LONDON PROTOCOL:
SPECIFIC GUIDELINES FOR ASSESSMENT OF *CARBON DIOXIDE STREAMS FOR DISPOSAL INTO SUB-SEABED GEOLOGICAL FORMATIONS*[1]

1 INTRODUCTION

1.1 Carbon dioxide sequestration in sub-seabed geological formations is a process consisting of separation of carbon dioxide from industrial and energy-related sources, transport to an offshore geological formation, and long-term isolation from the atmosphere[2]. This process is one option in a portfolio of mitigation actions for stabilization of atmospheric greenhouse gas concentrations with the potential for significant benefits at the local, regional and global levels over both the short and long terms. The intent of carbon dioxide sequestration in sub-seabed geological formations is to prevent release into the biosphere of substantial quantities of carbon dioxide derived from human activities. The aim is to retain the carbon dioxide streams within these geological formations permanently.

1.2 The risks associated with carbon dioxide sequestration in sub-seabed geological formations include those associated with leakage into the marine environment of the carbon dioxide and any other substances in or mobilized by the carbon dioxide stream. In general, there are different levels of concern regarding potential leakage that range from the local to the global over both the short- and long-terms. These Specific Guidelines deal with risks posed by carbon dioxide sequestration in sub-seabed geological formations over all timescales and primarily at the local and regional scale and thus focus on the potential effects on the marine environment in the proximity of the receiving formations.

1.3 For the purpose of these Guidelines, the following categories of substances are distinguished:

.1 the CO_2 stream, consisting of:

- .1 CO_2;
- .2 incidental associated substances derived from the source material and the capture and sequestration processes used:
  - .1 source- and process-derived substances; and
  - .2 added substances (i.e., substances added to the CO_2 stream to enable or improve the capture and sequestration processes); and

.2 substances mobilized as a result of the disposal of the CO_2 stream.

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1 These Specific Guidelines were adopted by the 2nd Meeting of Contracting Parties in November 2007.

2 Article 1.4.3 of the Protocol states that "the disposal or storage of wastes or other matter directly arising from, or related to the exploration, exploitation and associated offshore processing of seabed mineral resources is not covered by the provisions of this Protocol".

1.4 Annex 2 to the 1996 Protocol to the London Convention 1972, which contains the assessment of wastes or other matter that may be considered for dumping as a binding obligation to Contracting Parties, places emphasis on progressively reducing the need to use the sea for dumping of wastes. Furthermore, it recognizes that avoidance of pollution demands rigorous controls on the emission and dispersion of contaminating substances and the use of scientifically-based procedures for selecting appropriate options for waste disposal. Using Annex 2 as the basis, the "*Guidelines for the Assessment of Wastes or Other Matter that May be Considered for Dumping*"[3], as well as these Specific Guidelines were developed and are intended for use by national authorities responsible for regulating the dumping of wastes. Together they embody a mechanism to guide national authorities in evaluating applications for dumping of wastes in a manner consistent with the provisions of the London Convention 1972 or the 1996 Protocol thereto. When applying these Guidelines, uncertainties in relation to assessments of impacts on the marine environment will need to be considered and a precautionary approach applied in addressing these uncertainties.

1.5 The Guidelines should be applied with a view that acceptance of the disposal of carbon dioxide streams into sub-seabed geological formations does not remove the obligation under the 1996 Protocol to the London Convention 1972 to reduce the need for such disposal. This should be considered within the context of approaches to reducing greenhouse gas emissions and mitigating climate change.

1.6 The 1996 Protocol to the London Convention 1972 follows an approach under which dumping of wastes or other matter is prohibited except for those materials specifically listed in its Annex 1, and in the context of that Protocol, the Generic Guidelines apply to the materials listed in that Annex. When applying these Guidelines, they should not be viewed as a tool for the reconsideration of dumping of other wastes or other matter in contravention of that Annex 1.

