Nuclear Power and Non-Power Applications in the Context of Climate Change

A. Introduction

Nuclear technology's potential contribution to reducing climate change risks is currently dominated in the public perception by nuclear power. The complete nuclear power chain, from resource extraction to waste disposal including reactor and facility construction, emits only 1–6 grams of carbon equivalent per kilowatt-hour (g Ceq/kWh). This is about the same as wind power and hydropower, including construction and component manufacturing. All three, together with solar power, are well below coal, oil and natural gas (60–460 g Ceq/kWh) even taking account of carbon capture and storage.

But non-power nuclear applications also have a role to play in improving climate science, better understanding potential impacts of climate change, adapting to climate change, and developing mitigation alternatives in addition to nuclear power. Relative to nuclear power, the roles of these non-power applications are less significant at present, but they offer promise of becoming more widespread. While there is essentially no mention of any individual non-power application in the Fourth Assessment Report (AR-4) of the Intergovernmental Panel on Climate Change (IPCC), published in 2007, the report deals extensively with areas in which non-power applications play an important role in developing technological solutions, such as agriculture, water resource management, and ecosystem assessment and sustainability. For example, isotopic techniques for understanding ocean dynamics and for reconstructing past climates using records stored in ice cores are hardly mentioned in the AR-4, but they are fundamental to much of the science upon which the report's conclusions are based.

This paper summarizes two important developments in 2007-2008 in international efforts to limit the risks of climate change. The first, the publication of the AR-4, concerns climate science and the shared understanding of the scientific community of climate change trends, impacts, adaptations and mitigation. The second, the thirteenth Conference of the Parties (COP 13) to the UN Framework Convention on Climate Change (UNFCCC), concerns climate policy. The summary of the AR-4 is presented according to the three working groups of the IPCC: Working Group I (WG I) addresses climate science, Working Group II (WG II) addresses impacts and adaptation, and Working Group III (WG III) addresses mitigation. Included after each of these three sections is a summary of pertinent nuclear applications and their relevance to that section.

B. The Fourth Assessment Report of the Intergovernmental Panel on Climate Change

B.1. WG I: "The Physical Science Basis"[1]

WG I's report noted that over the past few years observations and related modelling of greenhouse gases, solar activity, land surface properties and some aspects of aerosols have led to improvements in the quantitative estimates of radiative forcing (the measure of the influence various factors exert in altering the balance of incoming and outgoing energy in the Earth-atmosphere system). Carbon dioxide (CO_2) is the most important anthropogenic greenhouse gas. Its global atmospheric concentration has increased from a pre-industrial value of about 280 ppm to 379 ppm in 2005. This far exceeds the natural range over the last 650 000 years (180 to 300 ppm). Moreover, the annual increase in carbon dioxide concentration from 1995 to 2005 averaged 1.9 ppm per year, which is the highest such increase since the beginning of continuous direct atmospheric measurements.

The improved understanding of anthropogenic influences on the climate system suggests, with very high confidence, that the global average net effect of human activities since the mid 19th century is a global mean temperature increase of 0.76°C (with an uncertainty range of 0.57°C to 0.95°C). The WG I report concludes, "Warming of the climate system is unequivocal, as is now evident from observations of increases in global average air and ocean temperatures, widespread melting of snow and ice, and rising global average sea level". Over the past half century, most of the observed increase in global average temperatures is very likely due to the observed increase in anthropogenic greenhouse gas concentrations.

In the near-term future (over the next two decades), a warming of about 0.2°C per decade is projected for a range of emission scenarios presented in the Special Report on Emissions Scenarios (SRES)[2]. Due to the inertia in the climate system, a further warming of about 0.1°C per decade is expected even if the concentrations of all greenhouse gases and aerosols were stable at their 2000 levels. Over the long term, continued GHG emissions at increasing rates, as projected by most recent global energy studies such as the OECD-IEA *World Energy Outlook 2007*,[3] would cause further warming and induce increasingly larger changes in the global climate system during the 21st century and beyond. The WG I report summarizes the best estimates and likely ranges for global average surface air warming for the six main SRES emissions scenarios. At the lower end of the spectrum, for a sustainability-oriented high efficiency, low energy demand scenario, the best estimate is a 1.8°C increase in global average temperature, with an uncertainty range between 1.1°C and 2.9°C. At the other extreme, the estimated warming for a rapid economic growth pathway relying predominantly on fossil fuels is 4.0°C, with an uncertainty range between 2.4°C and 6.4°C.

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[1] IPCC 2007. Summary for Policymakers. In: Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor and H.L. Miller (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

[2] IPCC (2000). Special Report on Emission Scenarios. A Special Report of WG III of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, UK,(http://www.grida.no/climate/ipcc/emission/index.htm).

[3] IEA 2007. World Energy Outlook 2007. China and India Insights. OECD-International Energy Agency, Paris, France.

B.2. Nuclear applications relevant to "The Physical Science Basis"

Environmental radionuclides, both naturally occurring and anthropogenic, as well as stable isotopes, are used to test and verify global models of atmospheric circulation patterns, ocean circulation patterns and precipitation patterns, in addition to the hydrological cycle. They thus underlie much of the modelling of these processes that is the basis for WG I's conclusions. Paleoclimatology and the historical connections it identifies between high GHG concentrations and climate change are also an important basis for WG I's conclusions. Stable isotopes in the Earth's natural archives of marine sediments, ice cores and corals provide a critical method of determining past environmental conditions, including temperature, salinity, acidity, humidity, biodiversity and circulation. Isotopes of hydrogen, oxygen and carbon, together with other isotopes are also used to date and obtain information on paleo-environmental conditions from non-marine climatic archives such as glaciers, lake sediments, tree rings, stalactites and stalagmites and groundwater. Specifically, oxygen isotopes are used to reconstruct historical atmospheric temperatures, making them valuable tools for climate change studies and models.

