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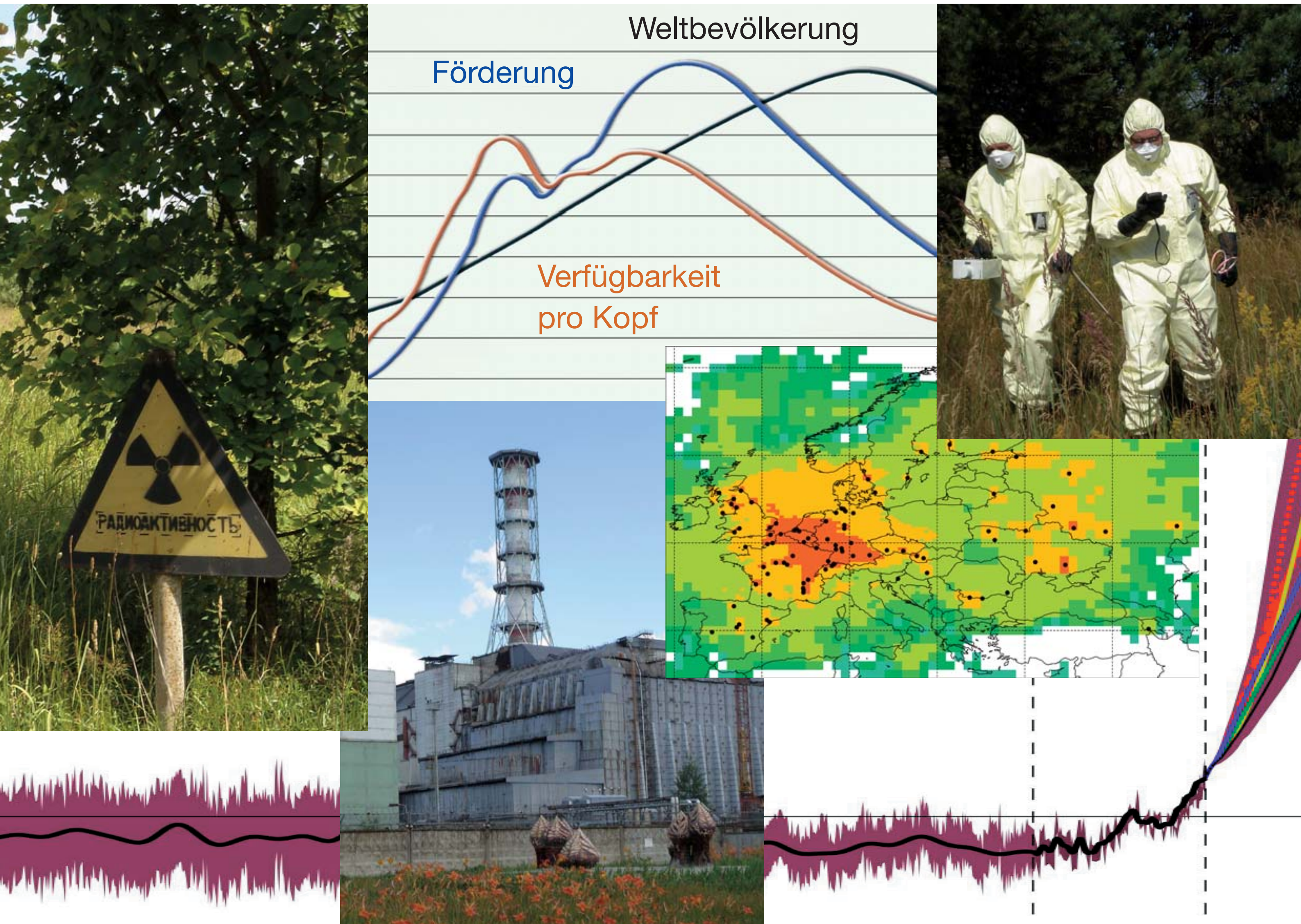
Nuclear Power, Climate Policy and Sustainability

An Assessment by the Austrian Nuclear Advisory Board



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SUSTAINABLE FOR NATURE AND MANKIND

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We create and we safeguard the prerequisites for a high quality of life in Austria.

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Wir sorgen für die nachhaltige Produktion insbesondere sicherer und hochwertiger Lebensmittel und nachwachsender Rohstoffe.

We provide for the sustainable production in particular of safe and high-quality foodstuffs and of renewable resources.

IMPRINT

Editor:

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Stubenring 1, 1012 Vienna, Austria, www.lebensministerium.at

Coordination: Helga Kromp-Kolb (Austrian Nuclear Advisory Board) and Andreas Molin (Lebensministerium)

Translation: The authors with the support of Patricia Lorenz, Susanne Morawetz and Ilse Tweer

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Preface

For many years Austria has followed a policy of exit from nuclear power. In the population and across all political parties there is wide-spread consensus that nuclear power is too risky an energy technology and that the use of nuclear energy burdens future generations irresponsibly with nuclear waste.

Meantime climate change has made the need to reduce green house gas emissions apparent. The foreseeable end of cheap oil and – somewhat later – of gas also requires a rethinking of energy policies.

Consequently I am frequently confronted with the question whether in the light of these developments a policy critical of nuclear energy was still legitimate, whether nuclear energy was not the lesser evil.

Policy, just like science, sometimes must pause and check its premises. In this spirit I have asked the Austrian Nuclear Advisory Board, the pertinent scientific advisory body of the Austrian Government, to take up this question. Have advances in science and technology made a revision of the Austrian energy policy regarding nuclear necessary, especially in view of climate change and "Peak Oil"? Has the nuclear option become sustainable?

The assessment has now been completed and the message is an inconvenient one: in spite of nominal safety improvements in nuclear power plants a long list of "near-misses" documents that severe accidents can never be excluded; nuclear installations can only marginally be protected against terrorist attacks; proliferation continues to be a serious problem and a sustainable solution of the radioactive waste problem is not in sight. But even if one were to overlook all these drawbacks a nuclear power scale-up would come too late to contribute significantly towards the solution of the challenges of climate change and "Peak Oil". Nuclear power is not even a cheap solution: energy efficiency measures and alternative energies are superior ecologically and economically. Maybe surprising for many: should nuclear be significantly up-scaled fissionable uranium would become scarce within a few decades, just like oil. The nuclear solution then leads to a plutonium economy – and fourth generation reactor concepts point in this direction – with all the associated dangers and significantly higher proliferation risks.

Thus nuclear power is not **the** convincing solution some claim; rather it is no solution at all. There is no reason to change the Austrian policy. Our focus on energy efficiency and alternative energies is far sighted and the right way to go. We are convinced that in following this path we also contribute to the awareness building that is necessary to achieve a sustainable and more responsible use of energy.

Josef Pröll
Minister for Environment

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Dedication

The Austrian Nuclear Advisory Board dedicated this assessment to its founding member and Vice-Chairman **Univ.-Prof. Manfred Heindler**, an internationally renowned critical expert on nuclear fission and fusion technologies and their application. He was strongly involved in the first version of the Assessment in 2000 and in developing the concept for the present, significantly enlarged and updated version as long as his health permitted. He has not lived to see the finalisation of this work. He passed away on May 13th 2006 in Graz, Austria.

The members of the Austrian Nuclear Advisory Board will miss him, his vigour and optimism, his sharp criticism and his valuable and constructive contributions.

Synthesis: Nuclear Power, Climate Policy and Sustainability

An Assessment of the Nuclear Option with regard to Climate Policy and Sustainable Development

January 2007

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An Assessment of the Nuclear Option with regard to Climate Policy and Sustainable Development
January 2007

Abstract

In the past years the issue of Nuclear Energy has been raised at various occasions, in particular with regard to Climate Change and the necessity to reduce greenhouse gas emissions and in view of the foreseeable end of cheap oil ("Peak Oil") and their global implications. Following the UN Framework Convention on Climate Change (UNFCCC) and the EU Sustainable Development Strategy, the political and societal solutions to these problems must be environmentally sound and sustainable.

Austria takes the view that electricity production from Nuclear Energy is neither sustainable nor environmentally sound and is therefore not suitable to contribute to the solution of the climate problem or the peak oil crisis:

- Even when ignoring the possibility of severe accidents, Nuclear Energy is burdened with a large number of environmental problems and risks, such as possibly health damaging low level radioactive emissions in normal operation and the worldwide unresolved problem of final repositories for nuclear waste.

- Cost cuts necessary as a consequence of the deregulation of the energy market have negative effects on safety culture and safety margins during construction and operation.

- Investment in Nuclear Energy impedes or at least delays investments in efficiency measures and therefore impedes sustainable, resources preserving solutions.

- The increasing world population, the growing scarcity of resources and the increasing global inequity are likely to raise the number of wars and augment terrorist activities: this prohibits the support of technologies and structures that enhance the vulnerability of a region, and calls for a rapid dismantling of such technologies and structures and for transformation of these into decentralized technologies and structures with high error tolerance and low potential of damage.

From today´s perspective, Nuclear Energy does not have the potential to contribute significantly to climate policy or to the solution of the problems connected to "Peak Oil":

- Limits to development potential and speed, availability of capital and qualified staff curb the possibilities of Nuclear Energy, even in case of strong political backing. In fact, the coming decade will more likely see a reduction of the contribution than an increase of the rather small nuclear contribution.

- As compared to energy efficiency, Nuclear Energy so far has not made a significant contribution to the reduction of greenhouse gas emissions; energy efficiency measures have proved to be

more effective and less costly and, in addition, have much higher potentials that can be drawn on in short term.

- Nuclear Energy could only make a substantial contribution towards the energy needs of the rapidly growing transportation sector through the nuclear production of hydrogen. In view of the large number of power plants needed to produce a relevant amount of hydrogen, this is not a viable option without solution of the above mentioned problems.

- The newer nuclear technologies in discussion at present offer no solution as the "inherent safety" is not yet proven nor all encompassing and as the development of Generation IV reactors seems to create more safety problems than it solves.

- Even an increase in technological safety of nuclear power plants would not reduce the risk they pose in view of war and terrorism; thus the vulnerability of regions with nuclear power plants would not decrease.

- Uranium reserves are limited. If Nuclear Energy is to contribute significantly to the global energy need the only path known at present leads to fast breeder reactors and the ensuing plutonium economy that is tied up with even greater safety problems and risks.

From a legal point of view the core of the applicability of the principle of sustainability lies in the distribution of the asset "environment" and the burdens of Nuclear Energy production between the present and coming generations. In analogy to the principle of proportionality of the law of the European Community the energy demand of the present generation must be kept as low as possible and at the least possible environmental costs; the costs and burdens of energy production are to be borne by the generations benefiting from it. The sustainability principle therefore rules out the use of Nuclear Energy in its present form and in others envisaged today.

Motivation and Context

In the past years the issue of Nuclear Energy has been raised at various occasions, in particular with regard to Climate Change and the necessity to reduce greenhouse gas emissions and with regard to the foreseeable end of cheap oil ("Peak Oil").

Climate Change and the human part in it are generally accepted scientific facts. Unfavourable impacts already observed and those yet to be expected have induced governments to take action toward climate protection. The UN Framework Convention on Climate Change (UNFCCC) signed 1992 defines a goal of "…*stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system. Such a level should be achieved within a time-frame sufficient to allow ecosystems to adapt naturally to climate change, to ensure that food production is not threatened and to enable economic development to proceed in a sustainable manner*". The steps necessary to achieve these goals and the sanctions in case of failure to implement them are decided on in annual Conferences of the Parties to the Framework Convention (COP).

The UNFCCC also obliges the signatories to promote sustainable economies and to support developing countries in the achievement of the obligations from this convention and to give them access to environmentally sound technologies and know-how. This implies that climate protection is to be achieved primarily by sustainable and environmentally sound measures.

Oil, with a share of 40% of the total global energy consumption, is at present the most important source of energy. It is also one of the most important raw materials of which essential every day things are made: chemicals and solvents, plastic, colours and varnish, wrappings, artificial fibres (clothes, carpeting, curtains), articles of hygiene and cosmetics (soaps, perfumes, lipsticks, hair sprays), medicines, fertiliser, pesticides and building material for infrastructure (roads). This list illustrates that oil, its availability and price is of eminent importance for the economies of the world.

According to recent estimates about half of the known oil reserves have been consumed. The production of oil from individual sources as well as the overall oil production follow a bell shaped curve: close to exponential increase in the first phase of the exploitation, then, when the pressure in the reservoir decreases the withdrawal of the remaining oil is accomplished with increasingly costly methods and the production drops continuously from year to year. Most reserves aside from those in the Near East are at or beyond the point of maximum production. The exploitation of the remaining oil is costly and production can not keep up with demand increase at the present pace. Alternatives to the oil dominated economy must therefore be found within a time span of a few decades.

Nuclear Energy is presented by some as a suitable means to achieve the necessary reductions of greenhouse gas emissions and as a significant contributor to the resolution of the upcoming oil crisis. The transportation sector is seen as special field of interest for Nuclear Energy: hydrogen produced by Nuclear Energy is to replace oil as the primary source of energy (currently more than 97 %).

Austria takes the view that Nuclear Energy is neither sustainable nor environmentally sound and is therefore not suitable to contribute to the solution of the climate problem or the “peak oil” crisis.

The Basic Problem

Important as CO_2-emission reductions and availability of energy are, more is at stake: Sustainability is a concept that involves both, a wide human ecological context and a long term horizon. It is defined as ”*a development that meets the needs of the present without compromising the ability of future generations to meet their own needs*” (Brundtland Commission 1987).

To comply with the requirements of sustainability a technology must be:

- environmentally and (macro-)economically sound and socially acceptable
- within human grasp (e.g. all potential technical, social and ecological consequences can be comprehensibly assessed)
- flexible and
- tolerant of errors.

The central criterion for the evaluation of a technology must be: Does the technology support or hinder sustainable development or is it neutral?

In the specific case it can be shown that Nuclear Energy

- degrades the environment (e.g. low level radiation is emitted in normal operation and there is a high potential for catastrophic events),
- is not acceptable socially, (e.g. is plagued with its close connection with nuclear weapons and therefore proliferation problems, is not adapted to socio-economic structures and safety cultures in developing countries, increases vulnerability of societies and regions due to threat by war and terrorism),
- is too complex and is associated with a damage and threat potential too great and reaching too far into the future to be within human grasp (e.g. reduction of safety in a deregulated energy market, final repository still unresolved, decommissioning of plants),
- is inflexible (e.g. requires follow-up measures through centuries and is tied to large units, difficult to steer due to intrinsic dynamics) and
- is intolerant of errors as past experience shows (e.g. Chernobyl accident) and the new reactor concepts tend to be even less tolerant than present plants.

This will be demonstrated in more detail in the following by reviewing some problem areas.

Problems of "Normal Operation"

Each phase of the nuclear cycle is associated with environmental loads – even if there are no events or accidents.

Uranium mining

After extracting uranium from the ore, remnants including decay products are left at the site and are stored on the surface as dumps or as mud in simple basins. This debris contains hazardous substances like the uranium decay product thorium-230 with a half-life of 77,000 years and its daughter products radium and the gaseous radon.

The isolation periods that would have to be reached in case of final disposal of these wastes are comparable to those of wastes from the operation of nuclear power plants.

For every ton of reactor fuel thousands to tens of thousands of tons of ore have to be mined. In the mining sites in New Mexico (USA) and Wismut (former DDR) more than 100 millions of tons of radioactive waste are deposited on the surface.

The Wismut region is so heavily contaminated that the German Radiological Protection Ordinance cannot be applied. Uranium mining in Eastern Germany has produced about 8,000 dumps and mud ponds. Rain water leaches out uranium, radium and other toxic substances that thus reach the groundwater. In case of sliding of dumps radioactive dust is released into the atmosphere. Clean up work is progressing and will continue till 2015, but surveillance will be necessary even after that.

The situation in other uranium mining areas is comparable. These facts are less publicised, especially if mines are located in the Third World or in less developed parts of industrial countries (e.g. where indigenous peoples live).

Normal Operation of Nuclear Power Plants

The discussion on the possible effects of increased cancer incidence near nuclear installations has been ongoing for many years. For the reprocessing plants at La Hague (France) and Sellafield (UK) there are numerous indications that cancer incidence is indeed enhanced. The evidence of increased occurrence of leukaemia, cancer and down syndrome near nuclear power plants is also growing. Recent findings are reported for Germany and the USA.

These results not expected by mainstream scientist might be an indication that the effects of low level radiation, especially in case of incorporation, are underestimated or that not all types of emissions are reliably monitored or possibly a combination of both. There are increasingly reliable indications for both explanations.

Uncertainties remain regarding the extent of the influence of low level radiation on genetic material, as the time scales to be considered are much longer. Applying accepted precautionary and safety principles of environmental protection, even low level radiation cannot be considered to be environmentally acceptable.

The Safety Problem

The type of risks nuclear power plants pose in case of severe accidents are of the type ”Damocles” according to the sociological classification scheme: severe accidents have low probability of occurrence but catastrophic consequences. In the case of nuclear power plants, the consequences of severe accidents can be far reaching and long term in character.

Since the start up of the first nuclear power plant safety regulations had to be tightened repeatedly in reaction to unforeseen incidents in different power plants. A considerable number of operating power plants therefore does not fully satisfy the safety standards presently recommended by the IAEA. Also, the methods to assess the safety status of nuclear power plants are insufficient regarding their completeness and reliability.

As nuclear power plants age and infrastructure capacity declines, the risk of accidents rises. The liberalisation of the energy market tends to aggravate the situation further, as nuclear safety is expensive and the drive for cost reductions and higher share-holder values leads e.g. to reductions of staff and endangers safety investments. In the last years there have also been cases of downgrading of safety standards.

A sequence of incidents in nuclear power plants in Europe, Japan and America have induced appeals from representatives of the nuclear industry for more self-criticism, care and circumspection – in short: improved safety culture. Even though it is questionable whether these incidents can already be attributed to the deregulation of the electricity market or the aging of nuclear power plants, they do show clearly, that efforts to enhance safety culture and safety measures must be stepped up. It is difficult to see this happening in the present economic constraints, with overall costs of Nuclear Energy still above that of other energy sources, in spite of high oil and gas prices.

For the coming generation of reactors (Generation III) concepts were modified to address a large number of foreseeable accidents passively ("inherent safety") and reduce core damage frequency. However, the "inherent safety" has not been proven for any reactor so far, and applies only to design base accidents, not to external dangers and certainly not to acts of war or terrorism. Liberalization of the electricity market and the decreasing governmental support for the nuclear industry forced a further redesign to reduce capital costs (Generation III+).

Concepts for Generation IV – essentially fast reactors – are under development internationally with the declared goals to be "inherently safe", proliferation resistant, economic and free of long lived high radioactive waste. Fast reactors suffer from a handful of drawbacks, which make them expensive to build and hard to operate. Considerable doubts are voiced on the feasibility of meeting these goals simultaneously. Safety problems in Generation IV reactors differ widely from those known for the earlier generations. However, it is very difficult to assess their safety at the present time, as they are only in the design phase, and studies addressing safety aspects are still limited.

Due to the limited availability of fissile uranium – estimates range between a few decades and a century depending on assumptions regarding the extent of nuclear build up and uranium resources – fast reactors must be implemented if a substantial and long lasting contribution by nuclear energy is envisaged. This would imply a plutonium economy.

Catastrophes are inherent in complex and coupled systems and therefore unavoidable, although the likelihood of their occurrence can be reduced. Nuclear power production necessitates very complex and coupled systems involving the implementation of sophisticated safety concepts such as redundant and diverse defence in depth. The latter in itself constitutes a factor of increased vulnerability. But safety measures are imperative, as the enormous energies concentrated in a very small volume together with highly dangerous materials in amounts sufficient to contaminate large areas with persistent deadly radioactive pollutants in principle cannot be contained sufficiently safely nor can handling be made proof against the human factor. By impelling physical laws the causal chains triggering accidents can never be fully eliminated by safety provisions of material containments and technical structures, nor can the evolutionary biological constraints of human nature be overcome by administrative, legal or psychological security measures.

The Problem of Radioactive Waste

The problem of disposing of high and medium level waste is not resolved. In principle three different options for final disposal are under discussion – none of them available at present in practice:

1. Surface or near-surface disposal with control and intervention possibilities (retrievable).

2. Permanent disposal in deep geological repositories which makes misuse difficult and has no need for security measures, but allows only limited information on the state of the waste containers etc. and no intervention.

3. Partition and transmutation of long-living radio nuclides, reducing the hazardous time period to max. 1,000 years; storage for this time period.

None of these options fulfils the demands for safety and social acceptability from today´s perspective.

In the case of deep geological repositories the limit of predictability by science is exceeded. Radioactive material could be released into the biosphere in some distant time, when people have even less knowledge or means to handle it than we do today. In the case of the near surface disposal, the limits of predictability of societal development are exceeded. Due to the long periods in question, safety can be guaranteed in neither case.

In the case of partitioning and transmutation there are open questions regarding safety and environmental pollution in addition to those of feasibility and affordability.

After several decades of nuclear power usage the industry still has not been able to present a socially, technically and economically accepted concept for final repositories. Instead, the number of interim storages and of nuclear power plants due for decommissioning grows. In a number of countries the capital necessary for decommissioning and storage has not been accumulated.

Thus, the justification of producing additional radioactive waste must be questioned. For the waste already produced a solution must be sought in a societal consensus procedure that minimises the disadvantages. A phase out of Nuclear Energy would limit the amount of nuclear waste and thus contribute to the minimisation of disadvantages.

Low level wastes are only partly disposed of in repositories. Large amounts are simply released into the environment for economic reasons. The resulting low level dosages are in contradiction with the precautionary principle that should be applied in health issues. This method of management of waste, although emitting radiation below established limits, also does not qualify as environmentally sound.

Transport, interim storage and reprocessing of radioactive waste are also connected with considerable risks.

Terrorism and War

In the present political situation and due to the rising world population, dwindling resources, climate change and increasing inequity military and terrorist activities must be expected to increase. “Small”, long lasting and regionally limited wars, pre-emptive strikes as well as interventions directed against nations that pose a real, a perceived or a claimed threat to peace, are becoming more frequent. In countries or groups that feel overpowered this can trigger or enhance terrorism. Installations with a high potential for catastrophe are tempting targets for sabotage, terrorism and military attacks. There is no reliable protection against such threats.

Nuclear power plants are especially threatened – even the most advanced, future, so called “inherently safe” reactors. There are a number of reasons, which could individually or in combinations lead to the choice of a nuclear power plant as target of an attack:

- The symbolic value: nuclear plants can be seen as the embodiment of technological development, as typical “high-tech”. In addition, nuclear plants represent a technology of dual character: civil and military.

- The long term effects: an attack can lead to large scale radioactive contamination by long lived radio nuclides. The social and economic consequences for affected states or groups of states can hardly be fathomed.

- The immediate effect on electricity production in the affected region: nuclear power plants are, where ever they are employed, important parts of the electricity supply network that feed into the net with high capacity. The sudden loss of such a plant can lead to the break-down of the whole system.

- The psychological effect on other nuclear states: a successful attack on one nuclear power plant could have far reaching effects on the nuclear industry also in other nuclear countries.

Similar considerations are valid for other nuclear installations or for nuclear transports.

A number of attempts at sabotage, terrorist and military attacks on nuclear plants document impressively the reality of this threat.

The vulnerability of nuclear plants to terrorism and war can be summarised as follows:

- All types of nuclear plants as well as transports of radioactive materials are vulnerable to terrorist attacks and war impacts. Significant releases with catastrophic consequences can be achieved.

- An attack on a nuclear power plant can lead to large radioactive releases. Relocation from large areas could be necessary and the number of deaths due to cancer could rise dramatically.

- The spectrum of the threat is extremely diverse and protective measures against terrorist attacks and impacts of war are only possible to a very limited extent. Some conceivable measures are in contradiction to the basic values of an open, democratic society.

Thus, also under the aspect of vulnerability to terrorist and military attacks clear draw-backs of a centralized, non-sustainable technology such as Nuclear Energy become apparent.

Emergency Planning

The necessary measures to minimise damage in case of an accident in a nuclear power plant and the inevitable consequences of severe accidents clearly demonstrate that Nuclear Energy is neither environmentally nor socially sound. This problem has been aggravated in the last few years by the increasing threat of terrorist attacks and war impacts on nuclear power plants.

In case of a severe accident a significant part of the highly toxic, radioactive components of the reactor core can escape into the atmosphere – possibly very soon after the initiation of the accident. The lead time that is available for emergency management measures is possibly extremely short.

The radiation exposure of the population, if high enough, can lead to immediate radiation damage and long term effects (cancer, genetic changes, etc.) endangering large parts of the population are certainly to be expected. Evacuations and relocations can lead to additional serious strains on the people affected.

In order to be prepared for such an event, a large number of very different measures need to be taken by the state. Early warning and alarm systems must be installed, plans for evacuation and stocking of supplies must be developed, infrastructure for decontamination and treatment of casualties must be put in place as well as many other things. This is a continuous, ongoing effort by the municipalities, states, etc., the costs of which generally are not covered by Nuclear Energy costs.

These efforts must also be made by countries on whose territory no nuclear power plants or other nuclear installations are in operation.

Within the last years efforts have been made to improve international catastrophe management. The aim is to develop generally accepted forecast models and other decision support instruments for events of large releases and to compile basic advance planning needs and reactive actions in a nuclear emergency. IAEA has earned merit in these efforts. And although the efforts are a step in the right direction, they also can not offer a sound solution. Even in case of optimal emergency planning and management one must expect that in case of an accident many of the measures envisaged will not be in force in time, due to short lead times and the uncertainties regarding accident development and extent. On careful examination these efforts only prove our helplessness in view of nuclear catastrophes.

Nuclear Proliferation Issues

The commercial nuclear fuel cycle provides two principal paths of proliferation – from enrichment facilities (by means of highly enriched uranium – HEU), and from reactor spent fuel (by means of reactor grade plutonium that is basically weapons usable).

Starting from fresh low enriched reactor fuel (about 3.5 % Uranium 235) highly enriched uranium (90 %) can be quite rapidly gained, because at 3.5 % enrichment over 80 % of the total enrichment work is already done.

Weapons made from reactor grade plutonium are more likely to pre-detonate and thus result in less than full yields – even so-called “fizzle” yields are possible. However, even the minimum expected fizzle yield for an implosion weapon fabricated from reactor grade plutonium is of the order of one kiloton. This is still 4000 times larger than the explosion of a typical 500-pound military bomb. If detonated in a large city it would have devastating consequences.

Producing a nuclear weapon from spent reactor fuel is considered to be within the technical capabilities of sub-national groups. The technology of reprocessing is described in open literature, and there was sufficient open literature on nuclear weapons even in the mid-1960s to allow three graduate students in the US to successfully design an implosion weapon with a 15 kiloton yield with two man-years of effort. The resources required for extracting weapons quantities of plutonium from spent fuel are relatively modest. A small, well-prepared group (of about six persons) could accomplish this in perhaps two months.

No other bulk electrical energy or process heat source (coal, oil, natural gas, hydroelectric power, wind power, solar power, biomass, etc.) has such proliferation concerns associated with it. The proliferation potential associated with the commercial nuclear fuel cycle is unavoidable with current and even more so with up-coming technology. Even in the best cases of future technology, the proponents of the technology call it “proliferation resistant“ – not “proliferation-proof“. The risk can be reduced, but it cannot be eliminated.

Timeliness

Every option that is to contribute to the achievement of the Kyoto goals must at the latest become effective in the period between 2008 and 2012. For time periods until 2020 and 2050 additional, even more ambitious greenhouse gas (GHG) emission aims are being negotiated. For the growing electricity demand and in view of the foreseeable scarcity of oil additional energy sources might be needed in about the same time frame. Bottlenecks in several areas make it improbable that Nuclear Energy, even if strongly backed by policy, would be in a position to make a significantly higher contribution than at present:

- In the very short term, nuclear energy can only respond to the increased demand and the call for GHG emission reductions by extending the life time of existing power plants. This, however, can only delay the loss of present capacities, it does not create new ones.

- The transition to so called “inherently safe” reactors, indispensable for significant further expansion of Nuclear Energy, will not be possible in time, as the time frame for development and testing is considered to be at least 12 years at present.

- For a demand oriented expansion of Nuclear Energy, expertise and work power are needed that cannot be supplied in sufficient quantities in time. Even now there are shortages of well trained staff in some nuclear countries.

