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The future role of nuclear power in Europe

Frequently Asked Questions (FAQ)

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The present document, "frequently asked questions" (FAQs), offers a collection of questions and answers that cover all essential aspects of the debate on the future role of nuclear power in Europe. The information is kept clear and simple and uses technical terms only where they absolutely necessary, nevertheless care has been taken to argue precise and scientific. In this way the FAQs are especially suitable for interested individuals who need a quick but accurate overview on the debate[1].

General

1. *In view of Climate Change – can we do without nuclear power?*

Yes. At the end of 2011 nuclear energy had a share of 5.6% out of the total demand for primary energy[2] (the share of nuclear generated electricity at the end of 2011 was 12.3%). The share of nuclear power is sufficiently small enough to be replaced by other forms of energy or measures, for example, efficiency measures. Efficiency measures contributed more to the growing energy need in the past decades than nuclear power and the potential of increased efficiency is not exhausted by far.[3]

2. *Can nuclear energy take the role of fossil fuels after "Peak Oil"[4]?*

No. Nuclear power cannot take the place of fossil fuels. Nuclear power is currently deployed primarily for electricity production, but fossil fuels on the other hand (especially oil) are used in a broader range of applications, most notably for transport of goods and personnel. The transport sector would have to be hydrogen/electric based – if nuclear power were to play a significant role in it. Apart from the fact that, to do so, a lot of research and development is still to be done, uranium resources are not unlimited. In a scenario where nuclear power build rates step up to supply not only the electricity which was previously based on fossil fuels, but also the energy needs of the transport sector, the uranium resources would be depleted within a decade[5].

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1 The FAQs are based on FAQs in Kromp-Kolb et al. (2007): "Nuclear Power, Climate Policy and Sustainability".

2 Primary energy is an energy form found in nature before conversion or transformation into other forms of energy, e.g. crude oil, natural uranium, energy stored in falling or flowing water, energy stored in wind, etc.

3 How this can be done has been outlined in the "Global Energy Assessment" (GEA) report from 2012, by IIASA -International Institute for Applied System Analysis, in its Efficiency Energy Pathway.

4 "Peak Oil" indicates the time when the global oil production rate begins to irrevocably sink, and oil prices rise due to scarcity.

5 In "Nuclear Energy Outlook", NEA No. 6348, 2008, the Nuclear Energy Agency of the Organization for Economic Co-operation and Development estimates that the uranium resources identified in 2007, accessible at a cost of less than USD 130/kgU, would be depleted by 2050, if nuclear power at that time were to provide 22% of the electricity needed in 2050 (the OECD/NEA "high" scenario). Fast breeders would have to be deployed in such a scenario. But there is almost no commercial experience with breeder and burner based nuclear power, and development still has to be done (see FAQ No 22).

3. *Is not nuclear power – clean and CO_2-free – the only sustainable solution to the energy dilemma?*

No. Nuclear power is neither sustainable nor CO_2-free. In order to meet the criteria for sustainability, a technology must be environmentally and (macro-) economically sound, socially acceptable, within human grasp (e.g. all potential technical, social and ecological consequences can be comprehensibly assessed), flexible and tolerant of errors. The technology must also support the development of sustainability. Nuclear power does not satisfy any of these criteria. Considering the complete fuel cycle, from uranium mining to final repositories, nuclear power is certainly not CO_2-free, although it produces less CO_2 than fossil fuel plants. Sovacool in 2008 estimated a mean value of 66 grams of CO_2 per kWh (with a range from 1.4 to 288 grams) for Pressurized Water Reactors (PWR) and Boiling Water Reactors (BWR), stemming mainly from mining and enrichment[6].

Energy Situation

4. *What is the current globally installed nuclear power plant capacity?*

Nuclear power plants produced 16% of the world's total electricity in 1996 but there has been a slow but steady decline since then, reaching 12.3% or roughly 2,500 TWh (2,500 Billion kWh) by end of 2011. A total of 435 units have then been in operation, with a total installed electrical generating capacity of 369 GWe[7] (including 55 nuclear power plants from Japan, where a decision if Japan will restart its nuclear power program is still pending).

5. *Will nuclear powers contribution to electricity generation increase in the future?*

As Niels Bohr said, "It is tough to make predictions, especially about the future." Nevertheless institutions like the International Atomic Energy Agency (IAEA), the International Energy Agency (IEA), the Nuclear Energy Agency of the Organization for Economic Co-operation and Development (OECD/NEA) publishes periodically projections on the nuclear build rates, and the share of nuclear generated electricity to total electricity production. The IAEA publishes on a yearly basis "Energy, Electricity and Nuclear Power Estimates for the Period up to 2050". In its 2012 edition, based on a country by country evaluation of plausible new nuclear power plant constructions, lifetime extensions, shutdowns, economic growth, etc, two scenarios were published. In a "low" scenario a slight increase in nuclear produced electricity in absolute numbers is predicted. However, the share of nuclear produced electricity as part of the total electricity production is predicted to decline. The

[6] Benjamin K. Sovacool, "Valuing the greenhouse gas emissions from nuclear power: A critical survey", Energy Policy 36 (2008) p. 2940– 2953

7 Numbers from "Energy, Electricity and Nuclear Power Estimates for the Period up to 2050", IAEA Reference Data Series, 2012 Edition

"high" scenario predicts a constant share[8].

The International Institute for Applied System Analysis (IIASA) in its "Global Energy Assessment" (GEA) from 2012 chose a different way for their projections: instead of assuming that current and confirmed new policies, with minor modifications and uncertainties, would be continued until 2050, they recognize that, "to achieve sustainable development all the needed attributes of energy services, that is availability, affordability, access, security, health, climate and environmental protection, must be met concurrently."[9]. To achieve this goal, the energy system must be changed dramatically, and possible "energy pathways" that could lead the world to a sustainable future are lined out. Interestingly, the GEA-efficiency "energy pathway" proposes a phase-out of nuclear power by 2050.

6. What changes are projected in electricity production between now and 2035?

According to the International Energy Agency (IEA) World Energy Outlook 2012 the total electricity generation in 2010 was 21,400 TWh. The "New Policy Scenario" of the outlook projects that electricity production worldwide will increase to more than 36,000 TWh by 2035 (an annual growth rate from 2010-2035 of 2.3%), with almost half of the increase expected to come from India and the People's Republic of China. Over the projection period, the shares of natural gas and non-hydro renewables are expected to increase. One-third of the capacity additions are projected to be required simply to replace retiring plants, and the remaining two-thirds represents growth in electricity demand expected between now and 2035.