The use of isotopes to understand the role of the oceans in climate change and the impact of climate change on marine ecosystems was reported in greater detail in Annex III of the Nuclear Technology Review 2007. That document described the use of radiocarbon (^{14}C), tritium (^{3}H) and other isotopes to analyze the major currents that transport and redistribute heat, carbon and nutrients throughout the oceans, and the use of carbon-13 (^{13}C), nitrogen-15 (^{15}N), phosphorus-32 (^{32}P) and other isotopes to map ocean productivity and track the transfer of CO_2 to seawater, marine biota and organic compounds. It also described the role of radio- and stable isotope analyses in paleoclimatology, the study of climate change over the Earth's entire history.

Both environmental radionuclides and stable isotopes are useful in developing and validating the General Circulation Models (GCMs) and Chemical Transport Models (CTMs) used in analyzing the build-up and circulation of GHGs in the atmosphere. GCMs simulate the mixing of the atmosphere, and CTMs predict the behaviour of chemical species in the environment. Improvement and validation of GCMs and CTMs requires the comparison of their predictions with measured data, and radionuclides are useful for this purpose as they are present in trace amounts, have a range of half-lives and chemical properties, and are produced in a variety of locations in the environment.

Radon (^{222}Rn) is an inert gas that escapes from soil into the atmosphere at ground level and has a half-life of 3.82 days, which is comparable to the lifetimes of short-lived atmospheric pollutants such as nitrogen oxides (NO_x), sulphur dioxide (SO_2), carbon monoxide (CO) and ozone (O_3), and the atmospheric residence time of water and aerosols. This time scale is also comparable to many important aspects of atmospheric dynamics, making radon a useful tracer for studying atmospheric processes at local, regional or global scales.

Useful radionuclides for testing CTMs include isotopes of lead (^{210}Pb, half-life 22.3 years) and beryllium (^{7}Be, half-life 53.2 days). ^{210}Pb is produced in the troposphere from the decay of ^{222}Rn, while ^{7}Be is produced from the action of cosmic rays in the stratosphere and upper troposphere. Both of these radionuclides attach to, and thereby mirror the behaviour of, circulating particles in the atmosphere.

Stable isotopes of oxygen, nitrogen, carbon, and heavier elements have been used in botanical and biological investigations and are increasingly considered useful in ecological studies.

Precipitation and the role of the hydrological cycle in climate change can be analyzed using stable isotopes and the methods of isotope hydrology. An important resource is the 45-year-old Global Network for Isotopes in Precipitation (GNIP), operated jointly by the IAEA and the

World Meteorological Organization (WMO) (Figure VII-1). It is a unique source of information that contributes to the predictive capacity of climatic and hydrological models as well as to the proper calibration of historical climate reconstructions on millennial and longer time scales.

B.3. WG II: "Impacts, Adaptation and Vulnerability"[4]

WG II's report describes observational evidence from all continents and most oceans that many natural systems are already being affected by regional climate changes, particularly temperature increases.

Observed changes in the hydrological cycle include increased runoff and earlier spring peak discharge in many glacier- and snow-fed rivers and the warming of lakes and rivers in many regions. Terrestrial biological systems show poleward and upward shifts in ranges in plant and animal species. Observed changes in marine and freshwater biological systems include shifts in ranges and changes in algal, plankton and fish abundance in high-latitude oceans and range changes and earlier migrations of fish in rivers.

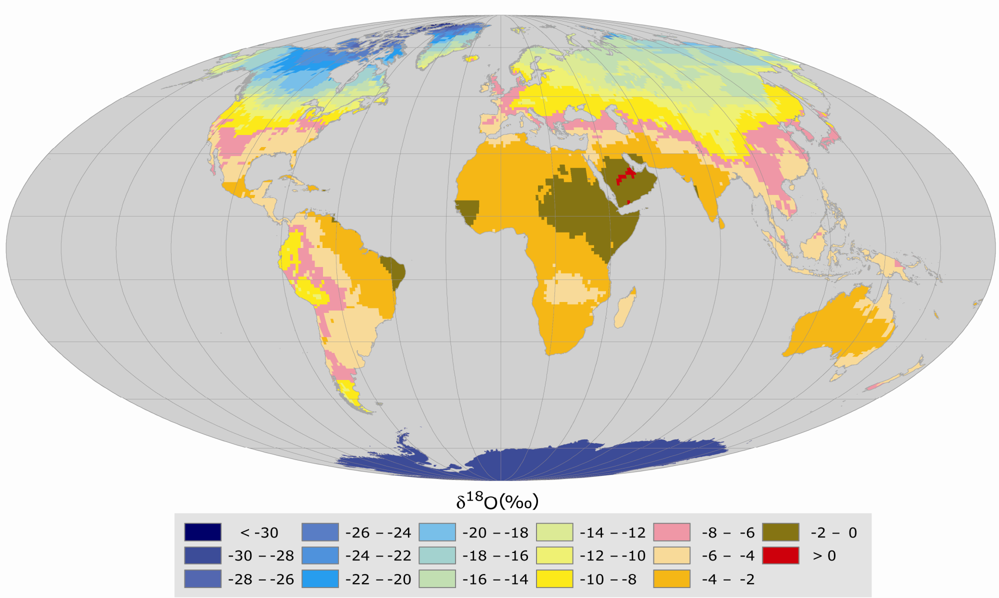

FIG. VII-1. Distribution of stable isotopes (^{18}O, ^{2}H) obtained from the IAEA/WMO Global Network of Isotopes in Precipitation (GNIP) are used for isotope hydrological studies and for validation of global and regional atmospheric circulation models.[5]

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[4] IPCC, 2007: Summary for Policymakers. In: *Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of WG II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change,* M.L. Parry, O.F. Canziani, J.P. Palutikof, P.J. van der Linden and C.E. Hanson, Eds., Cambridge University Press, Cambridge, UK, 7-22.