- Even if these problems could be overcome the foreseeable scarcity of (cheap) fissionable uranium would limit the contribution of Nuclear Energy. Only the fast reactors envisaged for the next generation but one will not be dependant on fissionable uranium. However, most of these reactors, as presently planned, lead to a plutonium economy.

- Developments necessary to create acceptance for the increasing amounts of high radioactive waste and to minimise negative impacts are not in view.

If Nuclear Energy is to play a non-marginal role in reducing CO_2-emissions, its rate of use would have to be increased at least at a rate that would correspond to the anticipated increase in fossil fuel consumption. This would require a rate of commissioning of nuclear power plants, which is far above that experienced in the ”golden” decades of Nuclear Energy, i.e. in the 1970ies and 1980ies. However, there is no basis for such a rate of deployment, neither regarding production capacity nor regarding the ability of host countries to absorb such a growth. It would also mean a drastic increase of the share of electricity in the energy mix, substantially above historical rates.

International Legal Framework

The economic use of Nuclear Energy entails transboundary risks which cannot be covered by national legal systems alone. This simple truism however is in clear contrast to the obvious interests of the nuclear power states to preserve their exclusive regulatory authority over their nuclear industry. For these reasons the respective international treaties and proposals for EAC directives do not go beyond stating general safety principles instead of safety standards. This position proves at deeper analysis to increase the potential threats and problems.

The Energy Perspective

Concepts that comply with the principles of sustainability and are thus environmentally and socially sound, free of potential for catastrophic events, flexible, transparent, etc. are called ”alternatives”:

- Alternative solutions in the more narrow sense are such that use energy fluxes rather than limited resources and that satisfy the criteria for sustainable technologies. An example for such an alternative is the use of passive solar energy or biomass.

- Alternative solutions in the wider sense are – as transitional solutions – technologies, which contribute substantially to the reduction of negative impacts or to the improvement of efficiency, such as e.g. co-generation systems.

Nuclear Energy is not considered to be an alternative solution of energy production.

An essential contribution to the reduction of energy demand and thus to the solution of the greenhouse problem is to be expected from service-oriented energy supply. Nuclear Energy is not service-oriented.

Nuclear Energy also proves to be a comparatively costly measure to reduce CO_2-emissions. Energy efficiency measures, renewable energies and alternative solutions in the wider sense replace 2.5 to 10 times as much CO_2 per unit investment.

While the search at first focussed on alternative means of energy production, it has become increasingly clear that the object must be to find alternatives to energy production, i.e. measures on the demand side (increased energy efficiency, reduction of demand by intelligent planning e.g. in the building and urban planning sectors).

Had the rate at which total world energy intensity decreased been slightly higher, e.g. 1.2 % instead of the historic 1 % per year, this would have equalled the total production of Nuclear Energy. A doubling of the rate to 2 %, which seems feasible, would lead to a world wide decoupling of economic growth and energy demand. This could be achieved through an economic policy of ”true prices”, i.e. with external costs included, rather than a policy of “cheap” energy. The reduction of CO_2-emissions due to Nuclear Energy and other CO_2-lean energy sources in the past was well below the contribution by efficiency increase and structural effects.

This implies that Nuclear Energy has the potential to slightly dampen the impacts of rising energy demand attached to desirable economic growth, while enhancing energy efficiency has the potential to avoid a rise in energy demand in a world with economic growth - and thereby initiate a successful climate policy.

There are studies that show that the Kyoto goals can be achieved in addition to nuclear phase out, if the political will is there. Even the long term aim of the European Union – the stabilisation of global temperature at +2 °C – is achievable without Nuclear Energy. Such scenarios include either the sequestration of a significant amount of CO_2 or a dampening of the energy demand curve.

The Economic Perspective

Even if only the energy production side is considered, increasing nuclear power is not a suitable instrument for climate protection from an economic point of view.

In a deregulated, competitive energy market investors prefer profitable options that have low and well-known technical, economic and political risks. Investment in Nuclear Energy is considered risky because of political risks (such as those arising from public opposition), technical risks related to safety and waste disposal issues, and economic risks associated with high initial investments, long and uncertain construction times and costs as well as liabilities for decommissioning and dismantling of nuclear power plants.

At present costs (planning, construction and operation) of electricity generated in nuclear power plants is expensive compared to that generated by coal and gas plants. Only if the present high prices for oil (above 30 US$ per barrel) remain valid over the operation time of 30 to 40 years or when assuming considerable, but not implausible cost reductions for all parts of nuclear power generation, but not for fossil energy, do prices converge. Increase of energy efficiency (reduction of energy intensity for supply of goods and services) is less costly and more effective regarding CO_2-emission reductions than any kind of additional energy supply.

The few nuclear power plants that have been ordered or are in construction in Europe (Finland) and the USA show that additional incentives are needed to trigger investments: government export credit guarantees, federal loan guarantees, low prototype costs, tax breaks, cost overrun guarantees in case of delays in the licensing process, assistance with historic decommissioning costs, etc. were offered.

The external costs and the need for regulation connected with the nuclear option are multiple and numerous compared to other energy options: on the national level specific regulatory bodies, radiation monitoring networks and costly emergency planning systems, on the international level especially the control of non-proliferation (e.g. CTBTO). The costs for these contributions, like the costs for environmental damages incurred in the complete fuel cycle, are generally not included in cost calculations for nuclear. Even the comprehensive comparative European study ExternE does not take account of the external costs for nuclear. Other subsidies also influence costs for nuclear: the advantageous regulations regarding decommissioning and waste management and the fact that the liability for damage resulting from severe nuclear accidents is not the sole responsibility of the operator but is partly borne by the state in which the plant is situated, partly by the member states of international conventions. In addition, liability is capped. It has been estimated that private insurance without a ceiling to liabilities would triple the electricity production costs in French nuclear power plants.

Hydrogen is no Solution

Hydrogen is not a primary energy source – it is an energy carrier, and must be created by using some other primary energy source (nuclear, wind, photovoltaic, biomass, etc.). Energy is required to create hydrogen, compress or liquefy it for storage, and distribute it. The overall efficiency of this centralized hydrogen economy is low and production methods are not yet mature.

Centralized, bulk hydrogen production, storage, and distribution carries with it risks of specific types of chemical accidents. A decentralized, "just-in-time" hydrogen economy is only just beginning to be explored. The security and terrorism threat implications of a hydrogen economy have barely begun to be considered.

The amount of hydrogen needed to support a hydrogen economy for light duty vehicles in the 25 EU states is of the order of 23 million metric tons per year. This is about half of the current world production. The production costs for this amount of hydrogen will run into the range of € 250-500 billion and require on the order of sixty EPR nuclear stations.

The environmental problems associated with the hydrogen economy, e.g. the effects of the release of hydrogen into the atmosphere, are only beginning to be addressed.

At present it is difficult to see hydrogen – nuclear or non-nuclear – as a significant contributor towards the solution of either the climate problem or the emerging energy gap; it is certainly not one that can be rapidly deployed.

Legal Aspects of Sustainability

The term "sustainability" as used in the Brundtland formula is not sufficiently clearly defined in the international legal context to be applicable to specific problems without concretion. It has to be augmented by additional values and objects.

The core of the principle of sustainability lies in an extended redistribution mandate: the distribution between the present and coming generations. Applied to Nuclear Energy this is a question of distributing the asset "environment" and the burdens of Nuclear Energy production among the present and coming generations.

The principle of proportionality of the law of the European Community may serve as base for concretizing the term "sustainability". In the energy context it requires that the present generations make do with the lowest possible energy demand and supply it with the least possible environmental costs. The costs and burdens of energy production should be borne solely by the generations benefiting from it.

Public International Law (especially international treaties) and Community Law show promising items with plausible procedural elements for giving the principle of sustainability legal relevance. Yet here too concretion is required for its applicability in individual cases.

The (IAEO) Convention on Nuclear Safety entered into force ten years after Chernobyl and about 40 years after the first nuclear power stations were put into operation. It contains only general safety principles, no specific safety standards. The legal autonomy of the nuclear power states remains untouched. Supervision of the compliance with the safety principles is restricted to a system of reports presented by the states to a tri-annual conference of the member states.

Attempts by the EU Commission to establish community wide security standards for Nuclear Energy failed, although they did not exceed the standards of the (IAEO) Convention already accepted by the EU Member States. However, in its first version, it contained a lean but promising system of supervision and provisions for the decommissioning of nuclear power stations. The real benefit of this attempt would have been the implicit establishment of the jurisdiction of the EAC and especially the European Court in matters of safety standards for nuclear power plants.

The costs of the dismantling of nuclear power stations, according to estimates by the EU Commission amount to 15 % of the total original investment, that is between 200 Million and 1 Billion Euro each. These costs arise after permanent shut down of the power plant, i.e at a time when no more income is procured. In view of planned life spans of 40 years this implies that the costs of decommissioning are shifted to a generation, that is not benefiting from the nuclear power plant.

The safety of permanent national repositories for spent nuclear fuel and high-level radioactive waste for the coming ten thousand years exceeds the capacity of all conceivable societal regulatory systems. In comparison: written human history covers 5000 years. In other words, the political systems of the nuclear power states are forced to project highly complex decision making systems over a period twice the span of hitherto written human history!

A closer look however reveals that the ten thousand years period is an arbitrary assumption. The half-life of many elements deposited is far higher – 16 million of years for Iodine-129 for example. The United States Court of Appeals for the District of Columbia Circuit in a judgement of July 9th, 2004 vacated the decision of the competent federal US authority to set up the Yucca Mountain permanent repository for spent nuclear fuel and high-level radioactive waste, because the compliance period of to 10 thousand years was considered insufficient.

The time dimension of the radiation problem ultimately proves the incompatibility of Nuclear Energy with the principles of sustainability.

Tuning In: Energy at the Turning-Point – From Oil to Sun

Peter Weish

April 2006

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Perspectives of Oil Production

The Age of Oil

The age of oil is about 100 years old. Cheap, abundant oil has manifested itself in many areas: huge urban concentrations, industrial complexes and gigantic traffic systems. Inexpensive energy also leads to inexpensive materials such as synthetics, steel, aluminium or glass. This resulted in a previously unimaginable economy of consumption and waste. The industrialization of agriculture has made food production completely dependant on oil.

The worldwide production of oil has now nearly reached its maximum, a situation that is called "Peak Oil". "*Today, we have extracted half of what is available, and know 90 % of all oil sources. We produce 22 Gb (Gigabarrel) per year, but discover only 6 Gb per year. Therefore we can say that today, for every four barrels of oil that we consume, only one barrel is found in addition. The present rate of oil field depletion is about 2 % per year.*" [Campbell 2000]

The Foreseeable End of Cheap Abundant Oil

Demand continues to increase, China is an impressive example, although production can no longer be increased at will. If demand supersedes production – and that could very soon be the case – significant, lasting price increases will be unavoidable.

"The coming years until the worldwide maximum of oil production is reached, there will probably be a series of dramatic ups and downs in oil price. Only after Peak Oil will the instability of the oil price be overcome. The market will then reflect the long term scarcity of oil. The price level will be significantly higher than the present level." [Schindler und Zittel 2000]

Gas prices will follow the price of oil. The result is higher energy costs for consumers, especially for heating and electricity, but finally, a rise in the price of goods in general will occur.

The Short-Sighted Societal Reaction

People, who in the past few decades have taken the rising oil consumption for granted, will probably look for direct replacements and will want to continue as before. The same is true for many sectors of economy that have become dependent on inexpensive energy and resources during the last decades.

The result is a supply oriented energy policy that calls for new energy sources and greater power plant capacity.

In order to cover increasing demand for fossil fuels, enormous investments in the further prospection and development of oil and "unconventional" energy sources would be needed. Ocean drilling, extraction of oil sands, etc. implies – besides environmental damage and high costs – an unfavourable energy balance.

Nuclear Energy

As the example USA shows, investments in armament and propaganda are being made in order to be able to resolve conflicts arising in the fierce competition for ever depleting supplies by force (war).

With the rise in price of natural gas, nuclear energy looses its cheaper competitor and is being propagated as more cost effective. Furthermore, because of its (supposed) lack of CO_2-emissions, nuclear energy has been publicized as the solution to the climate problem that - for many reasons - it cannot be. Even if one overlooks the undeniable dangers of nuclear energy, it still cannot be an alternative to oil, because it is dependant on non-renewable Uranium.

Jan-Willem Storm van Leeuwen and Philip Smith, summarize their detailed calculations: "*The use of nuclear power causes, at the end of the road and under the most favourable conditions, approximately one-third as much CO_2-emission as gas-fired electricity production. The rich uranium ores required to achieve this reduction are, however, so limited that if the entire present world electricity demand were to be provided by nuclear power, these ores would be exhausted within three years. Use of the remaining poorer ores in nuclear reactors would produce more CO_2-emission than burning fossil fuels directly.*" [Storm van Leeuwen and Smith 2003]

Insights published more than 30 years ago gain new actuality: "*By succeeding in tackling the environmental problem – the uncontrollable growth of energy consumption – at its root, energy shortage will prove to be a pseudo-problem and the development of nuclear technology will paradigmatically stand for a technological aberration.*" [Weish und Gruber 1973]

Hydrogen Economy as a Solution?

Hydrogen power is without a doubt a practical (it can be stored) and at first glance an environmentally friendly energy carrier, that must, however, be extracted e.g. from water with high energy input (preferably with electricity from solar panels). The large-scale conversion to a hydrogen powered economy would take a few decades and would inescapably cause considerably higher energy costs than those that current economy is adapted to. Currently there is a controversy considering the economic practicality of hydrogen power[1]. Critics point out that it would be more energy efficient to use the electricity needed for hydrogen production directly and additionally save the costs of installing a hydrogen infrastructure.[2]

A large scale hydrogen economy, with considerable leaks, appears from the ecological perspective to be not unproblematic [e.g. Schultz et al. 2003].

1 See references on hydrogen economy.
2 Compare Chapter 11 in this volume.

The Inevitable Crisis

The basic problem remains: the end of the oil age is not reached when the last barrel of crude oil is sold, but when cheap, abundant oil is no longer available. None of the alternatives envisaged can ever be as inexpensive as a ”gushing“ spring of oil. Because of this it is apparent that broad parts of the economy, such as the large scale traffic systems or the industrial agriculture cannot be maintained and if this is attempted, which must be feared, then significant damage to political economies is inevitable. For the loss of cheap energy, if not dealt with consequently and in time, means supply crises and breakdown of the economies. Jobs will be lost and high energy prices will lead to substantial reductions in energy services. Surprising and far-reaching ”domino effects“ with catastrophic consequences can be expected.

Industrial agriculture will become more expensive, food prices will increase (in industrial agriculture the production and provision of one Joule of food often demands 10-20 Joule of oil). Food provision can break down in large regions.

The consequences for economy and society can reach catastrophic dimensions.

Crisis and Chance

New Insights Gain Ground

The insight that the lavish use of energy and resources, as was possible in the age of oil, is not sustainable and that measures must be introduced immediately to reduce demand, initiates a healthy development towards a turning-point[3].

Consumer orientated energy policy, in many ways successful in many cases since the early 70’s, but never consequently followed up upon, is finally given priority.

Investments for structural adjustments are being made in the direction of lowering energy demand, decentralization, developing renewable energy systems and solar architecture. Backwards oriented investments (like those in new highways, and shipping routes) are being avoided. In short, an “energy turn”, as already conceptually developed in the early 70’s, is being consistently pushed forward.

A dramatic decrease in demand (cuts in quantitative and qualitative[4] waste of energy and material) will be achieved as a requirement for an ecologically sustainable energy supply from renewable energy sources.

When using renewable energy, the focus lies on the development of “soft” technologies. Decentralised production of biogas in grassland can serve as a good example.

Thus the “Power Plant Grassland” concept has several impressive advantages: Combined heat and power production can supply valuable peak electricity, the energy production is CO_2–neutral,

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3 This turning-point is described in the following, so that this positive utopia may motivate and give power to civil society and politics for brave changes, to prevent the dire consequences from being realized to their full extent.

4 An example for qualitative waste of energy is heating with electricity, a high quality energy.

and the sludge from biogas can be fed back to the grassland as valuable fertilizer. Because of its botanical compatibility it can be applied during the growth period, and there is no danger of contaminating ground water; the fertility of the soil is enhanced. Food and energy production can be coupled and even if this option is not taken, the maintenance of the agricultural system makes re-conversion to food production possible at anytime in the future.

The change in energy production consequently leads to a deceleration of the climate problem.

"Peak Oil" and the expected consequences present a decisive argument for the economy to address the dramatic downsizing of the use of fossil fuels as a source of energy in self interest[5]. It is apparent that every delay in making the necessary structural changes will be penalized by avoidable energy costs and is therefore, in the increasingly fierce competition, threatening survival. Economic selfishness develops in to a driving force for climate policy.

The current environmental situation could also improve, because the exaggerated production and the pursuant refuse are made increasingly unprofitable through a rise in energy and resource prices. Long-lasting goods and their upkeep would again have a better chance, with advantages for the user and the labour market.

"Eco-Taxes" and Legal Framework Create Meaningful Jobs

The alternatives friendly to life that were developed and implemented over the last few decades compliment each other.

Instead of the large scale energy consuming mono-culture of industrial agriculture, smaller scale forms of organic farming and gardening as well as new systems like perma-culture have developed. In this way, a secure supply of food is being secured for the future.

Generally, a process of decentralizing is being initiated. The orientation towards solar energy favours small-scale production close to consumers.

The "mega-cities" crisis-ridden by infrastructure problems that grew during the age of oil are beginning to "shrink for health". "Eco-villages" are being founded, in which people not only find meaningful "jobs", but create their "places for life" and a fulfilling and sustainable life style that is based on autonomy and self-sufficiency.

The environmentally damaging, resources squandering economy of waste will be replaced by a "society of repair".

The foreseeable dramatic rise in oil prices offers a chance for a relatively smooth conversion to a sustainable economy and society. The political challenge is to create the legal and economic framework for this development.

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[5] The political decision in Sweden to terminate dependence on oil and nuclear energy within the next 20 years is in the long term interest of the Swedish economy.

References

Campbell, C.J. (2000): BP Amoco Statistical Review of World Energy, Petroconsultants, LBST

Schindler, J. and Zittel, W. (2000): Der Paradigmenwechsel vom Öl zur Sonne. Natur und Kultur 1/1 2000, S. 48-69

Schultz et al. (2003): Air Pollution and Climate-Forcing Impacts of a Global Hydrogen Economy. Science Oct. 24, 2003, 624-627

Storm van Leeuwen J-W. and Smith, PH. (2003):
http://www.elstatconsultant.nl/ (Revision dated October 31, 2003]

Weish, P. und Gruber, E. (1973): Atomenergie und Umweltsituation. - Kramer Verl. Framkfurt/M.

Internet sites on “PeakOil“

http://www.oilcrisis.com/
http://www.energiekrise.de/
http://www.peakoil.net/
http://www.wolfatthedoor.org.uk/
http://www.wbgu.de/
http://www.elstatconsultant.nl/

References: Pro and Con Hydrogen Economy

Pro:
http://www.hyweb.de/gazette/Thesen_und_Gegenposition_Wasserstoff.pdf
http://www.bio-wasserstoff.de/pdf/Stralsund2005_paper.pdf

Con:
http://zeus.zeit.de/text/2004/42/Wasserstoff

Ulf Bossel: Elektronenwirtschaft statt Wasserstoffwirtschaft
http://www.eurosolar.org/new/de/downloads/SZA_bossel.pdf

1 The Revival of the Nuclear Debate: Climate Change and “Peak Oil”

Helga Kromp-Kolb and Franz Meister
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1 The Revival of the Nuclear Debate: Climate Change and “Peak Oil”

1.1 Motivation

As a result of the increasing manifestations of climate change and the foreseeable end of the era of cheap oil the debate on the use of nuclear power has experienced a revival in the last few years. The shortage of gas that threatened in consequence of the dispute over the price of gas between Russia and the Ukraine in the spring of 2006 has triggered a call for security of supply, enhanced energy autarky and a joint energy policy in Europe. This also brought nuclear energy back into the debate.

In about a dozen topical papers the present assessment of the Nuclear Advisory Board of the Austrian Federal Minister for the Environment discusses the question, whether the nuclear option could constitute a sustainable contribution to climate change and an alternative to fossil fuels when – sooner or later – the end of cheap oil sets in (“Peak Oil”) or when politically or economically motivated scarcity of supply occurs.

Preceding these papers an overview is given of climate change and the expected further climate development on the one hand and the background and the indications for the foreseeable end of cheap oil on the other.

1.2 Climate Change

1.2.1 Introduction

Climate has been changing as long as we can reconstruct the state of the earth, the changes being due to a number of very different factors, such as the intensity of solar radiation, the geometry of the earth´s movements in space or the composition of the atmosphere following the development of plants, volcanic eruptions, etc.. Recently, the influence of anthropogenic activities on the composition of the atmosphere and the reflectivity of the earth´s surface contribute to climate change. These cycles and changes in the drivers of the earth´s climate take place on very different time scales, ranging from millions of years to decades and years.

Changes in the earths orbit and inclination and their interactions e.g. lead to ice ages alternating with warm periods – a cycle on the order of 100,000 years, that can be reconstructed based on the analyses of sediments, ice cores, etc.. Changes in the intensity of solar radiation and volcanic eruptions are believed to have caused the “Little Ice Age”, which lasted for about 300 years in Europe following the medieval warm period and is documented e.g. in Breughel´s paintings of frozen canals in the Netherlands.

None of the “natural” drivers can, however, explain the rapid warming that has taken place globally over the last 150 years, and especially over the last few decades. Dynamic climate models based on equations describing the physical processes determining climate (so called General Circulation Models or Global Climate Models - GCMs), can only reproduce these features when anthropogenic influences are taken account of. This led the Intergovernmental Panel on Climate Change (IPCC), a scientific advisory body of the United Nations, to state in its Third Assessment Report in 2001 that “*there is new and stronger evidence that most of the warming observed over the last 50 years is attributable to human activities*.”

In spite of continuous assertions of the opposite by the media, these essential facts of climate change are no longer disputed in the scientific world. There is also agreement on the scenarios of future global climate change, based on our understanding of past and present climate, although uncertainties are much larger in this case.

1.2.2 Observed Climate Change

The last decades have shown increasingly clearly that global climate is changing. This change can be observed in time series of measured meteorological data, such as temperature or precipitation, and in developments within the geo- and biosphere. Some examples are presented below.

The global average temperature in the last century has risen by about 0.6 °C, the speed of the temperature increase and the temperatures reached being the highest observed in the last 1000 years [IPCC 2001]. The temperature increase can be observed throughout the lowest 8 km of the atmosphere. Temperature has increased more strongly at night, thus reducing the daily temperature amplitude. The time series also show that on a global level, the speed of change is increasing: 0.07 °C per decade between 1901 and 2000, 0.15 °C per decade between 1981 and 2000 [Schönwiese et al. 2004].

Although climate change is a global phenomenon, it can be strongly modified at the regional or local scale: while global temperature has risen by 0.6 °C over the last 150 years, Austria e.g. has registered a rise of 1.6 - 1.8 °C in the same period [Auer et al. 2001] and the arctic even of more than 4 °C [Hassol 2004].

The observed changes in precipitation are spatially less homogeneous and statistically significant trends over larger regions can frequently not be found in the available data series. Precipitation has increased globally by 0.5 - 1 % / decade – somewhat less in the tropics and significantly more in northern Europe. Some regions, e.g. southern Europe, have become drier. Frequency of intense precipitation events is rising and cloudiness has also increased [IPCC 2001].

The very small scale structure of precipitation characteristics can be demonstrated taking Germany for an example: overall precipitation increased in Germany between 1971 - 2000 by 16 %, in winter even 34 %. The increase is especially pronounced in the west and the south, where increased frequency of extreme monthly and daily precipitation sums are observed. The increase is smaller in the east, where even a decrease is documented for summer and the risk of draughts is enhanced. Almost throughout the country trends for the likelihood of monthly precipitation above 180 mm in the period 1901 - 2000 are positive [Schönwiese 2004].

With a few exceptions (e.g. in Scandinavia or New Zealand) glaciers are retreating world wide and perma frost is thawing – in the mountains as well as in the tundra. In the arctic the decrease in ice thickness and of the area covered by ice is especially dramatic [IPCC 2001, Hassol 2004].

In Europe the onset and the length of spring and summer defined by the phenological stages of indicator plants have changed by almost two weeks in the last decade, as compared to the 30 year period before [DWD 2002]. Some birds are hatching earlier in the year, others have changed their migration habits [Bairlein und Winkel 1998]. Comparisons with historical data show the migration of species to higher regions. In the arctic the polar bear population is threatened by the melting of ice [Hassol 2004].

1.2.3 Climate Change Scenarios

The same models used to reconstruct and understand past climate can be used to calculate future climate scenarios, based on assumptions regarding the development of world population, on economic and technological development, etc. and the resulting greenhouse gas emissions.

According to the scenarios developed by IPCC for 2100, CO_2-concentrations between 550 and 950 ppm are to be expected. Depending on the extent of greenhouse gas emission reductions temperature increases between 1.4 and 5.8 °C must be expected in the coming 100 years [IPCC 2001]. The observed warming will continue for well beyond the present century.

Climate models with the normal scale resolution of some 150 km (GCMs) need to be scaled down to higher resolutions in order to reproduce local and regional climate with sufficient accuracy. Even though the downscaling results are of considerable uncertainty, they afford the possibility to study possible climate change effects at an impact-relevant scale.

The global temperature increase of 1.4 - 5.8 °C translates to an increase of 0.1 - 0.4 °C temperature rise per decade in Europe, somewhat lower on the Atlantic coast and higher in the South and Northeast. Even more rapid warming is expected in continental Russia in winter. In summer a strong North - South gradient will develop as the South warms at double the rate of the North. [Prudence 2006]

Going to an even smaller scale, precipitation trends observed in Germany will be subject to considerable change: for Hessen and northern Germany a precipitation increase of up to 60 % is expected by 2040 - 2050, while the south and northeast of Germany would experience a decrease of about 30 %. The summers are expected to be warmer and drier, while precipitation increase in winter continues [Enke 2004]. Local and regional events of extreme precipitation can occur throughout the country [Schönwiese 2004].

As a result of the warming of the surface ocean waters and of the melting of polar and alpine glaciers, a rise in sea level between 55 and 88 cm is expected by 2100 [IPCC 2001]. More recent calculations indicate that the sea level rise could be significantly higher, and could reach about 4 m [Overpeck et al. 2006].

Changes in a large number of other meteorological parameters are tied up with the changes in temperatures and precipitation but cannot be described in this brief overview.

1.2.4 Extreme Weather Events

There are indications that the transition to a warmer climate will be accompanied by an increasing number of extreme weather events such as intensive precipitation, storms, draughts and heat waves. As yet there is no strict scientific proof of a causal connection between climate change and individual extreme events. From a statistical point of view however, a change in mean temperatures, e.g., will – the distribution remaining unchanged – lead to an increase in frequency of very high temperatures. If climate variance increases at the same time – and there are indications that this was the case in former periods of climate change – then the effect is enhanced. Calculations for Switzerland have shown for example that the exceptionally warm summer of 2003 in Europe, a once in one thousand years event, could be considered almost normal in the period 2070 – 2100 due to the expected increase in temperature variance [Schär et al. 2004].

Based on considerations regarding the physical processes involved in climate change, increased temperatures and an enhanced water cycle could e.g. make heavy precipitation more likely.

1.2.5 Consequences of Climate Change

Climate change is likely to affect every single person and practically all economic sectors worldwide directly or indirectly. Some Small Island States are threatened in their existence due to rising sea levels. In other, partly very densely populated countries like Egypt and Bangladesh, millions of people will loose their home and livelihood as land is lost to the sea. IPCC assessments show that developing countries, due to the limited means of adaptation, are especially vulnerable to climate change: scarcity of fresh water and significant yield losses e.g. for grains could lead to famine and mass migrations. Overall destabilisation of the world and increasing potential for conflicts must be expected. [IPCC 2001, Schwartz et al. 2003, WBGU 2003]

1.2.6 Climate Policy and Reduction Schemes

The first official reaction to climate change on a global level was the UN Framework Convention on Climate Change, signed by 154 states in Rio de Janeiro in 1992. It aims at the *“…stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system. Such a level should be achieved within a time-frame sufficient to allow ecosystems to adapt naturally to climate change, to ensure that food production is not threatened and to enable economic development to proceed in a sustainable manner.*” The Convention does not define the steps necessary in signatory states to achieve these goals, but it does give guidelines for future development. The concrete steps and the sanctions in case of failure to implement them are decided on in annual Conferences of the Parties to the Framework Convention (COP).

