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Preparation of a global legally binding instrument on mercury

Releases of mercury from the oil and gas industry

Note by the secretariat

1. At its second session, held in Chiba, Japan, from 24 to 28 January 2011, the intergovernmental negotiating committee to prepare a global legally binding instrument on mercury requested the secretariat, among other things, to prepare information on releases of mercury from the oil and gas industry for consideration by the Committee at its third session.

2. In response to this request, the secretariat called for submissions of relevant information from interested Governments, relevant non-governmental organizations and industry bodies. Annex I to the present note summarizes the available information, including both submitted information and information available in the public domain. References for the information sources used in preparing the present note are provided in annex II.

3. Mercury is present as a contaminant in virtually all fossil fuels, including oil and gas. Based on the information compiled and assessed by the secretariat to prepare the present report, reported levels of mercury present in oil and gas are extremely variable, both between and within geographical areas. The studies assessed in preparing the present report note that some of this variability may result from inconsistent sampling and analytical techniques. Some variability probably also stems from differing geological structures. This, however, does not account for all variations as there can be significant differences within a single oil or gas field. In general, average mercury levels are relatively low, although some reported values have been extremely high. Recent studies have concluded that mercury emissions from the oil and gas sector in the United States of America are 5 per cent of national emissions from coal combustion in the United States and that Canadian oil and gas sector emissions account for less than 4 per cent of that country's total anthropogenic mercury emissions. The large variability in mercury content may lead to a greater need for controls in some regions in the oil and gas sector where mercury levels are high in comparison with those areas with lower mercury levels. Based on the data currently available, the volume of oil and gas produced, refined and used globally may result in significant mercury emissions and releases, even though they are significantly lower than those associated with coal combustion.

4. The production of natural gas and of feedstocks for use in manufacturing chemicals already requires mercury removal for operational reasons, including to prevent corrosion, the poisoning of catalysts and the contamination of products, and for health and safety reasons. Various control technologies for use in oil and gas processing exist and are available to reduce mercury emissions and

* UNEP(DTIE)/Hg/INC.3/1.

releases. The contribution of the recovery of mercury from this sector to the overall supply of mercury may need to be considered by the committee. According to the available information, some countries require that mercury-containing wastes be handled as hazardous wastes in an environmentally sound manner. It is not clear, however, whether this is universal. Regulatory controls on materials that are permitted to be discharged to the environment, including Government restrictions on levels of contaminants, have brought about the treatment of wastes, such as produced water resulting from the primary separation of water, gas and oil, to reduce mercury levels. Such regulatory controls have been associated with environmental benefits, including the reduction of mercury levels in sediment, water and aquatic life. Some Governments are developing, or have developed, what are known as "zero-discharge" programmes, and have also instituted increased reporting requirements and industry monitoring. This supervision may result in improved knowledge about mercury releases and an overall reduction in pollution. Control of mercury emissions may, however, lead to additional recovered mercury entering the supply chain where mercury-contaminated waste is treated to extract the mercury.

5. Based on available information, it appears that, while levels of mercury in natural gas and oil are not generally high, the volume of oil and gas produced, refined and used may result in mercury emissions and releases that account for a significant proportion of national releases of mercury. The committee may therefore wish to consider whether specific controls on mercury emissions and releases from oil and gas production, processing, distribution and use should be recommended as part of the overall activities to reduce anthropogenic emissions of mercury. In considering this issue, the committee may wish to take note of the availability of control measures suitable for use in the oil and gas sector. In addition, the requirements for environmental protection from mercury emissions and releases already implemented by some Governments may give an indication that there is access to feasible and effective control options for the sector. In considering the possible approaches to managing emissions and releases, the committee may wish to consider a full range of policy options. The latest version of the draft negotiating text, set out in document UNEP(DTIE)/Hg/INC.3/3, provides options for control measures applicable to both emissions and releases that could be applied to the oil and gas sector should the committee wish to recommend this.

Annex I

Information on emissions and releases from the oil and gas sector

Background

1. The oil and gas sector is generally considered to comprise activities relating to the exploration and extraction of oil and gas. Petroleum refining may be considered to be part of the sector or as a separate but related industry. Oil and gas are extracted from many locations worldwide, both on land and offshore. Some locations produce both oil and natural gas, while others are limited to natural gas. Oil production in 2007 was estimated at around 84 million barrels per day, with around 34 million barrels produced by members of the Organization of Petroleum Exporting Countries (OPEC) and 50 million barrels by non-OPEC countries. Natural gas production was estimated at around 3,100 billion m3 in 2008, with the largest production occurring in the Russian Federation and the United States of America.