1.7 Contracting Parties should strive at all times to enforce procedures that minimize the potential for adverse consequences for the marine environment, human health, and other legitimate uses of the sea, taking into account technological capabilities as well as economic, social and political concerns.

1.8 These Guidelines are specific to the assessment of carbon dioxide streams for disposal into sub-seabed geological formations. Adherence to the following represents neither a more restrictive nor a less restrictive regime than that of Annex 2 to the Protocol. The relations between the elements of Annex 2 and these Guidelines are as follows:

.1 Carbon Dioxide Stream Characterization (Chapter 4, Chemical and Physical Properties);

.2 Waste Prevention Audit and Consideration of Waste Management Options (Chapters 2 and 3);

.3 Action List (Chapter 5);

.4 Identify and Characterize a Sub-seabed Geological Formation and the Surrounding Environment (Chapter 6, Site Selection and Characterization);

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[3] The 19th Consultative Meeting of Contracting Parties to the London Convention 1972 adopted these Guidelines in 1997 and are referred to in this document as the "Generic Guidelines".

.5 Determine Potential Impacts and Prepare Impact Hypothesis(es) (Chapter 7, Assessment of Potential Effects);

.6 Issue Permit (Chapter 9, Permit and Permit Conditions);

.7 Implement Project and Monitor Compliance (Chapter 8, Monitoring and Risk Management);

.8 Field Monitoring and Assessment (Chapter 8, Monitoring and Risk Management); and

.9 Mitigation or Remediation Plan (Chapter 8, Monitoring and Risk Management).

1.9 Further advice on a process of risk assessment and management of carbon dioxide streams proposed for sequestration into sub-seabed geological formations is provided in the "*Risk Assessment and Management Framework for CO_2 Sequestration in Sub-seabed Geological Structures*" that was adopted under the London Protocol in 2006.

2 WASTE PREVENTION AUDIT

2.1 The initial stages in assessing alternatives to sequestration of CO_2 streams into sub-seabed geological formations should, as appropriate, include an evaluation of:

.1 amount and form of the CO_2 streams and their associated hazards; and

.2 the sources of CO_2 streams.

2.2 In general terms, if the required audit reveals that opportunities exist for waste prevention at source, an applicant is expected to formulate and implement a waste prevention strategy, in collaboration with relevant local and national agencies, which includes specific waste reduction targets and provision for further waste prevention audits to ensure that these targets are being met. Permit issuance or renewal decisions shall assure compliance with any resulting waste reduction and prevention requirements. *(Note: This paragraph is not directly pertinent to the disposal of carbon dioxide streams into sub-seabed geological formations. However, it is important to acknowledge the obligation under the 1996 Protocol to the London Convention 1972 to reduce the need for such disposal. This should be considered within the context of approaches to reducing greenhouse gas emissions and mitigating climate change.)*

3 CONSIDERATION OF WASTE MANAGEMENT OPTIONS

3.1 Carbon dioxide sequestration in sub-seabed geological formations is a management option to be considered within the context of Contracting Parties' approaches to reducing greenhouse gas emissions and mitigating climate change.

3.2 Applications for disposal of carbon dioxide streams from carbon dioxide capture processes for sequestration into sub-seabed geological formations shall demonstrate that appropriate consideration has been given to:

.1 the incidental associated substances in the carbon dioxide stream and, if necessary, options for treatment to reduce or remove those substances; and

.2 other disposal and/or sequestration options, e.g., land-based underground storage.

3.3 Annex 2 to the 1996 Protocol identifies reuse and off-site recycling as options to be considered in this context. *(Note: These options are not directly pertinent to the disposal of carbon dioxide streams into sub-seabed geological formations.)*

3.4 According to paragraph 6 of Annex 2 to the 1996 Protocol, a permit to dump wastes or other matter shall be refused if the permitting authority determines that appropriate opportunities exist to reuse, recycle, or treat the waste without undue risks to human health or the environment or disproportionate costs. As stated in paragraph 3.3 above, reuse and recycling are not directly pertinent to the disposal of CO_2 streams into sub-seabed geological formations. The practical availability of other means of disposal and/or sequestration should be considered in light of a comparative risk assessment involving both sequestration in sub-seabed geological formations and the alternatives.