At the COP in 1997 in Kyoto, Japan, reductions in greenhouse gas emissions were agreed on for every signatory state that, in sum, amount to a reduction of 5 % of the emissions of industrialised nations in 1990. This is well below the reduction necessary from a scientific point of view to even stabilise greenhouse gas concentrations in the atmosphere. Nevertheless, the Kyoto Protocol is of great significance as it is – on becoming effective in 2005 - the first international treaty to prescribe in a binding way reductions of greenhouse gas emissions.

Meanwhile discussions about the post Kyoto period (beyond 2008 - 2012) have set in: the European Union is proposing emission cuts that are intended to limit the global temperature rise to 2 °C as compared to the pre-industrial period. When crossing this limit, severe consequences are expected and an unacceptable increase of the likelihood of large, non-controllable changes such as the die-down of the thermohaline circulation[1]. In order to achieve the 2 °C goal by the

[1] Frequently addressed as the Gulf Stream coming to a standstill.

year 2050 greenhouse gas emissions must be reduced globally by about 50 % compared to 1990, in industrialized states by about 80 %. This could be achieved by several energy paths, some of which include an increased contribution by nuclear energy and / or the sequestration of carbon dioxide, while others accomplish the same goal without either. It is important at what time “peak oil” occurs and how far energy efficiency has progressed by then and whether renewable energy sources have been implemented on a large scale. [WBGU 2003]

1.2.7 Possible Consequences for the Production of Nuclear Energy

Climate policy calls for measures to reduce greenhouse gas emissions (mitigation) and to adapt to changed climatic conditions (adaptation). Both types of measures can have effects on nuclear energy production.

The possible contribution of nuclear energy to greenhouse gas emission reductions is extensively discussed in other contributions to the Assessment. The essential conclusion of those papers is, that nuclear energy based on present day technology or technologies now in development, will not be able to make a significant contribution to the mitigation aims of the UNFCCC or, more specifically, the Kyoto Protocol. This includes the nuclear production of hydrogen to replace fossil fuels in the transport sector.

The shift of the demand for energy from winter (heating) to summer (cooling) due to climate change in mid- and higher latitudes is an example for adaptation. Whereas electric power supplies only a small part of the energy used for heating, it is at present the chief energy carrier for cooling. This means that whereas electricity demand in winter will not decline significantly, the electricity demand in summer will probably rise in the coming years. This could encourage further development of nuclear energy. However, technological developments leading away from the use of electricity for cooling are already emerging.

Finally, climate change can also influence the safety of nuclear power plants. This topic is discussed in the paper on nuclear safety in this volume.

1.3 “Peak Oil”

1.3.1 Introduction

“The conventional wisdom of the prevailing economic theories relies on the axiom that worldwide economic growth of a nature which implies continued growth in the production and consumption of energy-consuming hardware can continue for an indefinite length of time. That market forces will ensure that new resources and new technologies will always be at hand when access to the resources upon which our societies depend becomes restrained and present technologies therefore become obsolete.

History shows that man has hitherto succeeded in making life easier by means of new energy sources and technologies. From manpower to horsepower. From horsepower to coal-fired steam engines. From steam engines to oil-engines. Thus economic development has, so to speak, been a ride downhill with the wind behind us. However, there is nothing in sight which is so easy and cheap to get, handle, store, and to use in cars, buses, trucks, tractors, ships, and aeroplanes as oil from oil wells. Therefore, unless something unknown today turns up or our oil-based consumer *culture takes a turn towards less oil-dependent activities, we face an arduous ride uphill against a headwind when one day the supplies of cheap conventional oil become restricted.*

History may reveal that the prevailing axiom of sustainable economic growth is a theoretical derivative of the cheap-oil era. In contradistinction to economic theory, oil geologists have voiced concerns about future oil supply." [Illum, K. 2004]

1.3.2 The Role of Oil

Oil contributes about 40 % to the world energy consumption and is still the most important energy source of the world economy. Of all economic sectors it is most dominant in the area of mobility: 50-60 % of the oil is used in the mobility sector and 90 % of the energy for this sector comes from oil and gas.

Oil is also one of the most important raw materials of the world, many essential things of every day life are produced from oil:

- chemicals and solvents
- plastic
- paint and varnish
- wrappings, foils and plastic covers
- artificial fibres (carpets, clothes, curtains)
- articles of hygiene and cosmetics (soaps, perfumes, lipsticks and hairsprays)
- infrastructure construction (roads)
- medicines
- fertilizers and pesticides

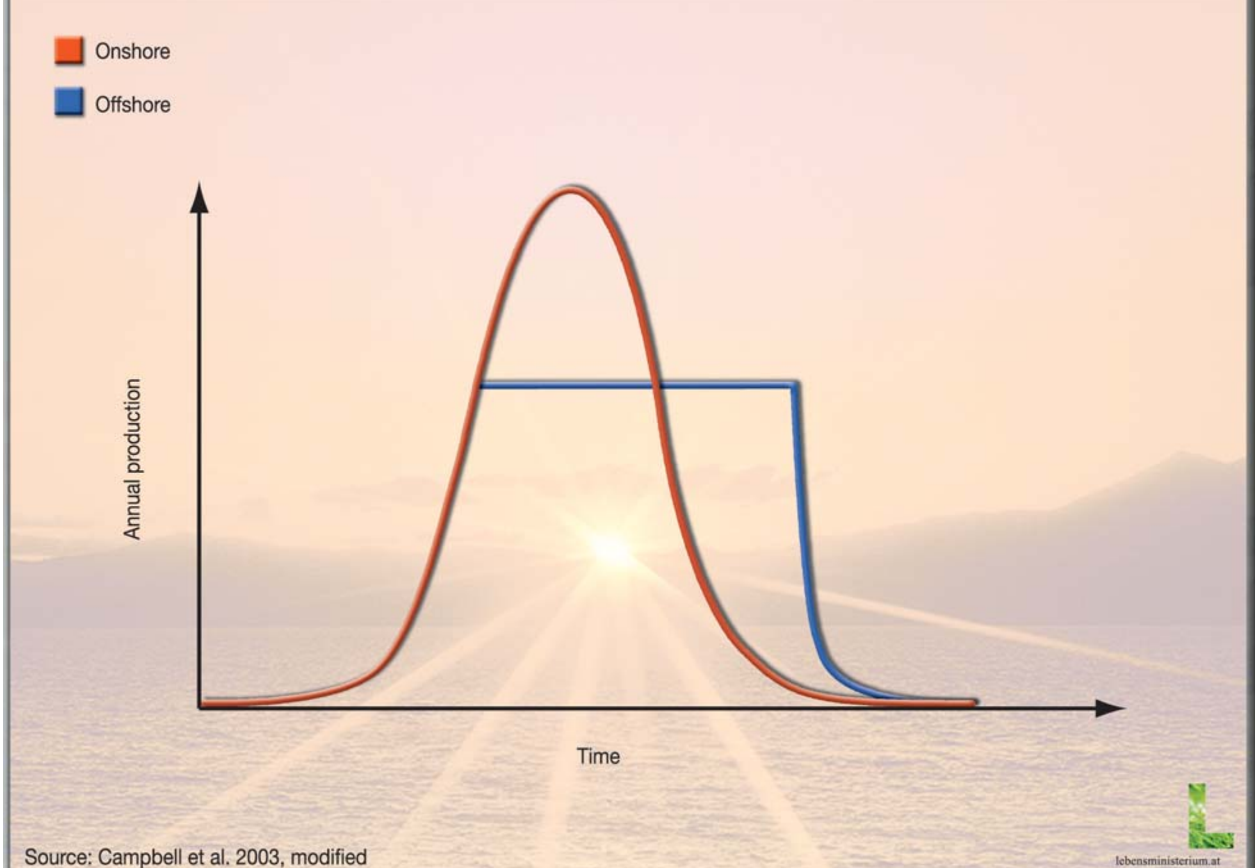
This list illustrates that oil, its availability and price are of eminent importance for the economies of the world.

1.3.3 Production Profiles of Oil Fields

The production of an individual oil field follows a bell curve: increasing until about half of the endowment of oil has been depleted and then dropping at about the same rates (Figure 1-1). When the pressure in the reservoir drops, the extraction of the remaining oil requires increasing efforts. Pressure can be enhanced artificially to a small degree (e.g. through the injection of gas or water) or the viscosity of the oil can be reduced through additives. These measures can influence the downward curve and therewith the production rate only within narrow limits. As long as the production of an oil field is on the up slope side of the bell curve, production rate can be increased by adding new drilling stations. Once the maximum production has been passed, the decrease in production can be slowed down through added technical and financial resources for economic reasons, but the trend in production rate is invariably downward from year to year. [Cambell et al. 2003]

The situation is somewhat different for offshore drilling: While onshore even a production declining by several percent per year can be economically viable for many years, as the original investment exceed the operating costs by far, offshore oil fields are exploited as fast as possible. When production rates fall below a certain limit, the high running costs of offshore oil platforms make their operation unprofitable. As the European oil production is mainly offshore, experts expect a very rapid decline at the end of the production plateau of the large, older oil fields [Cambell et al. 2003].

Fig. 1-1 **IDEALISED PROFILE OF OIL PRODUCTION ONSHORE AND OFFSHORE**



Source: Campbell et al. 2003, modified

Many examples document the typical production profile of oil fields: in 1991 the largest oil field in the western hemisphere since 1970 was found in Cruz Beana in Columbia. The production rate fell from 500,000 Barrel[2] per day at the time of peak production to 200,000 Barrel per day in 2002. In the mid-eighties 500,000 Barrel per day were produced in Forty Field in the North Sea – today production is down to 50,000 Barrels per day. One of the largest fields of the last 40 years, Prudhoe Bay, produced for almost 12 years, till 1989, 1.5 Million Barrel per day. Today the production rate is only 350,000 Barrel per day. The huge Russian Samotlor-Field produced a maximum rate of 3.5 Million Barrels per day at peak times, today the daily production is about 350,000 Barrel. In each of these oil fields production was maintained by introducing gas or water

[2] 1 Barrel = 159 litres

from above into the oil containing layer to maintain the pressure in the oil field. The largest oil field in the world, Ghawar in Saudi-Arabia, at present produces about 60 % of the Saudi Arabian oil, corresponding to about 4.5 Million Barrel per day. Some years ago, the oil gushed from the well through natural pressure. In order to achieve the same production rate now, 7 million Barrel of saltwater are added per day according to geologists – a clear signal for the up coming production decline in the largest oil field of the world.

As most oil fields outside the Middle East are near or beyond their production peak, an increase in production cannot be expected, rather production will drop year by year. The USA, once the most important oil producer of the world, has passed its production maximum 30 years ago and presently produces but 60 % of the rate in the early 70ies. For economical reasons attempts are made to reduce the production decline after the maximum. The European oil production is expected to surpass its peak within few years at the latest.

1.3.4 Availability of Oil

Thus the debate on the availability of oil is not only fed by the significant rise in international oil prices within the last years. However, when following the oil discussion, care must be taken as the term “availability” is used in different meanings:

- Availability in view of reserves, oil that is basically there and extractible;

- Availability in view of satisfying increasing demand measured against production rates per day;

- Availability with respect to safe access to production sites and transport routes and

- Availability in view of the development of prices.

The term “Peak Oil” designates the point in time when the maximum global production rate is reached. After “Peak Oil” the global production rate decreases, even if higher production costs are accepted. Thus “Peak Oil” does not mark the exhaustion of oil reserves, it only marks the time after which - if demand stays constant or increases - reduced production rates cause deterioration of availability and consequently rising prices.

“*The essential aspect is that from the moment when an oil field has passed its production maximum, the exact amount of reserves is no longer significant for the future production costs. Whatever the total amount proves to be at the end of production (compared to the initial estimates), the production rates will always drop. [….] Decisive for structural changes in the energy supply is not the (static or dynamic) reach of the reserves, that is “how long is there oil at the given production rate?”, but the question: from what point in time can the oil production no longer be increased for geological, technical and economic reasons but only drops in tendency?”* [Campell et al. 2003]. This fact makes the following debate on “Peak Oil” easier, as the numbers given for the size of the oil reserves differ widely and have also been subject to significant corrections, indications that large uncertainties are involved. By comparison annual production rates are much better known. In hindsight the point of maximum production is easy to determine: for most oil fields it lies in the past.

1.3.5 When Will "Peak Oil" be Reached?

World wide oil production has reached its highest level so far. "*We have extracted half of the available oil, and we know 90 % of all endowments. We produce 22 Gb per year, but we only find 6 Gb per year. Therefore we can say that for every 4 Barrel we consume we only find one new one. The present rate of exhaustion of the oil fields lies near 2 % per year.*" [Campbell 2000]

In the 10 years from 1990 to 2000 42 billion barrel of new oil reserves were discovered. In the same time the annual consumption was 250 billion barrels. In the last two decennials only three giant oil fields with more than a billion barrels were discovered, in Norway, Columbia and Brazil. From each field no more than 20,000 barrels are produced daily.

The hope of finding new large reserves of conventional oil is small among experts, as the development of oil necessitates certain natural preconditions making oil a limited resource. The peak of new discoveries occurred in the mid 1960ies; large fields have not been found since the early 90ies. [Petroconsultants 1995]

Thus the known reserves and their regional distribution will increasingly determine the course of production in the coming years: 90 % of the present oil production come from oil fields that are older than 20 years and 70 % from fields older than 30 years. According to the recently published report on "The worlds largest oil fields" compiled by the Colorado School of Mines, "*the 120 largest oil fields of the world produce 33 Million barrel daily, that is almost 50 % of the worlds enormous need. The 14 largest produce over 20 %, their average age is about 43.5 years*" [Simmons 2002].

According to competent estimates of internationally renowned geologists, such as the French Petroleum Institute, the Colorado School of Mines, the Uppsala University and Petroconsultants in Geneva, the effects of the diminishing oil reserves or oil production will be dramatically noticeable by the end of this decennium or even earlier.

Interestingly, differing opinions are generally voiced by economists, such as for example the chief economist of BP, Peter Davies, who believe that the market will regulate the availability of oil: oil prices will rise with shortages and make less easily accessible fields (e.g. unconventional reserves) profitable, thus making more oil available. This might be correct in principle, but it overlooks the fact that the decisive quantity is production rate, that is production per day or year, not the produced amount, and the achievable production rates for most unconventional fields are much lower than for conventional oil fields.

Pessimists [see e.g. Savinar 2006] believe "Peak Oil" to be the turning point in the history of the industrialised world, as it is dependant on cheap oil in all fields. This is true amongst others for industrialised agriculture that could only reach present production rates by using fossil fuel (coal, oil) and derivatives of oil (fertilizers and pesticides). "Peak Oil" is of central importance, because it must be expected that upon reaching it, prices will rise out of proportion and a world wide oil crisis will ensue. Demand will no longer primarily determine the price on the market, but the increasingly sparse supply (sellers market).

Of those experts concerned regarding "Peak Oil", some believe that "Peak Oil" outside of the OPEC region was passed in the year 2000, others expect it around 2010 [e.g. Campbell et al. 2003, Simmons 2002]. In any case the passing of "Peak Oil" has the consequence that OPEC will again grow in importance. OPEC members could determine production rates and thus also the price and thereby put growing political pressure on the industrialised nations. Especially Saudi Arabia, Iraq and Iran with their large oil reserves will gain in geopolitical importance.

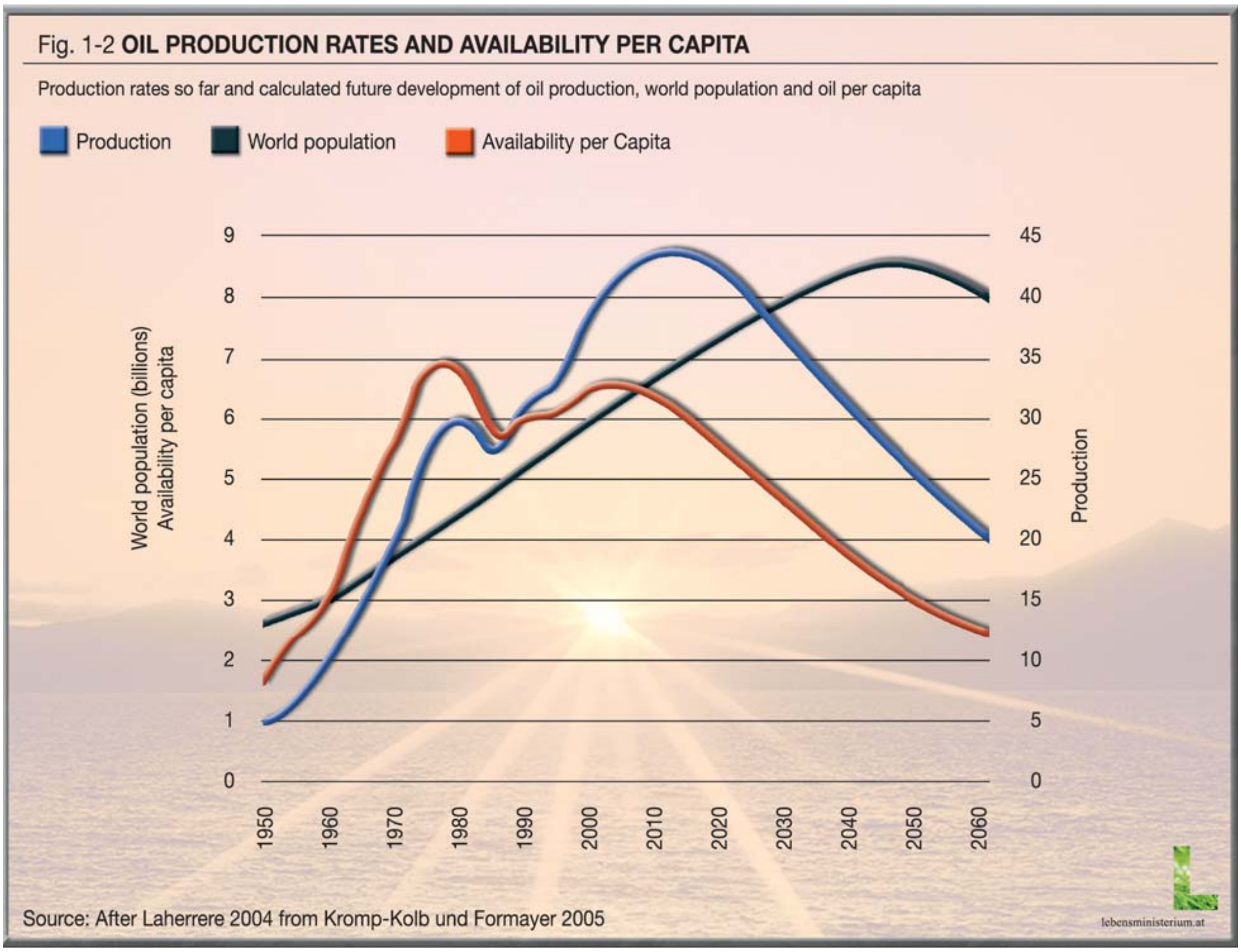


Fig. 1-2 **OIL PRODUCTION RATES AND AVAILABILITY PER CAPITA**

Production rates so far and calculated future development of oil production, world population and oil per capita

Source: After Laherrere 2004 from Kromp-Kolb und Formayer 2005

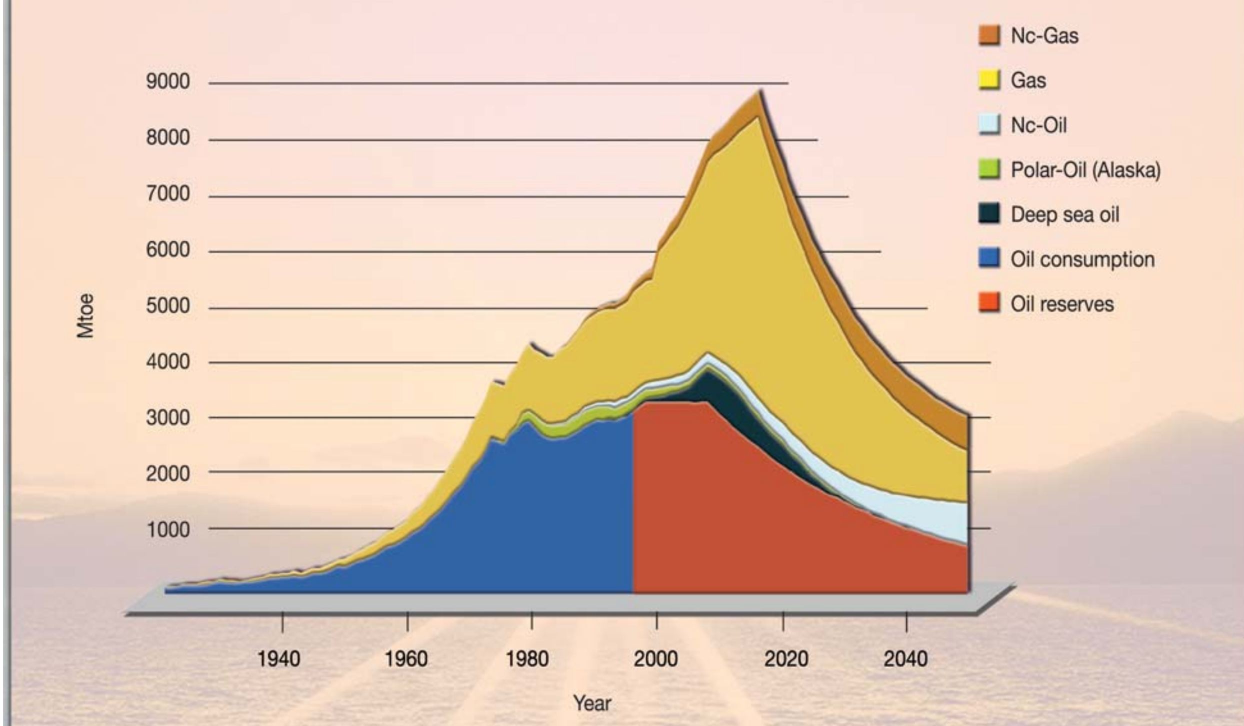
1.3.6 Gas

Gas is easier to extract than oil and the production rate responds to the market more easily than that of oil. The production rate is often constant over many years. Frequently, however, the drop at the end occurs much more rapidly than for oil.

The availability of gas has already notably dropped in some regions of the world. The US gas production has more or less reached its maximum and a supply crisis could occur soon. In Europe the situation will be similar in a few years. If consumption grows in agreement with the infrastructure being built world wide for the distribution of gas, the maximum production could occur around the year 2020 or even earlier [Campbell et al. 2003].

Fig. 1-3 **POTENTIAL PRODUCTION OF CONVENTIONAL OIL AND GAS UNTIL 2050**

Potential production of conventional oil and gas till 2050, as well as possible contributions by non-conventional energy reserves



Quoted from: Jörg Schindler, Werner Zittel (LB-Systemtechnik GmbH): „Fossile Energiereserven (nur Erdöl und Erdgas) und mögliche Versorgungsengpässe aus Europäischer Perspektive", Ottobrunn 2000. This study was commissioned by the German Bundestag, Committee on Education, Technology and Assessment of Consequences of Technology

lebensministerium.at

1.4 Conclusions

The necessity to protect the climate as well as the foreseeable shortage of oil and gas call for a search for new ways to cover energy needs.

On the one side the increase of energy efficiency and the implementation of renewable energy sources is demanded, on the other increased use of nuclear technologies is being brought into the discussion. This includes nuclear power plants for electricity production as well as for the production of hydrogen. Hydrogen, like electricity, is but an energy carrier, not an energy source, and must therefore be produced; a process requiring energy input.

When looking for a long term, future oriented solution, the answer to climate change and the scarcity of oil and gas must be sustainable – ecologically, economically and socially. The question whether nuclear technologies can meet this criterion, that is contribute significantly and in a sustainable manner, is treated in the following 11 expertises in this volume.

1.5 References

1.5.1 Climate Change

Auer, I., R. Böhm, W. Schöner (2001): Austrian Long-Term Climate - Multiple Instrumental Climate Series from Central Europe. Österr. Beitr. zu Meteorologie und Geophysik, Heft 25

Bader, S. und P. Kunz(1998): Klimarisiken - Herausforderung für die Schweiz, Schlußbericht des Nationalen Forschungsprojektes 31, v/dlf Hochschulverlag Ag.

Bairlein, F. und W. Winkel (1998): in: J. L. Lozan, H. Grassl, P. Hupfer: Warnsignal Klima – Das Klima des 21. Jahrhunderts. Geo ISBN 3-00-002925-7, pp 464

DWD 2002:
[http://www.dwd.de] (Bruns: phenological pie)

Enke, W., Th. Deutschländer und F. Schneider (2004): Eine regionale Klimaprognose für Sachsen und andere Bundesländer. 4. Annaberger Klimatage 2004, 12./13. Mai 2004

Hassol, S.J. (2004): ACIA. Impacts of a Warming Arctic. Cambridge University Press. ISBN 0 521 61778

IPCC (2001): Climate Change 2001. Synthesis Report. Cambridge University Press 2001 und Intergovernmental Panel on Climate Change. Climate Change 2001. Third Assessment Report. WG I

Latif, M. (2004): Simulationen zum globalen Klimawandel, 4. Annaberger Klimatage 2004, 12./13. Mai 2004

ÖGM (2003): Klimaerklärung der Deutschen Meteorologischen Gesellschaft, der Österreichischen Gesellschaft für Meteorologie und der Schweizerischen Gesellschaft für Meteorologie

Overpeck, J. T., B. L. Otto-Bliesner, G. H. Miller, D. R. Muhs, R. B. Alley and J. T. Kiehl (2006): Paleoclimatic Evidence for Future Ice-Sheet Instability and Rapid Sea-Level Rise. Science 24 March 2006, Vol. 311. no. 5768, pp. 1747 - 1750

Prudence (2006): Prediction of Regional scenarios and Uncertainties for Defining European Climate change risks and Effects PRUDENCE (EVK2-CT2001-00132) Final Report. Co-ordinator: Dr. Jens Hesselbjerg Christensen
[http://prudence.dmi.dk]

Schär, Ch., P.L. Vidale, D. Lüthi, Ch. Frei, Ch. Häberli, M.A. Liniger and Ch. Appenzeller (2004): The role of increasing temperature variability in European summer heat waves. Nature, Vol. 427, pp 332 - 334

Schönwiese, Ch. D., J. Grieser,J. Rapp, T. Staeger und S. Trömel (2004): Klimawandel und Extremereignisse in Deutschland, 4. Annaberger Klimatage 2004, 12./13. Mai 2004

Schwartz, P. and R. Randall (2003): An abrupt climate change scenario and its implications for United States national security. Imagining the unthinkable. Study for the US Pentagon, Washington

Swiss Re (2000): Sturm über Europa. Ein Unterschätztes Risiko. Swiss Re Publishing, Zürich

WBGU (2003): Über Kioto hinaus denken. Klimastrategien für das 21. Jahrhundert. Sondergutachten. Wissenschaftlicher Beirat der Bundesregierung: Globale Umweltveränderungen. Berlin 2003

Internet-Adressen

http://www.accc.at/
Homepage of the former Austrian Climate Change Commission. News and important links

http://www.proclim.unibe.ch
Homepage of the Swiss Climate Research Co-ordination Center ProClim

http://www.unfcc.de/
Secretariat of the UN-Climate Convention. Official documents

http://www.ipcc.ch
Intergovernmental Panel on Climate Change: Summaries of IPCC Reports

http://www.pewclimate.org/
Multinational Companies that support climate protection

1.5.2 “Peak Oil“

Aleklett, K. and C. J. Campbell (2003): The Peak and Decline of World Oil and Gas Production, Association for the Study of Peak Oil and Gas
www.asponews.org and
[http://www.projectcensored.org/newsflash/the_hirsch_report.pdf]

Bakhtiari, A. M. Samsam (2002): To see birth of New World Energy Order, Oil and Gas Journal, January 7, 2002

Campbell C. J. and J. H. Laherrère (1998): The end of cheap oil. Scientific American, March 1998
[http://www.dieoff.com/page140.htm]

Campbell, C. J., F. Liesenborghs, J. Schindler und W. Zittel (2003): Ölwechsel! Das Ede des Erdölzeitalters und die Weichenstellung für die Zukunft. Deutscher Taschenbuch Verlag, München, 260 S

Campbell, C. J.(2002): Forecasting Global Oil Supply 2000-2050. Hubbert Center Newsletter #02-3

Deffeyes, K. S. (2001): Peak of world oil production, Paper no. 83-0, Geological Society of America Annual Meeting, November 2001
[gsa.confex.com]

Engdahl, W. (2002): Mit der Ölwaffe zur Weltmacht, Wiesbaden 2002

Illum, K. (2004): Oil-based Technology and Economy - Prospects for the Future; A short introduction to basic issues and a review of oil depletion projections derived from different theories and methods Copenhagen 2004
[www.tekno.dk]

Kromp-Kolb, H. und H. Formayer (2005): Schwarzbuch Klimawandel. EcoWin Verlag, Salzburg. 222 S

Laherrère J.H. (2004): Present and future energy problems. HEC MBA, Sustainable development seminar, Jouy-en-Josas France, Septembre 8-9
[http://www.hubbertpeak.com/HEC-long.pdf]

Petroconsultants (ed.), Campbell, C. J. F. and J. H. Laherrère, The World’s Oil Supply 1930-2050, Genf, 1995

Savinar, M. (2006): “Life after the Oil crash“ or “The Oil Age is Over: What to Expect as the World Runs Out of Cheap Oil, 2005-2050
[http://www.lifeaftertheoilcrash.net/]

Schindler, J. und W. Zittel (2000): Fossile Energiereserven (nur Erdöl und Erdgas) und mögliche Versorgungsengpässe aus Europäischer Perspektive, (LB-Systemtechnik GmbH) Ottobrunn 2000

Simmons, M. R. (2002): The World’s Giant Oilfields, M. King Hubbert Center for Petroleum Supply Studies, Colorado School of Mines, January 2002

Internet-Addresses

http://www.oilcrisis.com/

http://www.energiekrise.de/

http://www.peakoil.net/

http://www.wolfatthedoor.org.uk/

http://www.wbgu.de/

http://www.elstatconsultant.nl/

2 Environmental Pollution Caused by the “Normal Operation” Nuclear Fuel Cycle

Helmut Hirsch and Peter Weish

September 2006

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2 Environmental Pollution Caused by the "Normal Operation" Nuclear Fuel Cycle

2.1 Introduction

In order to operate nuclear power plants an extensive system of technical plants and installations is required – starting from uranium mining up to the final disposal of radioactive waste.