7. How are renewables expected to expand between now and 2035 as a percentage of total electricity generation?

The International Energy Agency (IEA) projects in its 2012 edition of the "World Energy Outlook" (according to the so called "new policy scenario") that the percentage contribution of renewables to total electricity generation will increase from the current 20% level to 31% by 2035. The "new policy scenario" assumes that current policy measures, together with policies not enacted yet, but likely to be enacted, will continue to be active until 2035. The International Institute for Applied System Analysis (IIASA) in its "Global Energy Assessment" (GEA) from 2012 takes a different approach - it assumes in its scenario that actions necessary to reach the so called "two degree target"[10] are taken

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8 In the "low" scenario the yearly produced electricity was estimated to rise from 2518 TWh in 2011, to 3594 TWh in 2030, and to 3780 TWh in 2050. The share of nuclear in this scenario would decrease – from 12.3% in 2011, to 10.4% in 2030 and 5.0% in 2050. The "high" scenario predicts roughly a constant share (in 2011 12.3%, in 2030 13.6%, and in 2050 12.2%)

9 IIASA/GEA Council: Global Energy Assessment. Toward a Sustainable Future, Cambridge University Press, Cambridge UK and New York, USA, 2012.

10 The "two degree target" is a climate goal, aiming to keep the global mean temperature rise below 2°C relative to pre-industrial levels (an increase of 2 degree mean temperature is the upper limit for most

- these are more ambitious in the electricity sector, aiming for a share of renewable of 74% of total generation by 2050. The European Union is committed to the so called 20-20-20 target, which means that by 2020, a 20% reduction in EU greenhouse gas emissions from 1990 levels should be reached, the share of EU energy consumption produced from renewable resources should be increased to 20%, and EU's energy efficiency should be improved by 20%.

8. *What is the role of energy efficiency in all of these projections?*

Energy efficiency is of paramount importance in all energy scenarios. The International Energy Agency (IEA) projects that global energy intensity is expected to decrease by 1.8% per year between now and 2035, as compared to a decrease of only 0.5% per year over the past decade. Much of the economic potential of energy efficiency (80% in the buildings sector and more than 50% in industry) remains untapped, mostly due to non-technical barriers. Thus, significant potential remains in reducing energy consumption by improving efficiency. Scenarios that try to reach climate goals instead of projecting current trends, like the IIASA Scenarios, have more ambitious goals.

9. *Could nuclear power plants play a greater role in future electricity generation ?*

Probably not. If nuclear power were to play a greater role in future electricity generation (for more than 60 years) one of two conditions has to be met. The availability of the fissionable uranium isotope U-235 is limited, and therefore with current fission reactor technologies nuclear energy usage will be quite limited. So either one moves to fast reactors and breeders, which use plutonium as fuel (a "breeder-reactor" can breed more plutonium from the abundant isotope uranium238 than used as fuel), or nuclear power plant designs have to be altered to use thorium-232 to breed uranium-233 to be used as fuel.

Each possibility would have to overcome major technical obstacles. Plutonium-239 fuelled breeder reactors have historically performed very poorly. Except from India and China there are no large breeder reactor research programs underway or foreseen for the next several decades and commercial application cannot be expected until after 2060.

India seems to have the most active program in thorium breeder technology as it has only 1-2% of the world's uranium reserves, but an estimated 30% of the world's thorium reserves. But even India does not foresee operating large-scale thorium based reactors until after 2050.

Summarizing, a large-scale long term deployment of nuclear power for electricity generation seems unlikely, since the limited resources of uranium would make a shift to breeder technologies necessary, where many technical problems still have to be solved.

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ecosystems to adapt). To reach this goal atmospheric GHG concentrations must stabilize below 450 ppm . If one projects current trends into the future, the 2°C target will not be reached – which means, more radical changes in policy are needed.

Nuclear power Build Rates

10. Is nuclear power in a new phase of expansion, like in the 1970s and 1980s?

The 1970s/1980s saw a strong expansion of nuclear power, with an average of 19 new nuclear power plants (NPPs) a year. The main contributors for that development were Europe and North America. After the "Three Mile Island" and Chernobyl accident the nuclear expansion came to a halt, with roughly 5 new plants a year during the period 1990-2010. The main driver in this period was Asia, with some contribution by Europe and Russia. Starting about 2005 the discussion of a nuclear "Renaissance" began. But now, after the Fukushima Daiichi nuclear accident in March 2011 countries strategies differ significantly among countries.

In the European Union countries which decided to reduce their nuclear programs or phase out are expected to outweigh countries that are committed to expand, leading to an overall decrease in installed capacity. Asia is likely to see a growth in nuclear capacity by the year 2020, which is mainly driven by China. In Russia and other countries from the former Soviet Union an expansion of nuclear power is likely to be observed. In North America only few new NPPs are expected to be operational by 2020.

Summarizing, an expansion of nuclear power can be observed on a global level, but the expansion will by far not be as strong as in the 1970s 1980s, and will not take place in the European Union, the USA or Canada.

11. How much new nuclear generating capacity is projected to be constructed between now and 2030?

According to IAEA 2012 "Energy, Electricity and Nuclear Power Estimates for the Period up to 2050" by the end of 2011 the total installed nuclear power plant generating capacity world-wide was 369 GWe. The projections of future nuclear generating capacity are 421-508 GWe (low and high estimates) of nuclear capacity in 2020; 456-740 GWe in 2030; and 469-1137 GWe in 2050. These estimates take into account plant retirements at the end of their operating lifetimes. The IAEA projections for the nuclear power generating capacity in 2030 (both low and high scenario) were 10% higher before the 2011 Fukushima Daiichi nuclear accidents. However, even the IAEA low scenario always tended to be overly optimistic in the past. Taking into account only plans for future new builds, life time extensions and permanent shutdowns worldwide which have been announced to the public, one arrives at 410 GWe in 2020 (close to the IAEA low projection) and at less than 400 GWe in 2030.

12. Has the number of nuclear power plants in operation increased in 2012?

No. Only two new nuclear power plants were connected to the electrical grids and two units were restarted after long shutdowns. There were two permanent shutdowns in preparation for decommissioning and two planned units were cancelled. A total of 64 nuclear power plants world-wide were reported to be under construction at the end of 2012 with a total generating capacity of 62 GWe. Construction on three new units was started. Following the Fukushima Daiichi nuclear power plant accidents in March 2011, all 55 nuclear power plant units in Japan, after they were shut down for their scheduled refueling and annual inspections, were not operating for a longer period of time, and – with the exception of a few – have not been restarted again. It still remains to be seen if Japan returns to its previous policy on nuclear power.

13. Can the nuclear option be scaled up at will?

No. Current constraints on industrial capacities and human resources for the construction of nuclear plants make rapid up scaling on a large scale problematic and dependent on political decisions for medium to long term investment in the nuclear option.

