prospection and Exploration of Geological Resources.

2.1.1 Nature and ecology

Modern airborne mapping techniques employed at the beginning of the exploration phase pose no direct threat to the environment.

Depending on the applied techniques, the environmental consequences of geophysical prospection can extend over a period of months or years. Distinction must be drawn between gravimetric techniques and predominantly airborne magnetic measuring methods on the one hand, and seismic measuring methods on the other. The latter put geophysicists in a position to locate geological bedding boundaries at depths of several thousand meters by registering reflected compression waves. Indeed, the seismic reflection method is the most important prospecting tool, but it is not without consequences for the environment.

Even assuming a relatively brief disturbance, negative environmental impacts must be limited. Geophysical surveying teams, for example, live more or less self-sufficiently in remote areas for various lengths of time. Their access and transportation routes should preferably be by air or water, depending on the circumstances. Overland routes must include any deviations/detours necessary to avoid ecological disruption. With regard to blasting, the magnitude of the explosions used to generate pressure surges must reflect the state of the art. In some cases, vibroseismics may constitute a less disruptive alternative. Advanced receivers and amplifiers yield extensive information at lower pulse levels. Offshore blasting has destructive effects on marine life, particularly in the littoral zone. Alternative use of the air-pulse technique effectively protects marine flora and fauna.

On a regional basis, the most pronounced environmental consequences for nature and the ecology derive from deep drilling. If, however, state-of-the-art drilling equipment is (properly) used, the environmental impact frequently will remain far below what laypeople would expect. The main objective for drilling operations is to carefully plan, equip and conduct

terminal exploration projects such as to either avoid negative environmental impacts altogether or at least reduce them to a tolerable level.

In connection with the preparation of drilling sites and the construction of access roads, due consideration must be given to subsequent renaturation, and disruption of the surface must be limited to the necessary minimum. The topsoil must be protected as well as possible (in covered heaps, etc.).

Drilling must be conducted such as to preserve the intactness of the rock strata and water-bearing horizons in their original, virgin separations through appropriate casing and cementation programs.

The media required for drilling, in particular the drilling fluid, should be chosen with attention to low environmental impact and subsequently recycled to the greatest possible extent.

Borehole safety, which is understood mainly as uninterrupted control over the dynamic pressure situation and borehole stability, must be ensured by adequately sized casings and cementation in combination with a blow-out preventor serving as a drilling-phase closure system (state of the art). Preventive measures in the form of technical equipment and disaster plans must be taken to limit the consequences of blow-outs. Such precautionary measures can prevent major environmental damage, which, while seldom irreversible, can be very expensive to repair.

Unavoidable, unrecyclable mining refuse like borehole cuttings and spent drilling fluid must be properly disposed of. With due regard for the environmental circumstances, preference must be given to dilution, thermally optimized incineration and/or encapsulation.

The slim-hole drilling technique must be considered as an alternative to conventional deep-well drilling. The technique is characterized by a much-reduced diameter, minimal use of operating media, less technical inputs overall, and such substantial time savings that the cost of drilling can be cut in half. Slim hole drilling does, however, presuppose certain geological conditions and is inherently unfeasible for deep wells.

The exploration drilling phase is not complete until all appropriate protective measures have been taken to counter the adverse environmental consequences of activities pursued in connection with successful exploration, i.e., the discovery of an exploitable field, which may last several years.

Any well that remains dry must subsequently be properly plugged, and the attendant aboveground facilities, including access routes, must be either recultivated or surrendered to some other controlled form of utilization.

2.1.2 Sociology

Exploration projects can seriously alter the social fabric of a country or region. Practically overnight, they expose native social systems to the activities and influence of multinational

companies employing modern technical know-how. Conflicts of interest resulting from the immobility of prospective petroleum and natural gas deposits must be dealt with appropriately. The project must be integrated into the prevailing social structure as quickly as possible. That, in turn, requires the involvement of all social groups.

2.1.3 Human health and occupational safety

In general, urgent priority must be attached to occupational safety and to preservation of the health of petroleum and natural-gas exploration workers. The effects of such projects on parties not directly involved in the exploration work are insignificant.

The most obvious problems are those deriving from the difficult, privative work of geophysical surveying crews, especially in remote regions, and which continue through the end of exploratory drilling.

Since local personnel can be hired and trained relatively quickly for some of the work, appropriate individual support must be planned in. Medical care, hygiene and occupational safety must be guaranteed, and acceptance of worker protection measures, which demand a certain amount of training, must be ensured.

2.2 Production

Successful exploration is followed by the petroleum and/or natural-gas production phase,

which includes:

- **field development drilling, incl. complete preparations for production,**
- **aboveground installations and processing facilities,**
- **infrastructural measures.**

A substantial share of the petroleum and natural gas resources that took millions of years to develop has been used up within a relatively short span of time. In the interest of long-term utilization, the human race must exercise a sense of responsibility in dealing with those natural resources - which are only renewable in terms of geological time spans. In reality, however, traditional oil-producing countries tend to adopt volume-oriented production strategies, accepting substantial environmental consequences as attendant phenomena. Production strategies in general are heavily influenced by the demand situation and as yet inadequate alternatives.

The time between exploration and production should be used to carefully analyze the project's anticipated environmental impacts for the duration of an average production field life (15 to 25 years for an oilfield and 50 to 100 years for gas) - and beyond. The analysis must be based on timely local and individual registration of the sociological, cultural economic, climatic and ecological situation, which, of course, differs widely around the world. The results of analysis must then be incorporated into each and every relevant resource production project.

The beginning of the field development drilling work should coincide with the establishment of

requisite infrastructure, e.g., access routes, incoming and local service lines, and even the aboveground pumping facilities, processing plant, etc. With regard to the attendant environmental consequences, the reader is referred to the corresponding brief Road Building.

2.2.1 Nature and ecology

The long-term production phase of a typical petroleum/natural-gas project begins with the first regular output. Field development drilling prepares a deposit for production on the basis of the production geological and field engineering targets defined to reflect the underground conditions prevailing in the reservoir. The environmental consequences of exploration, as described in section 2.1.1 apply in full.

Especially in sensitive areas with valuable biotopes, the equipment used must be chosen with a view to minimizing space requirements. Thanks to advanced drilling technology (directional drilling with deflecting tools), a single onshore or offshore location now often suffices for tapping several square kilometers of a reservoir. And horizontal drilling can help to drastically reduce the overall number of boreholes.

Large-scale destruction or alteration of an area's flora and fauna (e.g., in a rain forest, tundra or coral reef) need not occur in connection with petroleum/natural-gas projects, which have relatively modest aboveground space requirements for technical equipment and infrastructure.

Through state-of-the-art plant dimensions in combination with necessarily redundant automatic monitoring equipment, emissions occurring under normal and disturbed operating conditions can be held at low levels.

Damage to the environment as a result of accidents, oil spills in particular, must be limited by safety-relevant controls, e.g., valving. Oil-contaminated water and soil must be rehabilitated by chemicobacterial means of artificially accelerating the biodegradability of hydrocarbons. A properly managed oil well causes no problems with regard to groundwater protection.

The economically efficient exploitation of natural energy vehicles must attach priority to controlling the environmental impacts while conserving the resource itself. For petroleum and natural gas, the conservation of resources covers both the effective utilization of their entire energy potential (by avoiding such activities as the pollutive flaring off of surplus production that cannot be directly utilized) and the alternative employment of high-tech production techniques.

2.2.2 Sociology and economics

The productive phase of an oil or gas field lasts on average about as long as a normal person's working life - if not even longer, as is frequently the case in gas production. That fact alone imposes a major social responsibility on the project. In continuation of the initial exploratory-phase measures, the living conditions, nutrition, education, health and cultural environment, including religion, of the personnel must be treated as importantly as the purely technical production facilities. Ghettoization must be countered, and the growth of social fabric must be

promoted. Industrialization must be conducted cautiously and in a manner to allow incorporation of the cultural heritage of the aboriginal society.

2.2.3 Human health and occupational safety

One of the project executing organization's most important tasks is to promote health care, not only among the workers themselves, but also throughout the entire project region.

The same applies to occupational safety, which can and should be implemented in imitation of measures applied in industrialized countries. The assignment of well-trained and qualified personnel to such tasks is a crucial prerequisite.

2.3 Handling and storage

Handling and storage is understood here as the last step following exploration and production. The rough-processed crude products are transported by pipeline, railroad car or road tanker, and by inland waterways and oceangoing vessels, all of which requires special infrastructure. The products are stored in aboveground tank farms and underground stores, cavities and pore spaces.

The transportation/shipping, distribution mechanisms and finished-product storage scopes are not covered by this brief; please refer to the briefs relevant to adjacent sectors, e.g., shipping, ports and harbours, inland ports.

2.3.1 Nature

The requirements stated in section 2.3.1 apply analogously to transportation.

The large-scale storage of crude oil and/or natural gas requires special environmental safety measures, particularly with regard to the prevention of fires and explosions. Special importance is attached to leakage detection, alarm sounding and catchment techniques. Underground tanks are preferable to aboveground tanks, though they do call for more sophisticated safety engineering.

As an alternative to tank farms, underground storage in depleted mines, rock caverns, salt caverns and pore spaces has the least extensive environmental consequences. Pore spaces are only suitable for storing gas, and salt caverns demand appropriate utilization or disposal options (proximity to the ocean) for the brine. Both alternatives - pore spaces and salt caverns - presuppose the appropriate geological formations.

2.3.2 Human health and occupational safety

The large-scale handling and storage of oil and gas poses hazards such as the escape of hydrocarbons and the possibility of accidental explosions. Technical transportation monitoring measures and redundant storage safety engineering substantially reduce the risks involved. Pipeline safety can be ensured via monitoring stations, self-acting pressure control devices and aerial line inspections. Storage tanks and piping must be protected against corrosion.

3. Notes on the analysis and evaluation of environmental impacts

The environmental impacts must be evaluated with due consideration of the individual, project-specific situation. Project planning should be conducted with emphasis on the potential sociological consequences and the earliest possible involvement of local nationals. Environmentally relevant experience drawn from comparable projects must be duly considered.

The training of local manpower for all levels constitutes an important step in the direction of responsible management with a capacity for controlling environmental consequences. The project must be implemented in line with the pertinent laws, standards, codes, limit values and technical know-how of industrialized countries.

4. Interaction with other sectors

As the profitability of exporting natural gas is limited by the long transportation distances involved, many countries neglect its production. In that connection, the technical utilization of liquid natural gas (LNG) would appear worthy of promotion, since the transport problems would be relativized by the use of accordingly large tankers. By reason of its high efficiency,

natural gas makes a good, nonpolluting substitute for other primary energy carriers.

The petroleum/natural-gas sector has numerous points of contact with other sectors, among the more important of which are:

- regional planning
- overall energy planning
- water supply
- planning of locations for trade and industry
- mechanical engineering, workshops, shipyards
- oil and fats.