2. In addition to oil and gas exploration, extraction and refining, some analyses also consider the combustion of oil and gas in final products as contributing to emissions from the oil and gas sector. In any case, oil and gas combustion and consumption may result in significant total emissions and releases of mercury. Oil consumption in 2007 was estimated at some 25 million barrels in North America, 17 million barrels in Asian countries not members of the Organization for Economic Cooperation and Development (OECD), 15 million barrels in European OECD member countries, 8 million barrels in Asian OECD member countries, 6 million barrels in Central and South America, 6 million barrels in the Middle East, 5 million barrels in European and Eurasian non-OECD member countries and 3 million barrels in Africa. Natural gas has been reported to meet approximately 23 per cent of global energy needs.

3. The extraction and use of fossil fuels has been identified as a significant contributor to mercury releases to the global environment. Mercury is widespread in sediments and sedimentary rocks in varying amounts; it may also be present in sealed layers, some of which contain fossil fuels, where it may be retained and increased in concentration. The mercury present in crude oil is believed to be a combination of volatile elemental mercury, both dissolved and suspended in the oil, and non-volatile species, possibly including suspended particles of mercury sulfide. This poses challenges for oil transportation and sampling. Because volatile mercury damages piping and storage containers, its presence in oil can require preventive measures in its treatment, storage and handling. Exposure to sulfur in the supply chain and refining process may be key to how volatile mercury behaves. For example, if hydrogen sulfide or other reactive species are present, they may react with mercury, producing mercury sulfide. Mercury sulfide has low volatility and low solubility in water and hydrocarbons, and therefore would be expected to remain in a solid, less damaging form.

4. In natural gas, the mercury present is almost always elemental, although trace amounts may be present as organic complexes. Mercury in natural gas poses similar problems to those experienced with oil during transport, storage and handling. Mercury emissions and releases can occur during extraction of oil or gas and during its refining, treatment, storage, transport and final use, with mercury sources including produced water resulting from the primary separation of water, gas and oil; flared gas; and venting from equipment.

5. Current understanding of the behaviour of mercury has been constrained by the fact that analytical methods and techniques for speciating mercury are limited in their sensitivity, which makes it difficult to interpret historical data.

6. The Global Mercury Assessment, published by the United Nations Environment Programme (UNEP) in November 2002, noted that although the primary contribution from fossil fuels to environmental emissions and releases of mercury was from coal combustion the combustion of other fossil fuels also contributed. The assessment reported that, in a small number of countries where the contributions of both oil and gas combustion and coal combustion had been estimated, releases and emissions from the combustion of oil and gas were between 11 and 14 per cent of the quantity of mercury releases and emissions from the combustion of coal.

7. Mercury levels in natural gas must be reduced to levels of 10 or fewer micrograms per cubic metre (µg/m3) before processing to prevent damage to heat exchangers and other equipment. This by-product or reclaimed mercury may become a source of supply to the market: while this does not directly result in releases to the environment, it may contribute to releases at a later date if the mercury is used improperly or in products that are disposed of inappropriately. In the Netherlands, in 1995,

6 tons[1] of mercury were recovered from domestic gas sludge or waste, while 85 tons were recovered from imported waste. Within the European Union, around 20–30 tons of mercury are recovered annually from natural gas.

8. The UNEP toolkit for the identification and quantification of mercury releases, which is intended to assist countries in developing inventories of mercury releases, recognizes the contribution to mercury emissions and releases to all environmental media of oil and gas extraction, refining and use. The concentration of mercury in crude oil is noted as varying from 0.010 to 30 parts per million (ppm), and examples of the use of control equipment, fuel substitution and flue gas cleaning related to the combustion of oil products as fuels are referenced. It also notes that the concentration of mercury in natural gas ranges from 0 to 300μg/m3, as reported in several studies.

9. The UNEP guide for reducing major uses and releases of mercury notes that oil extraction, refining and use can lead to significant mercury emissions and releases to air, land and water and can produce by-product mercury and mercury-containing sludge. The key factors to consider are the concentration of mercury in the fuel and the quantity of fuel burned. Where oil is burned, for example for power generation, flue gas cleaning systems with the primary aim of reducing sulfur dioxide and nitrate emissions may also reduce mercury emissions in a manner that is similar to the reduction of mercury emissions from coal-burning power stations. The guide states that, based on a comparison of mercury levels in crude oil with those in some refined products, it appears that mercury emissions during the refining process may be significant. The guide also notes that, as at the date of publication (June 2006), no specific measures were in place to deal with these emissions.

10. The guide also notes that releases of mercury to all environmental media may occur during the extraction, refining, cleaning and use of natural gas. In the case of offshore extraction, cleaning of natural gas may also occur offshore, possibly with local discharge. As a result of problems caused by the presence of mercury in natural gas, most mercury is removed from natural gas before its sale or use. The mercury may be recovered and marketed as a by-product or treated as hazardous waste. A report on global mercury supply produced for the second meeting of the Ad Hoc Open-ended Working Group on Mercury, which took place in Nairobi in 2008,2 estimates that by-product mercury from natural gas cleaning and non-ferrous metal mining currently contributes between 410 and 580 tons per year to the global mercury supply, while as much as 1,100–1,400 tons of mercury could be recoverable from these sectors, particularly if they were required to reduce atmospheric mercury emissions.