[5] Aggarwal, P.K., O. Alduchov, L. Araguas Araguas, S. Dogramachi, G. Katzlberger, K. Kriz, K.M. Kulkarni, T. Kurttas, B.D. Newman, A. Pucher, New capabilities for studies using isotopes in the water cycle, EOS 88 (2007) 537-538.

Looking ahead, WG II estimated the impacts of the range of future climate changes projected by WG I, based on the reference scenario of the OECD-IEA's *World Energy Outlook 2004*. By mid-century, drought-affected areas will likely increase, and heavy precipitation events are very likely to increase in frequency and increase the risk of flooding. Water supplies stored in glaciers and snow cover are projected to decline, reducing water availability in regions supplied by meltwater from major mountain ranges, which is where more than one-sixth of the world's population now lives.

Projected climate change related exposures are likely to cause increases in malnutrition and consequent disorders; increased deaths, disease and injury due to heatwaves, floods, storms, fires and droughts; more diarrhoeal disease; a greater frequency of cardio-respiratory diseases due to higher concentrations of ground-level ozone related to climate change; and changes in the spatial distribution of some infectious disease vectors.

Globally, the potential for food production is projected to increase with increases in local average temperature over a range of 1-3°C, but above this it is projected to decrease. However, in Africa, by 2020, between 75 million and 250 million people are projected to be exposed to increased water stress due to climate change, and, in some countries, agricultural production, including access to food, is projected to be severely compromised.

Increased insect outbreaks are virtually certain in view of the existing linkages between climate change, changes in pest and disease risks to plants and animals, and the related human health and food security effects. Direct effects of climate change are shifts in the distribution ranges of pests and an increase in the number of generations per year. Distribution shifts can occur as a result of natural expansions, or accidental introductions caused by increased world trade that result in the establishment of pests outside their natural distribution range. Diseases and pests posing particular risks need to be identified, their increased incidence, distribution and potential impact need to be foreseen, and suitable preventive and adaptation strategies and guidance on disease and pest surveillance and control need to be provided.

WG II's report assesses adaptation practices that have already begun as well as possibilities for the future, and it notes that adaptation will be necessary to address impacts resulting from the warming which is already unavoidable due to past emissions. The report also states that adaptation measures are seldom undertaken in response to climate change alone but can be integrated within, for example, water resource management, coastal defence and risk-reduction strategies.

B.4. Nuclear applications relevant to "Impacts, Adaptation and Vulnerability"

In some cases, nuclear applications can be used directly to develop adaptive responses to climate change impacts. But they can also be used to measure and analyze a broader range of impacts, which can also contribute more indirectly to the development of useful adaptations.

The use of isotopes to assess the impact of climate change on agricultural production was reported in greater detail in Annex I of the Nuclear Technology Review 2007. For example the Free-Air CO_2 Enrichment (FACE) approach together with isotopic techniques is valuable for investigating plant and ecosystem responses to changes in CO_2 concentration as this approach exposes plants to natural conditions with artificially elevated atmospheric CO_2 levels. The added CO_2 has concentrations of ^{13}C that are below ambient levels, which enables the amount of carbon sequestered and turnover in the soil under elevated CO_2 conditions to be quantified. Climate change also has impacts on crop water use efficiency through changes in plant transpiration and soil evaporation, and isotopic ratios of hydrogen and oxygen, together with carbon isotope discrimination techniques, are increasingly being used to investigate these dynamics.

Soil loss and erosion due to a higher frequency of extreme weather events are further expected impacts of climate change, and these effects can be assessed with a few different nuclear techniques. Erosion, for example, can be measured through the increasing use of environmental nuclide tracers, such as beryllium (^{7}Be), lead (^{210}Pb) and caesium (^{137}Cs). Sources of soil loss from agricultural catchments can be identified for the purposes of remediation using compound specific stable isotopes (CSSI) of carbon, hydrogen and nitrogen in plants, animal manure and soil samples. Information obtained through combined iso-source (IS) modeling that uses several isotopes and other sources to identify causes of soil loss can be used[6] to assess the effectiveness of different land use practices and soil conservation measures in response to changes in climate. Field studies (e.g. in New Zealand) have demonstrated the successful use of IS and CSSI to identify the contributions of various land uses (e.g. exotic pine forest, grazed pasture and native forest) to soil loss, to estimate their economic and social importance, and thus to facilitate appropriate remedial resource management practices.

Adaptation to the losses of soil and its constituents that are expected due to climate change will become increasingly important elements of land management practices under climate change scenarios. In this context, nitrogen, sulphur and carbon stable isotope ratios will be increasingly used to trace the use of land constituents and external inputs for crop productivity under different climate change scenarios and soil salinity and acidity conditions that are expected to worsen under those scenarios. Another technique, stable isotope probing (SIP), will allow the identification of soil microorganisms that can enhance the acquisition of soil nutrients for crop production, thus improving the conservation and management of land resources. Figure VII-2 shows the role of isotopic techniques in addressing food and biomass production, carbon sequestration in agro-ecosystems, bioenergy production on degraded or marginal soils, and increasing the availability and quality of water resources. A common link is the biogeochemical cycling of carbon and its coupling with the cycles of nitrogen (N), phosphorus (P), sulphur (S) and water. Interactive processes affecting coupled cycling of these elements are strongly influenced by the increasing global energy demand.