References to adjacent sectors have been included in the appropriate passages of the above text.

5. Summary assessment of environmental relevance

Global experience shows that the petroleum and natural gas industry can maintain an ecological orientation with the aid of modern science and technology. Environmental awareness must be promoted by applying the standards of the most advanced industrialized countries.

Risks and undesirable environmental consequences must be minimized by responsibly implementing each project in accordance with its own ecological and sociological significance. Interdisciplinary management with the direct involvement of all sections of the population is appropriate and advisable.

Ecologically oriented operations presume the existence and adequacy of the requisite control organs. In that connection, an environmental protection officer carrying the responsibility for training the workers and instilling them with environmental awareness can be a major asset.

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40. Coking plants, coal-to-gas plants, gas production and distribution

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Contents

1. Scope

This environmental brief covers various coal upgrading technologies, incl. coking and low-temperature carbonization as processes yielding the target products coke and gas plus tar products and diverse raw chemicals.

The relevant facilities can be installed and operated either separately or in conjunction with neighbouring industrial technologies; cf. environmental briefs Planning of Locations for Trade and Industry, Spatial and Regional Planning.

Interconnected operations can be characterized by proximity to either collieries or iron works.

While in the former case the working product coal can be conveyed directly to the upgrading facility located only a short distance away, close proximity to a metallurgical plant avoids the

necessity of transporting the product coke over long distances and enables direct supply of the gas to the consumer by way of a low-pressure network; blast furnace gas from the metallurgical plant can serve as low-sulfur fuel gas for, say, a coking plant.

If the coal upgrading facility is instead located separately and independently, substantial infrastructural measures will be required for conveying, loading, unloading and storing the working materials, process materials and products; cf. environmental briefs Transport and Traffic Planning, Railways and Railway Operation, Inland Ports.

In addition, the generated gas has to be compressed and purified to piped-gas quality before it can be supplied to the consumers.

The low-temperature-carbonization and coking processes, as applied to coal in the sense of this brief, are based on heating in exclusion of air in appropriate reactors.

Depending on the temperature at which the process takes place, distinction is made between:

- low-temperature carbonization (450 - 700C)
- medium-temperature coking (700 - 900C)
- high-temperature coking (>900C).

While the above processes do not differ at all in principle, the different temperatures yield different products and process conditions and call for the use of different reactor systems.

a) Low-temperature carbonization processes

Low-temperature carbonization processes, as applied primarily to lignite (brown coal), take place in fixed-bed reactors, fluidized-bed reactors or entrained-bed reactors.

The heat supply derives from:

- **the use of hot coke as a heat transfer medium or**
- **the direct supply of heat to the working material via hot cycle gas (circulation gas).**

The gas produced by low-temperature carbonization is cooled (condensed), detarred, compressed and purified prior to delivery. Residual coke is cooled by means of either wet quenching or cold gas before being supplied to the users.

Low-temperature carbonization processes are used primarily for obtaining tar products, diverse raw chemicals and low-temperature-carbonization gas. The incidental coke is of no particularly high quality and therefore not used for metallurgical purposes. Consequently, other uses must be found for such coke, preferably uses that do not require high crush resistance.

b) Coking processes

Hard coal is coked in batteries of regenerative horizontal chamber ovens. Distinction is made between top charging and stamping operation, depending on the extent to which the coal is likely to produce high-quality, adequately stable blast-furnace coke.

Coke ovens are heated indirectly by fuel gas, the heat of which is transferred to the charge (feed coal) via heating walls. The fuel gas can consist of partially purified coke oven gas, blast furnace gas or a mixture of combustible gases. Even if the entire operation is heated exclusively with coke oven gas, the plant will still yield surplus quantities of gas with calorific values ranging from roughly 16 000 to 20 000 kJ/m. Following appropriate purification, that gas can be supplied to diverse consumers.

Oven service equipment is needed to fill coal into the ovens (charging cars), transfer the coke to quenching stations (quenching cars) and convey the hot coke to the wet quenching or dry cooling plant.

Coke oven gas is produced above the charge at coking temperatures of 750 - 900C. Through riser pipes, the gas passes into a so-called collecting main, where it is sprayed with recirculating water to induce cooling and partial condensation, thus precipitating most of its crude tar content.

The next stage of treatment consists of additional cooling to approximately 25C, followed by final tar removal in electrostatic precipitators, and the primarily absorptive extraction of such constituents as H_2S, NH_3, HCN, CO_2, benzene and naphthalene.

Those ingredients are further processed according to various techniques to obtain:

- **ammonium sulfate (after transformation of H_2S into sulfuric acid)**

- Claus sulfur (with simultaneous cracking of ammonia)
- crude benzene and
- crude tar.

If the surplus coke oven gas cannot be injected into an LP (low-pressure) network, it is put through a gas compression stage that includes additional purification to remove H_2S and raw benzene/naphthalene and to lower its dew point.

Wastewater deriving from condensation of the gas and from the H_2S/NH_3 scrubbing stage is treated in multiple stages including distillation in so-called strippers and dephenolating processes (extraction, biological elimination).

Modern coking plants can handle between 6 000 and 10 000 tons of feed coal a day for a coke output of 4 500 - 7 500 t/d.

The attendant gas production amounts to between 80 000 and 150 000 m/h, and process wastewater accumulates at the rate of 80 - 150 m/h.

c) Classification of process options

From the standpoint of environmental protection, carbonization and coking are roughly equivalent.

With regard to production capacities and technological applications, however, coking takes priority over carbonization, as evidenced by the fact that most laws, regulations and guidelines pertaining to the control of emissions refer mainly to coking processes. Nonetheless, carbonizing facilities should be dealt with under the same premises.

2. Environmental impacts and protective measures

2.1 Environmental impacts

The erection and operation of coking and/or coal carbonizing plants at locations previously not used for industrial purposes alters the landscape and consumes land to an extent that depends on the size of plant.

In addition to ascertaining the potential effects of emissive pollution, it must also be determined to which extent the requisite extraction of water from given resources would interfere with existing ecosystems, since make-up water is required at various points of both operations. The required volume of water can range from 200 to 500 m/h; cf. environmental briefs Water Framework Planning, Water Supply.

Particularly in connection with coke oven batteries, emissions must be anticipated both from certain operating points (e.g., exhaust stacks) as well as from diffuse sources such as leaky

shutoff valves and cracks in the masonry of coke ovens.

The following emissions are deemed particularly relevant:

a) Air pollutants

Including:

- **suspended solids (coal and coke dust)**
- **gaseous and vaporous emissions, e.g.:**

  sulfur dioxide (SO_2)
  hydrogen sulfide (H_2S)
  oxides of nitrogen (NOx)
  carbon monoxide (CO)
  benzene, toluene, xylene (BTX)
  polycyclic aromatic hydrocarbons (PAH)
  benzo(a)pyrene (BaP)

b) Wastewater pollutants

Including:

- various nitrogen compounds
- phosphorus
- chemical and biological oxygen demand
- phenols
- polycyclic aromatic hydrocarbons
- cyanides
- sulfides
- BTX
- sum of all toxic substances classified as such on the basis of, say, toxicity toward fish (fish test).

c) Noise emissions

Coking plants have numerous noise emitters at all points of the operation. Each and every drive unit, for example, constitutes a source of noise.

The equipment used for mixing, crushing and screening coal and coke and for compressing gas is particularly noisy and therefore requires comprehensive noise-control measures. Otherwise, some emitters are liable to develop noise intensity levels significantly above 85 dB(A).

In order to preclude noise-induced detriment to human health, both the sound sources themselves and the general vicinity of such equipment are subject to certain emission and immission limits.

d) Soil and groundwater

The handling and storage of coking products, crude tar, crude benzene, sulfuric acid and various purchased chemical additives pose a hazard potential for soil and groundwater.

Environmental consequences result from emissions, the effects of which in the vicinity of the installations can be damaging both to human health and to nature and which are monitored by way of ground-level pollutant concentrations. Also, near-source pollution occurring directly at and around the workplace demands careful attention. In the interest of occupational safety, so-called maximum working-site concentrations (*MAK*-values), so-called occupational exposure limits, and technical concentration guidelines (*TRK*-values) have been specified.

Improper handling of substances constituting a hazard to water can cause contamination of the soil and groundwater; contaminated effluent can be toxic (toxicity as a common parameter), cause bad taste (phenols) and/or excessive fertilization and, hence, consumption of oxygen (nitrogen, phosphorus).

Consideration must also be given to the fact that the construction and operation of technical facilities affects the living conditions of sundry groups. The relevant socioeconomic and sociocultural aspects therefore have to be analyzed.

2.2 Protective measures

Environmental protection and occupational safety at coking plants are governed by statutory provisions; in Germany, these include the *TA-Luft* (Technical Instructions on Air Quality Control), the *Gefahrstoffverordnung* (Hazardous Substances Ordinance), and the Wasserhaushaltsgesetz (Federal Water Act).

In accommodation of amended laws with in part substantially more stringent provisions, technical advances have emerged which now enable comprehensive protection of the environment.

One such advance is the development of large coke ovens, so that the operation of new coking plants of equal capacity now requires less frequent opening (around 80%) and has a far smaller sealing area to be cleaned (approximately 65% reduction). At least the following basic emission control measures are now being implemented on new facilities:

a) Coal handling, including unloading, storage, conditioning (mixing, grinding) and hauling

- erection of stationary sprinkling systems over coal storage areas to keep the coal moist, with provision for climatic boundary conditions;
- minimized dumping heights for mobile discharge and transfer stations;
- use of enclosed conveyors;
- installation of dedusting facilities on grinding and mixing equipment, plus dust silos.

b) Coke oven batteries

- collection of charging gas and transfer by two separate routes to the crude gas, e.g., via so-called mini risers leading to the adjacent oven and then through the "real" riser into the collecting main;
- charging gas aspiration by means of stationary or mobile systems equipped for aftercombustion and dedusting;
- mechanical cleaning of charging hole lids and frames, plus sealing after each charge;
- mechanical cleaning (aspiration) of the oven roof;
- mechanical cleaning of the risers (closures equipped with water seals);
- installation of mechanical cleaning devices for the doors and chamber frames of the coke oven machines;
- collection and treatment of emissions emerging upon removal of the doors;
- use of special-purpose door maintenance cars;
- installation of tight door sealing systems with gas relief channels to avoid excessive gas pressure in the vicinity of the sealing elements;
- installation of aspiration hoods for the door and frame cleaning devices;
- leakage gas aspiration for emissions resulting from leakages around oven doors, with injection of exhausted air into the batteries' combustion air supply;
- use of combustion gases with sulfur contents safely below 0.8 g/m to limit SO_2 emissions;
- gradual air feed and internal/external flue gas recirculation to reduce NOx emissions in connection with heating of the ovens;
- use of highly heat-conductive stone linings for the heating walls;

- collection and purification of emissions from coke pushing.