Every step of this system is causing environmental pollution, even in case of normal operation without accidents. In some nuclear installations, as frequent events and malfunctions in spent fuel reprocessing plants demonstrate, there is not always a clear separation between normal operation and accidental events.

The environmental effects of radioactive waste management are discussed within a separate paper. Here, the seldom-evaluated sections, fuel supply, particularly uranium mining and the emissions from nuclear power plants during normal operation, will be discussed.

2.2 The Neglected Problem – Uranium Mining

Uranium is an element found in nature in form of different minerals. This does not mean that uranium is not hazardous. During mining, uranium is removed from geological deposits that usually are geochemically stable. The ore is crushed and the uranium is extracted by chemical methods.

Residual uranium and all the separated decay products are left at the site and stored on the surface in form of dumps or as mud in simple basins. The waste products of uranium mining contain hazardous substances like the uranium decay product thorium-230 with a half-life of 77,000 years – this is about three times the half-life of plutonium-239. Thorium decays to radium and gaseous radon.

The isolation periods required for final disposal of these wastes are comparable to those of wastes from the operation of nuclear power plants. But in this case, geological storage is not taken into consideration due to the large amount of material.

Depending on the uranium content of the ore, for every ton of LWR fuel thousands to tens of thousand of tons of ore have to be mined. The amounts of radioactive residuals remaining in the mining sites are respectively large. For example, in corresponding regions in New Mexico (USA) and Wismut (former GDR), more than 100 million tons of radioactive waste from uranium mining are deposited on the surface.

The Wismut region is so heavily contaminated that the German Radiological Protection Ordinance (Deutsche Strahlenschutzverordnung) cannot be applied. The uranium mining in Eastern Germany has left about 8000 dumps and mud ponds. Rainwater is washing out uranium, radium and other toxic substances that reach the groundwater. In case of slagheap sliding, radioactive dust is released into the atmosphere. Uranium can enter into many compounds that are chemically toxic dependent on their solubility.

The redevelopment of this region is an enormous and costly undertaking, which requires several decades. In 1990, the German Federal Government took over responsibility for this redevelopment project. By the end of 2004, the state-owned enterprise Wismut GmbH had spent about 4.4 billion Euros. More than two thirds of the reclamation activities have already been completed. However, the work still has to go on for many years: It is expected that it will be completed by 2015. After that, long-term measures like treatment of waste waters and monitoring of the environment will still be necessary [BMVBW 2005].

The situation in other uranium mining areas is comparable to that of the Wismut region before redevelopment. Since many of these sites are located in the Third World or in those parts of industrial countries where aborigines live, this fact is less publicized and costly redevelopment usually does not take place.

2.3 Normal Operation of Nuclear Power Plants

2.3.1 Radiation Effect on Human Beings

The increasing radioactive contamination of the biosphere due to radioactive emissions from normal operation of nuclear installations and accidents causes an increase of human radiation exposure. Since radiation always has long-term consequences any increase of radiation exposure is fundamentally a problem.

The following discussion focuses on human beings, since they belong to the most radiation sensitive organisms. It should not be forgotten, however, that, depending on circumstances, other creatures can also be severely damaged by radiation.

The effect of ionizing radiation on living cells is comparable to a shower of tiny projectiles that change bio-molecules and cell structures whenever they strike the tissue. The knowledge on radio-biological processes was promoted by the so called "Trefferprinzip" (hit principle) which shows the discontinuous nature of interaction between ionizing radiation and matter [Timofeeff-Ressovsky und Zimmer 1947]. The extent of radiation damage in the cell is mainly dependent on the absorbed dose (number of strikes) and on which structures or which bio-molecules were changed (location of the strikes). There also exists indirect radiation damage caused by radiochemically formed cell poisons like hydrogen peroxide or radicals. The whole-body-irradiation with doses of several hundreds rem (or several Sieverts, the new unit for equivalent doses) damages sensitive organ systems such as the epithelium of the intestine or the red bone-marrow so heavily that due to the failure of cells, death is to be expected after several days to weeks. A lethal radiation dose transfers less energy to the body than a cup of tea (1 rad = 2,388 * 10^{-6} cal/g. A lethal dose of 1000 rad (10 Gray) is - for a person weighing 70 kg - equivalent to a transferred energy of 1000 * 70000 * 2,388 * 10^{-6} = 167 cal. This warms the body by 0,0024°C). High doses cause the acute radiation disease with typical symptoms that cannot appear below certain threshold dose values.

The damage of the cell's genetic material can cause severe consequences: The desoxyribonucleic acid (DNA) of the cell nucleus containing the species-characteristic structure of genetic information can be changed chemically by a single ionizing event. This can be manifested as “misprint” in the genetic information during the following DNA biosynthesis (which precedes any cell division) because the structure of the changed molecule works as a matrix for the new one. In case of low-dose irradiation with ionizing radiation the organism does not show any symptoms of the acute radiation disease. Only few cells are destroyed which is practically negligible for the organism. But radiation damaged cells can survive, transmit the defect and thus “biologically replicate” the defect. The effect appears only after many cell generations in the form of deformities, cancer, leukemia, or genetic diseases, called long-term radiation damage. The temporal distance between irradiation event and appearing damage (latent time) can amount for different cancer forms to many years, in case of genetic changes up to many generations.

Paracelsus´ well known axiom “only the dose causes the poison” is loosing it’s validity for low level ionizing radiation. Based on state-of-the-art experiments, theoretical considerations and medical statistics on the effect of low-dose irradiation, no dose threshold of ionizing radiation can be assumed with respect to long-term somatic damages (cancer, leukemia). A harmless dose does not exist. This topic is covered by a vast amount of literature e.g. many UNSCEAR Reports or publications by John W. Gofman.[1]

The procedure that changes normal cells into cancer cells or into a pre-form of mutated germ cells can be understood as “one-strike-event”. The question “which dose is harmless?” is as senseless as the question “which intensity of gunfire is harmless?”. The appearance of strikes is in any case a matter of statistics. In case of low-dose irradiation the radiation is not less effective, the “shower of tiny projectiles” is only less dense. The strikes happen more seldom but the strike probability per projectile is the same. This is the meaning of the linear dose-effect-relation. Dilution of radioactive emissions and distribution of the radiation exposure to a larger number of individuals – for example by high exhaust chimneys in nuclear installations – reduces the individual risk of a long-term radiation damage including disease or death, but the risk group is increased, therefore, the total number of health damages remains equal.

2.3.2 Natural Radiation

The argument for nuclear energy uses very often the fact that mankind has always been exposed to regionally different radiation levels from natural sources. This natural radiation was obviously not harmful and could yield a useful measure for acceptable additional radiation exposure due to nuclear power. Counter arguments reveal that many detailed investigations show a relation between the natural radiation exposure and the increasing appearance of several health damages. Natural radiation is therefore not harmless, it might be the cause of a part of the “spontaneously” appearing cancer, leukemia or genetic diseases. Also, natural radiation is not a useful measure for the justification of additional exposure just because we are not responsible for it.

2.3.3 Cancer in the Near-Surroundings of Nuclear Power Plants and Reprocessing Plants

For many years the question of increased cancer frequency in the neighborhood of nuclear plants has been subject to controversy. There exist numerous references pointing to an increased cancer rate near the reprocessing plants La Hague and Sellafield. Also for the areas around nuclear power plants, the findings increase.

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[1] Gofman (1981) or Weish et al. (1986)

2.3.3.1 Findings in Germany

A study of the Institute for Medical Statistics in Mainz from 1997 showed that the frequency of leukemia for children was significantly increased in the neighborhood of German nuclear power plants [BMU 1998]. A very drastic example is the NPP Krümmel where in the adjacent village 17 cases of leukemia of children and juveniles have been registered since 1990.

Such a coincidence constitutes an important indication. It does not definitely prove, however, that there is a causal link between nuclear plant and illness. The radiation exposure derived from official emission and activity surveillance data are by far too low to explain these numbers. But it cannot be excluded that radioactive aerosols escaped unnoticed from the chimney, since the surveillance of the exhaust stream does not reliably record large particles. This shortcoming could basically also exist in other nuclear power plants.

In the same area, there is a large nuclear research center (GKSS) which could also be the source of unmonitored radioactive emissions, causing leukemia.

Comprehensive investigations, which were commissioned by the state governments of Lower Saxony and Schleswig-Holstein, could not definitely resolve the question whether there is a causal link between the emissions from Krümmel and/or GKSS, and the cancer cases in the region [Strahlentelex 2003]. In the last years, the debate focuses more on the research center and, in particular, on an accident which, some experts report, could have taken place there in 1986. Meanwhile, new cases of leukemia keep occurring. The last one of the 17 cases mentioned above was reported in February 2006 [Strahlentelex 2006].

Recently, the German Federal Office for Radiation Protection confirmed results of the Environment Institute (Umweltinstitut) Munich, that had found that an increase in the number of children’s cancer cases in the areas around nuclear power plants in Bavaria. For the period from 1983 to 1998, the number of children with cancer in the counties with nuclear power plants was about 20 % higher than average. The Federal Office for Radiation Protection has commissioned investigations of the issue of a possible accumulation of cancer cases on the federal level, in the framework of a comprehensive case-control-study, in 2002. The study is to be concluded in the second half of 2006 [Grosche et al. 2002; Krebsregister 2006; Umweltinstitut 2006].

2.3.3.2 Findings in Other Countries

In the United States, a significant reduction of infant mortality has been reported in 2001 from the vicinity of five nuclear reactors, after they had been shut down [Strahlentelex 2002]. An investigation of children’s cancer rates in the surroundings (48 km radius) of 14 sites with 24 reactors showed an increase by 12.4 % compared to the average. The authors of this study also emphasize the need for further investigations. They point out, however, that their results nevertheless already constitute “strong evidence” [Mangano et al. 2002].

In the midst of the 90s increased frequencies of leukemia around nuclear power plants were reported in Japan. In the early 90s an increased number of Down Syndrome cases around the Canadian NPP Pickering (Ontario) was observed, and some years before, an increased appearance of cancer in children and juveniles near the Scottish NPP Dounreay was noted[2].

[2] Regarding the situation in Great Britain, see also: Busby (1995)

A recent study of cancer in the vicinity of Trawsfynydd nuclear power station in Wales, which is shut down since 1993 but not yet fully decommissioned, shows a significant increase of female breast cancer, male prostate cancer, leukemia and other cancers [Busby 2006].

2.3.3.3 Cancer Cases in the Vicinity of Sellafield and La Hague

A study commissioned by the European Parliament concluded in 2001 that there is definitely an increase in children's cancer cases in the surroundings of the British reprocessing plant Sellafield, particularly in the village of Seascale. So far, investigation could not clarify the cause of this increase. In particular, it remains open whether there is a link to the nuclear plant or not. Further research is regarded as required [Schneider et al. 2001].

In early 2004, new observations of increased cancer incidence in the neighborhood of Sellafield have been published. They concern the coastal city Caernarfon and its surroundings, located on the Irish Sea, south-west of Liverpool. The leukemia rate found in this region is even higher than that in Seascale [Strahlentelex 2004].

In the surroundings of the French reprocessing plant La Hague (region Beaumont-Hague), an increase of leukemia cases has been observed in the mid-nineties for the age group of 0 to 24 years. An investigation of possible causes revealed a positive correlation of the likelihood of getting leukemia with frequent visits to local beaches (by the children concerned or by their mothers, during pregnancy), as well as with the consumption of fish and mussels from the region. 1997, the authors of this study concluded that there is convincing evidence for radiation being the cause of the increase in leukemia incidences [Pobel et al. 1997].

A further study commissioned by the French government [GRNC 1991] did not confirm those findings. The meaningfulness of this study, however, was very limited, since a number of important pathways contributing to radiation exposure had not been taken into account. In mid-2001 a new epidemiological study was published, which had been financed by several state institutions (among them the Direction Générale de la Santé). It supported the results from 1997. Further investigations are called for.[3] In the last years, however, no new reports have been published on this issue. Open questions remain.

The listing of such examples could be continued. All these facts indicate that the radioactive emissions during normal operation of nuclear power plants without accidental events can cause fatalities, even if the valid emission limits are observed.

The reason could be that low-dose radiation effects are systematically underestimated, that the emissions are not completely and reliably detected, or a combination of both. No clear proof is yet available.

2.3.4 Long-Term Consequences

While cancer or leukemia (somatic radiation damage) dies with the individual, genetic defects can accumulate within the human population. Especially within the civilization milieu the genetic burden is increasing. An organism affected from mutated germ cells transfers the genetic damage in all cells of it's body and transfers it to the next generation (provided that the genetic damage

[3] For a more detailed account of the events described briefly in this paragraph, see Schneider et al. (2001), Chapter 6.5.2.3 and 6.5.2.4

is not fatal in utero or before the age of reproduction). The symptoms of such genetic diseases can be mitigated or oppressed but curing them is certainly not possible.

Radiobiological research has identified mechanisms that can repair DNA defects. Occasionally, there appear arguments that based on these repair mechanisms low-dose irradiation is genetically unobjectionable. This thesis is untenable because of the following arguments:

- The repair mechanisms do not work with 100 % efficiency. A certain amount of un-repaired genetic defects remains. This fact is not only verified by experiments[4], it follows from the existence of a spontaneous mutation rate and from the existence of genetic diseases.

- In a variety of radio-genetic experiments it was proved that the number of (unrepaired) mutations is proportional to the radiation dose without threshold value.[5] Moreover, the DNA repair is not necessarily faultless. One of the known repair mechanisms that reconnects DNA string ruptures, is therefore called “error prone” [Calkins 1977]. Repair mechanisms cause in some cases the survival and division potential of cells that would have been eliminated from the germ route due to a DNA defect, thus they enhance the mutation rate.

Due to the biochemical and molecular-biological similarity of organisms, many radio-genetic relations are known from numerous investigations on microorganisms, plants and animals. A quantitative estimation of the mutation triggering effect of radiation for man is difficult or impossible because of the following reasons:

- Striking dominant[6] genetic diseases are relatively seldom. They are only the “tip of the iceberg”.

- Far more frequent are recessive mutations that are covered by the genetic disposition of the other parent. Recessive mutations appear if defective genes of both parents are transferred to the descendent[7]. Recessive mutations can be identified in cross-breeding experiments with short-lived organisms, with brief intervals between generations. The proof for human beings is only possible in exceptional cases.

- Therefore most genetic defects remain undiscovered over many generations, before they appear homocygote.

- The long time period of a human generation renders the observations more difficult.

- Since most diseases have genetic components an increased mutation rate will not only increase rare genetic diseases, but also increase many “normal” diseases.

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4 See e.g. Timofeeff-Ressovsky, N. V., Ivanov, V. I., Korogodin, V. J. (1972)

5 This effect was discovered by Hermann Joseph Muller who received the Nobel Prize for this discovery; Muller, H. J. (1927)

6 Dominant genetic dispositions are those that appear even in case they are only transferred by one of the parents. They cover the genetic heritage of the other parent which is called recessive.

7 Medical research has explained the genetic nature of many diseases of metabolism. A good example is the sickle cell anemia, the first genetic disease with detailed research on it’s biochemical cause. The beta-polypeptide chain of hemoglobin A, that is composed of a sequence of 146 amino acids, contains in position 6 valine instead of glutamine acid. A minimum “misprint“ in the genetic information, a single “faulty character“, can cause a severe incurable disease if both parents transfer the same genetic defect to their children.

- While a radiation-induced cancer concerns "only" a single individual – and this might be tragic – a single radiation-induced mutation can imply incurable diseases or deformity for many persons of future human generations.

- In a growing population esp. genetic defects that do not reduce the reproduction rate exhibit negative effects in a long-term because they are not eliminated like genetic lethal factors.

Due to this fact geneticists have warned already some time ago of an increasing human radiation exposure.

"Genetiker werden oft gefragt, welche Strahlendosis toleriert werden könnte. Die Antworten sind unterschiedlich und werden meist nur widerstrebend gegeben, denn es gibt auf diese Frage keine Antwort. Abgesehen von der Tatsache, daß das heute vorliegende Versuchsmaterial zwar eindeutig Erzeugung schädlicher Mutationen durch Strahlung beweist, aber für quantitative Aussagen den Menschen betreffend noch recht unvollkommen ist, müßte für eine solche Antwort festgelegt sein, ob wir eine Verdopplung, Verzehnfachung oder Verhundertfachung der heute durch Spontanmutationen bedingten Fehlgeburten, Mißbildungen und Erbkrankheiten für "tragbar" halten. Entscheidend in unserer Verantwortung für spätere Generationen ist die Tatsache, daß erst nach genügender Verbreitung der rezessiven Defekte durch weitere Fortpflanzung der heutigen Menschheit die Katastrophe über unsere Enkel und Urenkel hereinbrechen kann, auch wenn wir heute den Eindruck einer normalen Situation haben." [Bresch1970]

(Genetics scientists are often asked which radiation dose could be tolerated. The answers are different and are mostly given reluctantly, since there is no answer to this question. Besides the fact that the present experimental results show definitely the radiation-induced production of harmful mutations, for quantitative statements concerning human beings these results are still rather incomplete. For such an answer a commitment would be necessary that we consider a double, tenfold or hundred-fold number of today's spontaneous mutation induced miscarriages, deformities and genetic diseases as "acceptable". In our responsibility for future generations the fact is, that only after sufficient distribution of recessive defects by further reproduction of today's mankind the catastrophe might appear for our grand or great-grand children, even in case we have today the impression of a normal situation.)

Unfortunately, although there definitely is a relationship between low-dose irradiation and health hazards, it is very complex and cannot be proven in an individual case.

Regarding both cancer and genetic defects, it remains complex and difficult to establish causal links between the "normal operation" of nuclear installations and cases of illness. It can be stated in summary, however, that the evidence for such a link has become increasingly clearer in the course of the years.

2.4 References

BMU (1998): Epidemiologische Studien zum Auftreten von Leukämieerkrankungen bei Kindern in Deutschland; Bundesumweltministerium, BMU-1997-489; see also Strahlentelex, 12. Jahrgang, Nr. 264-265, Januar 1998, 4

Busby, Ch. (1995): Wings of death – Nuclear Pollution and Human Health. Green Audit Books Aberystwyth, Wales

Busby, Ch. et al. (2006): A Survey of Cancer in the Vicinity of Trawsfynydd Nuclear Power Station in North Wales; Report 2006/3, Green Audit Aberstwyth, June 2006
[www.llrc.org] September 2006

Bresch, C. (1970): Klassische und Molekulare Genetik, Springer

Calkins, J. (1977): General patterns of repair and their possible significance as necessary protection from environmental radiation exposure. In: Radioprotect. chem. comp. biol means (A. Locker u. K. Fleming ed.) Birkhäuser 1977, p. 19-29

Gofman, J.W. (1981): Radiation and Human Health, Sierra Club Books

GRNC (1991): Estimation des niveaux d’exposition aux rayonnements ionisants et des risques de leucémies associés de populations du Nord-Cotentin, Rapprt de Synthèse, Octeville, Juillet 1991

Grosche, B. et al. (2002): Häufigkeit kindlicher Krebserkrankungen in der Umgebung von Atomkraftwerken in Bayern; BfS-SH-04/2002, Wirtschaftsverlag NW, Bremerhaven 2002

BMVBW (2005): Jahresbericht der Bundesregierung zum Stand der Deutschen Einheit 2005; September 2005
[www.bmvbw.de/Anlage/original_939535/Jahresbericht-2005-zum-Stand-der-Deutschen-Einheit.pdf]

Krebsregister (2006):
[www.krebsregister.de] September 2006

Mangano, J.J., et al. (2002): Elevated childhood cancer incidence proximate to U.S. nuclear power plants; Archives of Environmental Health, Feb. 2003
[www.findarticles.com/p/articles/mi_m0907/is_2_58/ai_106471710/]

Muller, H. J. (1927): Artificial mutation of the gene. Science 66. 84

Pobel, D., & Viel, J.F.: Case-control study of leukemia among young people near La Hague nuclear reprocessing plant – the environmental hypothesis revisited; British Medical Journal, Vol. 314, 11 January 1997, 101-106

Schneider, M. et al. (2001): Possible Toxic Effects from the Nuclear Reprocessing Plants at Sellafield (UK) and Cap de la Hague (France); EP/IV/A/STOA/2000/17/01, Europäisches Parlament, STOA Unit, November 2001, Kapitel 5.6.5

Strahlentelex (2002), 16. Jahrgang, Nr. 364-365, März 2002, 6

Strahlentelex (2003), 17. Jahrgang, Nr. 392-393, Mai 2003, 5-6

Strahlentelex (2004), 18. Jahrgang, Nr. 412-413, März 2004, 3

Strahlentelex (2006), 20. Jahrgang, Nr. 462-463, April 2006, 3

Timofeeff-Ressovsky, N. V., V. I. Ivanov und V. J. Korogodin, (1972): Die Anwendung des Trefferprinzips in der Strahlenbiologie. Fischer Verl. Jena

Timofeeff-Ressovsky, N. W. und K. G. Zimmer (1947): Das Trefferprinzip in der Biologie. S. Hirzel, Leipzig

Umweltinstitut (2006):
[www.umweltinstitut.org] September 2006

Weish. P. und Gruber, E. (1986): Radioaktivität und Umwelt. Fischer, Stuttgart

3 Nuclear Safety

Georgui Kastchiev, Roman Lahodynsky, Nikolaus Müllner, Wolfgang Kromp, Helga Kromp-Kolb
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3 Nuclear Safety

3.1 Motivation

The accident at the Chernobyl reactor in 1986 demonstrated that the consequences (economical, environmental, health effects, etc.) can be extremely serious and can affect large areas over long periods of time. The expenditures e.g. of Belarus to mitigate the effects of the Chernobyl accident surpassed 10 % of the state budget even 10 years after the accident [Rolevich et al. 1996].

The transboundary character of the consequences of severe reactor accidents has been acknowledged by the Director General of the IAEA [ElBaradei, 1999]: "*Nuclear accidents do not respect national borders, a fact that was brought to the attention of the international community after the Chernobyl accident*."

The frequency of severe reactor accidents with large off-site releases of radioactivity for a single reactor is presently considered to range in the order of 1 in 100,000 (or 10^{-5}) and 1 in 10.000,000 years (or 10^{-7}) years, dependent on the reactor type, the maintenance, site characteristics, etc.. Just a few years ago, the numbers ranged down to 10^{-3} and 10^{-4}. None of these numbers includes all possible contributors, in particular they do not take account of deliberate attacks. There is general consensus that it is impossible to include terrorist and sabotage attacks in probabilistic risk analyses, since there is no basis for meaningful quantitative estimation of their probability. The same, of course, applies to acts of war.

In view of the consequences of severe reactor accidents with large off-site releases of radioactivity any evaluation of nuclear risk must consider the whole population of some 440 NPPs in operation world-wide, an even larger population in case of a marked nuclear renaissance.

Thus a relatively low probability of occurrence, but catastrophic consequences describe the risk of severe accidents imposed by nuclear power plants (NPPs). According to the systematic categorization of risk types by social scientists [Renn et al. 1998] this corresponds to the risk category "Damocles" [WBGU 1998]. It should be noted here that other nuclear facilities connected with nuclear power such as reprocessing plants and radioactive waste storage facilities are subjected to the same risk type of severe accidents.

Manifold risks – not treated in this report – encompass the whole civil nuclear fuel cycle of commercial power plants as well as research and military reactors (mining, milling, conversion, enrichment, reprocessing, radioactive waste management, or spent fuel management). Significant risks have accompanied the nuclear option from the first mining of uranium and will continue to do so to – eventually – the phase-out of nuclear energy. But even after that the risks involved in nuclear waste disposal will remain as a long-term commitment for timespans of geological scales. The military uses of nuclear power involve additional aspects such as safeguards and proliferation issues affecting civil nuclear facilities. Some of these issues are addressed in other papers in this volume. The purpose of this report is to provide an overview of the current status of the safety of commercial nuclear power plants only.

3.2 Commercial Nuclear Power Plant Designs and Main Generic Severe Accident Vulnerabilities

3.2.1 Overview

As of April 2006, there were 443 power reactors in operation worldwide, and 27 additional units under construction (IAEA Power Reactor Information System, PRIS, data). Collectively, the 443 operating reactors had a net electrical capacity of 370 GW, and produced about 16 % of the total electricity generation worldwide. There are eight countries for which nuclear power provides 40 % or more of total electricity generation; all eight of these countries are in Europe (Belgium, Bulgaria, France, Lithuania, Slovak Republic, Sweden, Switzerland and Ukraine). Of the sixteen countries that get more than 25 % of their electricity from nuclear power plants, thirteen are in Europe.

Currently operating power reactors in Europe fall into six broad types[1]:

- Pressurized water reactors (PWR and WWER);
- Boiling water reactors (BWR);
- Boiling light water cooled, graphite moderated, vertical pressure tube reactors (RBMK);
- Pressurized heavy water cooled and moderated, horizontal pressure tube reactors (PHWR);
- Gas-cooled reactors (MAGNOX & AGR); and
- Liquid-sodium cooled fast breeder reactors.

A sequence of “Generations” reflects the evolution of reactor designs.

Generation I: Some earlier designs falling in Generation I are still in operation, but most are intended to be shut down in the relatively near future. The first generation of NPP were experimental low power reactors to provide the experience needed to build the first series of commercial power reactors of the following generation.

Generation II: With some exceptions, most of the currently operating nuclear power plants are properly classified as Generation II, but exhibiting different levels of safety. The accidents at the NPP Three Mile Island (TMI-2) and at the NPP Chernobyl (Chernobyl-4) – Generation II reactors - emphasized the importance of safety.

Generation III: Generation II reactor concepts were modified to address a large number of foreseeable accidents passively and reduce core damage frequency (CDF) to values as low as 1.7 10^{-7} (AP-600, see [NRC-1]). Four Generation III units are in operation in Japan; all are Advanced Boiling Water Reactors (ABWR). A Generation III reactor (EPR) is under construction at the Olkiluoto site in Finland, and an EPR unit is planned for the Flamanville site in France.

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[1] These 204 operating units comprise 92 PWR, 56 WWER, 19 BWR, 12 RBMK, 1 PWHR, 22 gas-cooled reactors and 2 fast breeder reactors.