Contribution to Climate Policy

14. How are greenhouse gas emissions (GHG) expected to change between now and 2035?

The International Energy Agency (IEA) estimates in its World Energy Outlook 2012 that CO_2 emissions from fossil fuels combustion in 2011 reached a record high of 31.2 gigatons (Gt), an increase of 1 Gt, or 3.2%, compared with 2010. Fossil fuels combustion accounts for roughly 60% of the total anthropogenic GHG emissions (other emissions stem from deforestation, agriculture, fugitive emissions, etc) of roughly 50 Gt CO_2 eq. per year. The power sector in 2010, i.e. the sector associated with the production of electricity and heat, accounted for 12.5 Gt of CO_2 eq. emissions (25% of total emissions, 42% of energy related emissions).

The emissions are linked to the concentration of CO_2 in the atmosphere which is believed to be related to the global mean temperature. A concentration above 450ppm CO_2 in the atmosphere relates to an increase of more than 2°C relative to pre-industrial levels. Two degrees have been singled out as a critical limit for most ecosystems to adapt to temperature increase. That is why many countries, especially the European Union (EU) countries, committed to the “two degree target”, a climate goal, aiming to keep the global mean temperature rise below 2°C.

However, if one projects current trends (considering also policy changes which are already foreseeable today), into the future, the 2°C target will not be reached – which means, more radical changes in policy are needed. By 2035, the contribution of energy related CO_2 emissions are expected to increase to 37.0 Gt per year, which is believed to correspond to a global atmospheric temperature increase of 3.6°C by the end of this century.

15. Is not nuclear the best and cheapest way to reduce CO_2 emissions?

No. The IIASA Global Energy Assessment 2012 sees restrictions on the possible use of nuclear power to achieve climate goals. While in principle nuclear power can potentially contribute to climate stabilization, its use is controversial because of "the unresolved problem of long-term waste disposal, the risk of catastrophic accidents and the associated liabilities, and the possible proliferation of weapons-grade fissile material" ... and further … "an additional concern at present is the imbalance of R&D portfolios in favor of nuclear energy, leading to a diversion of government resources from other important options. Compared with actual nuclear generation capacity, R&D spending is among the highest levels of government support across all supply-side options"[11]. If one compares the costs for saving CO_2 emissions for the various options nuclear power cannot compete with energy efficiency. Energy efficiency measures not only allow to save CO_2 emissions, they also save energy – which means, that the cost of saving CO_2 emissions is negative (one gains money by saving CO_2). No option on the supply side can compete with that, especially not nuclear.

16. Can the development of nuclear power be rapid enough to meet the needs of climate policy and substitute fossil fuels?

No. The expertise and work force needed for such nuclear build up rates could not be made available in time. Even now there is a shortage of trained personnel in several countries. The nuclear power plants that are under construction will not be able to fully compensate current fossil energy sources. A considerable growth of nuclear electricity generation would enable nuclear power to just maintain its current percentage from total electricity generation – in the last decade this percentage has been slowly and steadily falling from 16% to 12.3%, and may decrease even further in the coming two decades.

17. Can the climate goals be achieved without expansion of nuclear power?

Yes. One of the commonly adopted climate goals is the so called "two degree target", which means that the overall greenhouse gas emissions, from the beginning of the industrial era up to a CO_2-neutral economy that must be achieved in the future should not surpass a certain limit (the limit is set such that the concentration of CO_2 in the atmosphere stays below 450 ppm). In this way the global mean temperature rise stays below 2°C, which have been singled out as a critical limit for most ecosystems to adapt. The IIASA Global Energy Assessment 2012, which draws an energy pathway

11 IIASA Global Energy Assessment 2012

that would be compatible with the 2°C up to 2050 considers nuclear power to be phased out. The stabilization of global temperature at +2°C can be achieved without nuclear energy, either by sequestration[12] of a significant amount of CO_2 or by reduction in growth rate of energy demand. Life style changes and a change in the political and economical framework can also contribute achieving the climate goals.

Uranium supply as nuclear fuel

18. Can current uranium production meet current demand at operating nuclear power plants?

No. Global annual uranium production is lagging behind demand since 1990 (in 2011, the production of 54,600 tonnes was by 20% lower than the demand of 68,000 tonnes).

19. Are uranium supply bottlenecks expected over the next two decades until 2030?

That could happen. For a while the gap between uranium demand and production has been closed in the past by excess production in the time before 1990, but these stocks are almost exhausted today. Currently, the difference between demand and production can only be made up by so-called "secondary resources" (dilution of highly enriched uranium from military origin to low enriched reactor fuel, re-enrichment of uranium tails, re-use of uranium from reprocessing, and uranium savings by plutonium use in mixed oxide fuel (MOX) fuel). Only the contribution of the first mentioned secondary resource is more than marginal today, but the US-Russian contract from 1992 on the down-blending of Russian weapon-grade uranium is running out in 2013. Furthermore, the expansion of primary uranium production is at present behind the big mining companies' planning. Thus, supply could become problematic in the nearer future. Realistic uranium production scenarios for the time period until 2030 have been provided and show that supply gaps could occur in the second half of the next decade even in a steady state nuclear energy scenario. Supply gaps are probable for nuclear expansion scenarios, in particular for IAEA 2012 high case[13], OECD/NEA 2008 high case[14] and World Nuclear Association (WNA) massive expansion estimates (low and high case)[15].

20. At the current rate of uranium demand, how long will known and reasonably foreseeable uranium resources last?

The International Atomic Energy Agency (IAEA) and the OECD's Nuclear Energy Agency (NEA) predict that at the current rate of demand, uranium resources will last for more than 100 years. However, that is only a theoretical statement. Actually, it would be better to take only "proven and probable

12 Binding or depositing CO_2 in reservoirs rather than emitting it into the atmosphere is called sequestration
13 IAEA 2012 "Energy, Electricity and Nuclear Power Estimates for the Period up to 2050"
14 OECD/NEA Nuclear Energy Outlook 2008
15 World Nuclear Association (WNA) 2013, „Nuclear Century Outlook Data", Webpage snapshot

reserves" for the prediction of such a figure. Reliable global figures on that reserve classification are not available, but one can estimate around 1.4 million tonnes of such uranium, leading to a figure of roughly two decades (by continuing the current annual demand of almost 70,000 tonnes). Of course, more uranium might be mineable beyond that amount. But the future availability cannot be predicted with certainty and depends on a number of factors leading to an increased uncertainty over time. Under these factors are the increases of mining costs while the uranium grade (uranium content in mineable ore) is decreasing. There is no doubt that uranium mining will become more cumbersome and expensive over time, thus probably having an impact on nuclear energy usage. Also, at some point in the future, the "CO_2-neutral" energy production will become questionable due to the increasing energy requirements of mining low grade uranium. A serious prediction on how long uranium resources will last is not possible, in particular since it is not certain how future nuclear energy use will develop.