c) Coke cooling

- use of dry coke cooling technology, comprising:

moistening of the dry cooled coke to suppress dust evolution at the transfer points
dedusting of the delivered coke
dedusting of surplus gas by means of bag filter
intergas generation to replace cooling cycle gas based on the use of low-sulfur gas;

- emission control measures for wet quenching, e.g., provision of baffle plates for the wet quenching towers.

d) Coke treatment

- installation of enclosed coke conveying equipment;
- encapsulation of coke screening plant;
- collection and removal of particulate emissions, e.g., at the feed bunkers, sieving lines, crushers, belt feeders, etc.;
- installation of remoisteners for dry cooled coke to limit dust generation at the coke

transfer points.

e) Gas treatment and coal-constituent recovery systems

- use of effective sealing systems/elements for pumps, valves and flanges;
- forced ventilation of tanks, water lutes, etc. and injection of the ventilation gases into the crude gas suction line;
- use of Claus systems with injection of tail gas into the crude gas (tail gas recirculation);
- provision of waste gas filtration and additional catalyst installation for the H_2SO_4 systems to extensively preclude SO_2/SO_3 emissions.

f) Wastewater treatment; cf. environmental briefs Wastewater Disposal and Mechanical Engineering, Workshops, Shipyards

- use of upstream strippers employing alkaline additives (e.g., caustic soda solution) to reduce the so-called fixed ammonia compound burden of the coking plant's process water;
- installation of multiple-stage biological wastewater treatment facilities, including a nitrification/denitrification stage to enable elimination of nitrogen compounds in the coking plant's process effluent.

g) Conservation of soil and water

- separate drainage systems for surface runoff and process wastewater (from gas treatment and coal-constituent recovery systems);
- placement of all tanks and apparatus used in the handling or treatment of substances constituting a hazard to water in collecting tanks; installation of intercepting sewers for wastewater, e.g., by way of biological water treatment;
- installation of monitorable tank bottoms (on strip footing); use of overfill protection devices;
- use of suitable materials and external anti-corrosion measures to substantially improve the availability of plant components.

h) Noise control

- noise control at the source, e.g., encapsulation of machines, pumps, etc.;
- noise control for structures, e.g., solid construction, sandwich construction, use of vibration dampers, partitions;
- erection of acoustical barriers;
- individual examination of noise sources with a view to satisfying equipment-noise and neighbor's-rights requirements.

The measures listed under a) through h) are technically tried and proven and routinely implemented for new facilities.

Stated in proportion to the total investment for a new coking plant, the cost of environmental protection measures accounts for 30 - 40 %.

The operational reliability and availability of environmental protection provisions - like that of the entire coking plant - is highly dependent on the qualifications of the operating personnel. Consequently, appropriate training is required to put the personnel in a position to operate and use the equipment in an expert, competent manner.

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3. Notes on the analysis and evaluation of environmental impacts

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3.1 General

Any evaluation of the detrimental effects of coking plant emissions must allow for numerous factors, some of which are difficult to quantify, e.g.:

- baseline pollution by other emitters,
- climatic influences, particularly of wind, on propagation behavior,
- accumulative capacity of surrounding ecosystems.

It has been qualitatively determined that some such emissions, BTX and benzo(a)pyrene in particular, have carcinogenic effects on humans and animals and that particulate emissions and some gases can cause diseases of the respiratory tract.

The fact that coking plants, most notably in the near vicinity of the coke oven batteries, have both definite and diffuse sources of emissions complicates the stipulation of tolerable emission levels, e.g., in the form of emission factors. This problem is evidenced in pertinent German directives and regulations such as *TA-Luft*, which states allowable concentrations in the exhaust gases/air from definite points, but also applies qualitative technical measures to the erection of numerous different systems and types of plant.

Hence, only a narrow selection of emission limits/factors is available for reference.

That information, however, is supplemented by *MAK/TRK*-values which define limits for airborne workplace pollution and allow for the registration and monitoring of emissions from diffuse sources.

3.2 Summary of limit values and standards

Proceeding on the basis of Germany's Federal Immission Control Act *Bundesimmissionschutzgesetz)*, the following directives and regulations apply in essence to the design and planning of coal processing in the Federal Republic of Germany:

- **Technical Instructions on Air Quality Control (*TA-Luft*) dated February 27, 1986,**
- **Limit values for pollutants in coking plant wastewater according to the Federal Water Act, section 7a,**
- **Limit values according to the Technical Instructions on Noise Abatement (*TA-Lrm*) dating from July 1984 (5th update),**
- **Hazardous Substances Ordinance.**

Additional directives and regulations to be heeded for planning purposes are listed in section 6 (References).

The following tables (1.1, 1.2, 2, 3 and 4) survey the presently valid limit values for emissions, pollutant concentrations and MAK/TRK-values according to German standards.

It must, of course, be kept in mind that more stringent requirements may apply, depending on the baseline pollution level (initial load) at the location in question.

The tables compare the emission limits imposed by various industrialized countries of Europe with those reflected in German standards. With few exceptions, as quickly becomes apparent, the German standards impose the most stringent environmental protection requirements.

***Table 1.1* - Emission limits according to *TA-Luft* (general exhaust emissions)**

Component	**Definition of**	**German**	**European**	**Remarks**

	mass-flow range	**emission limits**	**comparative values**	
Dust	> 0.5 kg/h < 0.5 kg/h	50 mg/m 150 mg/m	50 - 115 mg/m, 94 mg/m 150 mg/m	
NO_x (as NO_2)	> 5 kg/h	0.5 g/m	0.35 - 0.8 g/m, 0.55 g/m	0.35: Belgian outlier
SO_2	> 5 kg/h	0.5 g/m	0.5 - 0.8 g/m, 0.6 g/m alternative: limitation of annual load to 10 000 - 12 000 t	
H_2S	> 50 g/h	5 mg/m	5 mg/m	
HCN	> 50 g/h	5 mg/m	5 mg/m	
C_6H_6	> 25 g/h	5 mg/m	5 mg/m	
Benzo(a)pyrene	> 0.5 g/h	0.1 mg/m	no emission limit defined	

1) The comparative values derive from the Netherlands, England, Belgium, France, Spain, Austria, Sweden and Finland; the -values represent the arithmetic mean of the respective limit values.

Table 1.2 **- Emission limits for coking-plant waste gas/purified exhaust air**

Component	**Definition of mass-flow range**	**German emission limits**	**European comparative values**	**Remarks**
Coal plant	Dust	50 mg/m	100 mg/m	
Coal drying and preheating	Dust	100 mg/m	115 mg/m	
Coke screening	Dust	50 mg/m		
Coal charging (filling process)	Dust PAH for mass flows > 0.5 g/h	25 mg/m 0.1 mg/m	15 - 230 mg/m, 92 mg/m 0.1 mg/m, alternative: limitation of daily	15: Dutch outlier

			load to 2 kg	
Coke pushing (operation)	Dust	5 g/t coke	5 - 115 mg/m, 46 mg/m or 5 g/t coke	
Dry coke cooling	Dust	20 mg/m	20 mg/m	
Wet coke quenching	Dust	50 g/t coke	50 - 800 mg/m, 330 mg/m or 80 g/t coke	
Exhaust stack, coke oven batteries (new facilities)	NOx as NO_2 SO_2 CO Dust	0.5 g/m 0.8 g sulfur in UF gas 0.2 g/m 10 mg/m	0.2 - 0.8 g/m, 0.53 mg/m 0.5 - 1.7 g sulfur in UF gas 9 g sulfur in UF gas or 0.5 g H_2S in UF gas 100 - 200 mg/m, 130 mg/m	0.2: Dutch outlier 0.5: Spanish outlier
Exhaust stack of by-product plants (new	Dust CO NOx	 60 mg/m	50 mg/m 200 mg/m 0.1-0.35mg/m,	

facilities)	SO_3 (H_2SO_4 systems) SO_2 (H_2SO_4 systems) H_2S (Claus systems) Sulfur (tolerable emission level) Production capacity: < 20 t S/d Production capacity: 20 - 50 t S/d Production capacity: > 50 t S/d	SO_2-to-SO_2 conversion rate: > 97.5 % or 2500 mg/m 10 mg/m 3 % 2 % 0.5 %	0.225 g/m 60 - 10 mg/m, 70 mg/m 500 - 3000 mg/m, 1750 mg/m 10 mg/m 3 % 2 % 0.5 %	500: Austrian outlier

2) cf. table 1.1 footnote

***Table 2* - General administrative framework regulation (Rahmen-Abwasser VwV) on minimum requirements for the discharge of wastewater from coking plants, Appendix 46 (draft dated August 1990), valid for direct discharge**

Parameter		
Totals:		
NH_4-N		
NO_2	40	mg/l
NO_3-N		
Phosphorus	2	mg/l
BOD_5	30	mg/l
Filterable substances	50	mg/l
COD	200	mg/l
Phenol index	0.5	mg/l
PAH	0.1	mg/l
BTX	0.1	mg/l
CN (volatile)	0.1	mg/l

Sulfide	0.1	mg/l
Fish toxicity	4	(dilution factor)

Note: The above emission limits apply to undiluted coking plant wastewater occurring at the rate of 0.3 m/t of coal.

Coking plants equipped for HP gas treatment and with installations for collecting and recycling contaminated rainwater, or with appropriate supplementary process stages, can increase the specific wastewater discharge to as high as 0.42 m/t of coal.

Table 3 - **Standard immission values for noise emissions (July 1984)**

The noise immission levels are specified for:

a)	areas containing only commercial or industrial facilities and living quarters for supervisory and standby personnel, to:		70 dB(A)
b)	areas containing primarily non-residential buildings, to:	(daytime) (nighttime)	65 dB(A) 50 dB(A)
c)	areas containing nonresidential and residential buildings		

	accommodating neither mostly nonresidential occupants nor primarily residential occupants, to:	(daytime) (nighttime)	60 dB(A) 45 dB(A)
d)	areas containing primarily residential buildings, to:	(daytime) (nighttime)	50 dB(A) 40 dB(A)
e)	areas containing exclusively residential buildings, to:	(daytime) (nighttime)	50 dB(A) 35 dB(A)
f)	areas containing health resorts, hospitals, nursing homes, to:	(daytime) (nighttime)	45 dB(A) 35 dB(A)
g)	residential buildings attached to industrial/business premises, to:	(daytime) (nighttime)	40 dB(A) 30 dB(A)

Comments

- The acoustic engineering of industrial facilities and the requisite prognostical calculations rely heavily on the algorithms elucidated in VDI (Association of German Engineers) guideline 2714 (E) "Outdoor Sound Propagation" and VDI guideline 2571 "Sound Radiation from Industrial Buildings".

- If the above guideline values are exceeded and/or adulterated by superimposed extraneous noise to such an extent that accurate measuring becomes impossible,

appropriate correction factors must be allowed for, as generally laid down in *TA-Lrm* (technical instructions on noise abatement). If measurements cannot be conducted, sound propagation calculations must be performed.