11. An emissions report prepared by UNEP for the Governing Council at its twenty-fifth session[3] estimates that emissions from oil combustion are around 10 per cent of those from coal. The concentration of mercury in crude oils is thought to vary according to the origin of the oil, with levels ranging from 0.01–30 ppm according to an estimate published in 1987 and from 0.01–0.5 ppm according to a revised estimate published in 2005.

I. Mercury releases and emissions in the oil and gas industry: geographical distribution

12. A number of Governments submitted information on mercury emissions and releases in the oil and gas industry in response to the secretariat's request. This information is available on the secretariat website.[4] Further information was obtained from searches of public literature and in submissions from industry bodies and environmental non-governmental organizations. The information is presented below: first is information relating to specific countries presented in alphabetical order by country, followed by generic information on mercury releases and emissions in the oil and gas industry. A list of the information sources used in preparing the present report is available in annex II to the present report.

Australia

13. Estimates of mercury emissions in Australia in 2006 were 101 kg from oil refining and 101 kg from oil combustion. Each of these sectors individually accounts for 0.7 per cent of total annual emissions, with coal combustion in power plants producing 2,271 kg per year, or 14.8 per cent of total emissions. The largest source mercury emissions in Australia is gold smelting, producing 7,642 kg per

1 The word "ton" refers to metric tons.

2 UNEP(DTIE)/Hg/OEWG.2/6/Add.1.

3 UNEP/GC.25/INF/26/Add.1.

4 www.unep.org/hazardoussubstances/Mercury/Negotiations/INC3/tabid/3469/Default.aspx and then click on "Submissions".

year, or 49.7 per cent of total annual mercury emissions. No information on releases to other media was provided.

Canada

14. In a report published in 2007, Environment Canada presented a comprehensive study, including careful sampling and duplicate analyses performed at multiple laboratories. It reported mercury concentrations measured in 32 types of oil to determine the average concentration of total mercury present in crude oils refined in Canada, including both Canadian and imported oil. The volume-weighted average total mercury content was around 2.6 µg mercury per kg of oil (equivalent to 2.6 parts per billion (ppb) by weight). Low levels were found in Canadian oil, with an average of 1.1 µg/kg (1.1 ppb) in oil from eastern Canada and 1.6 µg/kg (1.6 ppb) in oil from western Canada, compared with 4.5 µg/kg (4.5 ppb) in imported oil. The concentration of mercury in crude oil ranged from 0.1 to 50 µg/kg (0.1–50 ppb), levels noted to be lower than those reported in the literature. No strong correlations between mercury concentration and either sulfur content or oil density were seen in the data set covered by this study. Environment Canada estimated that the upper limit of potential mercury emissions from processing or using oil in Canada in 2002 was 197–250 kg of mercury per year, noting that that did not include releases of mercury that might occur earlier in processing, such as during extraction, handling or transport.

15. In calculating total mercury releases from natural gas in Canada, an earlier study indicated that, in 1999, 5.9 trillion cubic feet (approximately 0.17 trillion m^3) of natural gas was produced. In pipeline gas, mercury levels ranged from less than 0.02 $\mu g/m^3$ to 0.1 $\mu g/m^3$. The highest levels seen in wellhead gas were approximately 2.3 $\mu g/m^3$. If this value were used as an assumed level of mercury in all gas, with a production rate of 167 billion m^3 of gas per year, the mercury associated with natural gas production in Canada would be of the order of 217 kg. If a lower level more consistent with average detected levels were used, the value would be 13.6 kg/year.

16. Based on these two studies, it is estimated that the total releases of mercury from the oil and gas industry in Canada are between 210 and 470 kg annually.

Croatia

17. The Government of Croatia reports that 800 kg of mercury collected from releases from the oil and gas sector is stored in Molve. It is managed as a hazardous waste and will be exported as such.

European Union

18. In a report entitled “Mercury flows and safe storage of surplus mercury”, it was noted that mercury must be removed from natural gas before processing to avoid damage to equipment, including the formation of amalgams with metals in the plant, leading to corrosion as a result of the weaker nature of the amalgam. Mercury can also contaminate catalysts, rendering them ineffective, in addition to forming deposits on steel pipe walls, which may lead to the classification of the equipment as hazardous waste. Mercury removed from natural gas is generally captured and recovered as mercury-containing sludge. In the Netherlands, around 14 tons of mercury was recovered from sludge in 2002 and 18 tons in 2003. Filtration also produced around 7 tons of mercury in 2002 and 6 tons in 2003. It is estimated that gas production in the European Union may generate around 26 tons of mercury per year.

Germany

19. The Government of Germany states that natural gas from Permian deposits in northern Germany can contain mercury at levels of up to 4,500 $\mu g/m^3$. Mercury can be released or extracted during various stages in the production process. The largest amount of mercury is produced as metallic mercury comes immediately after the mixed oil and gas passes through the drilling outlet, as a result of the relaxation and cooling of the gas in the mixture. Mercury can be present in various concentrations in sludge or slurry, and can be found in activated carbon filters. Mercury is currently removed from sludges and filters in a vacuum facility. In 2009, nine tons of metallic mercury were collected from the production of natural gas in northern Germany.