Generation III+: Liberalization of the electricity market and the decreasing governmental support for the nuclear industry forced a further redesign – NPP now have to be competitive on the market, and the designs were worked over to reduce capital costs (the Generation III+). It is claimed that fifty years of experience, best practices and engineering knowledge of light water reactors are reflected in the Generation III+ plant designs. Initiated by a generous support package from the US government, plans to construct more than a dozen Generation III and III+ reactors in the United States have been announced in recent months.

Generation IV: designs are under development internationally; construction of a demonstration unit of one Generation IV design (the PBMR modular gas-cooled reactor) is planned in the near future in South Africa.

Table 3-1 illustrates the different reactor types (with examples) and their corresponding "generation".

Tab. 3-1 **REACTOR TYPES AND GENERATIONS**

Generation	Short Description	Examples
I	Early prototype reactors; mostly built before or during the development of safety standards.	• Early Siemens BWR (Gundremmingen A) • BWR Siemens 69 (Isar 1) • WWER-440/230 (Novovoronezh 1, Bohunice V1, Kozloduy 1-4) • MAGNOX Gas-Cooled Reactor (Calder Hall, Chapelcross, Latina) • Early RBMK-1000 (Leningrad 1 & 2) • UNGG (French, all shutdown)
II	Commercial power reactors; generally designed to formal nuclear safety standards, with most incorporating the defense-in-depth concept and containment; not designed for severe accidents.	• AGR (Hinckley Point B) • BWRs (Leibstadt, Olkiluoto, Gundremmingen B & C) • CANDU (Cernavoda) • French N4 (Chooz & Civaux) • German Konvoi (Emsland, Isar 2, Neckar 2) • Westinghouse PWR (Beznau, Krško & Asco) • WWER-440/213 (Bohunice V2, Dukovany, Paks) • WWER-1000/320 (Temelín, Kozloduy 5 & 6) • Later RBMK-1000 (Chernobyl 3 & 4) • RBMK-1500 (Ignalina 1 & 2) • Fast breeder reactors (FBR) see section 3.2.2.6
III	Advanced reactors with improved safety; designed explicitly for severe accidents.	• Advanced BWRs (ABWR, SWR-1000; 4 Japanese ABWR units) • Advanced CANDU (ACR-700) • Advanced PWRs (AP600, EPR, WWER-1000/392)
III+	Generation III reactors with improved economics.	• Advanced CANDU (ACR-1000) • Advanced PWR (AP1000) • Advanced BWR (ESBWR)
IV	Advanced reactors with improved economics, enhanced safety, improved proliferation resistance, and reduced radioactive waste generation.	• Fast Reactors (GFR, LFR, MSR*, SFR, SCWR closed cycle) • Thermal Reactors (MSR**, VHTR based on PBMR or GT-MHR, SCWR open cycle)

- MSR* with metallic-clad fuel
- MSR** with fuel dissolved in salt

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The bulk of the presently operating commercial nuclear power plants being of Generation II, their safety features dominate nuclear safety at present.

Generation III plants are still very few. If the contribution of nuclear energy to overall energy production is to increase in future, nuclear risk in the longer term will be determined by the safety features of Generation III or III+ and – more likely – Generation IV plants (see section 3.2.3).

3.2.2 Main Generic Severe Accident Vulnerabilities of Presently Operating Nuclear Power Plant Types (Generations I and II)

3.2.2.1 PWR & WWER

PWR and WWER rely on pressurized light water for cooling and neutron moderation. With the exception of the WWER-440/230 and WWER-440/213 units, PWR have full containments. The WWER-440/230 and 440/213 units were originally supplied with large, low pressure confinements either with pressure relief valves (230) or with bubbler-condenser pressure suppression systems (213). Containements are the last physical barrier of a multi-step "defense-in-depth" concept to prevent large releases of radioactivity to the environment.

Broadly speaking, PWR NPPs can be vulnerable to containment bypass accidents involving steam generator tube rupture, or containment/confinement failure due to "interfacing LOCAs", "direct containment heating" or hydrogen combustion (particularly hydrogen detonation).

Many PWRs in Europe have been backfit with filtered venting systems as a means of avoiding containment failure in severe accidents, and as a means of reducing the source term from severe accidents. In addition, many PWRs in Europe have been backfit with supplemental "bunkered" systems to perform some safety functions in case the originally provided safety systems fail.

Containments and confinements are generally not designed to withstand rupture of the reactor pressure vessel (RPV). Therefore rupture of the RPV (itself an inner barrier of utmost importance) must be excluded through appropriate precautionary measures, such as careful RPV design and material selection as well as extensive pre- and inservice testing including PTS analyses and sampling. Radiation-induced embrittlement under load of pressurized thermal shock (PTS) poses a severe vulnerability (see also section 3.7.1).

3.2.2.2 BWR

BWR are direct cycle reactors where boiling water from the primary system produces steam which is directed to the turbine for power production. BWR have full containment, using pressure suppression systems to reduce pressure caused by steam release inside containment.

Broadly speaking, BWR NPPs can be vulnerable to containment failures caused by hydrogen combustion or overpressure due to long-term loss of containment heat removal. Severe accidents can also be caused by direct contact of core debris with the containment wall following reactor pressure vessel (RPV) failure, resulting in a large early release of radioactive material to the environment via the reactor building (see also 3.2.2.1 above, RPV rupture). Most of the European BWRs have been backfit with filtered venting systems or with supplemental bunkered systems.

3.2.2.3 RBMK

RBMK are boiling light water reactors with the cores arranged in vertical pressure tubes and moderated by graphite. (IAEA's PRIS database designates these reactors as LWGR, light water-cooled graphite-moderated.) The reactors are thus quite large in dimensions compared with PWR and BWR. RBMK lack containments in any conventional sense; some of the units have pressure suppression systems located under the core area which are capable of dealing with a small number of simultaneous pressure tube failures (out of about 1600 tubes total) [IAEA 1999].

The principal vulnerability of RBMK (notwithstanding the changes made in the aftermath of the Chernobyl accident) is that any accident involving large scale core damage is likely to proceed to a large release accident due to the lack of containment and the limited capacity of the pressure suppression system (where it is present) to mitigate pressure tube failures.

3.2.2.4 PWHR

The PHWR of the CANDU® type is cooled and moderated by heavy water (deuterium). The reactors use natural uranium fuel and are refuelled online by special machines. The CANDU design at the Cernavoda plant has a prestressed concrete containment with a passively actuated spray system (typically referred to as a dousing system) for pressure suppression.

CANDU reactors have relatively slow severe accident progression (compared with PWR) due to the presence of the moderator tank (calandria) which surrounds the fuel channels. The principal faster moving scenarios involve complete loss of heat removal, and transients without scram in which the positive reactivity of the core can result in core disruption and early containment failure [IAEA 2002].

3.2.2.5 Gas-Cooled Reactors

MAGNOX reactors are natural uranium metal fuelled reactors cooled by carbon dioxide and moderated by graphite. Six MAGNOX stations were shut down for decommissioning between 1988 and 2004. The remaining four operating MAGNOX stations have planned shutdown dates ranging from 2006 to 2010 [HSE 2004].

AGR, the second design of gas-cooled reactors operating in Europe, consist of a pre-stressed concrete pressure vessel (with a steel liner) which encloses enriched uranium fuel in stainless steel clad pins. The reactors are graphite moderated and cooled by high-pressure carbon dioxide gas. The reactors are refuelled online.

Few details about severe accident behaviour and vulnerabilities are available for MAGNOX and AGR facilities. In general, the use of gas as a coolant means that there is no phase change under accident conditions as there is with water cooled reactors. In addition, the large mass of graphite in the cores (more than 1000 metric tonnes) gives a very large thermal inertia and a correspondingly very slow temperature increase profile under accident conditions. The principal severe accident vulnerability would seem to be scenarios in which a sufficiently large opening is created by an external event, allowing the graphite moderator to burn.

3.2.2.6 Fast Reactors

There are only two fast reactors in operation now in Europe (Phénix, France and BN-600, Russian Federation), and one is being used only on an experimental basis, with electrical generation being incidental to the experimental programme.

The history to date of commercial fast breeder reactors has been rather poor, with only one of seven such reactors attaining anything remotely approaching commercial viability.

The main severe accident vulnerability of fast reactors appears to be the so-called "hypothetical core disruptive accident" (HCDA), resulting in destruction of the core in a reactivity excursion.

3.2.3 General Considerations on the Safety of Generation III and IV Plants (Advanced Reactors)

The few Generation III units which have begun operation and the few more under construction or planned for construction in the next decade are listed in Table 3-1. Whether Generation IV plant will ever become commercial in any relevant number or, on the contrary, Generation III plants might be skipped over and the significant increase of future nuclear energy will be delivered by Generation IV is controversial. The argument against Generation III is that the reasonably accessible resources of U^{235} needed to drive this generation of reactors are limited (for a time span on the order of few decades depending on assumptions (for details see Zittel et al. 2006 or Sholly, St. "Nuclear Generated Hydrogen Economy - A Sustainable Option?" in this volume)). If NPPs are to play a significant role in filling the gap that fossil fuels are likely to leave, sufficiently abundant fissile isotopes must be used. This implies a variety of still very hypothetic reactor designs based on the use of Pu^{239} and U^{233} by breeding U^{238} and Th^{232}. Practically all of these are Pu driven fast reactors except a thermal breeder type Thorium fuel based reactor. Very optimistic estimates expect deployment of the first of these reactors to be possible by 2015-2025 [DOE-1] (see also Weimann et al. "Timeliness of the Nuclear Energy Option" in this volume).

Safety problems in Generation IV reactors differ widely from those known for the earlier generations. However, it is very difficult to assess their safety at the present time, as they are only in the design phase, and studies addressing safety aspects are still limited.

In the discussion of Generation III, III+, and IV designs one often runs across the phrase "inherently safe". Inherently safe designs are intended to accomplish all safety functions (reactor shutdown, emergency coolant injection, decay heat removal, containment cooling) passively, without active systems and without operator intervention (except after long delay times, ranging from three days to a week or more). Furthermore, "inherently safe" refers only to accidents within the design basis. Compared to Generation I and II plants Generation III plants are designed with a more substantial external hazards design basis (e.g. higher seismic design base, reduced fire and internal flooding risks, higher aircraft crash resistance). Without underestimating the importance of these quantitatively increased safety levels, the new quality of "inherently safe" in the true sense of the word is still not reached, even without considering deliberate acts of safety impairment.

As already mentioned, all Generation IV designs (Table 3-1) are in the phase of planning, and not yet final. For this reason, estimating the actual safety levels is very difficult. However, fast reactors suffer a handful of drawbacks, which make them expensive to build and hard to operate. Some issues:

Small average lifetime of prompt neutrons: Compared to thermal reactors it is difficult for fast reactors to maintain control and prevent "prompt criticality" immediately resulting in an immense power surge, capable of destroying large parts of the reactor core within seconds.

Adverse properties of primary system coolants: The primary system coolants of fast reactors behave neutron poisoning (sodium, lead) or neutral at best (helium). Therefore, other than LWR, fast reactors do certainly not reduce and might even increase reactivity in case of LOCA (positive void coefficient). Calculations assuming reactivity excursion of possible channel type commercial FBR with sodium reveal core destruction to 80 % within 2 seconds [Tobita et al. 2006]. In addition, as opposed to LWR, the once destroyed (molten) core does not loose its reactivity in absence of the primary system coolant, since fast reactors do not need a moderator. The molten core likely will stay critical and continue to produce energy.

What can be seen here is the difference in safety standards that has to be adopted for LWR and FR. While the Generation III+ reactors are intended to be capable of withstanding any accident without operator intervention at least for three days without core damage, a FR may end up a few seconds after the beginning of an accident with 80 % of the core melted and ejected. This seems to be a rather daring generalization , but it is based on two intrinsic principles which can be found in all Generation IV fast reactor designs: first, once the fraction of delayed neutrons diminishes, the progression of a power and reactivity excursion is much faster than the one for a thermal reactor. And second, the beneficial effect of the moderator, which automatically renders the reactor sub critical once evaporated, is missing. No extensive analysis of initial events leading to reactivity excursions has been done, since very few organizations have the tools to do so. But it would not be a surprise if more initiating events leading to reactivity excursion like the one mentioned in [Tobita et al. 2006] could be found.

Activation of the primary coolant is an issue for metal cooled fast reactors. The half-life of Na^{22} with 2.6 years is comparably long, and large activities are expected. Shorter lived isotopes emit radiation at higher energies, are a safety hazard, and emphasize the need to take extra care in the design of the plants [Guerrini et al. 1999]. Lead or lead-bismuth-eutectics as coolant show similar activation chains.

Reaction of sodium with water and air is another topic relevant for the safety of the SFR [Guerrini et al. 1999]. Should there be a secondary to tertiary leak, a fire is to be expected. In the opinion of some, this issue is an obstacle in the deployment of fast reactors, especially together with the fact that large activity of the primary system coolant can be expected. Evgeny Adamov, who is very much in favour of the deployment of fast reactors, stated (regarding the Russian development of fast reactors) "… in the sodium coolant we have around 50 million Curies of radioactivity, so we do not need a fuel melt to have the same accident as at Chernobyl, only a fire … " [Adamov 1999].

Regarding the GFR it can be said that helium has a small heat capacity, and a LOCA in this gas cooled reactor might mean that heat removal from the core is lost at the same instant.

From a point of safety, the supercritical reactor is sometimes rated highest of Generation IV fast reactors due to its similarity to the “proven” LWR design.

It has to be noted that all fast reactors lead to a so-called Plutonium economy with all the attached adverse effects [Broda 1973]. From the aspect of safety and security the Thorium-originated alternative - due to the adverse radiotoxic properties of U^{233} and accompanying isotopes - would be comparable to the Pu^{239} based alternative.

Thus, while the thermal LWR is a proven technology, the fast reactor is largely virgin soil. For LWR an operational experience of more than 10,000 reactor years exists. The design has undergone an evolutionary development, reactors are designed to cover a large range of accidents already in the design basis, safety systems are kept as simple as possible, and are designed to intervene passively, thereby increasing reliability and reducing costs. A whole arsenal of computational tools exists, each of them very well validated by a vast number of separate and integral tests. The users are well aware what their codes can and cannot do. There is a certain independence of regulatory authorities from industry, since enough codes are available to check and cross-check claims on safety margins. Even independent bodies like universities can assess claims on safety of the plant designs. Inspite of these assets the safety levels reached are controversial.

For fast reactors the situation is completely different. A generous calculation[2] gives some 120 reactor years of operational experience. The experience with the existing reactors does not give rise to the hope that the deployment of fast reactors will be without friction. The materials used for fast reactors are different, the safety concepts will be different. In addition, fast reactors are more difficult to operate due to the intrinsic mechanisms mentioned. Of the total budget for the development of Generation IV reactors the part dedicated to safety research is small. It cannot be expected that the same knowledge and the same awareness on safety about the fast reactors will be present at their planned deployment as it is now for the LWR. Only very few codes exist to estimate the impact of initiating events on fast reactors, and the extensive validation matrices for such codes do not yet exist. Since the declining resources for LWR might push the early deployment of fast reactors, a huge financial effort to raise the standards of the safety analysis tools to the same level as they are for LWR would be needed, but there are no indications that this will happen.

The above mentioned problems are in striking contradiction to the most important design goals for the Generation IV reactors: inherent safety, proliferation resistance, economic performance and absence of long-lived high-level radwaste. Considerable doubts are voiced on the feasibility of meeting these goals: “*We have not found and, based on current knowledge, do not believe it is realistic to expect that there are new reactor and fuel cycle technologies that simultaneously overcome the problems of cost, safety, waste, and proliferation*” [MIT 2003, op. cit., p. 76].

3.2.4 Preliminary Conclusion

This overview of generic severe accident vulnerabilities of the most frequent reactor types and all generations shows that all have vulnerabilities that can lead to severe accidents and possibly large releases of radioactivity despite the efforts to eliminate such vulnerabilities and the undoubted improvements that have been achieved.

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[2] Based on operating data from PRIS and the Nuclear News World List of Nuclear Power Plants, March 2001, with additional information from general sources.

3.3 Hazards

3.3.1 Internal Event Hazard

Some types of events and failures at nuclear power plants are referred to under the broad heading of “internal event hazards”. Many types of internal events are common across a number of reactor types, while others are more-or-less specific to particular designs. Some internal event hazards are of the nature of technical system failures. Some types of accident initiators leading to situations where safety systems are required to respond include a loss of feedwater, various sizes of pipe breaks (leading to a loss of coolant accident or LOCA), loss of offsite power and a loss of service water.

Typical types of internal events studied in probabilistic safety assessments (see section 3.5) include the following

- Loss of coolant accidents (LOCA) with failure of emergency core cooling systems (ECCS) or residual heat removal systems.

- Transients involving a loss of feedwater or a loss of heat removal (including loss of essential service water).

- Loss of offsite power with failure of emergency diesel generators (resulting in so-called "station blackout").

- Transient events accompanied by a failure of automatic shutdown, so-called anticipated transient without scram (ATWS).

- Internal plant flooding caused by the rupture of a cooling water system pipe (from a system such as essential service water or the circulating water system), or actuation of a water-based fire suppression system.

Many of the most serious system failures in response to internal initiating events are due to single factors which affect multiple trains of the same system – a so-called “common mode” or “common cause” failure. An example of such a failure would be a single team of personnel which performs lubrication on all three pumps of a system, and systematically applies the wrong type of lubricant to the pump bearings. Then, when the system is called upon to operate, the bearings seize and all three trains of the system fail due to a common cause.

Operator actions in responding to initiating events can also cause system "failure". For example, premature operator termination of high pressure injection during the Three Mile Island Unit 2 accident led to core damage. Since the Three Mile Island accident, nuclear power plants around the world have switched from event-oriented emergency operating procedures (EOP) to symptom oriented EOP. The latter type of EOP does not require the operators to diagnose the accident during the relatively high stress period of accident response – instead the operators are directed to treat accident symptoms. In this way, it is commonly considered that the likelihood of operator error leading to system failure has been reduced. On the other hand, there is at least one case of operators failing to take action which prevented a severe accident[3].

A more pervasive and potentially more severe type of human interaction which can lead to or exacerbate internal event hazards involve weaknesses in the so-called "safety culture" of a nuclear power plant. Safety culture is defined as "*that assembly of characteristics and attitudes in organizations and individuals which establishes that, as an overriding priority, nuclear plant safety issues receive the attention warranted by their significance*" [INSAG 1991]. Safety culture issues are widely considered to have played a significant role in the Chernobyl Unit 4 accident. Another example of safety culture problems was provided by the discovery of operators sleeping on duty at the Peach Bottom nuclear power station in the United States in 1987 [NRC 1987]. The US NRC ordered a shutdown of the plant and imposed a more than million dollar civil penalty (at the time, this was the largest civil penalty ever). The plant remained shutdown for two years.

3.3.2 External Event Hazards

External events are considered to be hazards which do not originate in the design of the plant equipment[4]. External event hazards are considered to arise from natural phenomena hazards and man-made phenomena hazards; they are numerous and very divers (Table 3-2). In general, the hazard posed by external events is that they can cause common-cause failures of numerous systems.

External hazards that occur at the specific site should be taken into account by the design and are treated during the licensing procedure. However, external hazards can undergo changes in reality or in assessment during the operative phase of NPPs. Thus e.g. changes in flood extent or frequencies due to climate change, as extensively experienced presently, new evaluations of the seismic hazard due to improved methods of assessment or the development of commercial airplanes of increasing size, weight and speed should induce reassessments of the safety of NPPs vis-à-vis external hazards. The specific examples given here are addressed in more detail further on.

[3] The failure of operators to reset the scram in the case of the Browns Ferry fire in 1974; had the scram been reset, the control rod drive hydraulic system - which was the only system adding water to keep the core covered - would have cut its flow rate in half and the core would have been damaged due to insufficient makeup.

[4] Even though fires starting within the plant might be considered to be an "internal" event, they are generally treated as an external event.

Tab. 3-2 **EXTERNAL HAZARDS**

External hazards that need to be considered in the design, the licensing and the operation of nuclear plants

Natural Phenomena Hazards	Man-Made Hazards	Deliberate Acts
Asteroid Impact	Aerial Tramway Failure	Computer Vulnerability (Viruses, Hacking, Y2K)
Avalanche	Aircraft Crash	Criminal Acts Murder
Biodiversity changes	Air Pollution	Fallout from Distant Nuclear Weapon Use
Cave Collapse	Air Traffic Control System Failure or Strike	Riot
Climate Change	Boat or Ship Sinking	Terrorism
Comet Impact	Bridge Collapse	Assassination
Drought	Building Structural Collapse	Contamination of Food, Medicine, etc.
Dust Storm	Chemical Release	Contamination of Drinking Water
Earthquake	Criticality in Nuclear Facility	Hijacking
Earth Axis Rotation Aberration	Dam Failure	Hostage Situation
El Niño	Explosion	Mail Bombs
Epidemic	Fire	Military-Style Assault
Bacterial	Geomagnetic Storms	Snipers
Viral	Military Weapon Accident	Vehicle Bomb
Extreme Cold Temperature	Nuclear Power Plant Accident	Weapons of Mass Destruction
Extreme High Temperature	Nuclear Weapon Accident	Biological Weapons
Famine	Oil Spill	Chemical Weapons
Flooding	Ozone Depletion	Nuclear Weapons
Forest Fire	Pipeline Failure	Warfare (Conventional)
Geomagnetic Storms	Power Failure	Aircraft Attack
Hail	Refinery Accident	Artillery and Tanks
Hurricane	Soil Contamination	Infantry Assault
Landslide	Spacecraft Re-entry (Uncontrolled)	Landmines
Lightning Strike	Traffic Accident	Missiles and Rockets
Meteorite Impact	Train Collision or Derailment	Warfare (Weapons of Mass Destruction)
Perma frost thawing	Transportation Strike	Biological Weapons
Sandstorm	Tunnel Accidents	Bacteriological Agents
Sea level rise	Collapse	Viral Agents
Seiche	Fire	Chemical Weapons
Sinkholes	Flooding	Electromagnetic Pulse
Sleet	Water Pollution	Nuclear Weapons
Slope Failure		
Snow		
Solar Flare/Sunspot Activity		
Subsidence		
Tornado		
Tsunami		
Volcanic Activity		
Wildfire		

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3.3.2.1 External Natural Phenomena Hazards

There are a variety of external natural phenomena hazards (see Table 3-2) that could initiate a sequence of events resulting in a nuclear power plant accident. In many cases, when a probabilistic safety assessment (PSA) is performed for a nuclear power plant, external events (including natural phenomena hazards) are considered as part of the analysis.

3.3.2.2 External Man-Made Phenomena Hazards

Just as natural phenomena hazards can pose a risk of a nuclear power plant accident, so can man-made hazards (see Table 3-2). Many of these are very site specific e.g. in consequence of nearby hazardous installations and they may change over time, as the infrastructure near and the environment of the NPP change.

3.3.3 Adversary Actions

Another category of potential initiators of accidents at nuclear power plants is the broad category of “adversary actions”. The internal and external event initiators discussed above are assumed to be random events that occur at a more or less predictable rate. Adversary actions are different – they are deliberate acts directed against nuclear facilities with the aim of causing damage to the facility, economic losses (e.g., by causing a prolonged shutdown), energy shortages, or with the aim of causing a release of radioactivity to the environment.

Four categories of adversary actions can be distinguished, in roughly escalating order of severity (each discussed briefly below): vandalism, sabotage, terrorism and acts of warfare.

The history of the commercial nuclear power program has had numerous examples of acts of vandalism directed against nuclear power plants. Most countries do not discuss such actions publicly. The United States published the Safeguards Summary Event List (SSEL) which detailed (within limits) these events, possibly only up to the year 2000.

Such acts range from the harmless to the unexpectedly hazardous. There is always the danger in acts of vandalism that an act will be committed that, not clearly recognized by the perpetrator, nonetheless poses a risk of initiating a sequence of events that could end in an accident.

Acts of sabotage are typically performed by two types of perpetrators. First, there are acts of sabotage performed by persons with authorized access to nuclear facilities. Second, there are acts of sabotage perpetrated by persons who penetrate plant security provisions with the aim of causing damage to the plant. Whether intended or not, these more serious acts – which are deliberately intended to cause facility damage – could in some circumstances initiate a sequence of events resulting in an accident.

Without getting too specific, there are events on record at nuclear power plants in which: (a) valves have been closed to prevent safety system actuation; (b) foreign substances have been introduced into plant equipment in an apparent attempt to cause component or system failure in the event of actuation in response to an initiating event; and (c) fuel supplies for emergency generating systems have been tampered with in an apparent attempt to cause failure in the event of loss of offsite power. These sabotage attempts were apparently perpetrated by individuals with authorized access to the facilities – acts of so-called "insider" sabotage. There is also at least one incident on record in which individuals were apparently trying to cause a loss of offsite power to a nuclear power station. This is an example of "outsider" sabotage.

Since the terrorist attacks in the US in September 2001, and subsequent terrorist actions elsewhere in the world, there is obviously a concern that terrorist attacks could be directed against nuclear facilities. The possibility that aircraft could be hijacked and deliberately crashed into nuclear power plants has, following the September 2001 attacks on the former World Trade Center in New York and on the Pentagon in Virginia, received a great deal of attention, as has the potential for terrorist attacks against nuclear facilities in general [EPRI 2002; POST 2004; SKI 2003]. The German environment ministry (BMU) has had a study performed by the German nuclear safety expert group GRS concerning aircraft crash at nuclear power plants (the study is formally classified, but it has been widely discussed in the media nevertheless). However, there is little evidence that the largest civil aircraft in operation or going into commercial service soon have been considered in these assessments. Broadly speaking, the largest of these, the Airbus A380 has about the double to 4-fold take-off weight[5] in comparison to the aircraft that were used in the September 2001 terrorist attacks.

There are examples in the historical record of bombing attacks on a nuclear power plant construction site (Bushehr in Iran was attacked several times during the Iran-Iraq war). In addition, during the various conflicts which erupted in the wake of the breakup of Yugoslavia, military aircraft overflew the Krško nuclear power plant in Slovenia. (Nuclear facilities other than nuclear power plants have been destroyed in military attacks carried out by Israel and the United States.) For more examples see Hirsch, H. "Terrorism and War" in this volume.

Nuclear power plants are not designed for protection against military attacks. It is assumed that the military of the nation in which the power plant is located will provide protection against such threats. In the US nuclear legislation, there is even a prohibition against considering military attacks in licensing proceedings for nuclear power plants.

The consequences of military or terrorist attacks for NPPs could be extremely large radioactive releases into the environment.

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5 http://www.airbus.com

3.4 Commercial Nuclear Power Plant Accidents and Selected “Near Misses”

3.4.1 Severe Accidents in Commercial NPPs

There have been two severe accidents in commercial nuclear power plants. The Three Mile Island Unit 2 reactor (a PWR supplied by Babcock & Wilcox, now owned by Framatome ANP) in the United States suffered a partial core melt accident in March 1979 due to a loss of feedwater with a stuck-open relief valve and operator action to terminate emergency core cooling system operation. In this case, core debris was retained inside the reactor as a result of late re-initiation of forced cooling, and the containment survived a hydrogen combustion event, preventing a large release of radioactivity to the environment.

In April 1986, the Chernobyl Unit 4 reactor (an RBMK facility) exploded in a reactivity-initiated explosion [Steinberg et al. 1991], causing a large release of radioactivity to the environment and permanent evacuation of a 30-kilometer radius around the plant. The last of four reactors at the Chernobyl plant (Unit 3) was shut down in December 2000.

3.4.2 Chronology of Recent Incidents

Some types of events at operating nuclear power plants, while they do not result in an accident *per se*, are sufficiently close in circumstances that they are considered to be “precursors” of a severe accident. A more colloquial expression for a precursor – especially one in which the conditional probability of core damage was quite high – is a so-called “near miss”. A chronology of selected events is given in Table 3-3.