- "Nighttime" is understood as the eight hours between 10:00 p.m. and 6:00 a.m.

- In supplementation of the workplace ordinance *Verordnung ber Arbeitssttten* (section 15: protection against noise), the following provisions shall apply to workplace noise nuisance:

(1) The workplace noise level must be kept as low as possible for the type of operation in question. The workplace reference intensity, inclusive or exclusive of extraneous noise, shall not exceed:

55 dB(A) for primarily intellectual work
70 dB(A) for simple or mostly mechanized office work and comparable activities
85 dB(A) for all other activities; to the extent that the prescribed sound intensity level cannot be adhered to by available, reasonable means, it may be exceeded by 5 dB(A).

(2) The sound intensity level prevailing in breakrooms, duty rooms, rest rooms and first-aid rooms shall not exceed 55 dB(A). The reference sound intensity level shall be set by taking into account only the noise generated by installations inside the rooms plus the extraneous sounds entering the rooms in question.

***Table 4* - MAK-values (occupational exposure limits) and TRK-values (technical concentration**

guideline values)

Component	Limit values in Germany	Comparative values in Europe*	Remarks
Dust	6 mg/m	10 - 15 mg/m, 11 mg/m	
NOx (as NO_2)	9 mg/m	4 - 6 mg/m, 5.3 mg/m 30 mg/m NO	
SO_2	5 mg/m	1.5 - 5 mg/m 4.7 mg/m	1.5: Spanish outlier
CO	33 mg/m	29 - 57 mg/m 45 mg/m	29: Dutch outlier
Benzene	164) mg/m	3 - 32 mg/m	3: Swedish outlier
Toluene	375 mg/m	375 mg/m	
Xylene	440 mg/m	425 - 435 mg/m, 430 mg/m	

Benzo(a)pyrene	2-5 mg/m	2 - 5 g/m	
H_2S	15 mg/m	14 - 15 mg/m	
HCN	11 mg/m	10 - 11 mg/m	
NH_3	35 mg/m	17 - 18 mg/m	
Phenol	19 mg/m	19 mg/m	
Mercaptans	1 mg/m	1 mg/m	
Biphenyl	1 mg/m	1 - 1.5 mg/m	
Carbon disulfide	30 mg/m	30 mg/m	
Naphthalene	50 mg/m	50 mg/m	

3) cf. table-1.1 footnote

4) TRK-values

5) In the direct vicinity of the batteries, higher levels (measured in g/m) can be tolerated but then call for supplementary organizational and/or hygienic measures in addition to personal protective equipment, e.g., breathing masks.

Adherence to the permissible emission levels and the efficiency of the airborne emission control equipment must be monitored by measurements.

Subsequent to commissioning of facilities, it shall be determined by measurements whether or not the numerical data assumed at the planning stage correspond to the actual operating conditions. The measurements shall be conducted by neutral institutions, authorities or the like with due consideration of pertinent guidelines.

The *TA-Luft* and relevant VDI guidelines describe in detail the conduct of emission and ground-level pollution measurements.

3.3 Evaluation of environmental impacts

The aforementioned emission limits can be complied with by implementing the protective measures described in section 2.2.

Compared to existing facilities, the following reductions in emission levels (referred to a complete coking plant, including so-called diffuse sources) are foreseeable:

SO_2 by 20 - 40 %
NOx by 20 - 40 %
CO by 30 - 35 %
BTX by > 95 %
Dust by approx. 50 %
PAH by approx. 90 %
BaP by approx. 90 %

The following emissions can be completely avoided by replacing wet quenching facilities with dry coke cooling systems:

- **H_2S up to 80 g/t of coke, amounting to 160 t/a of H_2S for an annual coke output of 2 million tons;**
- **NH_3 up to 15 g/t of coke, amounting to 30 t of NH_3 per year.**

4. Interaction with other sectors

Coking plants are closely allied with the iron-producing industry (cf. environmental brief Iron and Steel). However, some coking plants are located near mines (see briefs on mining), with a coal processing facility (coal washing plant) operating at the mine.

New developments in the steel-making industry such as those enabling the use of both oil and coal in the blast furnace process can help reduce the specific coal requirement of blast furnace operation. At present, however, there is no sign of coke becoming dispensable as a fuel and mainstay medium (reducing agent) for blast furnaces.

References to other adjacent sectors are to be found at the appropriate text passages.

5. Summary assessment of environmental relevance

Without the safe and sure operation of comprehensive antipollution devices, coking plants can cause substantial pollution of the air, soil and water.

In addition to emission reduction measures to avoid pollution from definite sources, the avoidance of emissions from diffuse sources is also important. Moreover, the maximum allowable workplace concentrations (occupational exposure limits) must be observed.

Systematic implementation of well-tested modern environmental protection measures, in combination with the observance of pertinent rules and regulations, can ensure that coking plants, like other coal processing facilities such as carbonization systems, need not be classified as environmentally hazardous.

With due regard to local circumstances, official ordinances must ensure that environmental protection measures are properly executed.

To that end, it is advisable to designate environmental protection and environmental safety officers, who, with proper training and technical support, are in a position to assume supervisory functions and attend to the interests of environmental protection and occupational safety in connection with all relevant industrial activities.

Early involvement of affected groups (women in particular) in the planning and decision-

making processes enables consideration of their interests and helps alleviate environmental problems, e.g., in connection with the contamination of foodstuffs and/or health impairment in the vicinity of such undertakings.

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41. Thermal power stations

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Appendix A-7 - Minimum requirements as per German Federal water act (WHG), section 7a*

1. Scope

Thermal power stations are facilities in which the energy content of an energy carrier, i.e., a fuel, can be converted into either electricity or electricity and heat. The type of power plant employed depends on the source of energy and the type of energy being produced.

Possible energy sources include:

- **fossil fuels such as coal, petroleum products and natural gas**
- **residual and waste materials such as domestic and industrial refuse and fuel made from recovered oil**
- **fissionable material**

Thermal power plants can be designed for different fuel sectors in the interest of greater fueling flexibility and/or higher efficiency - one example being a combination power plant with a gas turbine running on natural gas and an oil- or coal-fired steam generator feeding a steam turbine.

Renewable sources of energy such as wood and other forms of biomass are not dealt with here, as they are the subject of a separate environmental brief. Nuclear thermal power plants have also been omitted from this catalogue. The frame of reference concentrates extensively on fossil-fueled power plants, in particular types using coal and petroleum products, the present and near-future use of which is of eminent importance in most developing countries. With regard to hydropower, the reader is referred to the environmental brief Large-scale Hydraulic Engineering.

As far as the form of energy being generated is concerned, there are three main types of thermal power stations:

- **condensing power plants used exclusively for generating electricity**
- **steam- or hot-water producing heating stations for domestic or industrial purposes**
- **district heating power stations, or cogenerating plants, for the simultaneous generation of electricity and available heat.**

It is important to note that, for economic reasons, process heat and heat for heating purposes should only be generated in close proximity to the users. For thermal outputs ranging from 50 to 100 MW, the distance between the power plant and the user should not exceed 2 to 5 km. Conversely, electricity can be economically transmitted over very substantial distances; cf. environmental brief Power Transmission and Distribution.

The unit power ratings of fossil-fueled thermal power plants range from a few hundred kW

(diesel stations) to more than 1000 MW (oil- and coal-fired stations). In many countries, preference is given to unit ratings of 200 - 300 MWel with deference to power system stability. The better the boundary conditions, the higher the achievable capacities.

2. Environmental impacts and protective measures

The environmental consequences of any given plant are both plant- and site-dependent. Thermal power stations can impact the environment in different ways and at different locations. A typical thermal power plant is likely to comprise the following principal components:

- **facilities for preparing and storing working materials**
- **facilities for burning fuel and generating steam**
- **facilities for generating electricity and available heat**
- **facilities for treating exhaust gases and solid and liquid residues**
- **cooling facilities**

In Appendix A-1, a thermal power plant is reduced to a block diagram showing the most likely material inputs, outputs and environmentally relevant flows of material.

Table 1 surveys the potential emissions occurring at different stages of the generating process:

Table 1 **- Potential emissions from thermal power plants**

Step of process						
Type of emission	Fuel storage and processing	Combustion and steam generation	Flue-gas cleaning	Power generation	Cooling systems	Treatment of residue
Particulates	*	*			*	*
Noxious gases		*				*
Wastewater	*	*	*		*	*
Solid residues		*	*			*
Waste heat		*		*	*	
Noise	*	*	*	*	*	*
Groundwater contamination	*					

As the table indicates, thermal power stations can affect the media air, water and soil, as well as human beings, plants, animals and the landscape.

The disposal of residues, e.g., those associated with oil- and coal-fired facilities, is dealt with in section 2.3.

The main environmentally relevant effects of a thermal power plant derive from the combustion process and its particulate and gaseous emissions. As a rule of thumb, the environmental impacts of thermal power plants, i.e., pollution, spatial requirements and residues, tend to increase in severity for gas, light fuel oil, heavy fuel oil and coal, in that order.

Prior to examining the environmental consequences and possible protective measures for the various domains, let us begin with a few basic introductory remarks. The running text contains information essential to the subject environmental consequences and protective measures, while the relevant technical measures are detailed in the appendix.

In addressing the environmental consequences of a thermal power plant, distinction is drawn between emissions, i.e., the release of pollutants from various parts of the plant, the smokestack in particular, and immissions, i.e., the actual environmental effects of the pollutants, normally referred to ground level - as indicated by the terms "ground level concentration/pollution" and "ambient air quality concentration/standards". Emissions and immissions are interlinked by a number of factors, e.g., plant-specific technical parameters (emission volumes, outlet velocity, temperature), meteorological factors (weather category, wind speed) and range-specific data (distance between the emitter and the ground-level pollution point). Parameters belonging to the first and last categories, e.g., height of stack and distance from residential areas, are more or less freely selectable for new power plants, while the actuating variables for existing plants all belong to the first category. According to the laws of physics (conservation of matter), practically all noxious emissions with the notable exception of CO_2, for example, eventually fall to earth. The height of the smokestack, the

outlet velocity of the exhaust, and the prevailing wind velocity determine the size of area that will be affected. From a technical standpoint, it is relatively easy to reduce ground-level concentrations for a given area by increasing the height of the smokestack. Since, however, the specific emission volume does not change, but is simply distributed over a wider area, the extent to which such a measure would aggravate the environmental impact outside of the subject area would have to be clarified.

Measures aimed at reducing the environmental consequences of thermal power plants can be categorized as follows:

- alteration of boundary conditions

incentives for the efficient utilization and conservation of energy, e.g., cost-covering power rates and taxes
appropriate siting

- nontechnical protective measures

regulations dictating the mandatory use of piped energy (district heating) in congested urban areas
compensation models for the replacement of major emitters

- technical protective measures

reduction of ground-level concentration, e.g., by extending the height of the smokestack
emission-reducing measures

* pollution-control measures to prevent or reduce pollution by combustion modification, e.g., choice of an appropriate low-impact fuel such as natural gas (in place of coal), homogenization of fuel to avoid peak emissions, efficiency-enhancing measures, and NOx limitation by combustion engineering measures

* post-combustion measures, i.e., flue gas clean-up.