4 CHEMICAL AND PHYSICAL PROPERTIES

4.1 Proper characterization of the carbon dioxide stream is essential. If the carbon dioxide stream is so poorly characterized that proper assessment cannot be made of the risks of potential impacts on human health and the environment, that carbon dioxide stream shall not be dumped.

4.2 Specific characterization of the carbon dioxide stream, including any incidental associated substances, shall take into account the chemical and physical characteristics and the potential for interaction among stream components. Such interactions could potentially affect the reactivity of the stream with the geological formation. This analysis should include as appropriate:

.1 origin, amount, form and composition;

.2 properties: physical and chemical; and

.3 toxicity, persistence, potential for bio-accumulation.

5 ACTION LIST

5.1 The Action List provides a screening mechanism for determining whether a material is considered acceptable for dumping. Each Contracting Party shall develop a national Action List to provide a mechanism for screening candidate wastes and their constituents on the basis of their potential effects on human health and the marine environment. An Action List can also be used as a trigger mechanism for further waste prevention or management considerations.

5.2 For carbon dioxide streams, this Action List will provide a screening tool to assess acceptability for disposal into sub-seabed geological formations taking into consideration the presence and magnitude of incidental associated substances derived from the source material and the capture and sequestration processes used.

5.3 Incidental associated substances could have operational implications on CO_2 transport, injection, and storage. If released, incidental associated substances could also have potential impacts on human health, safety, and the marine environment. Therefore, acceptable concentrations of incidental associated substances should be related to their potential impacts on the integrity of the storage sites and relevant transport infrastructure and the risk they may pose to human health and the marine environment.

5.4 Carbon dioxide streams must consist overwhelmingly of carbon dioxide consistent with the purpose of reducing greenhouse gas emissions. However, CO_2 streams may contain low concentrations of incidental associated substances derived from the source material and the capture and sequestration processes used. Actual types and concentrations of incidental associated substances vary depending mainly on the basic process (e.g., gasification, combustion, natural gas clean-up), source material and the type of capture, transport and injection process[4].

5.5 It should be stressed that no wastes or other matter may be added for the purpose of disposing of those wastes or other matter.

6 SITE SELECTION AND CHARACTERIZATION

6.1 Proper selection of a sub-seabed geological formation for the disposal of carbon dioxide streams is of paramount importance.[5] According to paragraph 11 of Annex 2 to the 1996 Protocol information required to select a dump-site shall include:

.1 physical, chemical and biological characteristics of the water-column and the seabed;

.2 location of amenities, values and other uses of the sea in the area under consideration;

.3 assessment of the constituent fluxes associated with dumping in relation to existing fluxes of substances in the marine environment; and

.4 economic and operational feasibility.

The requirements pertaining to the dumping of CO_2 streams differ from those applicable to the other wastes listed in Annex 1 to the 1996 Protocol because CO_2 streams are restricted to sequestration in sub-seabed geological formations. Accordingly, the following specific guidance is provided in relation to the selection of sites for the disposal of carbon dioxide streams into sub-seabed geological formations.

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4 Types and concentrations of incidental associated substances will vary on a case-by-case basis and over time as new technologies are developed and applied. For informational purposes, Sections 3.6.1.1 and 3.4.1 of the IPCC Special Report on Carbon Dioxide Capture and Storage (2005) provide currently available information regarding some impurities in CO_2 streams arising from capture processes related to fuel combustion systems including: SO_2, NO, H_2S, H_2, CO, CH_4, N_2, Ar, O_2, HCl and heavy metals. It should be noted that these substances may be different for CO_2 streams from other sources such as refineries, steel plants, etc. Substances may be added to the CO_2 streams to enable or improve the efficiency or reliability of the capture and sequestration processes, e.g., corrosion inhibitors.