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[6] Phillips, D.; Gregg, J. W. 2003: Source portioning using stable isotopes: coping with too many sources. Oecologia 136: 261-269; Gibbs, M. 2006. Source Mapping in Mahurangi Harbour. New Zealand Auckland Regional Council Technical publication TP321.

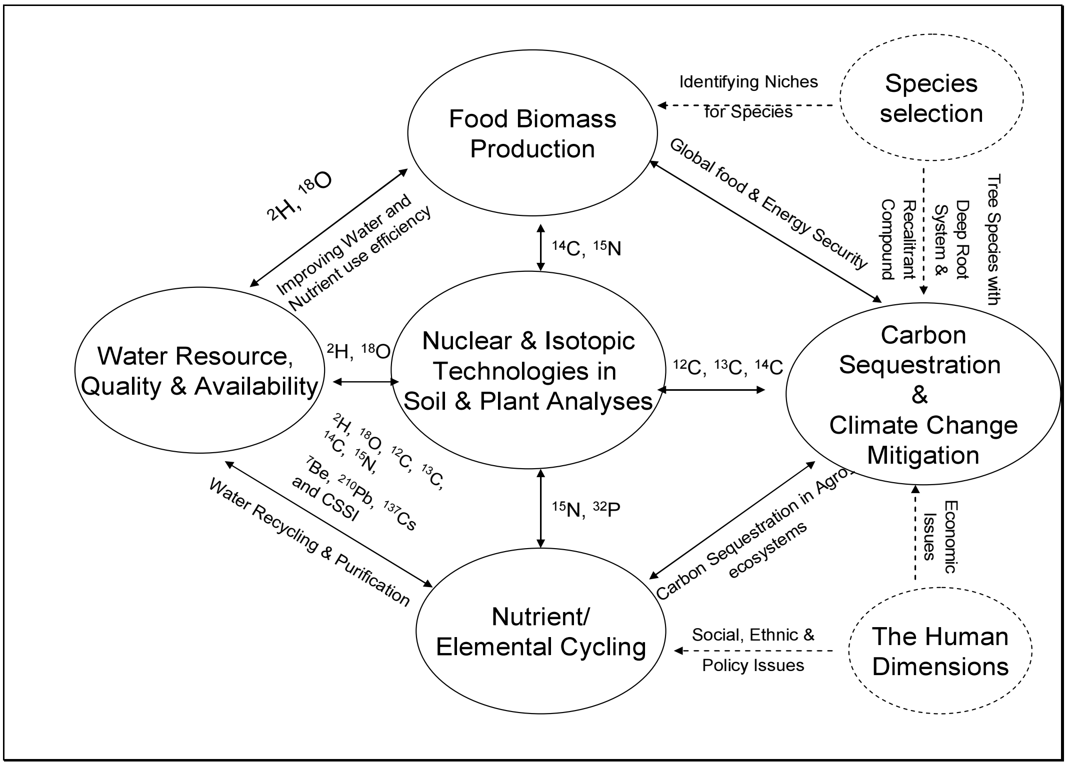

FIG. VII-2. Using isotopic techniques to address global issues of concern related to food security and climate change.

Isotope hydrology can be used to evaluate the impact of global change on the hydrological cycle, and isotope tools provide data to assess the effects that an accelerated hydrological cycle due to climate change can have on groundwater quantity and quality, and its interaction with surface water systems. Isotope techniques also can be used to collect the data and build the models needed to develop effective adaptive water management strategies. The WG II report encouraged the integration of climate change adaptations within, among other things, water resource management, which is consistent with the concept of Integrated Water Resources Management, supported by isotopic techniques, that is promoted by the Agency. The anticipated disruptive impacts of climate change on the hydrological cycle and precipitation patterns will compound the existing challenges of growing demand and stress, which will make the strategic management of water resources increasingly vital in supporting water security worldwide.

Another way in which nuclear techniques can contribute to adaptation efforts is through mutation techniques for plant breeding to develop crop varieties better suited to a changed climate. Nuclear techniques, e.g. gamma irradiation, can be used to generate varieties with genetically favourable traits, such as increased adaptability to drought and saline conditions, elevated and reduced temperatures, and biotic stresses brought about by climate change. These techniques can be combined with advanced biotechnologies such as high-throughput genomic screening applications, to enhance the efficiency of identifying useful mutants and their use in breeding new varieties.

Isotopic techniques can also be used to evaluate the efficient mobilization of different land constituents to meet the nutrient and water demands of newly developed crop varieties tolerant of harsher weather conditions and soils.

Finally, there are additional nuclear applications that can help countries to adapt to climate change. These include application techniques for the diagnosis and control of transboundary animal diseases, which may spread due to climate change. They include the Sterile Insect Technique (SIT), which may be in greater demand as insect populations expand in geographic range and new pests emerge as a consequence of climate change. As this occurs and international agricultural trade continues to grow, the application of ionizing irradiation (see the Food Irradiation Clearances Database under NUCLEUS) to control pests and food-borne microbes as a complement to SIT is likely to increase as well. More detailed information regarding these applications can be found in the main text of this report.