21. How long will known and reasonably foreseeable uranium resources last with increasing nuclear energy production?

Taking the IAEA 2012 projection, from a generating capacity of 456-740 GWe in 2030 (low and high case scenario) one might expect a yearly production in the range of 3,600 – 5,800 TWh. This can be compared with the 2011 nuclear generation of 2,518 TWh. Thus, by 2030, it can be expected that the consumption of uranium resources will be from 43% to 130% larger than today. So obviously, uranium resources, unless they are considerably expanded in the coming decades, will not last for the 21st century. According to the high case scenario about 2.4 million tonnes of uranium would be needed until 2030, an amount which is roughly the same as ever mined in the last 70 years until today. It is unbelievable that the mining industry could meet this huge demand. Even for the low case scenario one has to reflect on the design plans to operate currently constructed or planned Generation III and Generation III+ nuclear power plant designs for 60 years.[16] If the 456 GWe level of 2030 in the low case scenario is continued until 2070 the cumulative demand of uranium will increase to an amount which is comparable to the sum of all "identified" uranium resources which are listed by IAEA/NEA as mineable for production costs below 130 $ per kg uranium. It is unclear whether the mining industry will be able to meet this challenge.

22. Can plutonium breeding solve the uranium supply problem?

Fast fission reactors are under R&D for more than half a century, but that has not lead to a mature technology. Instead, a lot of technical, material, safety, security and economy problems have emerged. Even the efficient breeding of more plutonium than used in the reactor core has not

16 These Gen. III/III+ reactors are expected to account for much of the nuclear power plant growth between now and 2030 (by 2013 three Generation III/III+ reactor units are in operation, 17 in construction, and 112 are planned).

convincingly been demonstrated so far. Therefore, it is unclear if or when efficient plutonium breeding reactors will be available in the future. Interested parties of the Generation IV International Forum have the ambitious objective to demonstrate breeders in the 2030-ties. Even if that should happen breeders could play not a relevant role before the middle of the century. However, a climate friendly energy system has to be established in Europe already by 2050. If societies nevertheless decide then to start a large scale plutonium economy, they have to face serious ramifications by the huge amount of necessary plutonium handling, which will dramatically increase global dangers of nuclear proliferation. In sum, plutonium breeding is not the solution.

Security of Supply

23. Is uranium an indigenous source of energy, and contributes to the security of supply?

Certainly not in the European Union. Currently the mining activities in Kazakhstan, Canada, Australia, Namibia, Russia, Niger, Uzbekistan, the United States, China and the Ukraine account for 94% of the worldwide mined uranium. All countries with larger nuclear power programmes in the EU are highly dependent on uranium imports. Less than 2% of uranium demand of EU countries is provided by mines located on EU territory. Nuclear power cannot contribute to security of supply in the EU.

24. Could nuclear power plants support renewable energy, working in load follow mode?

No. Most of renewables (wind and photovoltaic) generate electricity depending on changeable weather conditions. In order to have strict balance between generation and consumption electrical grid needs sources operating in load follow mode (to vary their power output to match always changing demand during a day, or in the weekend). This function could be fulfilled by hydro and gas fired plants. Majority of existing nuclear power reactors are designed to operate as base load electricity sources to prevent negative consequences to the fuel and huge metal components from changing operating conditions (power, temperature, pressure), thermal cycles, fatigue, etc. This means that they should work at full power 24 hours per day with most designed to operate 12 months, and some 18 or even 24 months. Only a small number of existing reactors have limited ability to vary their power output to match changing demand during a day, or in the weekend. With these features nuclear power reactors have limited possibilities to regulate the balance between the production and the demand, as well as the frequency in the grid. Newer reactors also offer limited form of enhanced load-following capability, for example, the Areva EPR can slew its electrical output power between 990 and 1650 MW at 82 MW per minute. But if one considers that the share of intermittent renewable energy sources is likely to expand, this is not sufficient.

Questions related to the Fukushima accident

25. Can one rule out further severe accidents after Fukushima?

No. Although because of Fukushima natural disasters and severe accidents are now at the center of attention, and first improvements at NPPs were and are carried out to reduce the likelihood of further severe accidents (however, more improvements, and a new perspective on severe accidents are necessary), they cannot be completely ruled out. Few of the severe accidents and near misses that have occurred so far have any resemblance to one another, and it is likely that the next severe accident will be different from those that have already happened. Also, one must bear in mind that for the next 20-30 years at least (considering operating life extensions to Generation II nuclear power plants, and the fact that current nuclear power construction is more than half represented by old Generation II technology) most operating time will be from Generation II nuclear power plants with modest reductions of risk. Under these circumstances it is quite likely that another severe accident will occur within the next 20-30 years.

26. How could an accident like Fukushima happen, and can accidents like Fukushima happen again?

In Fukushima, a natural disaster occurred, against which the system was not designed. The tsunami which followed the earthquake was 14 m in height, and therefore exceeded the maximum height of 5.7 m against which the plant was designed for.. Events like this cannot be excluded; they may occur at sites of other plants where natural disasters exceed the limits assumed in the design of the plant. A periodic review of the assumed natural hazards and possible retrofitting of plants can reduce this risk, but cannot completely avoid it. Moreover, simply by protecting against tsunamis and flooding nuclear power plants are not immune from other future severe accidents. The dominant external sources of risk are site-specific, and can come from a wide variety of sources like sandstorms, hurricanes & tropical storms, earthquakes, volcanic eruptions, aircraft crash, LNG tanker accidents, and so on.

27. Can the accident at Fukushima be referred to as beyond the "maximum credible accident", and what are the lessons to be learned for the safety demonstration?

Yes, the Fukushima accident was beyond the maximum credible accident (or a beyond design basis accident). The term "maximum credible accident" has been used in the early days of nuclear safety to designate an accident against which the plant design was protected as a bounding case. Accidents that exceed this accident can be described as beyond MCA. Today, instead of a few bounding cases the concept of design basis accidents (DBA) has been introduced, and in case of accidents that exceed the design basis, one speaks of beyond design basis accidents (BDBA). Both concepts have in common that there are accidents against which the plant has to be protected; while others are considered to be too unlikely to occur (Fukushima was protected against a Tsunami up to 5.7 m – but the Tsunami that hit the plant was 14 m in height). In future, the safety demonstration of nuclear power plants will have to look closer on the so called beyond design basis accidents.

28. What has been changed by Fukushima? Did the safety of nuclear power plants improve?

Fukushima has brought natural disasters as cause of severe accidents in the focus of the attention of research, as well as severe accidents themselves. In response to Fukushima, many nuclear power plants evaluated, demonstrated or improved their safety margins in this regard, including implementing upgrades. However, the investigations and safety improvements as a result of Fukushima are different from plant to plant, which partly can be attributed to different regulatory requirements or different understanding of safety culture of different utilities, such that a single statement which would encompass all nuclear power plants is not possible.