5 Observations from engineered and natural analogues as well as models suggest that the fraction retained in appropriately selected and managed geological reservoirs is very likely to exceed 99% over 100 years and is likely to exceed 99% over 1,000 years. For well-selected, designed and managed geological storage sites, the vast majority of the CO_2 will gradually be immobilized by various trapping mechanisms and, in that case, could be retained for up to millions of years. Because of these mechanisms, storage could become more secure over longer time-frames. (IPCC SRCCS (2005), Summary for Policymakers, paragraph 25.) The expression "very likely" used in this statement indicates a probability between 90 – 99%, whereas the expression "likely" indicates a probability between 66 – 90%.

Characterization of the sub-seabed geological formation

6.2 Information required to select a sub-seabed geological formation shall include a geological assessment based on a characterization of the site[6]. The following are important considerations in selecting a sub-seabed geological formation for the disposal of carbon dioxide streams:

.1 water depth and injection and storage depth;

.2 storage capacity, injectivity and permeability of the geological formation;

.3 long-term storage integrity of the geological formation;

.4 the surrounding geology, including the tectonic setting;

.5 potential migration and leakage pathways over time and potential effects to the marine environment of leakage of CO_2;

.6 potential interactions of the injected carbon dioxide stream with the geological formation and the impacts on the relevant infrastructures and the surrounding geology, including potential mobilization of hazardous substances;

.7 possibilities for monitoring;

.8 mitigation and remediation possibilities; and

.9 economic and operational feasibility.

6.3 A significant amount of data will be needed to establish both the feasibility of a CO_2 injection site and also to provide evidence of the integrity of the site. Most data will be integrated into geological models that will be used to simulate and predict the performance of the site.

6.4 Capacity and injectivity of the sub-seabed geological formation are important considerations. The capacity and injectivity should be large enough compared to the total anticipated volume and injection rates in order to retain the carbon dioxide stream within the sub-seabed geological formation. The capacity of the storage site should be estimated on the basis of methodologies that are acceptable to the competent authorities.

Characterization of the marine area under consideration

6.5 Information should be given about location of amenities, values and other uses of the sea in the area under consideration, including the injection and storage site, and transport infrastructure where relevant, and the surrounding potentially affected area. This will include physical, hydrological, hydro-dynamical, chemical and biological characteristics of the water-column and the seabed.

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[6] See further Appendix 1 of the "*Risk Assessment and Management Framework for CO_2 Sequestration in Sub-seabed Geological Structures*".

6.6 Some of the important amenities, biological features and uses of the sea which may require consideration in determining the specific location of the site may include:

.1 coastal and marine areas of environmental, scientific, cultural or historical importance, such as marine protected areas or vulnerable ecosystems, e.g.,coral reefs;

.2 fishing and mariculture areas;

.3 spawning, nursery and recruitment areas;

.4 migration routes;

.5 seasonal and critical habitats;

.6 shipping lanes;

.7 military exclusion zones; and

.8 engineering uses of the seafloor, including mining, undersea cables, desalination or energy conversion sites.

Evaluation of potential exposure

6.7 An important consideration in determining the suitability of a carbon dioxide stream for disposal at a specific site is the degree to which potential leakage from the sub-seabed geological formation may result in increased exposures of organisms to substances that may cause adverse effects. Risk characterization for injection of a carbon dioxide stream into a specific sub-seabed geological formation would typically be based on site-specific considerations of the potential exposure pathways, the probabilities of leakage and associated effects of the CO_2 stream, including substances mobilized as a result of the disposal of the CO_2 stream on the marine environment.

6.8 Potential migration or leakage pathways from sub-seabed geological formations include:

.1 the injection well, other abandoned or active wells in the same geological formation;

.2 areas where permeable rock reaches the surface of the seabed (e.g., seabed outcrop);

.3 transmissive fractures of, or high-permeability zones within, the cap rock;

.4 the pore system in low-permeability cap rocks (e.g., if the capillary entry pressure at which carbon dioxide streams may enter the cap rock is exceeded) or degradation of the cap rock caused by reaction with acidified formation waters;

.5 areas where the cap rock is locally absent; and

.6 lateral migration along the storage formation (e.g., if a storage structure is overfilled beyond the spill point).