Indonesia

20. Some gas reservoirs in Indonesia contain mercury, and waste-containing mercury can be produced from gas field operations. There are no mercury recovery facilities in Indonesia; producers are responsible for their own waste management. It is estimated that one gas field generates around 680 kg of elemental mercury per year, with up to 36 kg of mercury in spent catalysts, 0.12 kg in activated carbon and 0.05 kg in sludge. The elemental mercury recovered is used in laboratories and for research or treated as waste, while the spent catalysts are sent to other countries for treatment.

Mercury-containing waste is stored in special licensed facilities applying special technical guidelines that are subject to a compliance and monitoring inspection programme.

Norway

21. In offshore oil and gas extraction operations, the total quantity of mercury released to the sea is slightly less than 20 kg annually, while emissions to air have increased from around 15 kg in 2003 to just under 20 kg in 2009. The two main sources of releases to water are drilling operations and produced water. Produced water is a result of the primary separation of water, gas and oil. In older oil fields, the oil reservoirs have relatively high water contents, resulting in an increased volume of produced water. The mercury concentration is very low, however, with annual production of around 8 kg of mercury from produced water for the past decade. Levels of mercury in produced water are verified by testing twice per year. Releases from drilling operations are now less than 10kg per year. Releases were previously higher as a result of the use in drilling fluid of baryte with a high mercury content, but following its replacement by ilmenite and baryte with lower mercury levels releases of heavy metals have fallen. Emissions to air arise from gas flaring, the use of natural gas in turbines and emissions from diesel in engines. In offshore operations, flaring is permitted only for safety reasons. Offshore emissions from natural gas and diesel are determined by using emission factors.

22. There are also a number of land-based facilities within the oil and gas sector in Norway. During gas processing, mercury is removed by filtration to ensure adherence to product specifications. Mercury-containing filters are replaced as needed, and used filters are handled as hazardous waste in an environmentally sound manner. Total mercury emissions from gas terminals are between 1 and 1.5 kg annually. At oil refineries, mercury emissions are too low to be measured, and are calculated using emission factors. Releases are close to zero, as refineries control the mercury content of crude oil received, with new oil sources evaluated before use. Oil refineries can cite elevated mercury levels as a justification for not using the oil.

Republic of Korea

23. A study of mercury levels in the Republic of Korea published in 2007 investigated the amount of mercury in fuel. Levels in automotive fuel were about 0.571 µg/L in petrol, 0.185 µg/L in diesel and 1.23 µg/L in liquid petroleum gas. Emissions for each type of vehicle ranged from 0.07 to 2.5 µg/hour for petrol vehicles, 0.1 to 1.9 µg/hour for diesel vehicles and 0.7 to 6.1 µg/hour for vehicles using liquid petroleum gas. The study reported an analysis of blood mercury concentrations in humans, grouped by place of residence. No information on the individuals was provided other than their place of residence. Levels were around 4.55 µg/L in individuals living within 50 metres of heavy traffic, while concentrations were 3.84 µg/L for people living more than 300 metres from traffic points. It was noted that there was currently no specific device in automobiles to reduce mercury emissions, and that emissions might be of local concern as they were emitted at ground level where direct exposure might be an issue. No estimate of the total mercury emissions from fuel use in the Republic of Korea was calculated.

Russian Federation

24. Based on information prepared for the Arctic Council by the Russian Federal Service for Environmental, Technological and Atomic Supervision and the Danish Environmental Protection Agency, concentrations of mercury in crude oil in the Russian Federation range from 8 to 360 µg/kg. Comparable levels are seen elsewhere in the region, with the highest levels of up to 1,150 µg/kg seen in Ukraine. Average concentrations of mercury in crude oil from all countries in this geographical region were assumed to be 300 µg/kg. This assumed value may, however, represent a worst case, as it is likely to be based on high-mercury crude oil. It was proposed in the report that, to obtain a more accurate estimate, oil samples from the main Russian oil fields should be analysed.

25. For gas fields, levels range from less than 0.1 to 70 $\mu g/m^3$, with levels in condensate ranging from less than 65 up to 623 µg/kg.

26. In estimating the total mercury mobilized as a result of the extraction of oil, an average concentration level for the Russian Federation of 180 µg/kg was used, along with an estimated total annual production of 336 million tons of oil, resulting in an estimate of 61 tons of mercury annually. While it is likely that much of this mercury is removed during the first stage of separation, the quantity removed and its final fate are unknown. The estimated mercury remaining in the oil during the refinery process is around 32 tons. Produced fuels are estimated to contain around 3.4 tons of mercury. This is in comparison to estimated total mercury released to the atmosphere from coal combustion in 2002 of around 14.3 tons.