Tab. 3-3 **CHRONOLOGY OF EVENTS, "NEAR MISSES" AND CLEAR INDICATIONS OF DEFICITS IN SAFETY CULTURE**

Year	NPP/Country	Accident/Event/...	INES
1958	Calder Hall / UK	Turbine failure	not included
1974	Shippinport / USA	Turbine failure	
1975	Browns Ferry / USA	Fire	not included
1979	Barsebäck / SWE	Turbine failure	not included
1980	Yankee Rowe / USA	Turbine failure	not included
1982	Metzamor / Armenia	Fire	not included
1983	Salem / USA	Anticipated Transient Without Scram (ATWS)	not included
1985	Maanshan / Taiwan	Turbine failure	not included
1989	Vandellos I / Spain	Turbine failure/ Fire	3
1989	Ignalina II / LIT	Fire	not included
1991	Salem Unit 2 / USA	Turbine failure	not included
1991	Chernobyl II / UKR	Turbine failure/ Fire	2
1993	Narora / India	Turbine failure/Fire	not included
1995	Leibstadt/ CH	hydrogen deflagration in an auxiliary steam generator	not included
1999	Blayais / FRA	Flooding/loss of offsite power	2
1999	Sellafield / UK	data falsification	not included
2001	Sizewell-B / UK	reactor pressure vessel head seal leakage	not included
2001	Cattenom-3 / FRA	Fuel damage	not included
2001	Hamaoka /Japan	double-ended steam line break	not included
2001	Philippsburg / GER	incorrect boron concentration	2
2002	Brunsbüttel / GER	pipe failure	1
2002	Davis-Besse / USA	RPV head Corrosion	3
2002	TEPCO / Japan	data falsification	1
2003	Paks 3 / HUN	extensive ex-core fuel damage during cleaning	3
2003	Kozloduy 3 / BG	Loss of coolant accident (LOCA)	1
2004	Vandellos 2 /SPA	Service Water System pipe break and loss of wall thickness due to corrosion	2
2004	Temelin/CZ	Spill of contaminated coolant	
2004	Sellafield THORP/ UK	Leaks in the heat exchanger tubes	not included
2005	Sellafield THORP/UK	Pipe failure in feed clarification cell	not included
2006	Kozloduy 5 / BG	ATWS / Mechanical Scram Failure	2
2006	Forsmark-1 /SWE	Two emergency dieselgnerators did not start when the unit was disconnected from the ordinary off site grid	2
2006	Forsmark-2 / SWE	INES-rating due to earlier event at Forsmark 1	2

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As can be seen, a number of serious incidents occurred over the past years, such as reactor pressure vessel head seal leakage at Sizewell-B (UK), incorrect boron concentration at Philippsburg (Germany), unprecedented fuel damage at Cattenom-3 (France), a pipe break in the reactor head spray system at Brunsbuettel (Germany), reactor pressure vessel head corrosion at Davis-Besse (US), extensive ex-core fuel damage at Paks Unit 3 (Hungary), data falsification at both Sellafield (UK) and TEPCO (Japan) and break of primary pipe in Kozloduy (Bulgaria).

Events, even without impact on the environment, can result in severe financial consequences due to plant damages, stand stills and fines. The costs at Philippsburg, Paks and Davis-Besse alone, including replacement power, stand at more than 570 million € (U.S. $ 667 million) to October 2003. Besides the financial disaster, the ensuing external reviews often show that a lot is wrong with the utility's safety organization as well.

One of the latest in the series is the incident at Forsmark, Sweden, where of the 4 emergency power diesels only 2 functioned when needed. As a result, Forsmark and 4 other reactors were temporarily shut down. At the end of 2006 there was no conclusive understanding why two diesel generators functioned and two did not. The incident demonstrated that the redundancy deemed sufficient was by no means satisfactory. In more general terms, calculated probabilities of failure – as e.g. for PSAs – apparently do not show the complete picture. Surprises can never be excluded. The investigations following the incident also revealed deficits in the safety culture at NPP Forsmark deemed sufficiently important by the regulatory body to warrant a law suit.

3.4.3 Lessons Learned or to be Learned

Prior to the Three Mile Island Unit 2 accident in 1979, it was quite typical for nuclear safety experts to assert that the likelihood of a severe accident in a commercial power reactor was of the order of one in a million per year (10^{-6}/a), notwithstanding the fact that the pioneering probabilistic safety assessment of its time (WASH-1400) estimated a likelihood far higher (one in 17,000 per year, or about 6×10^{-5}/a).

The occurrence of the TMI-2 accident after less than 1,000 reactor-years of operating experience with commercial power reactors was a wakeup call for the nuclear industry. Numerous improvements in human factors aspects of power plant operation, procedures, training, and to a lesser extent changes in plant design were accomplished in the decade that followed.

More specific to the European situation however, the Chernobyl accident in 1986 - resulting in a large release accident that spread contamination widely in Europe - caused a significant re-examination of nuclear safety and a recognition in most quarters that heavily populated Europe could ill-afford a large release accident. Thus notable safety improvements were made at European NPPs in the era since the TMI-2 and Chernobyl 4 accidents.

There has also been more extensive use of operating experience analysis and feedback, encouraged by the World Association of Nuclear Operators (WANO), the IAEA, and others. In addition, WANO and the IAEA have performed a variety of types of peer reviews (e.g. design, operations, radioactive waste management, regulatory oversight, safety culture, accident management, radiation protection, etc.).

But since then a number of incidents again showed shortcomings in the safety documentation, design of the systems and safety culture. Even the leaders of the nuclear industry came to the conclusion that complacency, overconfidence, self-satisfaction and negligence, shown in a number of incidents, threaten the whole nuclear industry.

An accident or significant safety incident will cripple the nuclear industry, IAEA Director General Mohamed El Baradei said in a video presentation at the American Nuclear Society meeting in New Orleans in November 2003. "*We cannot afford another accident*," he added. El Baradei said there is still a lot of work that needs to be done in the area of safety, particularly in the area of applying safety standards and safety culture uniformly across the industry.

The world nuclear power industry is in danger, threatened by the negligence and complacency that led to multiple "severe incidents" at nuclear plants in Europe, the U.S. and Japan over just the last few years, utility executives were warned at the biennial general meeting of the WANO held in Berlin, on 13-14 October 2003. The warnings were launched by senior WANO officials, but the message was brought home even more forcefully by those whose organizations had not heeded earlier signs and, in many cases, are still suffering the financial, social, and political consequences. WANO Chairman Hajimu Maeda warned that "*a terrible disease*" threatens nuclear operating organizations from within. It begins, he said, with "*loss of motivation to learn from others...overconfidence...(and) negligence in cultivating a safety culture due to severe pressure to reduce costs following the deregulation of the power market*." Those troubles, if ignored, "*are like a terrible disease that originates within the organization*" and can, if not detected, lead to "*a major accident*" that will "*destroy the whole organization. We must avoid the pitfalls of self-satisfaction which threaten us*".

"*Even a minor accident could be a disaster*," echoed Bruno Lescoeur, executive vice president, generation & trading, of Eléctricité de France, "*because it could question the acceptability of nuclear energy in France, and perhaps in the world*."

Armen Abagyan of Rosenergoatom said at the same time that lack of attention to operational events – he cited events in Russia, France, and the U.S. – "*may lead to a new burst of antinuclear opposition and adversely affect both Russian and the world nuclear industry.*"

Yet, the series of incidents that occurred and the deficits in safety culture that surfaced after these warnings show that they have not or not sufficiently been heeded. In fact, Brychanov, director of the Chernobyl NPP at the time of the accident, said in 2006 in an interview at the occasion of the 20th anniversary of the accident: "*Chernobyl has not taught anything to anyone*".

3.5 PSA, their Results and Implications

Probabilistic safety assessments (PSA) are by now nearly universally performed to identify the sequences of events which contribute most to the likelihood of a severe accident and in the case of Level 2 analyses, to the likelihood of a large release of radioactivity to the environment. Two measures of interest are the core damage frequency (CDF) and the large release frequency (LRF). The CDF provides an indication of how successful the design is in avoiding accidents. The LRF provides an indication of how successful the design is in mitigating accidents that nonetheless occur.

A state-of-the-art PSA in 2006 includes the following aspects:

- Internal events analysis at full power and at shutdown conditions (including refuelling and other types of outage evolutions).

- External events analysis at full power and at shutdown conditions, including both natural phenomena hazards and man-made hazards.

- Full analysis, on a best estimate basis, of the structural capability of the containment and of the effects of accident progression on containment integrity (Level 2 PSA).

- Uncertainty and sensitivity analysis.

The state-of-the-art PSA is maintained as a "living PSA" – that is, as changes are made to the plant design and to plant procedures (and as additional operating experience is gained), the changes are regularly reflected in revisions to the PSA.

Yet it should be understood that PSAs are never formally "complete": it is questionable whether state-of-the-art safety and risk research can cover all possible initiating events for NPP accidents [Sholly et al. 2000]; there are uncertainties in the results even for the accident contributors that are included in the PSA models; some sources of uncertainty have broad numerical bands that can make comparisons based on mean values difficult; some types of accident contributors are difficult to model probabilistically, and are usually excluded from safety and risk assessments, e.g.:

- independence of the nuclear regulatory authority and technical support organizations,

- influence of safety culture,

- adequacy of funding available for research into operating and safety issues,

- sufficient numbers of qualified staff in the whole nuclear infrastructure,

- economic stability of the energy economy sector,

- sabotage and terrorism, etc..

Aside from these theoretical weaknesses of PSAs, in practice very few state-of-the-art PSAs exist. Most PSAs do not cover the full range of aspects listed above.

PSA results of European NPPs – where available – are summarized in Table 3-4 below. At least Level 1 PSAs and, in Europe, very often Level 2 PSAs, have been performed of nearly all NPPs. In some cases, there are scope limitations (i.e., not all of the PSAs include external events and of those that do, often seismic events are not included for reasons which are seldom articulated). In the case of PSAs on the French NPPs, the PSAs are performed only on classes of plants, the argument being that the plants are so similar that a somewhat generic PSA can adequately represent all of the units in a class[6].

The point in the following table is not the plant-to-plant comparison – such comparisons are difficult and fraught with uncertainty due to differences in methods, data, scope, assumptions, etc. The point of showing these results is to give an impression of the range of results that are seen for European NPPs.

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[6] It is difficult to follow this argument, since even if the plants, their procedures, their operators (and their training), and their management were absolutely identical (and, of course, they are not), the external event hazards faced by the units vary from site to site.

Tab. 3-4 **PSA RESULTS FOR OPERATING NPPs**

NPPs	CDF [10^{-6}/a]	LRF [10^{-6}/a]	Comment on PSA	Source
PWR[1]				
Almaraz	5.9			CSN 2004
Ascó	22			CSN 2004
Beznau (2002)	7.9	0.26		HSK 2004
Borssele	4.5	0.03		ECN 2005
Gösgen-Däniken (1999)	18	0.31		HSK 1999
José Cabrera	22			CSN 2004
Santa María de Garoña	10			CSN 2004
Trillo	3.3			CSN 2004
Vandellós II	35			CSN 2004
WWER[2]				
Bohunice V1	27	21	internal & external events; following completion of upgrade & reconstruction programme, 2003	Gabko & Kovács 2004
Bohunice V1	54.3		shutdown PSA, 2003	Slovak 2004
Bohunice V2	11		internal events, full power, 2003	Slovak 2004
Bohunice V2	58		internal events, shutdown PSA, 2003	Slovak 2004
Kozloduy 3 & 4	16		internal & external events	Bulgaria 2004
Loviisa	170	5	internal & external events, shutdown events	STUK 2004
Mochovce	3.8		internal & external events, 2001	Slovak 2004
Mochovce	170		shutdown PSA, 2002	Slovak 2004
Paks	33 to 44		internal events, fire & flooding, shutdown events	HAEA 2004
Paks	290		seismic, average of four units	HAEA 2004
BWR				
Cofrentes (BWR/6, Mark III).	1.2			CSN 2004
Leibstadt	8.1	0.10	internal & external events, 1996	HSK 1996
Mühleberg (2002)	7.90	0.014		HSK 2002
Olkiluoto (ASEA-Atom BWR)	17	6		STUK 2004
PHWR				
Cernavoda Unit 1	14		internal events PSA	Romania 2004
Gas Cooled Reactors [3]				
Latina (MAGNOX) 1987	27		internal events PSA; core damage frequency for „unconfined events" (presumably involving failure of the vessel with core damage)	Volterra 1988
RBMK				
Ignalina	30		internal events and limited to Level 1 scope (no consideration of accident progression)	Uspuras 1999
Ignalina (Brand)	1000[4]			STUK 2000

1) PWR PSA results indicate a range of CDFs covering three orders of magnitude. These results cover a wide range of PWR designs from Framatome, Siemens, and Westinghouse, and the PSA vintages span the era from 1995-2003. In many cases, the results reported consider only internal events.

2) PSA results for WWERs span a wide range, but it must be recognized that there are three different basic designs (WWER-440/230, WWER-440/213, and WWER-1000), plus the unique Loviisa design (which includes a WWER-440 reactor with safety systems designed by Siemens, housed in an ice condenser containment). In addition, in some cases the designs of the units have evolved rapidly over the past 10 years. Some of the PSA studies include only internal events.

3) PSAs are performed for AGRs as part of their Periodic Safety Reviews (PSRs) [Magne & Shepherd 2003], however no published summaries of results of these PSAs have been identified.

4) It is to be expected that this high CDF value for Ignalina Block 2 in 2000 – a number that was entirely due to fire hazards – has been brought down by safety measures meanwhile.

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Available probabilistic safety assessments (PSA) indicate that Generation III and III+ designs have mean core damage frequencies that are a factor of 5 to 10 below the best Generation II designs and mean large release frequencies that are a factor of 10 to 100 below the best Generation II designs. However, as there is little or no operational experience with Generation III and III+, in most cases the PSA studies are design PSA studies with assumed site parameters which are asserted by the manufacturers to be enveloping of most site conditions.

Tab. 3-5 **PSA RESULTS FOR ADVANCED DESIGN REACTORS**

Advanced Reactor Designs*	CDF [10-6/a]	PSA	Source
ABWR (Generation III)	0.16		IRR 2004
ABWR II (Generation III+)	0.045	internal events only	IRR 2004
AP1000 (Generation III+)	0.51		IRR 2004
WWER-1000/392 (Tianwan design, Generation III)	5.4		IRR 2004
WWER-1500/448 (Generation III+)	0.048		

*) Advanced reactor designs range from Generation III and Generation III+ designs which are being or are soon expected to be deployed (e.g., ABWR, AP1000, EPR, and ESBWR) to more advanced Generation IV concepts that in most cases are not expected to be deployed until 2020 or thereafter (a possible ex-ception being a demonstration PBMR reactor expected to be built by South Africa).

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The PSA results for the Generation III and III+ designs reflect a combination of explicit consideration of severe accident prevention and mitigation in the design process, optimisation of system and structural design, and the traditional safety factors incorporated in nuclear power plant design. Generation III and III+ designs also tend to incorporate some "passive" designs to perform some important safety functions.

There is a "tension" between risk and cost considerations in all nuclear power plant designs. Regardless of where the line is drawn between design basis and beyond design basis accidents, there are always some extreme events that have the capability to damage the reactor core and containment and cause a release of radioactive materials to the environment. The measure of safety or risk then becomes an understanding of what it takes before such an event can occur.

3.6 Safety Standards

3.6.1 Early Evolvement of Safety Standards

Since the first commercial NPPs went into operation in the 1950s and 1960s safety codes and safety standards were continually raised, due to accidents such as Three Mile Island 2 (USA 1979), Chernobyl (USSR 1986), or severe incidents (e.g. a fire in the US reactor Browns Ferry), increasing operational experience, advanced methods in safety research and last but not least an increasingly critical approach of the public towards nuclear industry.

The rising safety standards often led to safety improvement programs for NPPs of older design, but these upgrading programs (backfits) could not always remove what appeared to be design flaws from a state-of-the-art safety standards perspective. According to Govaerts et al. [Govaerts et al. 1998]: "*Back in the late fifties and in the sixties, the plants were usually designed in a very conservative way, with margins to cover insufficient knowledge of material resistance, of thermal hydraulic aspects, of long term behaviour of structures, systems and components. The accident conditions taken into account in the design basis were much less drastic than in present designs (e.g. breaks of small diameter pipes only, no man made or natural hazards,...), not many systems were considered as safety related, with accompanying redundancy and physical separation requirements.*

When reassessing the safety of these plants the first obstacle is to know accurately the status of the plant. Original design data may be missing, the equipment qualification is incomplete or unknown, information can no longer be obtained from the original supplier. Moreover in some countries it seems there are no detailed requirements for keeping up to date the safety analysis documentary support when modifications are made during operation of the plant."

IAEA International Nuclear Safety Advisory Group Report INSAG-8 [INSAG-8, 1995] expects standards to continue to rise:

"1. Safety standards for nuclear power plants have undergone evolution and development since the first plants were designed in the 1950s. Many changes have occurred as the nuclear industry has matured and changes will continue to occur, as a result of increased knowledge and experience in both design and operation, and owing to a raising of the objectives for safety and reliability.

2. Most plants have a design life of 30 to 40 years or more, and it is inevitable that all plants will eventually be overtaken by the developing technologies and standards."

3.6.2 Present Safety Standards, Goals and Targets

The International Nuclear Safety Advisory Group (INSAG), which was established after the Chernobyl accident, defined minimum safety targets for currently operating NPPs and future NPPs. These safety targets are basically as follows [INSAG-3, 1988]:

- For existing NPPs, a core damage frequency (CDF) of less than 10^{-4}/a, and a large release frequency (LRF) of less than 10^{-5}/a.

- For future NPPs, a CDF of less than 10^{-5}/a and an LRF of less than 10^{-6}/a.

These values were not changed during the first revision of INSAG-3 in 1999 [INSAG-12, 1999].

Some countries have defined safety targets for their nuclear power plants or specified those established by the IAEA to greater detail. Thus Sweden, e.g. has no explicit regulatory requirement regarding maximum core damage frequency, but the utilities have established probabilistic safety objectives for their internal use. Safety measures shall be prioritised if CDF exceeds 10^{-5}/a with a high confidence, or probability of a release of more than 0.1 % of the core inventory, excluding noble gases, is higher than 10^{-7}/a [Swedish CNS 1998]. Stricter safety targets have also been established in the Netherlands, which requires a LRF of less than 10^{-6}/a.

General Provisions on the Safety Assurance of Nuclear Power Plants [OPB-88] were introduced in Russia since 1990 and are applicable to all projects which had not been commissioned before the introduction of OPB-88. These targets are more stringent by an order of magnitude than those established by INSAG 3: *"In order to exclude a required evacuation of the public in the vicinity of NPPs, it should be a goal not to exceed an accidental frequency of 10^{-7}/reactor and year for large releases of radioactivity"* [OPB-88, chapter 1.2.17].

In the last years the European Commission issued a proposal for adoption of common European safety standards and a revision [EC 2003/2004]. In spite of considerable efforts no acceptance by member states was reached (see relevant passages in Rotter, M. "Sustainability and the Production of Electricity by Nuclear Power Stations - The Legal Dimension" in this volume).

3.6.3 Compliance with Safety Targets and Standards

Not all NPPs meet the minimal IAEA safety targets for plants in operation as the following examples show. The US Nuclear Regulatory Commission in its Generic Letter (GL) 88-20, in November 1988, requested all licensees to perform an Individual Plant Examination (IPE) to identify any plant-specific vulnerabilities to severe accidents and to report the results. The following results were compiled on basis of an IPE database of the NRC from April 1997 [NRC, 1997]:

No. of plants in database	91	100 %
No. of plants at or above INSAG-3 safety goal for the CDF (10^{-4}/a)	12	13 %
No. of plants at or above INSAG-3 safety goal for large releases (10^{-5}/a)	24	26 %

This means that in that period about one fourth of the NPPs included in the statistics did not meet the INSAG goals for large releases and more than one tenth did not meet those for Core Damage Frequency. Unfortunately no recent update of these figures is available.

The Western European Nuclear Regulators Association (WENRA) in the course of its initiative to harmonize safety approaches in Europe published aggregated national assessments[7] of compliance with the WENRA Safety Reference Levels. This permits some conclusions concerning IAEA (non-quantitative) Safety Standards:

- There are several European countries where the formal legal requirements for nuclear safety do not conform to IAEA Safety Standards.
- There are a few European countries where IAEA Safety Standards are not completely implemented in all operating nuclear power plants.

These conclusions are noteworthy, given the seemingly universal consensus that IAEA Safety Standards, in principle, have to be adhered to in every country. Even apart from this, the WENRA effort made clear that there is a need for safety improvements in the NPPs of the European Union.

[7] The assessments are self assessments by the individual national regulatory bodies and are partially surprisingly optimistic.

Soviet design reactors are considered to have specific safety problems and there is general agreement in the West, that the safety levels of some of the soviet design reactors need to be raised urgently.

The IAEA developed specific extra-budgetary programs to improve the safety of nuclear facilities in Eastern European countries with Soviet designed NPPs (WWER and RBMK reactors) [IAEA 1999]: "*The objective of the Programme is to strengthen nuclear safety in countries of the region, and in particular to enhance the technical capabilities of regulatory authorities and supporting technical organizations, the nuclear safety infrastructure and human resources development"* because *"Despite the improvements in safety already achieved, much remains to be done at individual NPPs, particularly at the WWER and RBMK plants of the first generation.*"

The United States General Accounting Offices (GAO) in its Report on the Safety of Soviet Designed Reactors states that: "*Soviet-designed reactors in general exhibit deficiencies, including insufficient protection against fire, poor-quality materials and construction, and inadequate separation and redundancy of safety systems. Furthermore, many of these reactors are located in countries such as Russia and Ukraine that do not have fully independent or effective nuclear regulatory organizations that oversee plant safety. Of greatest concern are 25 of the 59 reactors that western safety experts generally agree fall well below accepted international safety standards and cannot be economically upgraded*" [GAO 2000].

The European Commission concluded in 1993: "*Although it is clear that Soviet-designed nuclear installations generally pose safety problems, the situation varies according to reactor types and to the way they are operated, as well as the countries concerned:*

- *WWER-230 and RBMK reactors show fundamental design deficiencies which cannot be fully overcome, whereas WWER-213 and WWER-320 reactors can be substantially upgraded, notwithstanding the questionable design of some plant components;*

- *the regulatory, technological, engineering and industrial environment varies from one country to the other."*[EC 1993]

The importance of socio-political and socio-economic factors was stressed in the follow-up of the Three Mile Island accident analysis [Kemeny 1979] as well as the Chernobyl accident analysis [Steinberg et al. 1991].

3.7 Factors Influencing Future Safety Status of Nuclear Power Plants: Emerging Issues

This section of the report briefly discusses some “emergent” issues, the nature and importance of which are still evolving.

3.7.1 Aging of Nuclear Power Plants

Aging leads to increase in risk of failure of individual components or the system as a whole. Aging of materials is an inevitable degradation phenomenon caused by various kinds of loads during usage. Mechanical properties (e.g. strength, toughness, elasticity) of very different materials such as vessel steel, fuel claddings or even reinforced concrete can be affected. Degradation by aging affects also electrical, electronic, opto-electronic and magnetic properties e.g. of parts in electronic devices. The loads to the materials can be of mechanical, thermal, chemical or radiological nature. If simultaneously applied, loads of different nature can result in synergistic enhancement of their deteriorating effects. Steel embrittlement in the core belt region subjected to simultaneous loads by neutron irradiation, chemical attack (e.g. corrosion by hydrogen diffusion) and fatigue by (alternating) mechanical stresses is an important example of aging. With aging progressing in time, an additional thermo-mechanical load transient (thermal shock) e.g. under emergency operation conditions could result in rupture of the aged steel component.

Although plants that were commissioned in the 1970s and 1980s were generally designed for operating lifetimes of 30-40 years [INSAG-14 1999], many of the earlier plants were not operated more than 20 or 25 years. The others are now entering the stage of systematically increasing risk.

Due to the difficulties and investments involved in licensing new power plants, some operating organizations are now investigating the possibility of extending the operating lifetimes of some plants up to 45, 50 or even 60 years. But, as the IAEA points out, this can involve additional risk: “*Nuclear Power plant ageing can, if not correctly managed, result in the operating safety level falling below the reference safety level set at the design and construction stages of the plant and accepted by the regulator prior to plant operation*.“ [INSAG-14 1999]

3.7.2 Decreasing Know How and Infrastructure Capacities

The original hopes connected with nuclear power as the unlimited energy source led to a boom in the nuclear industry, which attracted a large number of qualified scientists, engineers and technicians. The drastic decline of the number of nuclear power plants ordered and built in western countries over the past decades has led to a change of the situation: there is a lack of trained personnel, a decline of technical support organizations, an increasing shortage of nuclear grade spare parts, etc. “*Underlying the operation of nuclear power plants are the host activities – collectively called – infrastructure – in design, construction, regulation, education and research. While all of these activities help ensure safe and economic production of electricity, they have been declining in many of the OECD countries.*” [NEA 1996]

Nuclear industry is experiencing the problems every declining industry experiences, but in the case of nuclear, this implies increased risk at a time when aging of the plants would require additional precautionary measures.

3.7.3 Liberalization of the Electricity Market / Reduction of Saftey Margins

The liberalization of the electricity market has led to increased competition and will continue to do so, as customers learn to act in a deregulated market. There is some fear, that in consequence safety maintenance and upgrading might be jeopardized: "*As the most important safety concern, the regulatory authorities report that there are indications of work overload of the NPP organizations, and keen competition to get qualified specialists, at the same time as the economical competition becomes harder on the deregulated electricity market*" [Swedish CNS 1998]. Practical examples demonstrating consequences of the pressure on costs are reductions in staff (in Grohnde, Germany, e.g. staff was reduced from 340 to 300 between 1990 and 2004, the reduction involving 90 % technicians, and general revisions of turbines are now scheduled every 12 years rather than 6 years, thus doubling the inspection interval [Bruns 2004].

Another worrying example is the downgrading, of IAEA guidelines as well as national standards and regulations. Thus, the new IAEA guidelines for WWER-PTS analysis (see section 3.2.2.1) have reduced the safety margin in the structural integrity assessment compared to the previous guidelines significantly. This new version [IAEA 2006] was developed in parallel with the licensing procedure of the Temelin NPP, and they were immediately incorporated into the Czech legislation. At the time of start-up the former IAEA guidelines [IAEA 1997] were part of the Czech legislation. The demonstration of structural integrity of the Temelin RPV throughout the projected lifetime would not have been possible using the 1997 IAEA guidelines [Batishchev 2005, Austrian Expert Team 2001].

In other cases, standards and regulations are overruled by so-called "expert judgement"[8], a delecate procedure in view of the small pool of nuclear experts, the majority of which are tied in with the nuclear industry.

In Germany a working group of the German Ministry of Economy and Technology pointed out the necessity of studying the effects of changes in managerial and organizational structures in the energy markets due to mergers of utilities especially on the safety of nuclear power plants and their safety culture [BMWi Arbeitsgruppe 2000).

While it is questionable whether the serious nuclear incidents that occurred over the past few years can already be attributed to the cost reduction efforts in view of market liberalization, they clearly indicate that more efforts must be put into safety culture and safety measures. It is difficult to see this happening in the present economic constraints (see also Frogatt, H. "Nuclear Energy – The Economic Perspective" in this volume).

The nuclear industry has seen remarkable consolidation in the past decade and a half. There are fewer and larger organizations operating nuclear power plants worldwide. Many of these organizations are reporting record profits year after year. And yet these same organizations are complaining about the lack of nuclear-related graduates and a reduction in research and development.

The following passage, written in March 2006 by the Chairman of INSAG (and formerly Chairman of the US Nuclear Regulatory Commission), is illustrative [Meserve 2006]:

[8] See e.g. IAEA Experts Meeting 1998 in combination with Hofer et al. 2001.

The nuclear slowdown of the past two decades has resulted in a smaller cadre of highly qualified experts, fewer graduates in nuclear engineering, and less global financing for safety research than 20 years ago. Moreover, nuclear skills in the operators' organizations and in regulatory authorities may, in some cases, be getting thin. This concern is heightened by the trend in some enterprises with operational responsibility for nuclear reactors to rely increasingly on managers with financial experience, at the expense of those with nuclear experience. A focused effort to rebuild the nuclear infrastructure should be a high priority, but progress has been slow.

The same industry that does recognize that "*an accident anywhere is an accident everywhere*" does not seem to recognize that in a free market, in many cases governments have stopped subsidizing the nuclear industry. (There are, of course, exceptions.) Paradoxically, there continue to be calls for governments to provide funding for programs that are so obviously in the industry's own best that is inexplicable why the industry is not already funding the programs itself. For example, a 2003 MIT study (MIT 2003) recommended that the US Department of Energy provide $ 50 million (about € 42 million) per year for five years to fund a global uranium ore resource assessment. Such an assessment is perhaps needed (especially if the industry hopes to expand in the coming decades) but it is there is no reason why it should be the government's responsibility to fund it. If the nuclear industry - which is a mature industry providing 16 % of the world's electricity - cannot sufficiently perceive its own self-interest in understanding what its fuel resource base is, why should governments save that industry from its own short-sightedness? A free market will correct such errors in its own harsh way typical of such markets.