6.9 Simulation of the short- and long-term fate of stored carbon dioxide streams should be performed in order to identify potential migration and flux rates through potential leakage pathways and to assess the likelihood of leakage.

7 ASSESSMENT OF POTENTIAL EFFECTS

7.1 For the disposal of carbon dioxide streams into sub-seabed geological formations, the assessment should address risks posed by a leak from the carbon dioxide stream sequestration process. While the mechanisms resulting in risks from this process may differ from other wastes under the 1996 Protocol, the possible impacts can be identified and assessed within the framework of this Protocol. Further advice on a process of risk assessment and management of carbon dioxide streams proposed for sequestration in sub-seabed geological formations is provided in the *"Risk Assessment and Management Framework for CO_2 Sequestration in Sub-seabed Geological Structures"*, as adopted in 2006 under the 1996 Protocol.

Evaluation of potential effects

7.2 The main effects to consider in relation to a leakage of a carbon dioxide stream are those that result from the dissolution of carbon dioxide in the overlying water and sediments. The effects of carbon dioxide released to water bodies depend upon the magnitude and rate of release, the chemical buffer capacities of the water body and sediment, and transport and dispersion processes. High carbon dioxide levels and changes in marine chemistry may have profound effects on metabolism of various marine organisms. Changes of pH in sediments and seawater due to carbon dioxide leakage could lead to effects on speciation, mobility or bio-availability of metals, nutrients and other compounds. It is also important that the effects of exposure to incidental associated substances, any substances mobilized by the carbon dioxide stream and displacement of saline water by the carbon dioxide stream, are considered in the effects assessment.

7.3 The extent of adverse effects of a substance is a function of the level of exposure of organisms (including humans). Exposure, in turn, is a function, *inter alia*, of the physical, chemical and biological processes that control the transport, behaviour, fate and distribution of a substance.

7.4 The presence of natural substances and the ubiquitous occurrence of contaminants mean that there will always be some pre-existing exposures of organisms to all substances contained in any waste that might be dumped. Concerns about exposures to hazardous substances thus relate to additional exposures as a consequence of dumping. This in turn can be translated back to the increase in concentration of substances from dumping compared with the previous concentration before injection.

7.5 In the assessment for disposal, particular attention should be given, but not necessarily limited to sensitive ecosystems or species, sensitive areas and habitats (e.g., spawning, nursery or feeding areas, coral reefs), migratory species and marketable resources. There may also be potential impacts on other amenities or uses of the sea including: fishing, navigation, engineering uses, areas of special concern and value, and traditional uses of the sea.

7.6 The assessment should be comprehensive. The primary potential effects should be identified during the site selection process. The assessment for disposal should integrate information on characteristics of the carbon dioxide stream, conditions at the proposed sub-seabed geological formation, injection operations and proposed disposal techniques and specify the potential effects on human health, living resources, amenities and other legitimate uses of the sea. It should define the nature, temporal and spatial scales and duration of potential impacts based on reasonably conservative assumptions. It can be helpful to summarize these relationships in the form of a conceptual model as described in figure 2 of the "*Risk Assessment and Management Framework for CO_2 Sequestration in Sub-seabed Geological Structures*". When evaluating the spatial aspects of risk characterization, various factors are relevant to the potential area impacted, including injection volumes, the location of the CO_2 injection point and the geological characteristics of the storage reservoir and overlying structures (including potential monitoring activities).