29. What are the "stress tests", and could the stress tests improve the safety of NPPs in Europe?

In response to the Fukushima accident the European Council invited the European Nuclear Safety Regulators Group (ENSREG) and the European Commission to develop the scope and modalities for the stress tests with the support of the Western European Nuclear Regulators' Association (WENRA). One of the main objectives of the stress test was to evaluate the robustness of European NPPs by reassessing their safety margins against extreme natural events and natural disasters (such as in Fukushima), and in assessing the capabilities of the NPPs to cope with severe accidents. The stress tests were conducted for all European NPPs on the same principles. The plant operators reported their findings in operator reports, which have been assessed by the national regulatory authorities, and summarized in national reports. However, due to the large amount of materials discovered by the stress tests, and the very different level of improvements needed from plant to plant it will take years until the results of the evaluations can become fully effective.

30. Did Fukushima change the energy policy priorities?

Yes, but in different ways from country to country. Countries like Germany, Italy, Belgium and Switzerland have decided to phase out nuclear power, and even France seems to reconsider a partial phase out of its oldest nuclear reactors. The situation of Japan remains still unclear – after all units were shutdown during a period of evaluations, there are signs now that Japan might consider restarting its nuclear program. Countries such as China, after a pause and a review of their NPPs, continue with their nuclear expansion programs.

31. Are radioactive releases from Fukushima comparable to those from Chernobyl?

There is no precise information on releases. According to estimates from Institut de Radioprotection et de Sûreté Nucléaire (IRSN) and Tokyo Electric Power Company (TEPCO) (which differ between each other) releases of radioactive noble gases (mostly xenon-133) from Fukushima accidents were of the same order of magnitude as those from the Chernobyl accident, however, releases of radioactive isotopes of iodine and cesium were lower than the ones of Chernobyl (between 10-20%, and 70% respectively). Because of its chemical properties iodine and cesium are more relevant than noble gases, so summarizing one can say that the more harmful releases from Chernobyl were higher than the ones from Fukushima.

Safety and Security

32. Are the low irradiation doses that occur in normal operation of nuclear power plants harmful?

There is a wide range of opinions on this. The main existing evidence from experiments and the analyses of medical statistics suggest that there is no threshold dose - only the likelihood of damage is reduced at low radiation levels. There are claims that cancer occurs more frequent in areas near nuclear power plants in Germany, USA, Japan and Canada, and from the environment of the reprocessing plants in Sellafied (UK) and La Hague (France). However, the statistical evaluation of small sets of cases is always difficult, and there is no common agreement in the scientific community on this topic.

33. How is the safety of a nuclear power plant assessed?

There are two complementary approaches for assessing the safety of nuclear power plants: (1) the deterministic approach, and (2) the probabilistic approach. The International Atomic Energy Agency requires that both deterministic and probabilistic approaches be used in safety assessment of nuclear facilities, including nuclear power plants.

One difficulty with existing safety assessment guidance is that it tends to treat each nuclear power plant unit individually, irrespective of whether there is one unit or more at the site (some existing sites include nuclear power plants with six or seven units). The March 2011 Fukushima accidents demonstrate that all nuclear units at a site need to be considered simultaneously in safety assessments. The Fukushima accidents also demonstrate that all potential accident initiating events need to be considered in such assessments, even if they are considered by expert judgment to be very low in frequency.

34. Can probabilistic safety assessments (PSAs) give valid severe accidents frequencies for existing nuclear power plants?

No, that is not their aim. Publicly available PSA information suggests that existing nuclear power plants of Generation I and II have severe accident frequencies in the range of one accident every 10,000 years to one accident every 100,000 years [17]. But in the operating experience for commercial nuclear power of more than 15,000 reactor-years[18] there have been either three severe accidents or five, if one considers the Fukushima Daiichi accident to represent three separate accidents. Based on this, the severe accident frequency would be either one chance in 5,000 years or one chance in 3,000 years, thus higher than the range calculated by PSAs. This can be attributed to the fact that many PSAs have not yet considered external hazards, that the PSAs do not yet fully consider the influence of human reliability on severe accident likelihood, and that existing PSAs either do not model or only poorly model factors such as safety culture and management style. In addition, PSAs do not consider the risks resulting from sabotage, terrorism, or acts of war. Finally, most PSAs do not consider risks resulting from spent fuel pool severe accidents. So although a PSA should not be read as a guarantee that severe accidents are not going to happen more often than a certain number each year, PSAs are very helpful in assessing the comparative importance of the risks included in the assessment and therefore in setting upgrading priorities.

35. The safety of nuclear plants is continuously increasing. Has this not solved the safety problem?

No. The Chernobyl and the Fukushima accidents have clearly shown that even in nuclear power plants said to be safe, severe accidents can occur. In spite of a period of tightening of safety standards, the Fukushima accidents in March 2011 in which three Generation II reactors experienced large-scale core melting and serious containment impairments demonstrates that serious accidents still cannot be excluded. Besides, not all nuclear power plants comply with all safety guidelines of the IAEA, even though these are considered to represent the minimum level.

36. Will future, so-called “inherently safe” reactors solve the safety problem?

No. “Inherent safety” refers to safety features of a reactor that lead a reactor from a abnormal or dangerous situation back to a safe regime based on fundamental physical principles – for example, should the coolant of a light water reactor be lost (e.g. due to a pipe break), the nuclear fission chain

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17 Kola Unit 4 (VVER-440/213) (Rosatom 2010) has a core damage frequency (CDF) of , 1.3×10-4/a, Dukovany Units 1-4 (VVER-440/213) have a CDF of about 1.7×10-5/a (Czech Republic 2010)

18 With roughly 400 units in operation, the accumulated experience of operation of commercial nuclear power plants increases each calender year by 400 reactor-years.

reaction will stop – because the coolant is needed as moderator. A reactor design can rely more or less on inherent safety features, or passive safety systems and components. Even if sometimes Generation IV reactors are claimed to be "inherent safe", this can never be true for a reactor design as a whole: "it is not technically sound to claim that any reactor, be it a water reactor or some other type, is an inherently safe reactor. The use of this term is a misnomer and is inappropriate for any power generating technology. All energy technologies pose some risk, and it is necessary to evaluate the risks and benefits of each technology carefully and objectively before reaching decisions on new applications". [19]

37. Is it true that all power reactors under construction are Generation III?

No. Currently (2013), 65 nuclear power reactors are under construction, some of which date back to the early 80s. Forty of them belong to Generation II or Generation II+, most these old design reactors are constructed in emerging economies, but two also in Europe (Mochovce 3&4, less than 200 km from Vienna, Austria).

38. Why is the safety aspect focussed on so strongly in the case of nuclear power?

Nuclear risk is special because the likelihood of a severe accident is, in well designed plants, small, but the consequences if it does happen are potentially catastrophic. People and states that never profited from the operation of the power plant can be strongly affected, and impacted regions can become uninhabitable for centuries.

39. Does the cost pressure of the electricity market have impacts on the risk of accidents in nuclear power plants?

Yes. The need for cost reductions leads to staff reductions and endangers investments in safety measures. In some cases in the past years it has led to downgrading of safety standards and to a decline in safety culture.