3.7.4 Knowledge Management

As nuclear power plants (and their workforces) age and the end of operating lives of the power plants comes into clearer view, it is to be expected that there will be departures of experienced personnel from the industry as staff retires or takes up opportunities in other companies as the competition for experienced staff gets stiffer. Under such conditions, organizations operating nuclear power plants have a need to practice knowledge management - that is, to ensure that under all conditions the knowledge required to safely operate nuclear power plants (including maintaining the plants, upgrading their safety, managing their spent fuel and radioactive wastes, and ultimately decommissioning the plants) stays in the company.

Knowledge management is an important consideration for nuclear regulatory authorities, technical support organizations, and vendors as well as operating utilities. (The nuclear power industry is by no means unique in the knowledge management problems it is facing. Similar considerations also pertain to other industries and functions, such as maintaining the safety and reliability of nuclear weapons and space transportation systems.) Knowledge management will be an increasing important factor for countries that have decided to end their involvement with commercial nuclear power plants.

The IAEA nuclear safety review issued in 2005 (for the situation in the year 2004) succinctly states the issue [IAEA 2005b]: *It is generally agreed that existing safety knowledge has not been fully elicited and analysed to extract and share the lessons learned and embed them in the knowledge and behaviour of nuclear organizations. In his concluding remarks, the chair of a nuclear knowledge management conference in Saclay, France in September 2004 stated that "knowledge management is at the heart of safety culture and that the development of individuals is central to the process of knowledge management. ... A key challenge is to manage not only explicit knowledge, such as databases, documents and processes, but also tacit knowledge, such as personal knowledge, skills and aptitudes. For long term viability, it is essential to foster a corporate culture where sharing safety knowledge is a priority."*

3.7.5 Seismic Hazard

Many nuclear power stations are subjected to a higher earthquake hazard than previously assessed. On the one hand earthquake hazard was either neglected or strong earthquakes were assumed to be very unlikely to occur, at least during the lifetime of a plant. Although the reactor building itself may have been dimensioned to withstand earthquakes, the vulnerability of auxiliary components such as tanks, power lines, etc. was neglected and can lead to catastrophic consequences.

On the other hand new scientific methods, developed during the last 20 years, and taken account of in the recommendations of IAEA are not yet applied in practice by all member states. Possibly high costs for scientific investigations and even higher costs for the following upgrading of a plant did not favour the implementation of the new procedures. Formerly the presumed largest or any strong earthquake in the near or far region, at or near a given fault was selected and a diminuation of the intensity with distance between the epicentre (or the fault) and the plant was calculated. By adding a value of 0.5 or 1 to the thus calculated intensity a value for the safe shutdown earthquake (SSE) was determined. But it is obvious that the strongest known historical earthquake may not be the strongest possible along a given fault that could affect the plant. It is impossible to determine a maximum credible earthquake (MCE) from historical data that rarely exceeds 500 years.

However, the existence of such rare strong earthquakes in the past may be proven by the application of modern seismotectonic methods (paleoseismology, neotectonics, geomorphology). Thus the recurrence rate of rare large events needs to be sought from geological and palaeoseismological evidence, which may give information about events underrepresented in the historical catalogue. Earthquakes of very high intensity but very low probability could be found in the archives of the sediments and their age, date and size can be calculated. These results should then be considered in the siting procedure of new as well as during a seismic evaluation of existing nuclear power plants. Paleoseismological methods (geomorphological and neotectonic studies, trenching, dating the age of the youngest movements of faults) and the consideration of long recurrence intervals of strong earthquakes were recommended in the IAEA's safety guide S1, 1st revision,1991 and NS-G-3.3, 2002.

3.7.6 Climate Change

As can be seen from the geographical distribution of nuclear power plants between about 35° southern and 70° northern latitude, nuclear power plants were built and operated in many different climates. Thus it is not to be expected that the present climate change would make the production of nuclear energy in power plants impossible. However, many of the external hazards that could pose a threat to nuclear plants (Table 3-2) are directly or indirectly weather or climate dependant. This is true for natural hazards, their extent, intensity or frequency of occurrence, but also for man-made hazards, that frequently are connected to failures in plants or systems of neighbouring non-nuclear plants. In a wider sense, war and terrorism, and thus deliberate acts could be traced back to problems partially rooted in climate change or inadequate national and international mitigation and adaptation measures. As the design and the safety measures of every nuclear plant were licensed based on specific assumptions regarding external hazards, it must be ascertained that the safety standards can be maintained throughout the life time of each plant in spite of observed climate change and that expected in the near future.

Extreme heat can lead to exceedance of temperature limits inside nuclear power plants in place to protect the instruments that control the reactor and also to contain the potentially serious hazards in the event of a malfunction [Schwartz 2003]. Heat also can reduce the efficiency of the final heat sink and thus the yield of thermal power plants.

Increase in heavy precipitation events and in frequency and length of draughts have been observed simultaneously and are expected to continue as the climate changes. Draught is frequently associated with low water levels in rivers and streams. In the record summer of 2003 several power plants in Europe, including nuclear power plants, had to be shut down: the extremely hot weather and lack of rainfall had severely reduced supplies of river water with temperatures low enough to provide sufficient cooling [Schwartz 2003]. The increase of heavy precipitation events will probably result in more floods, unless re-naturalisation of rivers and banks lead to improved retention potentials. The authorities in France reacted after the 2000 flooding of the nuclear power plant Le Blayais, by requesting an update of the risk assessment for floods before the plant was allowed to start up again [NE 2000].

In specific circumstances extreme snowfall, hail and sleet could become relevant. Landslides e.g. are frequently a consequence such events. Root causes are frequently methods of soil cultivation, construction work or, in alpine areas, thawing of permafrost. In 2002 for instance, a huge landslide nearly 400,000 m^3 in size blocked a river, posing a threat of flooding a radioactive waste disposal site near Maylisu in the south of Kyrgyzstan [NE 2002].

The geographical pattern of occurrence of tropical storms (Hurricanes), storms and tornados, as well as their frequency and intensity are changing. This might make adaptations necessary in some nuclear power plants. In the 1998 hit of the Nuclear Power Plant Davis-Besse by a tornado the control room grew dark for a brief period, except for instruments and emergency lighting, and the plant shut down automatically. As telecommunication lines had been severed by the tornado, information exchange was severely hampered. The emergency situation lasted about 40 hours [NE 1998].

The scenarios for sea level rise have changed significantly during the last months. Rises of more than 1 m within the next 100 years now no longer seem impossible. This will be of importance for some nuclear power plants situated on the coast.

3.7.7 Increasing Social and Political Instability

World developments such as rapid increase of the world population under diminishing natural resources and the increasing inability of the human society to establish a fairer distribution of resources and welfare are likely to increase the risk of "adverse actions", especially of terrorism and acts of warfare [Bouthoul 1972, Heinsohn 2003].

Any installation with high potential for catastrophe (e.g. large volumes of dammed up water, high concentrations of toxic material and energy at the same spot) must be considered attractive targets and can in fact not reliably be safeguarded. This is especially true of nuclear power plants - already vulnerable to various other internal and external hazards as pointed out above. Vulnerability against deliberate attacks holds true even for the most advanced future "inherently safe" plants.

3.8 Summary and Conclusion

The accident at the Chernobyl reactor in 1986 demonstrated in the most dramatic way yet that in spite of the very low probability of severe accidents occurring in nuclear power plants, they do occur and their consequences (economical, environmental, health effects, etc.) can be extremely serious and can affect large areas over long periods of time. With 443 power reactors in operation worldwide and projections of large increases in nuclear power production – whatever the chances of realisation – nuclear safety is and obviously will continue to be an issue.

Nuclear safety problems are not limited to commercial nuclear power generation. Manifold risks – not treated in this report – encompass the whole fuel cycle from the first mining of uranium to – eventually – the phase-out of nuclear energy. But even after that the risks involved in nuclear waste disposal will remain as a long-term commitment for timespans of geological scales.

A sequence of reactor "generations" reflects an evolution of reactor designs featuring a variety of basic approaches to energy production as well as to reactor safety. The bulk of the presently operating commercial nuclear power plants are of Generation II, and their safety features determine nuclear safety at present. Generation III plants are still very few, and Generation IV is only in the process of being developed. If the contribution of nuclear energy to overall energy production is to increase in future in an environment of growing energy demand, nuclear risk will be determined by the safety features of Generation III or III+ and in the long run – due to the foreseeable limits of availability of fissile uranium – Generation IV plants.

For the coming generation of reactors (Generation III) concepts were modified to address a large number of foreseeable accidents passively ("inherent safety") and reduce core damage frequency. However, the "inherent safety" has not been proven for any reactor so far, and applies only to design base accidents, not to external dangers and certainly not to acts of war or terrorism. Liberalization of the electricity market and the decreasing governmental support for the nuclear industry forced a further redesign to reduce capital costs (Generation III+).

The declared aims of Generation IV – fast reactors – are to be "inherently safe", proliferation resistant, economic and free of long lived high radioactive waste. Fast reactors suffer from a handful of drawbacks, which make them expensive to build and hard to operate. Considerable doubts are voiced on the feasibility of meeting these goals simultaneously. Safety problems in generation IV reactors differ widely from those known for the earlier generations. However, it is very difficult to assess their safety at the present time, as they are only in the design phase, and studies addressing safety aspects are still limited.

An overview of generic severe accident vulnerabilities of the most frequent reactor types and the four generations shows that all have vulnerabilities that can lead to severe accidents with large releases of radioactivity despite the efforts to eliminate such vulnerabilities and the undoubted improvements that have been achieved.

There is a "tension" between safety and cost considerations in nuclear power plant design and operation. Safety codes and standards have been continuously raised but up grading of existing plants frequently do not keep up with this development. The US NRC found in 1997 that the about one fourth of NPPs assessed did not comply with INSAG goals for Large Release Frequencies and one tenth with those for Core Damage Frequency. More recently WENRA found that - contrary to the seemingly universal consensus – not all IAEA Safety Standards are adhered to in all European countries.

This, together with the nuclear accidents at Three Mile Island and Chernobyl, a series of incidents, "near misses", cases of flagrant deficits in safety culture, etc., demonstrates that the safety problem is not resolved by far. Emergent issues aggravate the situation.

- Aging of materials and components leads to a growing risk of accidents.

- Extending lifetimes of nuclear power plants aggravates the aging problem and enhances inherent risks.

- In consequence of its stagnation the nuclear industry suffers from lack of trained personnel, decline of technical support organizations, increasing shortage of nuclear grade spare parts, etc.; necessities the plants have enhanced demand for due to aging.

- Liberalization of the electricity market has led to increased competition and enhanced pressure on costs. There is some fear that in consequence investements in safety coul d be reduced. Practical examples demonstrating consequences of the pressure on costs are reductions in technical staff and increasing of inspection intervals.

- Downgradings of IAEA guidelines as well as national standards and regulations can be seen from the example of WWER-pressurized thermal shock analysis, comparing the safety margins of former 1997 with new 2006 IAEA guidelines that were incorporated into the Czech legislation in parallel. It was only possible through this "update" to demonstrate the structural integrity of the Temelin reactor pressure vessel throughout the projected lifetime. In other cases, standards and regulations are overruled by so-called "expert judgement", a delicate procedure in view of the small pool of nuclear experts, the majority of which are tied in with the nuclear industry.

- Many nuclear power stations are subjected to a higher earthquake hazard than previously assessed. New scientific detection methods taken account of in the recommendations of IAEA are not yet required in practice by all regulatory bodies.

- The specific assumptions regarding weather influenced external hazards must be reassessed in view of observed and expected climate change.

- One likely consequence of an increasing world population facing diminishing natural resources and their increasingly unequal distribution is increasing social and political instability. Nuclear power plants represent particularly attractive targets for sabotage and in armed conflicts and can in fact not be reliably safeguarded. This could become a serious problem as the number of clashes – increasingly on the territory of industrialized states – grows.

Catastrophes are inherent in complex and coupled systems and therefore unavoidable [Perrow 1999], although the likelihood of their occurrence can be reduced. Nuclear power production necessitates very complex and coupled systems involving the implementation of sophisticated safety concepts such as redundant and divers defence in depth. The latter constitutes a factor of increased vulnerability in itself [e.g. Sagan 2004]. But safety measures are imperative, as the enormous energies concentrated in a very small volume together with highly dangerous materials in amounts sufficient to contaminate large areas with persistent deadly radioactive pollutants in principle cannot be contained sufficiently safely nor can handling be made proof against the human factor. By impelling physical laws the causal chains triggering accidents can never be fully eliminated by safety provisions of material containments and technical structures, nor can the evolutionary biological constraints of human nature be overcome by administrative, legal or psychological security measures.

3.9 References

Adamov, E.O. (1999): Supply of Fuel for Nuclear Power – Present Situation and Perspectives, The Uranium Institute 24th Annual Symposium, 8-10 September 1999: London, © Uranium Institute 1999

AEAT (2001): AEA Technology plc, et al., Main Characteristics of Nuclear Power Plants in the European Union and Candidate Countries, EUR-20056-EN, prepared for the European Commission (Luxembourg), October 2001
[http://europa.eu.int/comm/energy/nuclear/publications/synopses_en.htm#20055]

Austrian Expert Team (2001): Austrian Technical Position Paper on Safety Aspects of Temelín Nuclear Power Plant. Expert Mission with trilateral participation according to chapter IV of the PROTOCOL of the negotiations between the Czech and the Austrian Government. July 2001
[http://www.umweltbundesamt.at/umweltschutz/kernenergie/akw/temelin/etemelk/etetrialog/]

Batishchev, M., I. Hinovsky, W. Kromp, N.Meyer, I. Tweer, G. Weimann and H. Wüstenberg (2005): ETE Roadmap. Item 3. Reactor Pressure Vessel Integrity and Pressurized Thermal Shock. Final Monitoring Report. Report to the Federal Ministry of Agriculture, Forestry, Environment and Watermanagement of Austria. Federal Environment Agency Ltd. Vienna, June 2005 ISBN 3-85457-792-3
[http://www.umweltbundesamt.at/umweltschutz/kernenergie/akw/temelin/roadmap/]

BMWi Arbeitsgruppe (2000): Nukleare Sicherheits- und Endlagerforschung in Deutschland, Bericht der vom Bundesministerium für Wirtschaft und Technologie (BMWi) berufenen Arbeitsgruppe, 21. Januar 2000

BNSA (2006): Bulgarian Nuclear Regulatory Agency (BNSA), Kozloduy NPP unit 5 shut down on 1 March 2006, News Release, 15 March 2006
[http://www.bnsa.bas.bg/news/060314.html]

Bouthoul G. (1972): Kindermord aus Staatsraison. Deutsche Verlags-Anstalt GmbH Stuttgart

Bruns, J. (2004): Fachsitzung “Mitarbeiter und Kernkraftwerke“, Jahrestagung Kerntechnik 2004

Bulgaria (2004): Republic of Bulgaria, National Report on Fulfillment of the Obligations on the Convention on Nuclear Safety, Third Edition (Sofia), September 2004
[http://www.bnsa.bas.bg/documents/reports/en/CNS_III_Bulgaria.pdf]

Carter Center (1995): The Carter Center: State of World Conflict Report; The Carter Center, Atlanta, Georgia, 1995

Chernobyl Forum (2005): Chernobyl Forum, Chernobyl: The True Scale of the Accident, joint press release of the International Atomic Energy Agency, the World Health Organization, and the UN Development Programme, 5 September 2005
[http://www.iaea.org/NewsCenter/Focus/Chernobyl/pdfs/pr.pdf[

CSN (2004): Consejo Seguridad Nuclear (CSN), España, Spain: Convention on Nuclear Safety, Third National Report, September 2004
[http://www.csn.es/descarga/infnac3ing.pdf]

EC (1993): Commission of the European Communities, Nuclear Safety in the Context of the Electricity Sector in Central and Eastern Europe and in the CIS, COM(93) 635 final, Brussels, Dec. 9 1993

EC (2003/2004): Proposal and Amended Proposal for a "Council Directive (Euratom) laying down basic obligations and general principles on the safety of nuclear installations" and Proposal and Amended Proposal for a "Council Directive (Euratom) on the safe management of the spent nuclear fuel and radioactive waste" [COM(2003)32], [COM(2004)526]

ECN (2005): ECN & NRG, Kerncentrale Borssele na 2013: Gevolgen van beëindiging of voortzetting van de bedrijfsvoering, ECN-C-05-094, NRG 21264/05.69766/C, prepared for VROM, November 2005 [http://www.ecn.nl/docs/library/report/2005/c05094.pdf]

Elbaradei, M. (1999): Statement to the General Conference, General Director, IAEA, Vienna, 27 September 1999
[http://www.iaea.org/worldatom/Press/Statements/1999/ebsp1999n010.shtml]

EPRI (2002): Electric Power Research Institute, Deterring Terrorism: Aircraft Crash Impact Analyses Demonstrate Nuclear Power Plant's Structural Strength, December 2002
[http://www.nei.org/documents/EPRINuclearPlantStructuralStudy200212.pdf]

ERI (2002): Energy Resources, Inc. (ERI), Sandia National Laboratories, and Oak Ridge National Laboratories, Perspectives on Reactor Safety, prepared for the US Nuclear Regulatory Commission, Technical Training Center, NUREG/CR-6042, Rev. 2 (Rockville, MD USA), March 2002

Gabko, P. and Z. Kovács (2004): "Implementation of the Integrated Level 2 Full Power and Shutdown PSA Model of the J. Bohunice V1 NPP in EOOS Risk Monitor", presented at the Electric Power Research Institute R&R Workstation 2004 Annual User Group Meeting (Juno Beach, Florida), 12-16 January 2004
[http://www.epri.com/r&rworkstation/UserGroup/04Jan/meetingmaterials/29)(Bohunice)V1EOOS.pdf]

GAO (2000): United States General Accounting Offices (GAO), "Nuclear Safety: Concerns With the Continuing Operation of Soviet-Designed Nuclear Power Reactors", Report to the Subcommittee on Energy and Water Development, Committee on Approriations, House of Representatives, April 2000, p. 17

Govaerts, P. and B. De Boeck (1998): Current issues in safety regulations, conference TOP SAFE 98, AVNuclear (Brussels)

Guerrini, B. and S. Paci (1999): Appunti di impianti nucleari, Parte II A: Filiere, Anno Accademico 1998/1999, University of Pisa internal document No RL 811 A (99)

HAEA (2004): Hungarian Atomic Energy Authority (HAEA), Republic of Hungary National Report: Document Prepared in the Framework of the Convention on Nuclear Safety, Third Report (Budapest), 2004
[http://www.oah.hu/web/portal.nsf/download/B8C9450F8EC4122CC1256F0F00324BCE/$File/3rd_natrep_hu.pdf?OpenElement]

Heinsohn, G. (2003): Söhne und Weltmacht. Terror im Aufstieg und Fall der Nationen. Orell Füssli Verlag AG, Zürich

HSE (2004): Health and Safety Executive, The United Kingdom's Third National Report on Compliance with the Convention on Nuclear Safety Obligations, Revision 3, September 2004 [http://www.hse.gov.uk/nuclear/cn3.pdf]

HSK (1996): Hauptabteilung für Sicherheit der Kernanlagen (HSK), Gutachten zum Gesuch des Kernkraftwerks Leibstadt um Leistungserhöhung auf 3600 MWth, HSK 12/420 (Würenlingen), March 1996

HSK (1999): Hauptabteilung für Sicherheit der Kernanlagen (HSK), Periodische Sicherheitsüberprüfung für das Kernkraftwerk Gösgen-Däniken, HSK 17/400 (Würenlingen), November 1999

HSK (2002): Hauptabteilung für Sicherheit der Kernanlagen (HSK), Sicherheitstechnische Stellunghahme zur Periodischen Sicherheitsüberbrüfung des Kernkraftwerks Mühleberg, HSK 11/800 (Würenlingen), December 2002

HSK (2004): Hauptabteilung für Sicherheit der Kernanlagen (HSK), KKW Beznau I: Sicherheitstechnische Stellungnahme der HSK zur Periodischen Sicherheitsüberbrüfung, HSK 14/816 (Würenlingen), November 2004

Hughart, J. L. (2000): Chemical Hazards During the Recent War in Croatia, ATSDR, U.S. Department of Health and Human Services, Atlanta
[http://www.atdsr.cdc.gov/OFP/terrorism/croatia.html]

IAEA (1997): Guidelines on Pressurized Thermal Shock Analysis for WWER Nuclear Power Plants, IAEA-EBP-WWER-08, IAEA Vienna 1997

IAEA (1998): International Atomic Energy Agency (IAEA), Upgrading of Fire Safety in Nuclear Power Plants: Proceedings of an International Symposium Held in Vienna, 18-21 November 1997, IAEA-TECDOC-1014 (Vienna), April 1998
[http://www-pub.iaea.org/MTCD/publications/PDF/te_1014_prn.pdf]

IAEA (1999): International Atomic Energy Agency (IAEA), Final Report on the Programme on the Safety of WWER and RBMK Nuclear Power Plants, IAEA-EBP-WWER-15 (Vienna), February 1999
[http://www-ns.iaea.org/downloads/ni/wwer-rbmk/wwer_15.pdf]

IAEA (1999): International Atomic Energy Agency, General Conference, unofficial electronic version, GC(43)/INF/8, 31 August 1999
[http://www.iaea.org/GC/gc43/documents/gc43inf8.html#gc43inf8sea]

IAEA (2001): International Atomic Energy Agency (IAEA), The International Nuclear Event Scale (INES) User's Manual: 2001 Edition, IAEA-INES-2001, jointly prepared by IAEA and the OECD Nuclear Energy Agency (Vienna), February 2001
[http://www-news.iaea.org/news/inesmanual/INES2001.pdf]

IAEA (2002): International Atomic Energy Agency (IAEA), Heavy Water Reactors - Status and Projected Development, IAEA-TRS-407 (Vienna), May 2002
[http://www-pub.iaea.org/MTCD/publications/PDF/TRS407_scr/D407_start.pdf]

IAEA (2003): International Atomic Energy Agency (IAEA), Extreme External Events in the Design and Assessment of Nuclear Power Plants, IAEA-TECDOC-1341 (Vienna), March 2003
[http://www-pub.iaea.org/MTCD/publications/PDF/te_1341_web.pdf]

IAEA (2004): International Atomic Energy Agency (IAEA), Experience Gained from Fires in Nuclear Power Plants: Lessons Learned, IAEA-TECDOC-1421 (Vienna), November 2004
[http://www-pub.iaea.org/MTCD/publications/PDF/TE_1421_web.pdf]

IAEA (2005a): International Atomic Energy Agency (IAEA), Environmental Consequences of the Chernobyl Accident and Their Remediation: Twenty Years of Experience, Report of the UN Chernobyl Forum Expert Group “Environment” (EGE) (Vienna), August 2005
[http://www.iaea.org/NewsCenter/Focus/Chernobyl/pdfs/ege_report.pdf]

IAEA (2005b): International Atomic Energy Agency (IAEA), Nuclear Safety Review for the Year 2004, IAEA/NSR/2004 (Vienna), August 2005
[http://www.iaea.org/Publications/Reports/nsr2004.pdf]

IAEA-2006: Guidelines on Pressurized Thermal Shock Analysis for WWER Nuclear Power Plants, IAEA-EBP-WWER-08(Rev.1), IAEA Vienna, January 2006 IAEA Experts Meeting 1998: Report on Experts`Meeting on Integrity and Brittle Fracture Safety Assurance of the Mochvce NPP RPV, IAEA Headquarters, Vienna, Austria, 14-18. September, 1998 (Appendix 6.1)

IEA (1999): International Energy Agency (IEA), KEY WORLD ENERGY STATISTICS from the IEA, Edition 1999

INSAG (1991): International Nuclear Safety Advisory Group (INSAG), Safety Culture, INSAG-4, International Atomic Energy Agency (Vienna), February 1991
[http://www-pub.iaea.org/MTCD/publications/PDF/Pub882_web.pdf]

INSAG (1992): International Nuclear Safety Advisory Group (INSAG), The Chernobyl Accident: Updating of INSAG-1, INSAG-7, International Atomic Energy Agency (Vienna), November 1992
[http://www-pub.iaea.org/MTCD/publications/PDF/Pub913e_web.pdf]

INSAG-12 (1999): International Nuclear Safety Advisory Group, Basic Safety Principles for Nuclear Power Plants, 75-INSAG-3 Rev. 1, INSAG-12, IAEA, Vienna, 1999

INSAG-14 (1999): International Nuclear Safety Advisory Group, Safe Management of the Operating Lifetimes of Nuclear Power Plants, INSAG-14 Report, IAEA, Vienna, 1999

INSAG-3 (1988): International Nuclear Safety Advisory Group, Basic Safety Principles for Nuclear Power Plants, INSAG-3 Report, IAEA Safety Series No. 75, 1988

INSAG-8 (1995): International Nuclear Safety Advisory Group, A common basis for judging the safety of nuclear power plants built to earlier standards, INSAG Series No 8, IAEA, Vienna, 1995

IPCC (2001a): Climate Change 2001. Synthesis Report. Cambridge University Press 2001 und

IPCC (2001b) : Intergovernmental Panel on Climate Change. Climate Change 2001. Third Assessment Report. Working Group I

IRR (2004): Institute of Risk Research (IRR), Comparison of a Tokamak Fusion Power Plant with Possible Nuclear Fission and Nuclear Fusion Competitors in 2050, SERF-3 Report, Task TW1-TRE/DFCA, University of Vienna (Vienna), October 2004

Jensen, S.E. and E. Nonbøl (1999): Description of the Magnox Type of Gas Cooled Reactor (MAGNOX), NKS-2, Risø National Laboratory (Roskilde, Denmark), 1999

Kemeny, J. et al. (1979), Report of the President's Commission on the Accident at Three Mile Island, President's Commission on the Accident at Three Mile Island (Washington, DC USA)

Kemeny, J.G. (1980): The President's Commission on the Accident at Three Mile Island, The Need for Change: The Legacy of TMI, 1980
[http://www.threemileisland.org/resource/item_detail.php?item_id=00000138]

Kopchinsky, G. (1997): Situation and Problems in the Power Generating Industry in Ukraine (Kiev, Ukraine), October 1997

Hofer, P., W. Kromp, N. Meyer, E. Seidelberger and I. Tweer (2001): Walkdown II Follow-up: Integrität des Reaktordruckbehälters im KKW Mochovce 1: Absicherung der Ergebnisse des Walkdown II und unterstützende Begleitung der IAEA-Untersuchung, Erstellt im Auftrag des Bundesministeriums für Land- und Forstwirtschaft, Umwelt und Wasserwirtschaft. Risk Research Report 34.Universität Wien. Dezember 2001

Latif, M. (2004): Simulationen zum globalen Klimawandel, 4. Annaberger Klimatage 2004, 12./13. Mai 2004

Magne, L. and C. Shepherd (2003): Status of Probabilistic Safety Assessment Methodology and Applications in Europe, 2nd International ILK (Internationale Länderkommission Kerntechnik) Symposium (München), 28-29 October 2003
[http://www.ilk-online.org/download/symposium2003/11_Magne-Shepherd.pdf]

Meserve, R. (2006): Nuclear Safety: Impressive & Worrisome Trends, IAEA Bulletin 47/2, March 2006
[http://www.iaea.org/Publications/Magazines/Bulletin/Bull472/pdfs/nuclear_safety.pdf]

MIT (2003): Massachusetts Institute of Technology (MIT), The Future of Nuclear Power (Cambridge, MA USA), July 2003
[http://web.mit.edu/nuclearpower/pdf/nuclearpower-full.pdf]

Mlady, O. (1999): NPP Temelin Safety Analysis Reports and PSA Status, International Conference on the Strengthening of Nuclear Safety in Eastern Europe, Vienna 14-18 June 1999, Austria, p. 235-259

MuRe (2001): Winterstürme in Europa (II), Münchner Rückversicherung 2001

NE (1998): Nuclear Engineering International Vol 43 No 529 August 1998

NE (2000): Nuclear Engineering International Vol 45 No 547 February 2000

NE (2002): Nuclear Engineering International Vol 47 No 576 July 2002

NE (2004): Nuclear Engineering International Vol 49 No 599 June 2004

NEA (1996): OECD Proceedings, NEA, Infrastructure for Nuclear Energy Deployment, proceedings to the workshop in Paris, France 1996