Risk assessment

7.7 The risks of disposal should be described in terms of the likelihood of exposure, i.e., leakage of the carbon dioxide streams and associated effects on habitats, processes, species, communities and uses. The precise nature of the assessment will differ from project to project depending on disposal site characteristics and the surrounding environment. It should also take account of the capacity to intervene or mitigate in the event of leakage. This depends on the availability of relevant infrastructure at, or near to, the site to reduce the extent of exposure and concomitant effects. Emphasis should be placed on biological effects and habitat modification as well as physical and chemical change. The risks should be sufficiently described or quantified so that it is clear what variables should be assessed during monitoring.

7.8 When evaluating exposures and effects from incidental associated substances and substances mobilized as a result of the disposal of the CO_2 stream, the following factors should be considered:

.1 magnitude to which the release increases the concentration of the substance in seawater, sediments or biota in relation to existing conditions and associated effects, and

.2 the degree to which the substance can produce adverse effects on the marine environment or human health.

7.9 Given the time-scales associated with carbon dioxide sequestration in sub-seabed geological formations, it may be necessary to consider characterization of the risks at different stages of a project. The risks during injection and in the short-term may be different to the longer term risks depending upon site-specific considerations. Consideration of risks over time will be important in the design of monitoring programmes.

7.10 Paragraph 14 of Annex 2 to the 1996 Protocol requires an analysis of each waste disposal option to be considered in the light of a comparative assessment of human health risks, environmental costs, hazards, economics and exclusion of future uses. If this assessment reveals that adequate information is not available to determine the likely effects of a proposed option, then this option should not be considered further. In addition, if the interpretation of the comparative assessment shows the sequestration option to be less preferable, a permit for this option should not be given. *(Note: This paragraph will not be directly pertinent to the disposal of carbon dioxide streams into sub-seabed geological formations when there are no alternative options and then justification of such activities should be considered within the context of approaches to reduce greenhouse gas emissions and mitigating climate change.)*

Impact Hypothesis

7.11 The risk characterization should lead to the development of an "*Impact Hypothesis*". This is a concise statement of the expected consequences of disposal. It provides the basis for deciding whether to approve or reject the proposed disposal option and for defining environmental monitoring requirements. Key elements in the development and testing of the Impact Hypothesis are:

.1 characterization of the CO_2 stream;

.2 conditions at the proposed storage site(s);

.3 preventive and/or mitigating measures (with appropriate performance standards);

.4 injection rates and techniques;

.5 potential release rates and exposure pathways;

.6 the potential impacts on amenities, sensitive areas, habitat, migratory patterns, biological communities and marketability of resources and other legitimate uses of the seas, including fishing, navigation, engineering uses, areas of special concern and value, and traditional uses of the sea; and

.7 the nature, temporal and spatial scales and duration of expected impacts.

7.12 The aim of sequestration of carbon dioxide streams is to ensure their permanent containment in sub-seabed geological formations in a manner that avoids significant adverse consequences for the marine environment, human health and other legitimate uses of the sea. Qualitative and quantitative elements could be defined to test the Impact Hypothesis such that – as a whole – these are consistent with that aim.

7.13 In the case of multiple carbon dioxide sequestration projects, Impact Hypotheses should take into account the potential cumulative effects of such operations. It is also important to consider the possible interactions with other uses of the sea, either existing or planned.

7.14 Each assessment should conclude with a statement supporting a decision to issue or refuse a permit for disposal.

7.15 Monitoring programmes will need to be designed to test the Impact Hypothesis(es).

8 MONITORING AND RISK MANAGEMENT

8.1 Monitoring is used to verify that permit conditions are met and that the assumptions made during the permit review and site selection process were correct and sufficient to protect the marine environment and human health. Monitoring also allows for effective management of sequestration sites. It is essential that such monitoring programmes have clearly defined objectives which may then be used to trigger mitigation or remediation plans.

8.2 Monitoring during the injection phase of CO_2 streams should be conducted to evaluate operational aspects of the sequestration process. Aspects that should be monitored include but are not limited to:

.1 injection rates;

.2 injection and formation pressures;

.3 mechanical integrity; and

.4 properties and composition of the CO_2 streams.