27. In natural gas, the gas condensate contains around 1.4 µg/m^3, with the gas-condensate liquid containing 270 µg/kg and the unstable gas condensate 470 µg/kg. Gas for consumers contains very low levels of mercury at around 0.05 µg/m^3. It is estimated that the quantity of gas and gas condensate produced annually may contain between 2 and 10 tons of mercury. In gas pipelines, mercury tends to condense on pipeline walls, followed often by amalgamation with the pipe material, resulting in very low mercury levels at the end of the pipes. This mercury may remain in the pipes or may be released to the environment should the pipes be opened or damaged. Flared gas is likely to emit 65 kg of mercury annually, with the use of natural gas likely to result in very low emissions of mercury.

South Africa

28. The Government of South Africa estimates that oil refineries process around 18.1 million tons of crude oil per year and emit some 160 kg of mercury. This is compared with the total mercury emissions from all industries of 20 tons, with coal-fired power plants estimated to release around 9.75 tons of that amount. Based on increases in oil consumption, it is considered that mercury emissions from crude oil could increase in the future.

Thailand

29. In a study on the fate of mercury in a natural gas processing plant in Thailand, levels of mercury in natural gas ranging from 10 to 25 µg/m3 were seen, with mercury found in the gas, condensate, produced water and sludge. During processing, around 65 per cent of the mercury partitioned to the sludge, with some of it recovered as elemental mercury. Twenty-eight per cent was found in the condensate (concentrations of 500–800 ppb), 4 per cent in the produced water (30-800 ppb) and 3 per cent in the treated natural gas. At this plant, located offshore, the sludge and produced water were treated and then disposed of by deep well injection.

30. Environmental mercury has been tested in Thailand by analysing seawater, river water and sediment, in addition to aquatic species. Oil and gas extraction, production and processing were not the only sources of mercury in the environment, with a number of industries contributing to environmental media. While no specific information on the industries was provided, the testing is seen as a useful mechanism for investigating overall environmental levels of mercury.

31. In tests performed at 100, 500 and 2,500 metres from the shore, levels were similar in 2001 (up to 90 ng/L), 2002 (up to 80 ng/L) and 2003 (up to 88 ng/L). All complied with the environmental standard of 100 ng/L. In the river water, levels varied from 0.05 to 1.5 µg/L, lower than the established standard of 2 µg/L. Sediment tests carried out in 1998 showed levels from 0.005 to 2.135 mg/kg dry weight, while in 1999 the levels were 0.003 to 0.827 mg/kg dry weight. In 1998, a small number of tested samples contained mercury at levels higher than the standard level of 1 mg/kg used in Australia and New Zealand. By 2001, tested sediments ranged from less than 0.10 to 0.35 mg/kg dry weight, with an average of 0.23 mg/kg dry weight, while in 2002 the range was from 0.21 to 4.96 mg/kg dry weight along the eastern seaboard. In other areas levels were lower, with all tested sediments containing mercury at levels lower than those found in the quality guidelines of a number of countries.

32. Mercury levels in fish ranged from less than 0.003 up to 0.063 mg/kg wet weight, below the standard prescribed by the Ministry of Public Health in Thailand of 0.5 mg/kg wet weight. Samples of shrimps and molluscs tested were also below the standard level. In offshore testing in 1995, levels exceeding the standard were found. By 1996 and 1998, however, levels had fallen to below the standard. Tissue samples taken offshore in 1998 had mercury levels ranging from 0.023 to 1.57 mg/kg wet weight, with two samples exceeding the standard. Based on these results, it was concluded that there was some risk to human health. In 2001, lower levels were found in fish tissue, with the maximum detected concentration being 0.51 mg/kg wet weight.

33. Thailand has set strong waste management goals, including a move to a zero-discharge programme, and treatment systems are in use by oil and gas operators. An extensive monitoring programme is in place to measure the effectiveness of removal technologies. It is recognized that more information on fish consumption patterns is needed to determine more accurately the acceptable mercury level in fish tissues.

34. In 1990, 1993 and 1996, testing for contamination carried out around an oil platform showed little evidence of significant contamination. The level of mercury in seawater was comparable to background levels, while in sediment there was a localized increase in concentration around the platform, reaching background levels within 500 metres. Although a slight elevation of mercury levels in fish was seen around the platforms, levels were below the Food and Agriculture Organization of the United Nations standard of 0.5 µg/g wet weight. As a waste strategy, the mercury-contaminated sludge was re-injected into depleted reservoirs, while produced water was treated to remove the mercury and other contaminants before discharge. While produced water could also be re-injected into wells along

with sludge, concerns about possible cross-contamination or seepage to the surface need to be allayed before this technique is more widely used.

United States of America

35. The United States Environmental Protection Agency assessed releases of mercury (including air, solid waste and wastewater emissions) from the production, processing and combustion of petroleum and natural gas in a report published in September 2001. The report notes that the estimates resulting from the assessment provide a rough, but preliminary, idea of the amounts that may be involved. They were based on educated estimates of mercury concentration and the most recent throughput or activity data. The report noted that the total mercury concentrations in crude oil could not be statistically treated, in part because of the uncertainties in the analytical data and also because the origin of many of the data reported in the literature was not well documented.