40. Will many nuclear power plants not be shut down anyway once they reached their age limit?

Due to rising energy needs and lack of acceptance for new plants successful attempts are being made to extend the life time of plants. Unfortunately, however, the safety risk grows at a certain age[20)], mainly because some components suffer from material fatigue due to intense strain. To continue an old plant with a lifetime extension program is often cheaper than building a new plant – and public acceptance is higher, even though the risk from these plants is higher. Just weeks before the

19 OECD/NEA Issue Brief: An analysis of principal nuclear issues No. 5, June 1989

20 As in automobiles, technological problems in nuclear power plants generally occur with the highest frequency at the beginning of operation, and again towards the end of plant life.

accident, Fukushima Daiichi 1 has been granted an additional ten years lifetime extension after 40 years of operation.

41. Are cyber attacks relevant for nuclear power plants?

There are different opinions on this. Problem awareness regarding cyber attacks and preventive and mitigative measures by e.g. Computer Emergency Response Teams or Computer Security Incident Response Teams would be important. As cyber attacks cannot be prevented, attackers are believed to generally have a lead of about 2 years over protective technologies. One example of a cyber attack on a nuclear installation has been reported, “stuxnet” – an internet worm, that infected windows PCs. The worm stayed dormant unless special Siemens software is found on the target machine, and a Siemens S7 PLC hardware controller is connected to the target machine – in this case the worm performed a layered attack, until it gains control of the S7 PLC. Those Siemens hardware has been procured by Iran for its uranium enrichment program, which the worm succeeded to delay by one to two years. An article in the New York Times, naming US and Israel secret services jointly responsible for the development of the worm has never been officially contradicted.

42. Are nuclear power plants possible targets for terrorist attacks or military action?

Yes. Nuclear power plants are potential targets for military or terrorist attacks due to the extensive damage (or at least psychological impact and social disruption) which such an action could cause. In the past, nuclear reactors have already been under military attack as part of counter-proliferation strategies.

43. What consequences could terrorist attacks or military actions on nuclear installations have?

Attacks on nuclear power plants can lead to radioactive releases that equal those of the most severe nuclear accidents. Even in case the reactor can be shut down in time, large amounts of decay heat are produced for days and weeks afterwards. Therefore shutdown alone may not be sufficient –if reactor core cooling is interrupted by terrorists or military action, the event could lead to a nuclear disaster. Besides possible long lasting impacts of such an attack, the effects on electricity supply could also be relevant.

44. How do plants prepare against terrorist attacks?

Information on the defenses against terrorist attacks, for obvious reasons, is kept secret. Technical measures and increased controls at nuclear sites, as well as precautions taken by the police, the secret service or the military can reduce the risks, but cannot eliminate them. However, it is known that NPPs prepare for events such as loss of the command and control infrastructure, as it could happen after a deliberate plane crash at the site. It is also known that several nuclear installations in some states are protected by missile defense, but whether such measures are sufficient and effective against all possible kinds of attack can be doubted.

Effects of Climate Change on Safety of Nuclear Installations

45. Are earthquakes and tsunami frequencies or intensities increasing due to climate change?

Possibly. The melting of landlocked ice (mountain glaciers, Greenland ice sheet, etc.) is a visible feature of global warming. The ensuing reduction of weight on the land can cause changes in tensions in the earth's crust and thereby trigger earthquakes and tsunamis. Whether this is already noticeable is a matter of scientific debate. Damage potential through tsunamis can also be enhanced by climate change induced dying of coral reefs and mangrove forests along the coasts, as their dampening effect on the waves is lost.

46. Does an increase in extreme weather events threaten the safety of nuclear installations?

Not necessarily. Although an increase in frequency and intensity of extreme weather events is to be expected as warming progresses, so far increases can only be proven for selected elements and regions. In general it will be possible to upgrade nuclear installations to withstand more extreme situation, but this will occur only on condition of regular re-assessments of design base events to monitor the progress of climate change. Summarizing, extreme weather events will become more likely, and since the decision, which events are inside the design bases and which are not is largely based upon probability, the design bases defenses will have to be upgraded. This means that the cost of nuclear electricity is going to rise due to climate change.

47. Does an increase of the mean global temperature influence the operation of nuclear power plants?

Yes. An increase in mean global temperature might have an effect on the available water sources, and nuclear power plants, as conventional thermal power plants, rely on water sources for cooling. There is not only a feedback from energy use to global warming, but also from global warming to energy – termed as the Energy-Water Nexus. Fresh water sources are expected to decline in future due to global warming, and coal / gas / nuclear produced electricity is expected to compete with agriculture for water.

Emergency Management

48. Can an effective emergency management solve the problem of a severe nuclear accident?

Emergency preparedness is a *conditio sine qua non* for an effective emergency management. It is understood as a condition which enables public to react and respond adequately to a nuclear emergency situation. Emergency preparedness requests appropriate and reliable information structures and tools, an annual adequate training for all levels of the society. If all conditions are met, emergency management can mitigate the effects of a nuclear accident – e.g. timely intake of iodine tablets blocks radioactive iodine from the glands. However, they do not protect from other consequences of radiation. Emergency management certainly cannot solve the problem of a severe nuclear accident.

49. Could emergency management have provided effective help in past nuclear accidents?

The accidents of Three Mile Island (USA) and Chernobyl (former USSR) show that whatever emergency management plans were available at the time, they were insufficient. Even in the recent past – in 1999 – during the accident in Tokai Mura in Japan, officials were informed too late and the start-up of counter measures was too slow. Nevertheless - or because of this - there is manifold and extensive need for action to be better prepared for future nuclear accidents. The emergency measures undertaken in the more recent Fukushima accidents appear to have avoided direct early health effects (none have been reported to date); however the efficacy of these actions in terms of cancer risks remains to be seen.

50. Can states that decided not to use nuclear power get by without emergency management?

No. Radioactive clouds are not hindered by state borders; they can be transported some hundred kilometers within one day. The Chernobyl accident has illustrated this impressively. Thus, also states that do not harbour nuclear power plants can be affected by nuclear disasters and must plan and take potentially expensive protective action against the case of emergency. The initial expectation of controlling and limiting of the risk to the site has moved to emergency preparedness and management by the public.

Radioactive Waste

51. Are any final disposal facilities for high level radioactive waste from commercial nuclear power plants in operation?

No. There is still not, in 2013, a single high level radioactive final waste disposal facility in operation in the world. A geological repository for spent nuclear fuel at the Olkiluoto site in Finland has been under construction since 2004. Licensing is in progress or in preparation for a few other repositories (e.g. Osthammar site in Sweden). Even though a small number of final disposal facilities may come into operation within the next 15 years, there is no operating experience at the present, and the concept of a final repository has yet to be proven in practice.