The order in which the protective measures are taken is subject to the principle of attaching priority to avoidance or reduction over subsequent rectification. First of all, pollution-control measures must be taken to preclude, or at least minimize, the occurrence of pollutants, before any further-reaching post-combustion technical remedial processes are initiated.

One very important relevant measure is to achieve higher efficiency, e.g., by erecting combination power plants or opting for the combined generation of heat and power (cogeneration) in efficient heating power stations with an accordingly low specific pollution level. High efficiency is also the most effective way to reduce CO_2 emissions and, hence, their greenhouse effect. For additional means of reducing CO_2 emissions, e.g., through the use of renewable sources of energy for power generation, cf. the brief Renewable Sources of Energy.

With regard to environmental consequences, distinction is made between direct consequences, e.g., the emission of pollutants, and indirect consequences such as the transfer of pollutants from the atmosphere to water via scrubbing processes (assuming that the liquid effluent is not subsequently processed) or the environmental impact of limestone mining and attendant road traffic, e.g., the transfer of limestone by truck from the mine to the power plant. Moreover, consequential problems can arise, e.g., the need to properly dispose of the gypsum resulting from flue-gas desulfurization processes (FGD).

The environmental consequences and potential protective measures applicable to the aforementioned areas are explained below.

2.1 Air

The particulate and noxious gas emissions from thermal power plants primarily and directly pollute the air.

Eventually, the particulate emissions and, for the most part, the noxious gases and any atmospheric transformation products that may have formed (e.g., NO_2 and nitrate from NO) fall to earth either by way of precipitation or dry deposition, thereby imposing a burden on the water and/or soil, with resultant potential damage to flora and fauna.

Depending on the fuel employed (type, composition, calorific value) and the type of combustion (e.g., dry or slag-tap firing), given amounts of pollutants (particulates, heavy

metals, SO_x, NOx, CO, CO_2, HCl, HF, organic compounds) become entrained in the exhaust gases. Table 2 shows the potential concentration ranges of different emissions for various fuels in facilities devoid of flue-gas emission control measures.

Table 2 **- Potential ranges of pollutant concentration levels in untreated gas Type of fuel**

Type of emission	Natural gas	Light fuel oil	Heavy fuel oil	Hard coal	Lignite (brown coal)
Sulfur oxides (SO_x) [mg/mSTP]	20 - 50	300 - 2000	1000 - 10000	500 - 800	500 - 18000
Oxides of nitrogen (NOx) [mg/mSTP]	100 - 1000	200 - 1000	400 - 1200	600 - 2000	300 - 800
Particulates [mg/mSTP]	0 - 30	30 - 100	50 - 1000	3000 - 40000	3000 - 50000

Table 2 lists the noxious emissions in mg/mSTP, as prescribed by the applicable German rules and regulations [*TA-Luft (Technical Instructions on Air Quality Control),* and *Grofeuerungsanlagenverordnung (Ordinance on Large-scale Firing Installations*)]. SO_x and NOx are postulated as SO_2 and NO_2. Some emissions are limited in terms of mass flow, e.g., in

kg/h, or of minimum separation efficiency (cf. Appendix A-6). With a view to enabling conversion of the stated concentrations to other units such as ppm, g/GJ or lb. of pollutant per 10^6 BTU energy input, as commonly employed in the U.S.A., Appendix A-6 includes an appropriate conversion table.

The ranges quoted in table 2 for oxides of sulfur relate to differences in fuel-specific sulfur content, whereas many countries use large quantities of indigenous fuels like lignite with comparatively low calorific values and high sulfur contents. Such a combination naturally produces relatively high SO_X concentrations in the (untreated) flue gas.

The lesser part of the NOx concentrations derives from the nitrogen content of the fuel (fuel NOx). The major share results from the oxidation of atmospheric nitrogen at combustion temperatures exceeding 1200C (thermal NO_X). Consequently, high combustion temperatures go hand in hand with relatively high NOx emission levels. Appropriate combustion engineering measures that are

relatively inexpensive for new plants can keep the emissions at the lower end of the respective range. However, care must be taken to ensure that a high quality of combustion is maintained. Otherwise, excessive combustion engineering measures aimed at reducing NO_X emissions could result in a disproportionate increase in other emissions, e.g., carbon monoxide and combustible (unburned) hydrocarbons.

In general, CO_2 emissions are mainly limited by controlling the burnout process such as to minimize the discharge of CO and the escape of combustible hydrocarbons. Unlike particulates, SO_2, NOx and halogen compounds, CO and combustible hydrocarbons effectively defy retentive measures. Combustible hydrocarbons in particular include numerous chemical substances that can cause toxicological problems, e.g. benzpyrene.

Plants fueled with coal or heavy fuel oil also emit small amounts of hydrogen chloride and hydrofluoric acid (HCl and HF) ranging from 50 to 300 mg/mSTP. As a rule, the concentrations stay well below the SO_2 levels and respond favorably to desulfurization processes, by which they are reduced even more than S_2.

There are many combustion-stage and post-combustion alternatives for use in reducing air pollution from thermal power plants. Appendix A-2, for example, sketches out an integral set of $DeNO_x$, particulate-control and desulfurization measures for the flue gas of a steam generating facility. The various measures are individually described in the following subsections.

2.1.1 Dust control

Dust control for power plants can be based on ordinary and multiple cyclone separators and electrostatic precipitators or fabric filters - with the order of mention corresponding to their respective separation efficiencies: from 60 % - 70 % for cyclone separators to >99 % for

electrostatic precipitators and fabric filters. To be sure, the cost of the various options rises disproportionately for increasing separation efficiency. The separation efficiency of electrostatic filters depends on the number of consecutive fields. Like fabric filters, they can achieve extremely low residual emission levels, i.e., about 50 and 30 mg/mSTP, respectively. The drawback of cyclone separators is that they tend to eliminate coarse particles much more efficiently than respirable - and, hence, toxicologically critical - microparticles. Fabric filters are very good at separating out fine dust and its accumulated heavy metals. The capital outlay for flue-gas dust control depends

on such parameters as the type of fuel, the required separation efficiency and the technique employed. As a rule, the initial cost ranges from 20 to 70 DM/kW$_{el}$, while the operating expenses amount to 0.1 - 0.6 DM/MWh. The high-ash fuels used in some countries makes flue-gas dust control a difficult problem - including

the proper disposal of the dust yield, either by recycling it in, say, building materials, or by depositing it in a landfill. Certain characteristics of the fly ash may require the use of additives to obtain a solidified product that is less susceptible to leaching, this with a view to preventing groundwater contamination.

2.1.2 Desulfurization

SO_x from combustion plants can be reduced either by combustion modification measures (use of low-sulfur fuel, direct desulfurization in the furnace, dry-additive method) or by post-

combustion clean-up measures such as extracting the SO_X from the flue gas.

The use of low-sulfur fuels is frequently precluded by economic considerations. In each case, the lowest total-cost concept must be ascertained. For example, while the use of a low-sulfur fuel may increase the cost of operation, it could save the cost of installing and operating desulfurization equipment, thus yielding lower overall costs for the power station. Of course, such considerations must also account for other criteria, e.g., using indigenous fuels in order to assure their safe supply.

Like solid fuels, sulfurous petroleum products are also amenable to pre- and post-combustion measures. The pollution-control measure of choice is to hydrate the sulfur by adding hydrogen in order to extract the product from the oil, e.g., as vacuum gas oil or a remanent of atmospheric or vacuum distillation. Such processes are only cost-efficient for large capacities and therefore only feasible for oil refinery applications. In a thermal power station, the appropriate measures for reducing SO_X emissions are restricted to the use of a low-sulfur petroleum product, mixing different fuels and, primarily, flue-gas desulfurization according to the same principle as that employed in solid-fueled facilities (described below and in Appendix A-3).

For coal-fired power plants, particularly in response to the pronounced compositional variance observed in the indigenous coals of many countries, appropriate mixing and homogenization can have the positive effect of lowering the peak-value extremes that have to be accounted for in the design of desulfurization systems. Consequently, major importance must be attached to

a conscientious analysis of the calorific values and the water, ash and sulfur contents

of fuel deriving from, say, different sections of a coal mine. It is also important to ascertain the possible extent of spontaneous desulfurization attributable to the presence of calcium compounds in the coal.

Coal can be desulfurized directly at the mine or pit as part of a process in which sulfur and various inert constituents are extracted primarily by wet methods. Depending on the type of coal and on the kind of sulfur linkage, the sulfur content of the coal (glance coal in particular) can be reduced by 5 % to 80 %. No such conditioning measures, however, can reduce the organosulfur content. Sulfite in the form of pyrite (FeS_2) can be separated out if it is freely present in the raw coal or is so coarse-grained in intergrowths that it becomes amenable to removal following crushing.

Direct in-boiler desulfurization is applied to solid fuels in fluidized-bed combustion systems. Separation efficiencies of 80 % to 90 % are achievable. Dry additive techniques remove between 60 % and 80 % of the sulfur from coal (cf. Appendix A-3 for details).

Flue-gas desulfurization techniques enable SO_2 separation efficiency levels of 90 - 95 %. Since flue-gas desulfurization equipment is expensive to install and operate, it is more judicious in some cases to install a component-flow desulfurization system in which only part of the flue gases are desulfurized, while the remaining, undesulfurized flue gases can be used for heating the treated gases.

Of all the described alternatives, flue-gas desulfurization is the most expensive and elaborate. In each case, particularly for retrofitting projects, the spatial integration options must be carefully investigated in advance.

A comparison of the aforementioned pre- and post-combustion desulfurization measures shows that the former offer the lower separation efficiencies, but are also less expensive and more conducive to retrofitting. Fluidized-bed combustion, however, is an exception to the rule, as it can only be implemented in new facilities (maximum capacity of commercial-scale systems to date: 150 MWel).

All methods of desulfurization and dust control involve the consequential problem of properly recycling or disposing of the residues and, possibly, of wastewater resulting from operation of the equipment (cf. section 2.3).

Depending on the size of the plant, the process employed, the separation efficiency achieved, and other factors, the investment cost of a desulfurization system can amount to anywhere from roughly 30 to 550 DM/kW$_{el}$. Also the increase of auxiliary power consumption to run the system is unavoidable. Dry-additive methods are the least expensive, while regenerative techniques producing compounds of sulfur as their end product are the most costly.

The various desulfurization processes also and incidentally precipitate halogen compounds such as HCl and HF even more efficiently than sulfur.