36. The report identifies the stages of processing at which mercury can be released. The main solid wastes are produced during drilling, although some are also generated during production and maintenance. Solid waste from oil and gas processing can be placed in a reserve pit for storage, and may be solidified before disposal. Following storage in a reserve pit, some solids can be broken up and thinly applied to soil. Regular monitoring of soil constituents is required, and once a certain level of contamination is reached, no more wastes may be applied. Some commercial facilities will accept solid waste from oil and gas processing. An increasing amount of drilling waste is reused or recycled, with treatment to remove impurities followed by reuse in the drilling of other wells. Drilling waste is also used as landfill cover, roadbed construction, dyke stabilization and the plugging and abandonment of other wells.

37. During extraction, hydrocarbon liquids, natural gas and water are separated. At the wellhead, mercury may be present in both dissolved and suspended forms, and its entry to the separated phases depends on physical, chemical and kinetic factors. Any ionic mercury should enter the water phase, while elemental and organic forms should partition to the liquid hydrocarbon fraction. The distribution of mercury included in a suspended phase will depend on the particle size and whether the suspended material is water soluble or fat soluble. Mercury attached to large particles can be removed in the water phase or retained as sludge that will be removed during cleaning. Colloidal mercury will be retained by the liquid hydrocarbons during separation. The partitioning of mercury into the gas phase is complicated as the short residence time in the separator does not allow a true equilibrium to be reached.

38. Mercury is not generally lost from fluids, such as oil, during transport. In gas production, reactions can occur with steel pipes, particularly with wet gas, resulting in corrosion with a mercury-rich layer being deposited on the pipe surface.

39. During refining, various stages may contribute to the removal of mercury from oil or gas. In the desalting phase, the oil is washed with water to remove soluble salts, which can result in the removal of suspended and ionic mercury. In the distillation process, mercury levels decrease in the higher temperature fractions of crude oil. Suspended mercury sulfide is not present in filtered crude oil. Where crude oil is not filtered, mercury sulfide is not generally present, as suspended particles of mercury sulfide tend to remain in the bottom fraction in primary distillation and with heavy oil and coke in vacuum distillation. The average mercury content of petroleum coke is around 50 ppb, and the mercury is generally present as mercury sulfide or mercury selenide. Refinery wastewater generally has a low mercury content of around 1 ppb.

40. In gas processing contaminants are removed either by cryogenic separation or by liquefaction. The former may result in the condensation of mercury. Removing mercury from the gas is essential to safe operations, as any condensed liquid mercury present in the gas could attack the aluminium heat exchangers.

41. The main routes of possible environmental contamination by mercury in the oil and gas production and processing sectors are releases to wastewater or solid waste streams or air emissions. Produced water may be discharged into the environment or re-injected. Wastewater from the production and processing of oil and gas in the United States is regulated through permit programmes to protect groundwater and surface water.

42. An estimate was made in 2004 of the amount of mercury released into the Gulf of Mexico as a result of offshore exploration and drilling of 0.8 tons per year. This was based on the maximum concentration of 1 ppm of mercury in the baryte used in the drilling fluid, along with data on baryte discharged per foot of well drilled. The 2001 Environmental Protection Agency report made rough estimates of the mercury in wastewater from oil and gas production and refining in the United States by deriving a concentration estimate from compiled published information about mercury levels in

wastewater and applying it to estimated production rates for the era around 1999.With an estimate of around 1 ppb of mercury in each of 0.5 trillion litres of water, there would be around 250 kg mercury entering the aqueous environment from oil and gas production in the United States annually. Mercury content in refinery wastewater is more problematic to estimate. Using an estimate of less than 1 ppb of mercury, with around 1.5 billion barrels produced annually, however, leads to a figure of around 250 kg of mercury in refinery wastewater annually.

43. Mercury can be emitted to air from final fuel combustion, fugitive emissions and gas flares. Gas flaring occurs when gas is co-produced with oil, and where flaring the gas is a cheaper option than collecting and transporting it. It is estimated in the 2001 Environmental Protection Agency report that gas flaring from wellheads in the United States results in mercury releases of around 7 kg annually. This does not include any mercury in flares at refineries. Fugitive gases emitted at wellheads are estimated to contribute around 10 kg to total mercury emissions annually.

44. During petroleum production, transportation and processing, mercury emissions are not likely to be more than 185 kg, assuming an average concentration of 10 ppb in the oil. While it is recognized that mercury will be present in the solid waste streams generated during refining, it is difficult to estimate its quantity.