52. Are transports and deposits of nuclear waste not essentially safe?

No. Transports as well as interim storages can cause significant radioactive releases in case of accident or attack. High level radioactive waste has to be shielded for very long time frames – the safety of final high level radioactive waste repositories has to be demonstrated for up to a million years, which is practically impossible. There is a consensus, that deep geological storage might be the most appropriate for final disposal – nevertheless, knowledge gaps and unsolved questions regarding final repositories in deep geological formations exist.

53. Is deep geological disposal or surface storage the more responsible form of waste handling?

There are pros and cons for surface storage, as well as for deep geological disposal. It is impossible to foresee whether societies in some centuries or millennia will be able to maintain control over the repositories. Deep geological storage strives to solve the waste problem "now" and to prevent the access to weapon-grade materials. But to guarantee a safe and geological stable site over thousands of human generations is cumbersome. Surface storage has the advantage of a smaller probability that the knowledge how to handle the waste is lost. The waste could remain accessible, in case there is the need to find a different location, or in case better solutions to deal with the problem are available in the future. However, the radiological legacy would be left to a large number of future generations, the burden of handling the waste, preventing nuclear proliferation and the risk of radioactive releases.

54. Can radioactive waste be rendered harmless by transmutation and is its research recommendable?

Transmutation requires complete new, very complex, challenging and expensive spent fuel reprocessing technology to separate various types of radioactive elements coming along with nuclear waste. Further challenges are the necessary fabrication of new fuel elements composed partly of those highly radioactive parts separated from the waste and the research and demonstration of appropriate fast reactor types enabling effective burning of parts of the waste. While a demonstration of such technology will need at least several decades of time also the intended use of transmutation technology will again require many decades and a very substantial amount of money. The environmental costs and benefits as well as new safety and security challenges associated with the use of this technology have not been assessed comprehensively so far. Furthermore the overall benefits seem to be questionable: most of the fission products – also long living ones – cannot be effectively incinerated, the destruction efficiency of transuranic elements (like plutonium) depends highly on the separation efficiencies achievable on industrial scale. Today, one cannot expect that transmutation technology could sometime make a safe and secure long term final waste repository unnecessary. Only waste amounts – and therefore necessary repository space – and radiotoxicity could be reduced to some extent. Not until detailed and independent prospective science and technology assessment has been carried out, expensive investment in researching transmutation technology seems not to be recommendable.

55. How can the problem of nuclear waste be solved?

There is no satisfactory solution to the waste problem. Therefore, the amount of waste that is additionally produced must be minimized. For the waste already accumulated, a consensual solution must be sought in a wide and open public debate.

Proliferation

56. Have nuclear weapons ever been proliferated from the commercial nuclear fuel cycle?

While it is in principle possible to do so, proliferation from the commercial nuclear fuel cycle has not explicitly and openly taken place yet. However, of the countries known or strongly suspected to have developed nuclear weapons, not all have used dedicated production facilities to produce the nuclear material for their weapon programmes; some (such as Israel and North Korea) have relied on research reactors (but not the commercial nuclear fuel cycle). Nonetheless, the first larger commercial reactor (Calder Hall, England) was also the first plutonium provider for the UK weapons programme and the Soviet Union operated dual-use reactors which provided electricity for the public and plutonium for the military. Furthermore, in most of the states becoming a nuclear weapon state there was no definite separation line between commercial and military nuclear programmes like in France, China or India.

57. Can spent fuel from commercial nuclear power plants be used to make nuclear weapons?

Yes. It is widely recognized among experts that nearly all plutonium is "weapons usable". So-called "weapons-grade plutonium" comes from non-commercial reactors from which the spent fuel is discharged after a relatively short period of "burn up" in the reactor. This maximizes the relative percentage of Plutonium-239 (more than 90%), which is desirable for nuclear weapons. But also “reactor plutonium” discharged from a commercial reactor or a larger research reactor can be used for the fabrication of weapons. However, as prerequisite mastering plutonium separation from spent radioactive fuel is necessary.

58. Is uranium enrichment relevant for proliferation dangers?

Yes. Uranium enrichment is unavoidable for current nuclear energy programmes, but the technology has its origin in the first military nuclear programmes of the 1940s and was used to produce highly enriched uranium for weapon purposes. One globally increasingly important enrichment technology – gas centrifuges, which are proliferating from European origin – is in particular civil-military ambivalent. Centrifuge cascades can easily be used or effectively reconfigured to produce not only low enriched uranium for reactor fuel but also highly enriched, weapons-grade uranium. A very small, clandestine facility could produce significant amounts for a weapons program over a year or so and is undetectable from outside. At present, the Iranian nuclear programme illustrates that centrifuge enrichment is a proliferation prone technology, but is the technology of choice now on a global scale. Unfortunately, no proliferation resistant technology is at disposal today.

59. Can nuclear weapons be designed and built by "newcomers"?

Yes, with appropriate technological know-how a state can build nuclear weapons. Most aspects of first generation nuclear weapon design are more or less public knowledge, as are the early improvements to those designs. It is, however, difficult to develop more sophisticated designs in which the physical size and weight are minimized, and in which the weapons are designed for delivery by missiles rather than by aircraft or other means. Access to weapons usable material, like highly enriched uranium or plutonium, is likely to have become easier with the global increase of these materials.

60. Can proliferation be prevented?

The international community of states – under lead by its powerful nuclear weapon states and the IAEA – makes considerable efforts to curb nuclear proliferation. However, it is hard to believe that nuclear proliferation can be stopped while current available nuclear fission technology is used in many national nuclear energy programmes. The main reasons are the civil-military ambivalent nature of the technology and the contradictions inherent in the current non-proliferation regime, which is striving to prevent proliferation while encouraging the spread of civil usage of ambivalent technology, which can open the door to military programmes. The problems of the regime are intensified by its unbalanced rights and duties assigned to various groups of member states. The proliferation problem is currently highlighted by the problematic access to or use of sensitive technologies like reprocessing or enrichment and the use of plutonium or highly enriched uranium in civil programmes. Therefore, relying only on IAEA safeguards, which cannot provide a one hundred percent security, is problematic, especially as long as voluntary improved safeguards ("additional safeguards protocol") are not valid in all states. Unilateral export control measures are undermined by indigenous efforts to get access to sensitive technology and by commercial interests of the supplier states. Without tackling the technical core problem of civil-military ambivalence a sustainable solution of the proliferation problem is not in sight.

Economy and competitiveness

61. Does nuclear power offer commercial advantages?

No. The financial risk to invest into new NPPs is quite high due to the enormous – and still raising – capital costs. Therefore, several countries that are considering embarking again on nuclear power construction programmes, e.g. Finland and the US, have implemented a direct or indirect financial support programme for the nuclear sector. In the case of the US, this involves a complex series of measures which are likely to cost the taxpayer some $13 billion for a six to eight reactor programme. Even though many external cost of nuclear power are not included in comparative price calculations, nuclear power is not cheaper than most alternative technologies. Energy efficiency improvement (reduction of energy intensity for the supply of goods, services and private end use) is even more advantageous regarding investments as well as CO_2-reduction potential than nuclear power.