B.5. WG III: "Mitigation of Climate Change"[7]

As presented in the previous sections, WG I (Physical Science) of the IPCC AR-4 confirmed the increasing anthropogenic influence on the climate system due to the emission of GHGs, the bulk of which originates in burning fossil fuels. WG II presented discernible impacts of climate change, particularly in sensitive ecological systems, analysed the vulnerability of societies and ecosystems services to changing climatic conditions, identified adaptation options and their limitations and concluded that beyond certain magnitudes of climate change (for most systems and regions more than a 2°C increase in global mean temperature above the pre-industrial level) adaptation possibilities become exceedingly expensive or vanish altogether. Therefore, drastic mitigation action, i.e. a 50% reduction of global GHG emissions by 2050, is required which immensely increases the importance of low-carbon emitting energy technologies including nuclear power.

WG III (Mitigation) analyzed GHG mitigation options and costs in large world regions (OECD, Economies in Transition (EIT), and Non-OECD/EIT), across a range of economic sectors (energy supply, transport, buildings, industry, etc.), and over two time horizons: medium term (up to 2030) and long term (through 2100). Many mitigation technologies and practices that could reduce GHG emissions are already commercially available. Technical solutions and processes could reduce the energy intensity in all economic sectors and provide the same output or service with lower emissions in transport, building and industry. Fuel switching and modal shifts (from road to rail, from private to public) in the transport sector; heat recovery, material recycling and substitution in industry; improved land management and agronomic techniques and energy crop cultivation in agriculture; and fuel switching, efficiency improvements, the increased use of renewables and nuclear power as well as carbon capture and storage could result in significant GHG reductions in the energy sector. Aggregating the options for each sector, the economic mitigation potential is estimated to be between 0.7 (waste management) and 6 (the buildings sector) gigatonnes of CO_2-equivalent[8] ($GtCO_2$-eq) annually on the basis of carbon prices less than \$100/tCO_2-eq in 2030.

The assessment confirmed that, compared to other anthropogenic sources, GHG emissions from the energy supply sector have been growing at the fastest rate between 1970 and 2004. Currently, energy-related CO_2 emissions (including feedstocks) comprise by far the largest share (about 60%) of total global GHG emissions and this is likely to remain the case over the coming decades. In the absence of additional policy interventions (relative to those already in place), annual GHG emissions from energy production and use are projected to reach 34-52 $GtCO_2$ by 2030 (compared to 28.6 $GtCO_2$ in 2000).

[7] IPCC, 2007: *Climate Change 2007: Mitigation. Contribution of WG III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* [B. Metz, O.R. Davidson, P.R. Bosch, R. Dave, L.A. Meyer (eds)], Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

[8] The definition of carbon dioxide equivalent (CO_2-eq) is the amount of CO_2 emission that would cause the same radiative forcing as an emitted amount of a well mixed greenhouse gas (carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O)), perfluorocarbons PFCs, hydrofluorocarbons (HFCs) and sulphur hexafluoride (SF_6) and ozone-depleting substances (ODS: chlorofluorocarbons (CFCs), hydrochlorofluorocarbons (HCFCs), halons) or a mixture of well mixed greenhouse gases, all multiplied with their respective greenhouse warming potentials to take into account the differing times they remain in the atmosphere.

This implies, as Chapter 4 of the WG III report puts it, that "[T]he world is not on course to achieve a sustainable energy future. To reduce the resultant GHG emissions will require a transition to zero- and low-carbon technologies". Options and costs of doing so in the electricity sector are summarized below by using data from Chapter 4 of the WG III report.

The IPCC estimates the mitigation potential in terms of GHG emissions that can be avoided by 2030 by adopting various power generation technologies in excess of their shares in the baseline scenario (the reference scenario in OECD-IEA's *World Energy Outlook 2004*). The technologies include fuel switching within the fossil portfolio, nuclear, hydro, wind, bioenergy, geothermal, solar photovoltaic (PV) and concentrating solar power (CSP) as well as coal and gas with carbon capture and storage.

The IPCC analysis assumes that each technology will be implemented as much as economically and technically possible taking into account practical constraints (stock turnover, manufacturing capacity, human resource development, public acceptance, etc.). Each technology is assessed in isolation, i.e. possible interactions between deploying various technologies simultaneously are not accounted for. The estimates indicate how much more (relative to the baseline) of each technology could be deployed in major world regions at costs falling in various ranges. Mitigation costs reflect differences between the cost of the low-carbon technology and the cost of the technology it replaces.

Given the overwhelming share of fossil fuels in electricity generation, the first option is to replace existing fuels and technologies by less carbon-intensive fossil fuels and more efficient technologies, respectively. For example, replacing a conventional coal power plant with a thermal conversion efficiency of 25% by an advanced plant with 34% efficiency reduces CO_2 emissions by 27% (from 973 to 710 gCO_2/kWh). Fuel switching brings even more benefits: replacing the same conventional coal plant by a combined cycle gas turbine (CCGT) burning natural gas at 50% efficiency reduces CO_2 emissions by 58% (to 404 gCO_2/kWh).

Another possibility to reduce carbon emissions from fossil fuel combustion is carbon capture and storage (CCS). However, according to the IPCC, its "[P]enetration by 2030 is uncertain as it depends both on the carbon price and the rate of technological advances in cost and performance". The potential global emissions reductions from CCS used with coal- and gas-fired power plants are estimated at 0.49 and 0.22 $GtCO_2$-eq, respectively.

Utilizing realistically available potentials for the fuel substitution options would result in total reductions of 1.07 $GtCO_2$-eq (or 1.78 $GtCO_2$-eq together with CCS) in global GHG emissions in 2030. These are considerable yet insufficient reductions with respect to meeting the ultimate objective of the UNFCCC: "avoidance of dangerous anthropogenic interference with the climate system". Therefore, other energy sources and technologies are needed to supplement or even substitute fossil fuels.