45. There was a large variability in mercury levels in crude oils observed in a survey of studies that was included in the 2001 Environmental Protection Agency report. A further study analysing crude oil processed in the United States in 2004 from 170 sources showed an average mercury concentration of 7.3 µg/kg, with a range from below the limit of detection (0.5 µg/kg) to 600 µg/kg. It was estimated that the total mercury present in oil processed annually within the United States was less than 5 per cent of the mercury present in coal over the same period. In samples of imported oil, oil from Asia had the highest average level at 220 µg/kg. The lowest average levels of mercury, at 0.8 µg/kg, were seen in oil imported from the Middle East, while average mercury levels across oil imported from other regions (Africa, Europe, South America and North America), ranged between 1.3 and 8.7 µg/kg.

46. A 2002 Environmental Protection Agency study showed that in refined products mercury levels varied, with light distillates and fuel oils having levels of around 0.001 ppm, petrol and diesel of less than 0.005 ppm and petroleum coke of around 0.050 ppm. A mass balance model used for United States petroleum production indicated that, if the level of mercury was around 0.010 ppm, there would be approximately 8,500 kg in total crude oil and around 7,000 kg in refinery products. Estimating that around 15 per cent of refinery products (such as asphalt and lubricant oils) were not destined for combustion, around 6,000 kg of mercury would be emitted by the combustion of refinery products in 1999. Mercury in natural gas for distribution tends to be low. Values were measured at less than two detection limits: 0.02 µg/m3 and 0.2 µg/m3. Using these two limits would likely lead to around 10_100 kg of mercury emissions, based on the combustion of natural gas in 1999. The combustion of fuel oil is likely to liberate around 11 tons of mercury per year, with mercury in petrol of around 0.46 tons, mercury in distillate oil of around 0.21 tons, mercury in residual oil of around 0.16 tons and mercury in jet fuel or kerosene of around 0.10 tons. It is not clear what percentage of this mercury may be captured in flue gas.

47. In a later study of mercury uses and releases in the United States, it was estimated that in 1996 there was around 7 billion gallons of residual oil and 6.1 billion gallons of distillate oil used in the United States, divided between utility, non-utility and residential uses. The estimated mercury content in the oil was 0.004 ppm in residual oil and 0.001 ppm in distillate oil. It was estimated that air releases of mercury following combustion were approximately 0.4 tons per year for utility use, 5-7.7 tons per year for non-utility use and 2.8–3.2 tons per year for residential use. Releases to solid waste were most commonly seen in the utility sector, where air pollution controls are more common. It was estimated that there were releases of less than 0.55 tons per year in the utility sector and less than 0.13 tons per year in non-utility uses, with residential releases being negligible. Limited data were available on mercury emissions and releases in oil refining in the United States.

48. The national emissions inventory of the Environmental Protection Agency is the primary source of air emissions data for the United States. It includes emissions data supplied by state, tribal and local government environmental agencies. The Environmental Protection Agency supplements these data with data gathered during the development and implementation of its regulations and with data from the toxics release inventory and other federal agencies. The national emissions inventory is under constant review with the aim of improving data quality. The most current national mercury air emissions estimates are from 2005, and were used to prepare 2005 national air toxics assessment. Mercury emissions estimates from this inventory include less than 0.1 tons per year from the use of oil as fuel for electric power generation units and about 2 tons per year from the use of oil as a fuel for

boilers and process heaters in industrial, commercial and institutional settings. The Environmental Protection Agency is gathering new information from the industry over the next several months related to atmospheric emissions of pollutants, including mercury, from the petroleum refining industry.

Other information on mercury levels in oil and gas

49. In the North Sea in 1995, levels of 50–150 µg/m^3 were found in gas near the German/Netherlands median lines, while much lower levels of 10 µg/kg in oil and 5 µg/m^3 in gas were found in the central North Sea fields in waters belonging to the United Kingdom of Great Britain and Northern Ireland. In oil, condensate and water samples taken from fields in the northern North Sea and Irish Sea waters belonging to the United Kingdom, levels were again lower at 1 µg/kg in oil and 1 µg/ m^3 in gas. The high levels in the southern North Sea notwithstanding, mercury levels in the water around production facilities were within normal ocean levels at 0.005 µg/litre of water.

50. In an East Asian natural gas processing plant, with raw gas containing mercury at 70 µg/m^3, based on production values it was estimated that around 220 kg of mercury was extracted per year. Acid gas removal and sulfur recovery removes around 22 kg/year. In drying processes, another 3 kg/year is removed, with 45 kg/year removed in the condensate. In sales gas, there may be up to 150 kg/year present.

51. In one report, mercury values as high as 5,000 µg/m^3 were reported in natural gas in northern Germany, with much lower levels recorded in Africa and the United States. In the same report, some samples of crude oil had extremely high values (30 ppm), while most were less than 0.010 ppm. In refinery products, levels were less than 10 ppb in liquid petroleum gas, from 0.22 to 3.2 ppb in petrol, from 0.4 to 3 ppb in diesel, from 3 to 60 ppb in naphtha and up to 250 ppb in petroleum coke. This shows that the mercury levels in oil and gas are low.