Monitoring during the injection phase may contribute to significantly reducing risks both during injection and over the long-term.

8.3 The Impact Hypotheses form a basis for defining the monitoring programme and should be designed to ascertain that changes in and around the receiving environment are within those predicted. The following questions must be answered:

.1 What testable hypotheses can be derived from the Impact Hypothesis?

.2 What measurements (type, location, frequency, performance requirements) are required to test these hypotheses, and determine the levels and consequences of any deviations from the expected outcome?

.3 How should the data be managed and interpreted?

8.4 For sequestration of carbon dioxide streams in sub-seabed geological formations, baseline information is required such that changes that arise due to sequestration of carbon dioxide streams can be monitored. Suitable specifications of existing (pre-disposal) conditions in the receiving area should already be contained in the application for a permit.

8.5 Due to the potentially large area of prospective sequestration sites, there will be a need to give serious consideration to the strategic design of monitoring programmes that use modelling and direct and indirect monitoring tools in a way that makes detection of CO_2 migration and potential leaks over a large area possible[7]. Moreover, long-term monitoring of potential migration or leakage of carbon dioxide streams from sub-seabed geological formations, including substances mobilized by these streams, should be undertaken over a time-scale which will allow effective verification of predictive models (performance-based system). As confidence grows that CO_2 is not migrating from the reservoir, the frequency of monitoring can be decreased.

8.6 Site-specific monitoring programmes can be designed to track the potential migration of CO_2 and, as appropriate, other substances at sequestration sites based on the initial risk characterization and sub-surface modelling. The choice of type of monitoring tool will be dependant on the size and other characteristics of the project (e.g., type of geological formation, type of injection scheme, etc.). Monitoring programmes should reflect the need for different technologies, measurements and time-frames for monitoring at the various stages of a project. Additional monitoring may be required in the case of emergency situations such as leaks.

8.7 The monitoring programme should confirm the integrity of the sequestration site and contribute to safeguarding human health and the marine environment. Monitoring programmes

[7] A risk-based and performance-based methodology for monitoring the CO_2 retention of geological storage sites is provided in the IPCC Guidelines for National Greenhouse Gas Inventories (2006). This will be used by countries for their greenhouse gas inventories, and provides advice for monitoring of sequestration sites in sub-seabed geological formations.

should also be designed to minimize the impact of monitoring on the marine environment. The monitoring of sequestration of carbon dioxide streams may include:

.1 performance monitoring that correlates to how well the injected carbon dioxide stream is retained within the intended sub-seabed geological formation;

.2 monitoring the surrounding geological layers to detect migration of the carbon dioxide stream and the substances mobilized as a result of the disposal of the CO_2 stream, as appropriate, within and beyond the intended sub-seabed geological formation;

.3 monitoring the seafloor and overlaying water to detect leakage of the carbon dioxide stream, or substances mobilized as a result of the disposal of the CO_2 stream, into the marine environment. In this context, special attention should be given to abandoned wells and faults that intersect the sub-seabed geological formation or to any changes in the security of the cap rock during and after injection (faults, cracks, seismicity); and

.4 monitoring marine communities (benthic and water column) to detect effects of leaking carbon dioxide streams and mobilized substances on marine organisms.

8.8 The permitting authority is encouraged to take account of relevant research information in the design and modification of monitoring programmes. New and more efficient monitoring techniques and practices are likely to evolve and should be considered as monitoring programmes evolve. In any case, the (modified) monitoring programme should relate to the baseline information and the Impact Hypotheses.

8.9 Monitoring should be designed to determine whether impacts differ from those predicted over the short- and long-terms. This can be achieved through the acquisition of data that provide information on the extent of change that occurs as a result of the sequestration operation. Monitoring the seafloor and marine communities may be included, especially if it is suspected that migration of CO_2 above the formation could extend to the seafloor and in the event that the storage site is in the proximity of sensitive or endangered habitats and species. In order to determine the impacts, monitoring of the seafloor or of the marine community should take into account CO_2, the incidental associated substances, and the substances mobilized as a result of the disposal of the CO_2 stream.