A large number of studies estimated the life-cycle GHG emissions from a suite of power generation technologies. Figure VII-3 presents a summary.

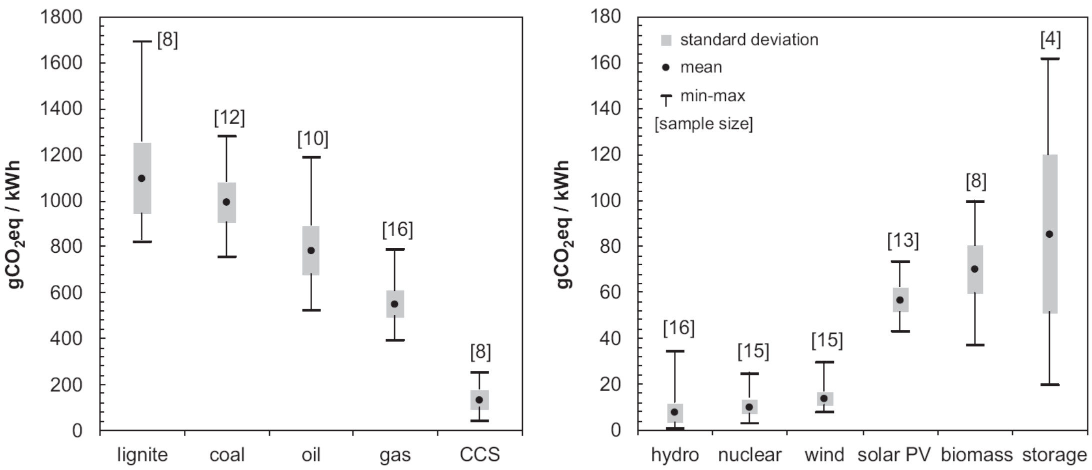

FIG. VII-3. Summary of life-cycle GHG emissions for selected power generation technologies[9].

B.6. Nuclear applications relevant to "Mitigation of Climate Change"

The principal nuclear application that can contribute to mitigating climate change is nuclear power. Figure VII-3 shows that nuclear power, together with hydro, wind and CCS technologies, is one of the lowest emitters of GHGs in terms of gCO_2-eq per unit of electricity generated on a life-cycle basis.

Of the low-carbon power generation technologies assessed by the IPCC, Figure VII-4 takes a closer look at those with a mitigation potential of more than 0.5 $GtCO_2$-eq. The figure shows the potential GHG emissions that can be avoided by 2030 by adopting the selected generation technologies. The width of each rectangle is the mitigation potential of that technology for the carbon cost range shown on the vertical axis. Each rectangle's width is shown in the small box directly above it. Thus nuclear power (the yellow rectangles) has a mitigation potential of 0.94 $GtCO_2$-eq at negative carbon costs[10] plus another 0.94 $GtCO_2$-eq for carbon costs up to \$20/tCO_2. The total for nuclear power is 1.8 $GtCO_2$-eq as shown on the horizontal axis.

The figure indicates that nuclear power represents the largest mitigation potential at the lowest average cost in the energy supply sector, essentially electricity generation. Hydropower offers the second cheapest mitigation potential but its size is the lowest among the five options considered here. The mitigation potential offered by wind energy is spread across three cost ranges, yet more than one third of it can be utilized at negative cost. Bioenergy also has a significant total mitigation potential but less than half of it could be harvested at costs below \$20/tCO_2-eq by 2030.

[9] Weisser, D. (2007) A guide to life-cycle greenhouse gas (GHG) emissions from electric supply technologies. Energy 32:1543–1559.

[10] In the IPCC report, mitigation options with net negative costs (no regrets opportunities) are defined as those options whose benefits such as reduced energy costs and reduced emissions of local/regional pollutants equal or exceed their costs to society, excluding the benefits of avoided climate change.

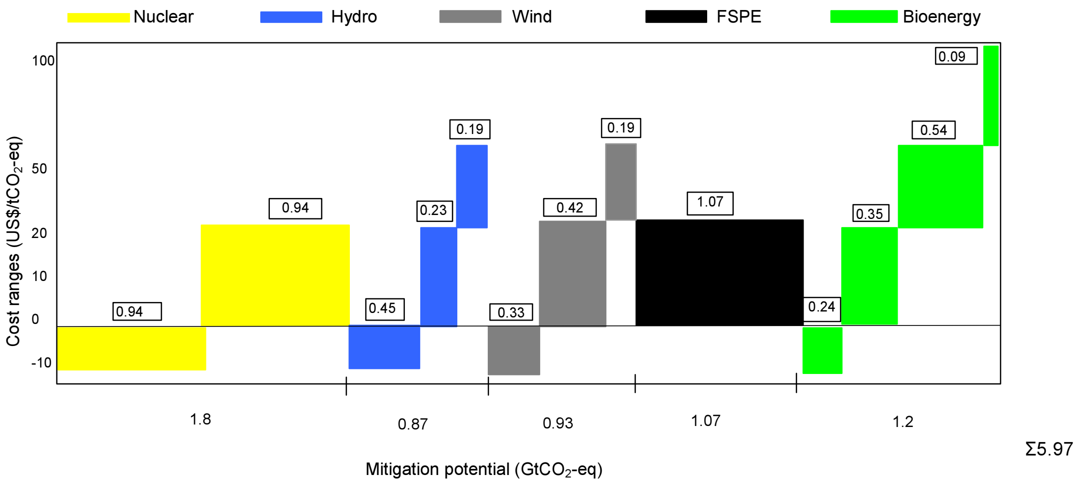

FIG. VII-4. Mitigation potential of selected electricity generation technologies in different cost ranges. (Source: based on data in Table 4.19 of the WG III report)