52. It was proposed in another study that mercury levels in hydrocarbon reservoirs were a increasing as a result of a rise in the use of deeper and hotter reservoirs and in the processing of gas at lower temperatures. The levels of mercury were recognized as a problem, with a greater emphasis on health, safety and environmental issues. It was noted that mercury was found in various geologic environments, in particular where there was low temperature mineralization within one kilometre of the surface. In particular, rocks of volcanic, metamorphic and hydrothermal or exhaustive origin were likely to have higher mercury levels. Increased knowledge of the geologic structures generally associated with higher mercury levels make it possible today to predict mercury levels with greater accuracy than previously based on proximity to volcanic formations, the content of carbon dioxide in the reservoirs, regional trends and other considerations. This may assist in planning for well tests and establishing controls required during processing.

II. Measures to address mercury in the oil and gas sector, including control technologies and national and regional controls

53. Mercury removal processes have been developed that are effective for both wet and dry gases, with little risk of capillary condensation (or overloading of the adsorbent material by condensed liquid). The removal of mercury from near the point of extraction, such as from feed gas, may be preferable so as to minimize the chance of accidental releases. In such cases, however, the crude oil must be relatively clean or there is the risk of fouling the removal equipment with solid matter. Fixed-bed adsorbents are self-contained systems and can thus minimize the attention needed from plant operators. By recycling spent adsorbents, mercury releases to the environment can be avoided. Dedicated systems for removing mercury are more commonly seen at gas processing facilities and at facilities producing feedstocks for chemicals, there being less incentive for their installation at fuel production facilities. Available systems include mercury removal sorbent beds, which feature the coating of the substrate with reactive compounds and retention of the stable mercury compound by the sorbent bed. For gas treatment, sulfur can be effective, but for moist gas or liquids metal sulfide systems may be needed. To treat liquids containing mercury, iodide-impregnated carbon, metal sulfide on carbon or alumina, silver or hydrogenation and metal sulfide may be effective treatments, including for the effective removal of organic mercury.

54. Mercury can also be removed from natural gas streams using adsorbent units (such as HgSIV units), which are molecular sieve products containing silver on the outside surface of the molecular sieve pellet or bead. These can be used either as stand-alone units or combined with existing dryer units to obtain mercury-free dry gas. In some installed units, mercury levels can be reduced from feed gas levels of 25–50 µg/m^3 to output levels of below the limit of detection (0.01 µg/m^3).

55. Some producing countries have implemented regulatory controls on the oil and gas industry to tackle mercury emissions and releases. Many Governments restrict and regulate discharges of

mercury, requiring companies to account for mercury in all produced waste streams and in products sold commercially. Offshore discharge of produced water is restricted and may require water treatment such as filtration and chemical treatment. The use of control technologies to remove mercury from oil and gas is required in many sectors, including extraction, processing and use, to meet concerns of corrosion, poisoning of catalysts and health and safety.

56. In Norway no gas flaring or burning at production sites, other than that which is required for operational safety, is permitted without special approval. Canada reported in 2003 that the introduction of monitoring and regulation programmes had reduced emissions by 70 per cent. In some countries, facilities have been put in place to reduce gas flaring, with consequent reductions in mercury emissions, including programmes to liquefy natural gas for export, or to use the gas on-site. In Nigeria, some facilities are using gas that would otherwise have been flared or vented to operate platform equipment, to produce cement and fertilizer and to produce gas usable as fuel in cars. It has been suggested that, as these activities would otherwise have used additional fuel sources that might contain mercury, they can result in an overall reduction in mercury emissions even when additional emission controls are not in place. In some cases companies are re-injecting natural gas into wells rather than venting it. While this procedure entails additional costs, it may facilitate oil production due to an increase in pressure in the wells.

57. In both Indonesia and Thailand extensive regulatory controls are in place to minimize releases of mercury to the environment. These include inspection and compliance mechanisms to ensure that mercury levels in the environment do not exceed specified standards.

58. In the United States controls are in place on allowable uses of solid and liquid wastes from the oil and gas industry, primarily based on the level of contamination by mercury and other substances of concern and possible environmental effects.

59. A 2008 study by independent consultants presented at an industry forum recommends that mercury management in oil and gas processing facilities should be based on detailed risk assessments. The study suggests that if mercury levels are less than 5 ppb for liquids (5 $\mu g/m^3$ for gases) the risk should be considered to be low and recommends that the focus should be on monitoring total mercury to ensure that no increases occur, with an emphasis on known hot spots in the process. For mercury levels between 5 and 100 ppb in liquids, it may be necessary to determine the species of mercury present. If more than 75 per cent of the mercury present is elemental mercury, worker protection measures to avoid inhalation and dermal absorption should be applied and monitoring should be more frequent and detailed. For high-risk sources, with mercury concentrations of more than 100 ppb, detailed speciation, frequent monitoring and stringent controls are required. Environmental protection is considered more difficult in such cases.

Annex II

Information used in the preparation of the present report

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