8.10 The results of monitoring (or other related research) should be reviewed at regular intervals in relation to the objectives and can provide a basis to:

.1 modify the monitoring programme;

.2 implement, when necessary, the measures included in the mitigation or remediation plan;

.3 modify the operation, or close the site;

.4 update risk assessments;

.5 modify or revoke the permit; and

.6 modify the basis on which permit applications to sequester CO_2 streams in sub-seabed geological formations are assessed.

Mitigation or Remediation Plan

8.11 Although the aim of disposal of carbon dioxide streams into sub-seabed geological formations is to have no leakage, a mitigation or remediation plan should be in place to enable a rapid and effective response to leakage to the marine environment. Seismicity in the area, which could potentially lead to leakage, should be considered in these plans. The mitigation or remediation plan should consider the likelihood that carbon dioxide streams will migrate or leak as well as the types and magnitudes of potential effects of such migration or leakage over time. The requirements of the mitigation or remediation plan and the corresponding preventive and corrective measures are determined by national authorities on the basis of the potential impact of the migration or leakage on human health and the marine environment both in the short- and long-terms. If leakage poses a significant risk to the marine environment and cannot be controlled by any mitigation or remediation operation, injection should be ceased, or be modified, or the CO_2 may be transferred to a more suitable location depending upon site-specific factors.

9 PERMIT AND PERMIT CONDITIONS

9.1 A decision to issue a permit should only be made if all impact evaluations are completed and the monitoring requirements are determined. This includes an adequate site characterization, an assessment of the likelihood for migration and leakage and associated impacts, and a suitable risk management plan. The provisions of the permit shall ensure, as far as practicable, that marine environmental disturbance and detriment are minimized and the benefits maximized. This includes reporting and documentation of the characteristics of the sequestration site and injection and closure operations after injection ceases. Any permit issued shall contain data and information specifying:

.1 purpose of the permit;

.2 the types, amounts and sources of materials in the carbon dioxide stream, including incidental associated substances, to be disposed into the sub-seabed geological formation;

.3 the location of the injection facility and sub-seabed geological formation;

.4 the method of carbon dioxide stream transport; and

.5 a risk management plan that includes:

  .1 monitoring (both operational and long-term) and reporting requirements;

  .2 a mitigation or remediation plan as discussed under paragraph 8.11 above; and

  .3 a site closure plan including a description of post-closure monitoring and mitigation or remediation options.

9.2 If disposal of carbon dioxide streams into sub-seabed geological formations is the selected option, then a permit authorizing this activity must be issued in advance. It is recommended that opportunities are provided for public review and participation in the permitting process. In granting a permit, the hypothesized impact occurring within the boundaries of the dump-site, such as alterations to the physical, chemical and biological compartments of the local environment is accepted by the permitting authority. If the information provided is inadequate to determine whether a project would pose significant risks to human health or the marine environment, the permitting authority should request additional information before taking a decision on issuing a permit. If it becomes evident that a project would pose significant risks to human health or the marine environment, a permit should not be issued.

9.3 Regulators should strive at all times to enforce procedures that minimize the potential for adverse consequences for the marine environment, human health, and other legitimate uses of the sea, taking into account technological capabilities as well as economic, social and political concerns.

9.4 Permits should be reviewed at regular intervals, taking into account any changes to the composition of the CO_2 stream, results of monitoring, and the objectives of monitoring programmes. Review of monitoring results and updated risk assessments will indicate whether field programmes need to be continued, revised or terminated, and will contribute to informed decisions regarding the continuance, modification or revocation of permits. This provides an important feedback mechanism for the protection of human health, the marine environment, and other uses of the sea.

9.5 Because the aim of disposal of carbon dioxide streams into sub-seabed geological formations is to store CO_2 permanently, permits and other supporting documentation, including site location, monitoring results and mitigation or remediation plans should be archived and retained for long periods of time.

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