2.1.3 De NO_x

The available means of nitrogen removal also comprise pre- and post-combustion alternatives. With regard to sulfur content, a careful choice of fuel can do much to limit NOx emissions. On the other hand, the NOx formation process is more complicated than the conversion of fuel sulfur into SO_2, as described in section 2.1. The combustion modification measures aim to reduce the rate of NOx formation during the combustion process, essentially by lowering the maximum temperature of combustion. This can be achieved by design measures, e.g., the combustion-chamber geometry, burner design and configuration, staged air supply, reduced excess air, and such operational measures as reduced combustion-air-preheating temperature or the use of low-nitrogen fuel.

The post-combustion DeNO_x measures are concerned with reducing the exhaust-side NOx emissions by various means designed to remove the NOx either alone or together with SO_x.

The only process to have gained commercial-scale acceptance to date is the selective catalytic reduction of NOx (SCR method). In this process, ammonia (NH_3) reacts with NOx in a catalytic converter to form water and nitrogen. The process therefore produces no residues (like those from dust-control and desulfurization processes) that would require subsequent disposal. The SCR process takes place at temperatures of 300 - 400C and can be integrated either on the raw-gas end, e.g., upstream of the air preheater (SCR (ρ) economizer) or on the clean-gas end behind a desulfurizing system (SCR (ρ) FGD).

SCR-base processes achieve NOx separation efficiencies of approximately 80 - 90%.

Another approach that is particularly well-suited for relatively low separation efficiencies of about 60 % or less is the SNCR process (selective non-catalytic reduction), in which NOx reduction is achieved by spraying ammonia into the boiler at a temperature of some 1000C.

The initial cost of flue-gas DeNO$_x$ equipment depends on the size of the plant, the required separation efficiency, configuration, etc. and ranges from roughly 120 to 250 DM/kW$_{el}$.

2.1.4 Greenhouse effect

The greenhouse effect, i.e., the long-term warming of the earth's atmosphere due to the presence of anthropogenic trace gases, is chiefly attributable to the accumulation of gases such as carbon dioxide (CO_2), methane (CH_4), chlorinated fluorocarbons (CFCs), tropospheric ozone (O_3) and nitrous oxide (N_2O) - with the order of mention corresponding to the relevant significance of the gases. Their specific contributions to the greenhouse effect are widely variant. Methane, for example, has roughly 21 times the effect of CO_2, but occurs globally in much smaller mass volumes than does CO_2 as the end product of any combustion process involving carbonaceous (organic) fuel.

The principal protective measure to counter CO_2 emissions is to ensure high combustion efficiency, e.g., by way of a combination or cogeneration process.

Other measures like the use of renewable sources of energy - hydropower in particular - for generating electricity, in addition to measures aimed at steering the demand for electricity, are very important, but would never suffice to render superfluous the generation of electric power in fossil-fueled thermal power plants.

2.1.5 Diffuse emissions

In addition to the aforementioned types of emissions, most of which emanate from the smokestack, thermal power plants can also emit pollutants from other areas (cf. table 1). Particulate emissions, for example, can occur in connection with fuel storage, handling and processing. Such emissions can be extensively reduced by suitable measures such as moistening with water or enclosing/encapsulating critical areas. The same applies in effect to the storage and handling of petroleum products, i.e., via suitable contrivances on the tanks and pumping facilities, either to minimize evaporation or to return the condensate to the system. Such measures can be of major importance in countries with a warmer climate than that encountered in Central Europe.

2.2 Water

Most water in thermal power stations is used for cooling. After absorbing enough heat to raise its temperature by 4 - 8C, the water normally is returned to the extraction point. Power plants designed for non-circulating water cooling require about 160 - 220 m/h•MWel (with cooling water losses usually staying below 2 %).

In pure power generation, the cooling water absorbs approximately 60 % to 80 % of the fuel's energy content as waste heat. Less energy is wasted by plants with inherently higher efficiency, e.g., cogenerating facilities. Depending on local conditions, the waste heat can impose a thermal burden on surface water, e.g., cause an increase in the temperature of a river, with the volumetric flow and/or water regimen as an actuating variable. Particularly in developing countries, water bodies are subject to pronounced seasonal variation. Oxygen depletion therefore has two main causes: accelerated consumption due to rapid metabolism, and the lower solubility of oxygen in warm water. Oxygen deficiency can be seriously detrimental to aquatic life.

The in/out temperature gradient of cooling water can be limited by putting it through a cooling tower (once-through or circulation cooling) before it is returned to the river. Depending on the prevailing climatic conditions, however, such cooling systems involve major evaporative water losses and, hence, locally elevated atmospheric dampness. Such problems can be avoided or minimized by the use of closed-loop cooling systems in combination with dry or hybrid cooling towers. Natural-draft cooling towers are relatively expensive to build but comparatively inexpensive to operate, while induced-draft cooling towers have the disadvantage of operating on electricity, the generation of which increases the overall ecological burden.

Apart from their cooling-water consumption, power plants have very modest water requirements (0.1 - 0.3 m/h•MWel) for topping up the steam cycle, cooling the ashes and operating certain types of flue-gas purification equipment (spray absorption, wet processes).

Water effluent from thermal power stations, particularly from coal-fired plants, can pollute surface waters.

The following types of wastewater can occur in power plants:

- **regenerate from the conditioning of makeup water and desalination of condensate**
- **water used for washing condensate filters**
- **effluent from coal handling and coal storage**
- **sensitive wastewater, e.g., from pickling and conservation**
- **ash-laden water (deslagging water) from liquid ash removal**
- **water from the boilers, turbines and transformers**
- **cooling-tower discharge and makeup-water conditioning**
- **wastewater from flue-gas purification.**

The quantities of such wastewater depend on the type of fuel and on various plant-specific boundary conditions and can be expected to range between 10 and 100 l/h for each MWel power output. Such effluent can be polluted by entrained suspended solids, salts, heavy metals, acids, alkalies, ammonia and oil.

Wastewater treatment can be based on physical, chemical and thermal methods. For some forms of wastewater, e.g., filter backwashing water and coal-storage effluent, physical treatment in the form of filtration, sedimentation and/or ventilation will usually suffice. Other forms of wastewater such as regenerate from makeup-water and condensate polishing, flue-

gas cleaning water or other wastewater streams require chemical treatment - flocculation, precipitation, neutralization - or even thermal treatment - evaporation, drying - before they can be discharged; cf. environmental briefs Wastewater Disposal and Mechanical Engineering Workshops, Shipyards.

As mentioned in section 2, wastewater occurring as a consequence of certain flue-gas desulfurization processes can contain various pollutants deriving from the flue gas. The composition of such wastewater depends on a number of parameters, e.g., the type of fuel, the process water and the quality of the additives.

As a rule, wastewater from flue-gas cleaning requires physicochemical conditioning in the form of neutralization, flocculation, sedimentation and filtration to remove heavy metals and suspended solids (gypsum, etc.).

The amount of wastewater occurring in connection with wet desulfurization methods having gypsum as a by-product depends mainly on the chloride content of the coal and on the permissible concentration of chloride in the washings. In a typical hard-coal power plant, flue-gas desulfurization processes can yield wastewater in quantities between 20 and 50 l/h per MW of power output.

The high water solubility of calcium chloride ($CaCl_2$) entrained in the wastewater makes it an unprecipitable saline emission.

If no salt is allowed to be discharged into the receiving water, the FGD wastewater can be evaporated to yield dry, water-soluble salts requiring controlled disposal, e.g., in an underground sensitive-waste depot. Since the evaporation process requires high energy inputs, it should be ascertained for such cases whether or not an effluentless method (dry process, spray absorption) would be suitable.

Apart from the aforementioned direct effects, power plants can also have indirect effects on water. Consider, for example, the "acid rain" phenomenon involving the washout of airborne pollutants (SO_x, HCl, NOx) from power plants in connection with natural precipitation.

2.3 Soil and groundwater

Thermal power plants can have multifarious impacts on soil and groundwater. The soil quality, for example, can be adversely affected by dust sediment, particularly in the near vicinity of the plant. The seriousness of ground-level pollution depends on the heavy-metal content of the dust. The chemism of the soil can be altered by acidic precipitation (acid rain) characterized mainly by the acid formers SO_2 and NOx. Under unfavorable conditions, acidification can pass from the soil to both the groundwater and surface waters. The extent of soil and groundwater pollution does not depend on how much particulate matter and acid formers are contained in the exhaust, but rather on the absolute quantities emitted in the course of a year (total annual emissions) and on the conditions of distribution. Thus, it is important to limit such emissions by separation capacities commensurate with the size of the power plant.

The ground and, even more so, the groundwater in the immediate vicinity of the power plant are threatened by the escape of water-polluting substances, the main sources of which are various weak points in the collection and purification of wastewater, the leakage of oil and oil-containing liquids, and storage areas for oil, coal and residues.

The deposition of residues also has consequences for the soil and, even more so, for the groundwater. Power-generating residues consist primarily of slag, fly ash, remanents from flue-gas desulfurization, and sludge from the treatment of raw water and effluent. The residual quantities depend in part on the processes employed; in general, however, it may be said that, the lower the quality of the coal, the higher the quantity of residues.

Slag and fly ash can be put to various uses (for roadbuilding or as cement aggregate), depending on their composition. To the extent that they cannot be recycled, such substances must be disposed of at suitable dumps (e.g., above groundwater level). In Germany, these matters are regulated by *TA-Abfall* (Technical Instructions on Waste Management).

Part 1 in Appendix C of the catalogue of particularly sensitive wastes specifies aboveground deposition in the form of a mono-type hazardous waste dump for solid reaction products resulting from the purification of combustion-plant exhaust gases, excluding gypsum; cf. briefs Solid Waste Disposal, Disposal of Hazardous Wastes.

The nature of FGD residues depends on the method employed (cf. Appendix A-3) and may occur in recyclable form, e.g., gypsum. The quantities depend on the sulfur content and the

calorific value of the fuel, the degree of desulfurization, and the additives involved. Prior to choosing a particular desulfurization process, it should be ascertained whether or not the respective remanent substances occurring as by-products of the different processes could be marketed in the respective country. This would require a detailed local market analysis, appropriately involving local contractors/consultants. Potential uses for the residues (as building materials) must be investigated; in their absence, it must be clarified whether or not and under which conditions the substances can be safely disposed of.

The following table compares the quantified residues of flue-gas desulfurization in facilities fired with heavy fuel oil and two different types of coal:

	Hard coal	**Lignite**	**Heavy fuel oil**
Calorific value [kJ/kg]	28 000	10 000	40 000
Sulfur content [weight %]	2.0	2.0	2.0
Degree of desulfurization [%]	85	85	85
SO_X in raw gas [kg/MWelh] [mg/mSTP]	14 4 000	38 8 600	9.5 2 850
SO_X in treated gas [kg/MWelh] [mg/mSTP]	2.1 600	5.7 1 300	1.4 427
Residual quantities [kg/MWel]	**Hard coal**	**Lignite**	**Heavy fuel oil**

(process-dependent)			
Gypsum	32	87	22
Sulfite/sulfate	36	97	24
Sulfur	6	16	4
Sulfuric acid	18	50	12

When both fly ash and desulfurization products (gypsum or a sulfite/sulfate mixture) require disposal, it is advisable to mix the products first. A blend of fly ash and desulfurization products can be hardened to stabilize the water-soluble constituents (stabilizate) and reduce their leachability.