The mitigation potential of nuclear power is based on the assumption that it displaces fossil-based electricity generation. The mitigation volume estimated by IPCC for nuclear power reflects the contribution it could make to global climate protection by increasing its share of 16% in the global electricity mix in 2005 to 18% by 2030. This figure is consistent with the IAEA's high projection for that year.[11] The potential nuclear share in the electricity mix and the resulting additional (above baseline) power generation are presented in Figure VII-5 for the three large global regions and the world. The red bars, for which the scale increases from left to right on the top axis, show the potential percentage of nuclear power in each region's electricity mix. The blue bars, for which the scale increases from right to left on the bottom axis, show the potential generation from nuclear power in TWh/yr above the baseline scenario. The dashed portion of the bottom bar indicates that its value of 2743 TWh/yr (shown in the box) is off the scale to the left. The boxed numbers on the right show the corresponding carbon emissions avoided in each region and in the world as a whole.

Developments in the world energy markets since 2004 and more recent projections put forward by many national and international organizations suggest that the role of nuclear power over the next two decades is likely to be even more significant than suggested by the IPCC assessment. Beyond climate change concerns, the persistence of drastically higher fossil fuel prices and supply security risks has given additional impetus to (re)considering nuclear policies in many countries. The baseline scenario in the above IPCC estimates assumes a crude oil price of $25 per barrel on average for the period up to 2030. Even the high oil price scenario averaged $35 for the same period. Natural gas prices are projected to follow oil prices in each scenario. Few analysts today expect oil prices to return to the $20-30 range in the medium term. Hence the cost and supply security advantages for nuclear power are likely to remain for the next two decades.

[11] International Atomic Energy Agency (IAEA) (2007) Energy, Electricity and Nuclear Power Estimates for the Period up to 2030. IAEA, Vienna, Austria.

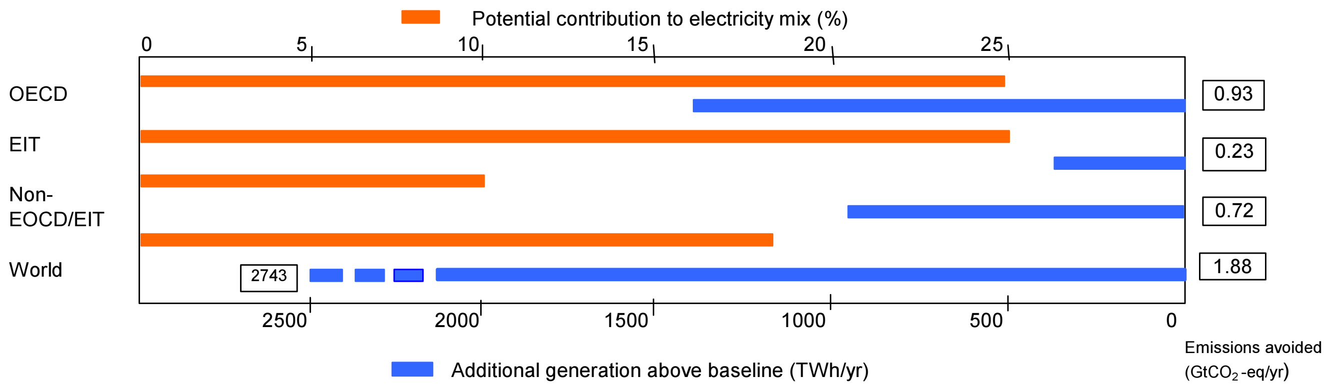

FIG. VII-5. Nuclear power shares, generation volumes and avoided GHG emissions. (Source: based on data in Table 4.11 of the AR-4 WG III report)

Non-power nuclear applications also have a role to play in another mitigation technology, carbon capture and storage (CCS), both geological CCS and agricultural CCS.

Carbon capture and storage (CCS) is one means of reducing GHG emissions, and isotope hydrology can facilitate CCS by assessing subsurface aquifers and coal beds that can be used for the storage of CO_2. Geological storage of CO_2 occurs naturally, with the Earth's subsurface already the largest terrestrial carbon reservoir (through coal and oil deposits, etc.). Deep saline aquifers in sedimentary basins can potentially be used for CCS carried out by injecting CO_2 from stationary sources through a pipeline into the rock formations. Isotopic tools can contribute by mapping and modelling CO_2 distribution, its interactions with groundwater, and possible leakages from formations in order to maintain reservoir reliability.

CCS has potential applications in agriculture as well, as carbon and nitrogen isotopic techniques are being applied to quantify the role of soils in the release of GHGs and to identify soil microorganisms that can effectively use GHGs such as methane (e.g. methane-oxidizing soil bacteria) as a principal source of carbon energy, thus reducing GHG emissions.

Nuclear technologies such as laser-ablation stable isotope ratio mass spectrometry (LA-IRMS), in combination with conventional soil micromorphology, can use ^{13}C to help develop sustainable land and resource management strategies to maximize the carbon sequestration potential of soils. Analysis of carbon isotopes can reveal carbon distributions in soil to provide a better understanding of short-term carbon storage, and also of the quality of soil carbon stocks and their decomposition-storage (sequestration). This information is significant in exploring CCS strategies as these processes are subject to changes in vegetation (e.g. from cropping to biofuel), plant cover intensity, land management practices, and climate variations under both rainfed and irrigated conditions.