62. Are existing nuclear power reactors competitive in free market conditions?

Proponents of nuclear power claim that existing nuclear power reactors are competitive compared with other thermal electricity generating sources. While this may be true in many cases, it is also true that economic conditions are changing nowadays, and an example of the contrary is already in place. In the US, the economic circumstances led one of the country's largest energy producers, Dominion Corporate, to decide to shut its single-unit Kewaunee NPP (PWR 583 MW, 1974, in Wisconsin) in the second quarter of 2013. When Dominion bought Kewaunee in 2005, Midwest power prices were in the range of $40-50/MWh, wellhead natural gas prices were $6-10 per million Btu and US electricity demand was growing. Today, Midwest power prices are around $30/ MWh, gas is $2-3/mBtu and the US has had 5 years of no growth in electricity demand. It wasn't economically justifiable anymore to keep the plant in operation.

63. Will the construction costs for nuclear power plants drop?

No. A comparison of cost developments shows that costs for nuclear power have risen, while those of alternative technologies dropped. In addition, the estimates for construction times and costs for nuclear power plants are known to be inaccurate and typically are underestimated before construction begins. There is no reason to expect that this will change in the near future. On the contrary, post Fukushima upgrades of safety requirements will tend to raise prices and extend construction times.

For example Olkiluoto, the first Generation III+ reactor that is constructed in Finland by AREVA, an EPR with a installed capacity of 1.6 GWe, was estimated to be constructed in four years, at a cost of 3.2 billion Euros. Today the estimated construction time is eleven years, and the cost is 8.5 billion Euros (this means 5,300 Euros per installed kWe).

64. Is nuclear power subsidized by public enterprise?

Yes. Subsidies for nuclear are higher than for renewables or for fossil fuels.[21] In addition, the costs for regulatory bodies, radiation monitoring networks and costly emergency planning systems on the national level, and e.g. non-proliferation activities (e.g. Comprehensive Test-ban Treaty Organization, CTBTO) on the international level are born by public enterprise. Besides, nuclear does not bear the insurance burden other industries are compelled to bear.

65. What would the financial losses be for a severe accident in Europe?

In the beginning of 2013 the French Institute of Radioprotection and Nuclear Safety (IRSN) estimated a total cost of roughly 120 billion EUR for a severe accident at a 900 MW reactor in France with limited release of radioactive materials to the atmosphere. The figure could double if weather and other conditions were unfavorable. 77% of these total costs would be due to “image costs” (such as consumer rejection of products, even if clean, as well as impacts on tourism and exports) and the cost of replacement power. After a severe accident with uncontrolled radioactive releases to the atmosphere the total cost would be 430 billion EUR.

66. Do insurances adequately cover nuclear risks?

No. The international liability regime for nuclear damage (Vienna Convention and Paris Convention) divides liability between the operator, the state in which the facility is located and member states of the conventions. In addition there is a fixed ceiling for nuclear damage. If Europe’s nuclear utilities would be required to fully insure the full cost of a severe accident, this would increase the cost of electricity generation considerably.

Legal dimension

67. Could the problems and risks of nuclear energy be solved at the international level?

The risk of other nuclear accident in the future cannot be excluded. The risk of the misuse of nuclear

21 In 2007, the German Institute for Economic Research (Deutsches Institut fuer Wirtschaftsforschung, DIW), published a study were it estimated that from 1950 to 2006 a total equivalent of 54 billion Euros in subsidies have been spent on nuclear power in Germany. This are 2,000 Euros per installed kWe.

technology by other governments or by terrorists is present and not under control. As long as the nuclear threat exists a lot of measures could reduce the existing risks. Their realization depends on the political will of the governments. Some of the most important measures e.g. to reduce the risks of a further nuclear accident are:

- more real and mental independence of the nuclear authorities from the nuclear community;
- within the EU binding and precise objectives for nuclear safety that represent the state of the art including protection against core melt events;
- more control by the civil society supported by independent experts and a radical change to a real transparency by operators and authorities.

Neutrality of technology?

68. Should Europe subsidize nuclear power as renewable energy sources to achieve its climate goals?

No. As outlined in the "Global Energy Assessment" (GEA)[22], if the climate goals are to be kept, i.e. if the increase of the global mean temperature should be kept below 2 °C, one has to think of a new energy supply system which is based primarily on renewable energies and energy efficiency measures. By projecting current policies into the future, assuming single technological "quick fixes" like carbon capture and sequestration, one can see that the climate goals are not going to be met. Drastic changes are necessary to meet the climate goals – GEA draws a scenario with a high share of intermittent renewable electricity generation, supplemented by devices that can store an excess of produced electricity, and deliver it quickly if needed.

- Nuclear power does not fit in such a scenario. It is not suitable as backbone for electricity together with renewable energy sources. Since electricity production from renewable energy sources is intermittent, a complementary electricity production facility has to be able to quickly fire up and reduce its production (load follow mode), something that nuclear cannot offer very well. Further, nuclear power does not contribute to security of supply in Europe.
- Nuclear power is not an "infant technology", contrary to renewables. One cannot expect that R&D investments in nuclear return the same benefit as they do for renewables[23]. The total possible funding for research is limited – funding nuclear on even footing with renewables deprives renewables of much needed sources. To deploy funding mechanisms as cost effective as possible and to strive simultaneously for sustainable solutions, renewables

[22] IIASA, "Global Energy Assessment Toward a Sustainable Future", 2012
[23] EC COM(2013) 253 final, Brussels, 2nd May 2013, show that overall R&D costs for nuclear in the European Union outweighs all renewable supply options, but innovation and development of renewable energy sources of the last 20 years overtook developments in the nuclear sector by far.

should have the precedence.

- Danger of lock-in: The nuclear power plants which are currently constructed have a design lifetime of 60 years, without counting lifetime extension programs. Investing now in nuclear power influences the energy infrastructure for more than 60 years. Since nuclear power plants are not compatible with a high share of intermittent renewable energy sources, expansion of nuclear power in the EU endangers the EUs energy road map objectives, where the various renewable energy technologies have to play the role of the new "work horses" of the energy system.
- CO_2 emissions should not be the only criterion that is looked at. Countries that are now committing to nuclear power programmes will have to invest heavily in nuclear research in coming years and decades, since fundamental problems, like treatment of high level radioactive waste, safety and protection against severe accidents, and dealing with declining uranium resources are yet to be solved. These Investments are missing for the development of renewables, where they are known to yield a higher benefit. Furthermore nuclear power carries the danger of proliferation, nuclear power plant constructions are notoriously late, and costs for nuclear builds rarely stay in the planned budget.

Since it is debatable if the currently open questions related to nuclear power can be answered at all, one would assume that it should be preferable to support low CO_2 technologies, or even CO_2 neutral technologies which do not suffer from the above mentioned problems.