Desulfurization processes with useful end products require appropriate treatment of the wastewater. The resultant sludge contains large amounts of heavy metals and therefore should be treated as sensitive waste.

2.4 Human health

Adverse effects of thermal power plants on human health can derive from the direct impact of noxious gases on the organism and/or their indirect impact via the food chain and changes in the environment. Especially in connection with high levels of fine particulates, noxious gases

like S_2 and NOx can lead to respiratory diseases. SO_2 and NOx can have health-impairing effects at concentrations below those cited in the German smog ordinance. The duration of exposure is decisive. Injurious heavy metals (e.g., lead, mercury and cadmium) can enter the food chain and, hence, the human organism by way of drinking water and vegetable and animal products. Climatic changes such as warming and acidification of surface waters, *Waldsterben* (forest death) caused by acid rain and/or the greenhouse effect of CO_2 and other trace gases can have long-term detrimental effects on human health. Similarly important are the effects of climatic changes on agriculture and forestry (and thus on people's standard of living), e.g., large-scale shifts of cultivation to other regions and/or deterioration of crop yields. Hence, the construction and operation of thermal power plants can have both socioeconomic and sociocultural consequences; appropriate preparatory studies, gender-specific and otherwise, are therefore required, and the state of medical services within the project area must be clarified in advance. Early, comprehensive involvement of the concerned sections of the population in the planning and decision-making process can help reduce and avoid points of conflict.

Noise, as an item of emission from thermal power plants, has direct effects on humans and animals. The main sources of noise in a power plant are: the mouth of the smokestack, belt conveyors, fans, motors/engines, transformers, flues, piping and turbines.

At least some of the personnel working in power plants are exposed to a more or less substantial noise nuisance.

Diverse noise-control measures can be introduced to reduce immissions to a tolerable level, whereas the primary goal must be to protect the power plant staff. To the extent possible, power plants should be located an acceptable distance from residential areas, and all appropriate noise-control measures must be applied to the respective sound sources at the planning and construction stages.

Two particularly effective measures are the use of sound absorbers to reduce flow noises and the encapsulation of machines and respective devices to reduce airborne and structure-borne sound levels. Appropriate enclosures constitute an additional means of simultaneously reducing both the emission and immission of noise. Incidentally, enclosures also provide weather protection and are therefore used widely in power plant engineering.

2.5 Landscape

Power plants have substantial spatial requirements. The extent of land consumption is generally higher for coal-fired facilities than for gas- or oil-fueled plants. With regard to siting, cf. environmental briefs on Spatial and Regional Planning, Planning of Locations for Trade and Industry.

The landscape is also affected by construction of the roads needed for delivering operating media and disposing of residues; cf. environmental briefs on railways, roads and waterways. The associated mining activities to obtain coal and, say, limestone (for desulfurization purposes) and for disposing of residues not to be recycled also tend to alter the landscape. In

connection with the disposal of residues, priority should be given to landfilling schemes (e.g., in worked-out strip mines) or land reclamation in coastal areas. Both alternatives avoid the need for separate dumping facilities and put the residues to an advantageous use. The residues, of course, should be environmentally benign, either by nature or by reason of appropriate treatment to impart, for example, a low level of leachability. Additionally, it must be ascertained whether or not and which measures (sealing, controlled drainage, conditioning of percolating water) will be required to keep soluble heavy metals and other substances contained in the residues from passing into the groundwater or coastal water (cf. sections 2.1.1 and 2.3).

Moreover, attendant pollution can cause damage to forests, lakes and rivers, resulting in serious permanent changes in the landscape.

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3. Notes on the analysis and evaluation of environmental impacts

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3.1 Immissions Limits for Air

As already explained in section 2, the decisive atmosphere-specific environmental impact parameter is "ground-level pollution", i.e., the effects of air pollution on humans, animals, plants and inanimate objects. In evaluating the environmental consequences of thermal power plants, air pollution is normally of central interest. With the exception of CO_2, the main pollutants are increasingly regulated by the particular immission limits adopted by different countries. In actual practice, concrete projects must attach primary importance to abiding by the applicable standards. In some countries, those standards are even more stringent than those stipulated by Germany's *TA-Luft* (Technical Instructions on Air Quality Control). To the extent that the relevant standards have not yet been set or have been set too high, recourse should be taken to the long-term standards prescribed by *TA-Luft* with regard to impairment of human health and, in part, to the protection of vegetation, materials, water bodies, etc. (cf. Appendix A-4).

If in connection with a concrete project the relevant standards will obviously be exceeded by the baseline pollution load or foreseeable developments, then the promotion of thermal power plants must be ruled out from the beginning on environmental grounds. According to *TA-Luft*, exceptions can be made for new power plants if the additional burden attributable to the planned facility will not exceed 1 % of the long-term immission limits (irrelevance clause).

If an existing power plant contributes considerably toward substantial transgression of the relevant immission limits, the first step to take is to investigate the possibility of its - economically feasible - relocation. If the results of the study indicate retention of the existing site, the annual relevant pollutant concentrations attributable to the power plant must be

significantly reduced in absolute terms by appropriate rehabilitation measures. If the contribution of the existing power plant toward the overall pollutive burden does not exceed 1 % of the standard values after rehabilitation, the irrelevance clause may be applied by way of analogy to the exemption provisions for new plants.

Whenever the relevant standards are significantly exceeded, care must be taken to prepare an appropriate sanitation concept for the affected sphere of influence. Such a concept must provide for the reduction of pollution from sources not standing in direct connection with the project of interest.

With regard to the immission limits listed in Appendix A-4, the reader's attention is called to the fact that the particulate, sulfur dioxide and nitrogen oxide values serve as vitally important indicators for the environmental consequences of thermal power plants. The limit values for hydrogen chloride, cadmium and lead gain significance, when those elements are more abundantly present than normal in the fuel. In such cases, all considerations concerning the environmental relevance of the thermal power plant must be made subject to an analysis of the fuel to be used.

As far as German immission limits are concerned, it should be noted that they only come to bear in increasingly rare cases, because steady cuts in pollutant releases have enabled extensive compliance in most areas in recent years. Any requirements exceeding the immediately prophylactic scope are substantiated on the basis of the pollution prevention principle. Pollution limits are not schematically transferable to other situations and other

countries, because, for example, the sensitivity of the local vegetation, the prevailing climatic and weather conditions, and the composition of the local soil(s) can be wholely different, hence justifying either more stringent or more lenient standards. Those specified in *TA-Luft* give due account to the protection of human health. As such, they are more stringent for clean-air areas than for regions in which high levels of baseline pollution already prevail.

3.2 Emission limits for air

As explained in section 3.1, the premier measure for limiting the environmental consequences of thermal power plants is adherence to the pertinent immission limits. Nonetheless, power plant emissions also should be appropriately limited - since an ounce of prevention is better than a pound of cure. As mentioned in section 2, there are a number of tried & tested commercial-scale pollution control technologies, each with its own particular benefits and drawbacks. One frequent drawback is the relatively high cost of efficient technology. The extent to which a less complex and therefore less expensive approach could significantly reduce the adverse environmental impacts of a thermal power plant should be ascertained in advance.

For example, it certainly would make sense to eliminate particulate emissions with a relatively low-cost cyclone instead of a more efficient and accordingly more expensive electrostatic precipitator or fabric filter, particularly since the high cost of the latter could be regarded as prohibitive, with the result that, ultimately, no dust control effect whatsoever is achieved. According to that same line of reasoning, it would be better to install a single-field electrostatic

precipitator than none at all on the grounds that a multiple-field unit would be too expensive. Moreover, the use of more elementary processes has the added advantage of simplifying the operation, maintenance and repair of the equipment while offering a higher level of operational reliability.

Appendix A-5 lists the main laws, rules and regulations governing the release of power plant emissions to the air, water and soil in the Federal Republic of Germany.

As a rule of thumb for concrete projects, the emission limits adopted by the developing country or countries in question should be adhered to. In some cases, of course, this could result in transgression of the comparatively strict emission limits prevailing in the Federal Republic of Germany. Depending on the general context, though, that still could be regarded as tolerable. Nevertheless, the pollution prevention principle dictates that every attempt be made to install appropriate emission control technologies, even on a stage-by-stage basis if necessary, e.g., by first installing a cyclone separator and leaving room for the eventual retrofitting of an electrostatic precipitator.

Appendix A-6 summarizes the essential emission limits for airborne pollution from large-scale combustion plant in the Federal Republic of Germany.

As the table shows, the requirements differ according to type of fuel and size of installation (the latter expressed in terms of thermal output), whereas the larger installations generally are expected to satisfy more stringent environmental protection standards.

Other European Countries go by emission limits similar to those applying in Germany, particularly by way of EC Directive 88/609, most notably for SO_2. The Japanese and U.S. American emission limits are also comparable, but how stringently they are enforced depends on local circumstances (competent authorities, baseline pollution levels, etc.). Appendix A-6 also lists the emission standards for new, large-scale coal-fired power plants in selected countries, along with the corresponding EC standards, for the indicators SO_x, NOx and particulate emissions. Also included is a conversion chart for converting SO_2 and NOx units from mg/mSTP to ppm or lb/10^6 BTU.

The limit values prescribed in Appendix A-6 can be achieved at justifiable expense for favorable fuels, i.e., for those with high calorific values and low sulfur contents. For unfavorable fuels, however the stipulation of low emission limits can be rather problematic. For example, according to table 2, it would take a separation efficiency of roughly 98 % to limit the SO_x emission level to 400 mg SO_2/mSTP for a raw gas concentration of roughly 18 000 mg SO_2/mSTP. For such fuels, however, stipulation of an 85 - 95 % degree of desulfurization corresponding to the justifiable techno-economic expenditures would be more advantageous.

In some countries, the only available fuels are of such inferior quality that the emission levels listed in Appendix A-6 cannot be adhered to, and higher levels are therefore permitted.

It would be inappropriate to simply transfer the emission limits of, say, the Federal Republic of

Germany to other countries, since identical limitations in combination with inferior fuels would call for more sophisticated purification technology than that required in Germany. To maintain a like level of expenditures, one must work from the given emission levels and automatically arrive at higher limit values. It should be noted in that connection, that some of the fuel used in the Federal Republic of Germany does not meet standard German specifications.

From the standpoint of environmental protection, emission limits serve merely as expedients denoting a certain state of technological development under a certain set of boundary conditions. The primary purpose of environmental protection, however, must be to protect human health, the vegetation, water bodies, etc. In other words, the primary objective of such provisions is to comply with the <u>immission limits</u> (cf. section 3.1). The factors governing ground-level pollution were discussed in section 2.