In crop production, soil investigations of isotopic ratios of nitrogen and carbon can be used in combination with ^{18}O and ^{2}H concentrations to develop management practices such as irrigation scheduling and fertigation for nitrogen-fixing crops that harness atmospheric carbon and nitrogen into biomass, and hence ecosystems, for sequestration.[12] Transfer of carbon and nitrogen into productive biomass (e.g. starch, animal feed, biofuel) can also be achieved using a combination of mutation

[12] Detailed information regarding these topics and techniques can be found in Annex I of the Nuclear Technology Review 2007.

induction and efficiency enhancing biotechnologies for the development of mutant crop varieties capable of absorbing more of these GHGs.

In the production of grain crops, roughly 50% of the aboveground biomass, such as straw, either goes unused or increases CO_2 emissions through burning. This potential resource thus has a negative economic and ecological impact. The development of mutant grain crops with enhanced biomass productivity that would increase the digestibility of aboveground biomass (e.g. through decreased or modified lignin to increase bioavailability to ruminant animals of lignin harboured carbohydrates), would decrease both CO_2 (from burning and decomposition) and methane production (from husbandry).

C. Thirteenth Conference of the Parties (COP 13) to the UN Framework Convention on Climate Change (UNFCCC)

The AR-4 constitutes the IPCC's latest assessment, per its mandate, "on a comprehensive, objective, open and transparent basis [of] the latest scientific, technical and socio-economic literature produced worldwide relevant to the understanding of the risk of human-induced climate change, its observed and projected impacts and options for adaptation and mitigation". The IPCC and its reports are policy relevant without being policy prescriptive.

The Conference of the Parties to the UNFCCC, on the other hand, focuses precisely on the policy issues raised by the IPCC assessments. This section switches from a discussion of the AR-4, as the principal development in 2007 on the assessment of climate change, to a discussion of the thirteenth Conference of the Parties (COP 13) to the UNFCCC, as the principal development in 2007 in terms of climate change policy.

COP 13, in Bali, Indonesia in December 2007, marked a step forward in managing the risks related to global climate change. The fundamental issue and the centrepiece of the Conference was the design of an international binding framework to address climate change after 2012 when the Kyoto Protocol's first commitment period expires. The Kyoto Protocol, which entered into force in February 2005, requires most developed countries to limit their GHG emissions in the 'first commitment period', which started on 1 January 2008 and runs through 2012.

"Qualified success" probably is the best characterization of the outcome of COP 13. Many parties had hoped for quantitative GHG emission reduction targets by 2020 based on the findings of the IPCC AR-4 which indicate a need for a 25-40% reduction by the developed countries and peaking of global emission within 15 years as prerequisites for capping global mean temperature rise at 2°C. This ambitious 'destination' was not agreeable. Indeed several parties argued that such quantified emission limitations were premature at this stage and that the basic principles of a post-2012 climate policy architecture should be agreed on first before specifying the destination.

Instead, the Bali Action Plan (also called Bali Roadmap), which charts the way forward, was successfully negotiated at the eleventh hour. The decision frames a two-year process to finalize and adopt a post-2012 global climate agreement, including GHG emission reduction arrangements to be completed by COP 15 in 2009. At the core of the Action Plan is the recognition that "deep cuts in global emissions are required to meet the ultimate objective of the Convention", which is the avoidance of dangerous anthropogenic interference with the climate system. It was decided "to launch a comprehensive process to enable the full, effective and sustained implementation of the Convention through long-term cooperative action…" Cooperative action was further delineated to encompass (i) "measurable, reportable and verifiable nationally appropriate mitigation commitments or actions, including quantified emission limitation and reduction objectives, by all developed country Parties, while ensuring the comparability of efforts among them, taking into account differences in their national circumstances"; and (ii) "measurable, reportable and verifiable nationally appropriate mitigation actions by developing country Parties in the context of sustainable development, supported by technology and enabled by financing and capacity-building".

More specifically, (i) mitigation action and quantified emission reductions are expected for all developed countries and (ii) for the first time developing countries agreed to contribute to climate mitigation reflecting one of the UNFCCC's basic principles of "common but differentiated responsibilities and respective capabilities", i.e. taking into account social and economic conditions and other relevant factors.

COP 13 established an Ad Hoc Working Group (AWG) on Long-Term Cooperative Action to instigate the process leading to a post-2012 climate policy architecture. Technological development and transfer are important components of the COP 13 decision but the document does not contain details on specific technological options for mitigation in this context.

In addition, COP 13 adopted and approved numerous decisions encompassing a wide range of issues, including the final design of the Adaptation Fund under the Kyoto Protocol, a decision on reducing emissions from deforestation in developing countries, and outcomes on technology transfer, capacity building, the Kyoto Protocol's flexible mechanisms, the adverse effects of combating climate change, national communications, financial and administrative matters, and various methodological issues.

Nuclear power was not centre stage at COP 13. The call of one party to eliminate the current exclusion of nuclear power from the flexible mechanisms (the Clean Development Mechanism (CDM) and Joint Implementation (JI)) under the Kyoto Protocol trailed off without further debate. The architecture, the international flexibility mechanisms and the implementation rules of a yet-to-be-concluded post-Kyoto agreement will determine how important a role nuclear power will play in international climate policies (beyond that at the national level). While the work of the newly established AWG is expected to revolve around the nature of relative magnitudes of developed and developing parties' obligations, discussions on international flexibility mechanisms might surface ideas that could be favourable or unfavourable for the opportunities for nuclear power under a post-Kyoto agreement.