3.3 <u>Monitoring of pollution levels</u>

As a rule, it takes very sensitive instruments to accurately measure pollutant concentrations, since the levels in question can be situated several orders of magnitude below the emission concentrations. Still, certain conclusions can be drawn concerning past pollution by studying the proposed site and its surroundings. The baseline pollution level will be all the higher, of course, if other power plants and/or emission-intensive industries are located in the near vicinity or if the proposed site borders on a major traffic artery. A conflict of purposes could arise in that cogeneration, for example, as its high efficiency and accordingly low emission

levels requires a nearby consumer, normally some form of industrial enterprise. If the consumer is characterized by relatively high emissions, the correspondingly high baseline pollution level could partially or even entirely counteract the environmental merits of cogeneration.

With regard to emission measurement, care should be taken to ensure that the scope of supply for the power plant includes instruments for measuring dust, SO_X and NOx emissions. Such pollutants are relatively easy to monitor with the aid of mobile local instruments applied to flues or breeching. The requisite gas analyzers operate according to different principles. Differentiation is made between photometric and physicochemical measuring processes.

Photometric processes operate on a purely physical basis (nondispersive infrared process, nondispersive ultraviolet process), while the physico-chemical processes are based on a chemical reaction. Such instruments offer resolutions extending to 1 ppm.

Particulate concentration levels are monitored primarily by physical techniques, e.g., using graphimetric and radiometric instruments.

3.4 Emission limits for wastewater/effluent

In the Federal Republic of Germany, effluent from water treatment and cooling systems is subject to discharge limitations pursuant to section 7a *Wasserhaushaltsgesetz - WHG* (Federal Water Act) and Appendix 31 of the *Rahmen-Abwasser VWV* General Administrative Framework

Regulation on Wastewater as listed in table 3.

Table 3 **- Discharge limitations for effluent from water treatment and cooling systems Closed-loop systems of:**

		Power plants	**Industrial processes**	**Other steam-generating sources**
		Random sample		
Settleable solids	mg/l	0.3	0.3	0.3
Available chlorine	mg/l	-	0.3	-
Hydrazine	mg/l	-	-	5.0
			2-hour composite sample	
Chemical oxygen demand				
(COD)	mg/l	30	40	-
Phosphorus (P_{tot})	mg/l	3	5	8
Vanadium	mg/l	-	-	3
Iron	mg/l	-	-	7

Source: *Rahmen-Abwasser VWV* (General Administrative Framework Regulation on Wastewater), Appendix 31 (Aug. 13, 1983)

To the extent that a flue-gas desulfurizing system produces wastewater, the minimum discharge requirements put forth in Appendix 47 of the General Administrative Framework Regulation on Wastewater as per section 7a Federal Water Act dating from Sept. 8, 1989, shall apply (cf. Appendix A-4).

The discharge of effluents other than those described in section 2.2 is governed by additional appendices to the General Administrative Framework Regulation as per section 7a of the Federal Water Act; its Appendix 49, for example, applies to oily wastewater.

The above requirements are in line with the stringent provisions of the German Federal Water Act, which stresses the importance of prevention and prescribes limits based on the hazard levels of the respective substances. Moreover, the *Abwasserabgabengesetz* (Wastewater Charges Act) rewards users who satisfy the requirements of section 7a, WHG (75 % lower wastewater charge) or who maintain existing facilities at least 20% below the prescribed limits (setting off the cost of investment against the past three years' wastewater charges.

For a concrete project, the type and nature of tolerable water pollution naturally depends on the size, quality and manner of utilization of the receiving water. Weak, sensitive recipient bodies must be analyzed in any case. Particularly in tropical countries, the water flow rate can

vary widely on a seasonable basis - a fact that must be given due consideration. In that connection, consideration must be given to either relocating the plant or, as discussed in section 2.2, installing a dry cooling tower. Apart from the pollution load, the tolerable thermal load on the receiving body must be critically examined for each concrete project. According to the recommendation of the German Lnder working group on water *LAWA*, the maximum temperature increase of a receiving body in a temperate climate zone should not exceed 3 K.

3.5 Noise

Depending on the local situation, the noise immission requirements for power plants can differ widely. According to the *TA-Lrm* (Technical Instructions on Noise Abatement) in the Federal Republic of Germany, the following noise immission limits (guide values) should be complied with:

	day dB (A)	night dB (A)
areas containing only nonresidential buildings areas containing primarily nonresidential buildings areas containing nonresidential and residential buildings areas containing primarily residential buildings	70 65 60 55 50 45	70 50 45 40 35 35

areas containing exclusively residential buildings		
areas containing health resorts, hospitals, nursing homes		

The concrete-case values also depend on the baseline noise-immission levels.

As a rule, power plants should be located as far as possible from residential areas. According to the North-Rhine/Westphalian spacing ordinance *Abstandserla*, a distance of 800 m or more means that the power plant can be expected to cause no impairment. In a number of German cities, power plants are situated much closer to residential areas, particularly in the case of cogenerating facilities, since the district heat produced by the power plant suffers substantial transmission losses with increasing distance to the consumer heat sinks.

The distance between a power plant and the nearest residential area depends primarily on the noise immission levels encountered at the points of interest, i.e., where the noise is measured. Noise immissions from the boiler and turbine plant can be substantially reduced by the application of noise control measures to the façade.

The delivery of fuel and process materials and the hauling away of residues (incl. the loading and unloading of trucks, railroad cars, barges, etc.) contribute substantially to the overall noise pollution levels from a power plant. For a coal-fired plant, the noise caused by the coaling system must also be allowed for. Consequently, delivery and removal activities, as well as operation of the coaling system, often have to be restricted to the daytime hours.

4. Interaction with other sectors

Power plants release certain pollutants into the air, water and soil. If a substantial number of small individual industrial furnaces with relatively poor pollution characteristics can be replaced by a single central thermal power plant, or if such a plant is able to provide process heat as well as electricity to industrial enterprises, the resultant gain in efficiency and environment-friendly technology can yield a relative improvement in the overall emission/immission situation. Within that context, cogeneration appears as a favorable option, as long as the plant can be located in an industrial zone or integrated into an industrial complex with adequately large heat demand.

Power plants require diverse operating media. The relevant interaction with other industrial sectors is particularly pronounced in the case of coal-fired power plants. The sectors of essential relevance include mining, of course, as the coal source, and the nonmetallic minerals industry as a supplier of lime products for flue-gas desulfurization. If gas is used as fuel, the power plant will interact closely with the natural gas industry, and oil-fueled plants depend on oil producers, refineries and petroleum-product storage and transport firms. Reciprocity between a thermal power station and such other sectors involves the entire system catena, e.g., from the mining of the fuel to the disposal of residues (cf. section 5). Additionally, the power plant's water consumption must be viewed in context with the public water supply system, if both are competing for the same scarce water resources.

Relations with yet other industrial sectors can be entered into in connection with the disposal of residues. Fly ash and slag, for example, can serve as aggregates in the cement industry, and a number of byproducts from flue-gas desulfurization (gypsum, stabilizate and compounds of sulfur) can be useful in the cement, plaster or chemical industry (e.g., as fertilizer), depending on their properties and degree of purity. Such connections can help reduce the exploitation of natural resources like gypsum. Fly ash and desulfurization products (gypsum, sulfite, sulfate) can also be used in the construction of roads and dams or as fillers for purposes of recultivation (backfilling of mines).

5. Summary assessment of environmental relevance

As explained in sections 2 and 3, thermal power plants have negative environmental impacts in the form of emissions extending from particulates, noxious gases (SO_x, NOx, CO, CO_2, HCl, HF, ...) and waste heat to noise pollution. Diverse measures such as appropriate siting, the use of efficient, environment-friendly technologies (cogeneration, i.e., the combined generation of heat and power) and the avoidance or reduction of noxious emissions can substantially alleviate such negative environmental consequences. Nonetheless, it is not always possible to limit the environmental consequences to an acceptable scale, particularly if inferior fuel is used, the power plant is unusually large, or the surroundings (human population, flora and fauna) are particularly sensitive.

For the purposes of an environmental impact assessment, the entire system catena - from the production and transportation of fuels and chemicals to their in-plant combustion and on to the disposal of residues and the consumption of energy produced in other areas, e.g., a user industry - must be given thorough consideration. Such a holistic approach helps identify additional burdens resulting from, say, transportation of the fuel or residues by truck, as well as reductions ascribable to such aspects as credits granted for the replacement of older, less ecologically sophisticated combustion plant.

Since the primary objective in the erection of an environmentally compatible power plant must be to reduce pollution of the environment, the siting and baseline-pollution evaluation aspects are exceedingly important. However, a conflict of goals can arise by reason of the fact that the positive effects of reduced emissions - thanks to cogeneration, for example - can be partially or entirely negated by the necessity of locating the plant in the near vicinity of an industrial complex in which the pollutant concentrations already have contributed to baseline pollution in the area in question.

Regarding the limitation of particulate, SO_X and NOx emissions by thermal power plants, various well-proven commercial-scale techniques are available. Since, for economic reasons, many countries prefer to fuel their power plants with indigenous coal characterized by high ballast and sulfur contents, special attention must be paid to reducing both of those pollutants. Depending on the local boundary conditions and in consideration of the overall situation, every attempt should be made to reduce emissions to below 150 mg/mSTP

particulates and/or 2000 mg/mSTP SO_2. Technically feasible measures for low-NOx combustion should be incorporated at the planning stage to ensure limitation of NOx emissions. Depending on the type of fuel in question, such pollution-control measures can confine NOx emissions to the 200 - 600 mg/mSTP range (excl. slag tap firing).

In general, priority should be attached to a combination of avoidance and combustion-modification measures, e.g., high efficiency, with favorable effects on CO_2 emissions. Secondary measures in the form of post-combustion flue gas clean-up, for example, should remain just what the name implies.

In assessing the environmental compatibility of a thermal power plant, proper monitoring is extremely important, since the best of all emission-control measures can only be as efficient as the attendant monitoring. One suitable approach would be to appoint one or more in-house environmental protection officers.

The following catalogue of criteria should be applied to the planning and evaluation of the environmental relevance of thermal power plants:

- **efficiency in the production and ultimate use of electricity and/or heat (subsidized rates?);**
- **substantiable necessity of the project (size of plant, interaction with other sectors);**
- **description and analysis of the project and its impacts (technical concept, choice of fuel, emission sources, control systems, safety considerations);**

– discussion of siting alternatives and determination of baseline pollution levels and the prospective overall burden at the selected location (ground-level pollution, ambient air pollution, effects on water, soil, flora, fauna, human health, physical and cultural assets);
– ascertainment of the environmental relevance of effects emanating from the anticipated overall burden, plus measures aimed at reducing relevant environmental burdens (siting, avoidance measures, pollution control by pre- and post-combustion measures).

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