NEI (1997): Nuclear Energy Institute, Source Book Soviet-Designed Nuclear Power Plants in Russia, Ukraine, Lithuania, Armenia, the Czech Republic, the Slovak Republic, Hungary and Bulgaria, Fifth Edition (Washington, DC USA), 1997

Nonbøl, E. (1996): Description of the Advanced Gas Cooled Type of Reactor (AGR), NKS/RAK2(96)TR-C2, Risø National Laboratory (Roskilde, Denmark), November 1996

NRC (2002): US Nuclear Regulatory Commission (NRC), Davis-Besse Reactor Vessel Head Degradation Lessons-Learned Task Force Report (Rockville, MD USA), 30 September 2002
[http://www.nrc.gov/reactors/operating/ops-experience/vessel-head-degradation/lessons-learned/lessons-learned-files/lltf-rpt-ml022760172.pdf]

NRC (1987): US Nuclear Regulatory Commission (NRC), Shutdown Order Issued Because Licensed Operators Asleep While on Duty, Information Notice Nr. 87-21 (Washington, DC USA), 11 May 1987
[http://www.nrc.gov/reading-rm/doc-collections/gen-comm/info-notices/1987/in87021.html]

NRC (1992): US Nuclear Regulatory Commission (NRC), NRC Region I Augmented Inspection Team (AIT) Review of the November 9, 1991 Salem Unit 2 Turbine-Generator Overspeed and Fire Event, NRC Docket Nr. 50-311, 07 January 1992

NRC (1993): U.S. Nuclear Regulatory Commission (NRC): Status Report from NRC Incident Investigating Team; NRC, Washington, DC, February 10, 1993

NRC (1997): [http://www.nrc.gov/NRC/NUREGS/SR1603/index.html]

NRC (2003): US Nuclear Regulatory Commission (NRC), Regulatory Effectiveness of the Anticipated Transient Without Scram Rule, NUREG1780 (Rockville, MD USA), September 2001.
[http://adamswebsearch2.nrc.gov/idmws/doccontent.dll?ID=032810194: &LogonId=4b01c689 8110eb138ba19bd2ea60f796]

NRC (2004): US Nuclear Regulatory Commission (NRC), Note to Editors: NRC Issues Preliminary Risk Analysis of the Combined Safety Issues at Davis-Besse, NRC News Release Nr. 04-117 (Rockville, MD USA), 20 September 2004
[http://adamswebsearch.nrc.gov/idmws/ViewDocByAccession.asp?AccessionNumber=ML0426 40170]

NW (1994): Ignalina Sabotage Deadline Passes Without Blow-Up, Bomb Not Found; newsletter article, Nucleonics Week, Washington, DC, November 17, 1994

NW (1995): U.S. Intelligence Warns Against Chechnyan Attacks on Reactors, newsletter article, Nucleonics Week, Washington, DC, December 22, 1995

OPB-88 (1988): OPB-88 General Provisions for Ensuring Safety of NPPs, PNAE-G-1-011-89, Moscow 1989 (in Russian)

Perrow, Ch. (1999): Normal Accidents. Living with High Risk Technologies. Princeton: University Press, 1999

POST (2004): Parliamentary Office of Science and Technology (POST), Assessing the Risk of Terrorist Attacks on Nuclear Facilities, Report 222 (London), July 2004
[http://www.parliament.uk/documents/upload/POSTpr222.pdf]

Reactor Harmonization Working Group RHWG (Harmonization of Reactor Safety on WENRA Countries)

Renn, O. and A. Klinke (1998): Management and Policy: Political Strategies and Instruments Of the Risk Types, SRA conference 1998, Paris

Rogovin, M. (1980): Three Mile Island: A Report to the Commissioners and to the Public, Special Inquiry Group, US Nuclear Regulatory Commission
[Vols. I & II, 1980. Vol. I, http://www.threemileisland.org/resource/item_detail.php?item_id=00000150;
Vol. II, Pt. 1, http://www.threemileisland.org/resource/item_detail.php?item_id=00000151;
Vol. II, Pt. 2, http://www.threemileisland.org/resource/item_detail.php?item_id=00000152;
Vol. II, Pt. 3, http://www.threemileisland.org/resource/item_detail.php?item_id=00000153]

Rolevich, I. et al. (1996): Report for Belarus, One Decade After Chernobyl, Summing up the consequences of the accident, IAEA, Vienna, 1996

Romania (2004): Government of Romania, Convention on Nuclear Safety: Romanian National Report, Second Revision, August 2004

Sagan, S. (2004): Sagan Scott D., The Problem of Redundancy Problem: Why More Nuclear Security Forces May Produce Less Nuclear Security; Risk Analysis, Vol 24, No 4, 2004

Schwartz, P. (2003): Environmental News Network, Thursday, September 11, 2003
[http://www.enn.com/news/2003-09-11/s_8086.asp]

Scranton, W. et al. (1980): Report of the Governor‘s Commission on Three Mile Island, 1980
[http://www.threemileisland.org/resource/item_detail.php?item_id=00000149]
Sholly, St., A. Gazsó, P. Hofer, W. Kromp and H. Kromp-Kolb (2000): “Integrated Risk Assessment”, 3rd International Conference of the European Society for Ecological Economics ESEE 2000, Vienna 2000

SKI (2003): Statens Kårnkraftinspektion (SKI), The Tolerance of Swedish Nuclear Power Plants to Stress from External Sources, SKI PM 03: 15, 2003

Slovak (2004): Slovak Republic, National Report of the Slovak Republic Compiled in Terms of the Convention on Nuclear Safety, September 2004
[http://www.ujd.gov.sk/NS_SR_2004_angl.doc]

Slovenian CNS (1998): National report on the fulfilment of the obligations of the convention on nuclear safety, the first Slovenian report in accordance with article 5, Ljubljana, August 1998

Steinberg/ Shteynberg N. A. et al. (1991): Causes and Circumstances of the Accident at Unit 4 of the Chernobyl Nuclear Power Plant on 26. April 1986, Report by a Commission to the USSR State Committee for the Supervision of Safety in Industry and Nuclear Power, Moscow, 1991

STUK (2000): Såteilyturvakeskus (STUK), Experiences from the LNPP-P&DSA Review: Lessons Learned from RBMK Safety Studies, STUK-YTO-TR-168 (Helsinki), September 2000
[http://www.stuk.fi/julkaisut/tr/stuk-yto-tr168.pdf]

STUK (2004): Såteilyturvakeskus (STUK), Finnish Report on Nuclear Safety: Finnish 3rd National Report as Referred to in Article 5 of the Convention on Nuclear Safety, STUK-B-YTO 234 (Helsinki), September 2004
[http://www.stuk.fi/julkaisut/stuk-b/stuk-b-yto234.pdf]

Swedish CNS, 1998: Sweden´s First National Report under the Convention of Nuclear Safety, 1998

Swiss Re (2000): Sturm über Europa. Ein Unterschätztes Risiko. Swiss Re Publishing, Zürich

Tobita, Y., H. Yamano, I. Sato (2006): Analytical Study on the Elimination of Severe Recriticalities in Large Scale LMFBRS with Enhancement of Fuel Discharge. Technical Meeting on Severe Accident and Accident Management Toranomon Pastoral, Minato-ku, Tokyo, Japan, March 14-16, 2006

Thomas, St. (1999): Economic and safety pressures on nuclear power: a comparison of Russia and Ukraine since the break-up of the Soviet Union, Energy Policy 27(1999), 745-767

Thompson, G. (1996): War, Terrorism and Nuclear Power Plants; Institute for Resource and Security Studies/Greenpeace International, London, March 1996

Uspuras, E. (1999): Status of Ignalina‘s Safety Analysis Reports, presented at the International Conference on the Strengthening of Nuclear Safety in Eastern Europe (Vienna), 14-18 June 1999
[http://www.lei.lt/insc/plants/ISAR_PAP.htm]

Volterra, E. (1988): Operating Experience With the Latina MAGNOX Reactor, in Technical Committee Meeting on Design Requirements, Operation and Maintenance of Gas-Cooled Reactors, IWGGCR-19, International Atomic Energy Agency (Vienna), 1988
[http://www.iaea.org/programmes/inis/aws/htgr/fulltext/iwggcr19_17.pdf]

Wiss. Beirat. (1998): Wissenschaftlicher Beirat der Bundesregierung, Globale Umweltveränderungen Welt im Wandel: Strategien zur Bewältigung globaler Umweltrisiken, Jahresgutachten 1998

Zittel, W. and J. Schindler (2006): Uranium Resources and Nuclear Energy. Background Paper prepared by the Energy Watch Group. EWG-Series No 1/2006

4 Radioactive Waste

Helmut Hirsch
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4 Radioactive Waste

4.1 Introduction

Radioactive waste from civil use of nuclear power represents a long-term hazard. Radiotoxicity is especially due to nuclides that do not exist in nature or appear only in trace amounts (for example plutonium isotopes, neptunium-237).

The amount of radioactive waste is continuously increasing. Nuclear power plants around the world produce about 10,000 tons of spent fuel per year.

Aside from that, the civil use of nuclear power generates many other streams of radioactive wastes. The spent fuel elements contain the highest amount of radio nuclides, but other radioactive wastes can also be problematic.

The largest total quantity of radioactive wastes is produced during uranium mining and in the first steps of processing. At Wismut in the former DDR about 95,000 tons of uranium concentrate (Yellow Cake) were produced until 1989 from some 124 million tons of ore [Lowson and Browon 1995]. This is equivalent to 1,300 tons of ore per ton of uranium concentrate, or about 10,000 tons of ore per ton of LWR fuel.

Further radioactive wastes are produced during enrichment, fuel element manufacture, as secondary waste during the NPP operation, in relatively small amounts during the fuel storage and in large amounts during spent fuel reprocessing. Radioactive wastes that originate during nuclear power related research and development should also be mentioned (for example from the operation of material test reactors or test facilities for waste processing).

Since the largest amount of the total radiotoxicity of radioactive wastes results from spent fuels, these will be the main consideration of the following.

4.2 Transport, Intermediate Storage and Reprocessing

Transport of radioactive wastes, especially spent fuel elements, is potentially hazardous.

The containers used are built to be very resistant to accident conditions but they are not completely safe. Severe accidents during the transport on rail, road or ships can lead to leakage, especially during long fires or due to severe mechanical impacts. Furthermore, the containers are vulnerable to terrorist attacks (for example with armor-piercing weapons). Significant radioactive releases can result in these cases. In case of unfavorable weather conditions, such releases could make it necessary to relocate the population within a radius of more than 5 km from the accident site [Deppe et al. 1992].

Further possible hazards result from radioactive contamination of the outside of transport casks or of transport vehicles that can get detached and then lead to radioactive pollution of persons due to inhalation, ingestion or skin contact. The risk factor due to direct radiation from the cask should not be neglected either.

The intermediate storage of radioactive wastes includes potential safety hazards as well.

During the storage of spent fuel with forced cooling, especially in water pools, loss of cooling or loss of water inventory can result in severe radioactive releases due to the large Cs-137 inventory of a spent fuel pool (can be many cores worth of Cesium). At many nuclear power plant sites, the spent fuel pools are less protected against external events (including terror attacks) than the reactor, since they are located outside the reactor building, or in a part of this building encloses by thinner walls than the reactor itself. This applies to most U.S. NPPs, but also to several NPPs in the EU.

In case of the dry spent fuel storage installations with natural ventilation that are increasingly favored, external impacts (especially fires) can trigger severe accidents. The storage in modified transport casks is connected with the additional problem of guaranteeing the tightness of the casks and the future handling of the stored fuel over long periods of time.

The reprocessing of spent fuel elements implies the separation of most of the uranium and plutonium, but also the distribution of the remaining nuclides within a large waste volume. In Sellafield or La Hague one ton of spent fuel with a volume of about ½ m^3 leads to about 10 m^3 of radioactive waste [COGEMA and BNFL 1990].

Reprocessing processes have a significant hazard potential in the event of an accident, particularly with respect to storage of liquid high level waste in tanks. Even during normal operation significant radioactive emissions are produced. Therefore the OSPAR Commission stated in June 2000:

"...that nuclear reprocessing facilities in the North-East Atlantic area are the dominant sources of discharges, emissions and losses of radioactive substances and that implementing the non-reprocessing option for spent nuclear fuel would, therefore, produce substantial reductions of discharges, emissions and losses of radioactive substances into the North-East Atlantic..."

The Commission called for a review of the existing emissions from reprocessing plants with the aim of ending reprocessing and taking other measures to minimize the risk of accidents involving the existing inventories of high level waste produced by reprocessing to date [OSPAR Commission 2000].

The overall radioactive emissions from the La Hague and Sellafield reprocessing plants are to be reduced to *"close to zero"* by the year 2020. The 15 countries which are cooperating in the framework of OSPAR, including France and Great Britain, agreed on the details of the further action in June 2003. To achieve consensus, far-reaching compromises were required. The reductions of the emissions will be implemented very slowly, and exceptions are granted for certain nuclides, to provide the plant operators with more flexibility. Considering this, it appears questionable whether the goal of *"close to zero"* will actually be reached by 2020 [Nuclear Fuel 2003].

4.3 Final Disposal of Radioactive Wastes

4.3.1 The Hazardous Potential of Wastes

Radioactive wastes from the civil use of nuclear power exhibit a considerable long-term hazard potential that cannot be neglected for millions of years, which is unique within the industrial society.

It has to be pointed out that this statement is exclusively bound to the commercial use of nuclear energy. This is not necessarily true for radioactive wastes from the use of radioactive materials in medicine, research and industry.

Several numbers can prove this unique long-term hazard, considering the amount of 400,000 tons of spent nuclear fuel, corresponding to 40 times the actual global production per year of about 10,000 t [Fukada et al. 2003] (for nuclear power plants usually a total operation time of about 40 years is assumed).

In order to illustrate the hazard, the amount of water will be determined that would be required to dilute this amount of waste so that this water could be used as drinking-water fulfilling the corresponding limits (observing the limits does not mean that no health hazards are possible).

Basis for the determination of the water amount is the Euratom Directive 96/29. National regulations in force in the EU countries are partly more stringent than this Directive. For example, if the calculation were based on the German Radiation Protection Ordinance, significantly greater amounts of water would result.

The calculations are performed for the time period after disposal of 1000 and 1 million years, respectively. For simplification only the respectively dominant radio nuclides are considered, the real radiotoxicity will therefore be higher than the given values for this reason alone.

Tab. 4-1 **REQUIRED DILUTION VOLUME FOR SELECTED NUCLIDES IN SPENT FUEL**

Time	Nuclide	Dilution volume (Euratom)
after 1,000 yrs	Plutonium (alpha)	3 Mio km^3
after 1 Million yrs	Neptunium-237	1,500 km^3

lebensministerium.at

For comparison: The total volume of groundwater on earth is estimated to be about 4 millions km^3. The Atlantic Ocean contains about 350 millions km^3, the Baltic Sea about 23,000 km^3.

It is also of interest to compare with chemotoxic wastes. For simplification only cadmium, one of the most toxic heavy metals, is considered. In order to dilute the same amount (400,000 tons) of cadmium to the limits according to the German drinking-water regulation an amount of about 80,000 km^3 would be necessary.

These results show roughly, that for tens of thousands of years the toxicity of radioactive wastes is by far higher than that of chemotoxic wastes, and is therefore a unique problem. For periods of hundreds of thousands to a million of years the radioactive waste repository and the heavy metal deposit are increasingly similar with respect to their toxicity. This is also true for the nature of the deposited wastes (long-term dominance of uranium and other also chemotoxic metals; moreover, in a final repository non-radioactive heavy metals like lead which is being used as shielding material in waste containers can be present).

This consideration shows that also the final disposal of pure chemotoxic wastes is very problematic, thus the amount of these wastes should be reduced significantly.

4.3.2 Options for the Final Disposal and their Evaluation

In principle, three different options for final disposal are possible (final disposal is defined as the deposition of wastes into a repository without temporal limitation):

- Storage in deep geological repositories with temporally restricted control and correction possibilities (about 100 years). A variation would be a deep geological repository with the principal option of long term retrievability.

- Surface or near-surface disposal with temporally unlimited control and correction possibilities (retrievability).

- Partitioning and transmutation of long-living radio nuclides with limitation of the hazardous time period to max. 1,000 years; storage for this time period.

Several ”exotic” variations can be either assigned to the named options, like the disposal in the ocean ground, in the arctic ice or in very deep bore holes (geological repositories), or should be considered as far-fetched like the plans to launch radioactive waste into space.

4.3.2.1 Geological Final Disposal

Geologic disposal is the option favored worldwide and also has first priority in most EU-countries.

The main problem with this option is the fact that a reliable safety assessment is not possible for the required time periods (millions of years). Natural sciences are reaching their limits in their ability to make safety predictions.

On this point there is an extended agreement between all participating scientists.

“Wegen der langen zu betrachtenden Zeiträume kann weder die Richtigkeit der Beweisführung belegt noch eine Fehleinschätzung korrigiert werden.”
[Niedersächsisches Umweltministerium 1993]

(Due to the long time periods that have to be considered neither can the correctness be proven nor can a mistake be corrected.)

“Wenn auch die für die Sicherheitsanalyse bedeutsamen Ereignisabläufe noch nicht alle im Detail aufgeklärt und verstanden, die Eingangsdaten für Modellrechnungen mit Unsicherheiten behaftet

und folglich auch die zum Einsatz gelangenden Modelle noch nicht vollständig entwickelt sind, so herrscht international doch Einigkeit darüber, daß der Nachweis der Sicherheit eines Endlagers über einen Zeitraum bis zu 10,000 Jahren auf analytische Weise erbracht werden kann." [FZK 1998]

(Although the safety assessment relevant event procedures are not explained and understood in detail, the input data for the modeling simulations include uncertainties and the used models are not yet fully developed, there exists an international agreement that the safety assessment of a final disposal can be performed analytically for a time period up to 10,000 years.)

"Allerdings setzt sich zunehmend die Erkenntnis durch, dass eine Modellvalidierung [beim Nachweis der Langzeitsicherheit] im strengen Sinn nicht durchführbar ist." [FZK 1998]

(Nevertheless it is increasingly recognized that a model validation [for the assessment of long-term safety] cannot be performed in a stringent way.)

"In the context of geological disposal, because of the long timescales involved, it is not possible to demonstrate safety directly and recourse must be made to other, less direct, evidence." [Pather 2005]

Difficulties already exist in finding an appropriate criterion for long-term safety. It can be questioned whether the maximum individual dose for people due to the releases from final disposals are useful as only or central criterion for safety. Additional requirements to protect the living environment and the environmental media have been discussed [Endlagerhearing 1993]. However, this aspect generally received relatively little attention in the last years. The latest IAEA Safety Requirements for geologic disposal do discuss the protection of the environment as well as the protection of human health, but only in rather marginal manner [IAEA 2006].

There are demands to discuss the use of doses as criterion in a more rational way and to define additional long-term safety indicators.

"....radiation doses are not assessable with any certainty for periods of time longer than a few hundred years ... we appear to be unable to find a suitable indicator to demonstrate the long-term safety of waste disposal... " [Gonzalez 1998]

Moreover, many unsolved problems exist that render the predictions even more difficult, for example, with respect to the development of gases in a geological repository, and concerning the effect of colloids in the groundwater for the transport of nuclides:

"Die Beherrschbarkeit der Gasbildung in dichtem Salzgestein in Folge von Korrosion und Zersetzung der Abfälle stellt ein besonderes Problem dar." [Erklärung der deutschen Bundesregierung 2000]

(The control of gas development in dense salt deposits due to corrosion and decomposition of the wastes is a specific problem.)

"Although the three projects [EU-Projekte HUMICS, CARESS and TRANCOM] have significantly improved our understanding of colloid facilitated radio nuclide transport, further research is required if long-term predictions of the performance of a waste repository are to be made." [Warwick et al. 1999]

In 2004, a report on the safety of geologic disposal in Switzerland was published by the OECD's Nuclear Energy Agency (NEA). This report clearly shows that there is still a large number of open problems [OECD NEA 2004]. Further work is recommended in order to reduce the existing uncertainties. Need for clarification is seen, for example, regarding the behavior of the backfill material which is to be used in Switzerland (Bentonite) and the interaction of this material with other components in the repository. There are also questions regarding geochemical retention, the validity of the use of natural analogues and diffusion processes in clay – in short, regarding many issues of significance for the safety of final disposal. Furthermore, it is emphasized that the dose rates determined by modeling are merely indicators; they cannot be regarded as long-term prognoses. A review of the Swiss disposal plans by Austrian experts agreed with most of the findings of the NEA. This review also came to the conclusion that further vital questions like the possible effects of erosion by meltwater in a future ice age and the homogeneity of the clay formation envisaged as host rock also require clarification [Hirsch et al. 2005]. The work performed in Switzerland so far has been accepted as proof of feasibility of final disposal ("Entsorgungsnachweis") in mid-2006, by the Swiss government [BFE 2006]. The open questions, however, remain.

At the international conference on final disposal DisTec in April 2004, unsolved problems were also reported from other countries, for example Belgium, France and Germany [DisTec 2004]. It became clear that a comprehensive data base for the modeling of the reactions occurring in a repository in salt (which is one of the media most favored for final disposal) does not yet exist.

In an IAEA technical report on geologic disposal which was published a few years ago, 13 subject areas are listed in the summary where there are still deficits and further work is considered necessary in order to enlarge the scientific and technological basis for final disposal [IAEA 2003]. This concerns basic issues like methods for the evaluation of site data, how to deal with lack of knowledge and uncertainties when assessing a site, mechanisms of radiolysis around canisters with spent fuel as well as questions of gas transport in geologic media.

In view of these problems and open questions it is not astonishing that world wide no final disposal exist for high-level, heat generating wastes from the civil use of nuclear power.

4.3.2.2 Retrievability in Geological Repositories

The existing uncertainties for geological final disposal and the lack of control and possibilities for correction measures are increasingly seen as disadvantages of the "classic" final repository. Therefore, more and more countries are studying the option of retrievability.

Between 1985 and 1999 almost all EU countries, including Switzerland, with Nuclear Programs, began an active engagement in retrievability [Vrijen 1999].

Nevertheless there is a demand to intensify the respective investigations: *"Why isn't the option of retrievable disposal explored more carefully?"* [Gonzalez 1998]

During the last years, the trend towards retrievability appears to have become more noticeable. In one EU member state, the Netherlands, it is obligatory that radioactive wastes – if they are geologically disposed at all – are retrievable. The period of time for which this is considered as feasible is seen as *"restricted to a maximum of a couple of hundred years"*, however [JC/NL 2006].

In France, reversibility (which is a concept similar to retrievability, but further-reaching) is also considered important. The French waste disposal agency ANDRA estimates the duration of reversibility at 200 - 300 years [JC/FRA 2006]. In the new French waste bill which was passed in June 2006, reversibility is specified for a minimum of 100 years [Nuclear Fuel 2006b].

The specific applicability and usefulness of retrievability in geological final disposal with the aim of increased safety, however, is rather limited.

Retrieval of waste from a geologic repository that is typically in a depth of several hundred to thousand meters, is principally always possible as long as the location is known and the required expenses are accepted.

The problem results from the fact that in a refilled final disposal mine no information exists on the state of the repository and its environment. It is therefore not possible to retrieve wastes in a controlled way and in time in case of unexpected events that impair the safety.

A retrieval in case of detected radio nuclides in the near-surface groundwater, indicating that radio nuclide migration has already taken place over hundreds or thousands of years, will not be helpful.

Moreover, every attempt at retrieval will be aggravated due to the fact that no information on the conditions in the repository is available.

Measures like piping in the waste containing bore holes or the coloring of the refill material in order to facilitate the re-discovering are not expensive and will not negatively affect the safety of the repository, but do not change the lack of information on the state of the repository. Sensors to control temperature, strain, humidity, etc. in the area of the repository are limited with respect to their lifetime, so that no reliable information can be expected not even for several hundreds of years.

Another possibility would be to leave the repository mine or parts of it open to allow the access to the waste. But this would yield additional risks such as an increased hazard of flooding, possible stability problems of the geological deposit, or the risk that the mine will be surrendered without appropriate refill.

“Such implications could increase uncertainty in the initial conditions for the safety assessment by the long-term period.” [Vrijen 1999]

In case of surface or near-surface disposal the retrievability is given over long time periods. This option is fundamentally different from the geological final disposal and will be evaluated separately.

4.3.2.3 Controlled Surface or Near-Surface Disposal

The controlled storage of radioactive wastes as final disposal, i.e. with unlimited time horizon (in contrast to the temporally limited intermediate storage) is a concept of only minor interest within the “nuclear community”.

In France, long-term surface disposal was selected as one of several options to be investigated in the waste bill of 1991 [Damveld & van den Berg 2000]. The new waste bill of 2006 stipulates that a long-term storage facility for long-lived high level waste is to be constructed by 2015. A geologic repository is to be operational in the same year [Nuclear Fuel 2006b]. Deep geologic disposal is the preferred option in France; the parallel development of long-term controlled storage clearly shows, however, that a back-up strategy is regarded as necessary.

In the Netherlands a governmental resolution from May 1993 states that, the final disposal of radioactive wastes has to be performed according to the principles of “isolation, management and control” [Damveld & van den Berg 2000]. Therefore, as mentioned above, retrievability is obligatory in case of geologic disposal. At the moment, however, only controlled storage at the surface is actually planned. The waste is to be stored in buildings, at first for a time period of at least 100 years [JC/NL 2006].

A number of non-governmental organizations (NGOs), environmental groups and university scientists in Western Europe and the USA call for controlled long-term disposal, in combination with appropriate institutionalised long-term monitoring (”Nuclear Guardianship“; [Macy 2005]; [Kromp and Lahodynsky 2006]). In these considerations disposal is not limited to buildings on the surface. Different concepts for underground, but near the surface storage, are thinkable, to enhance protection against unwarranted access and natural disasters.

However, controlled disposal over the required time periods can also not be considered as a realistic perspective. While natural sciences reach their predictive limits in the case of the geological final disposal, the impossibility of predicting social developments over hundreds, much less millions of years makes unlimited controlled disposal questionable.

Significant radioactive releases within short periods of time can occur in all modes of final repositories, including geological repositories. The likelihood of such releases, however, is much larger for surface or near surface disposal, as the total radioactive inventory is already within or very near the biosphere.

4.3.2.4 Partition and Transmutation

This option, as well as the retrievability, has been discussed more frequently within the last few years.

Currently, the problems in connection with their industrial implementation are not foreseeable in detail. It is more than likely, however, that the problems to be expected will include accident potential, pollution caused by reprocessing, proliferation vulnerabilities and massive costs [National Academy of Science 1996].

Practically the complete partitioning of all long-lived nuclides would be required in order to secure that the remaining wastes need a safe storage only for short time periods. At present, separation levels of about 99 % are reached in reprocessing plants. Much better separation would have to be achieved in order to avoid long isolation times of the remaining wastes.

A technology of ”super-reprocessing” would have to be developed (partition of all actinides and long-living isotopes with an efficiency of 99.99 % and more), that would have to be performed without environmental pollution (in contrast to today’s reprocessing practice) and without catastrophic potential.

Moreover, the specific transmutation methods - based on neutron sources or special reactors – exist today only in laboratories.

Generally it is expected, that appropriate methods for reprocessing and transmutation will – if at all – be available only after several decades [Kacsóh 1999]. This means that this option cannot be considered as a solution for the already existing waste or the radioactive waste produced in the near future.

This is in agreement with expert estimations at the conference 'Euradwaste 1999' of the European Commission on partition and transmutation:

"It will require a few decades to install partitioning facilities capable of separating the most hazardous radionuclides from conventional reprocessing waste streams and to gradually introduce in an industrial power production reactor park fast neutron reactors or accelerator driven systems to transmute these radionuclides.

Once the installations for partition and transmutation have been introduced, the balances between the production and destruction of plutonium and of the hazardous radioanuclides will only be reached after several decades due to the long time span of the nuclear fuel cycle.

It is therefore necessary, and whatever the scenario, to have operational geological repositories to safely dispose of existing and future conditioned high level and medium level nuclear waste, which cannot be transmuted." [COGEMA and BNFL 1999]

The experts of the podium discussion pointed out that the implementation of partitioning and transmutation is only an option if nuclear power will be used over long periods of time.

It was also pointed out that the feasibility of this option is, from today's view, basically questionable and thus it is not clear whether the efforts for the development over the last decades and the billions of Euros spent will ever be proven worthwhile.

"Solange jedoch nur Laborexperimente zur Machbarkeit der Transmutation durchgeführt werden – und hier steht die Forschung momentan –, kann das große theoretischen Potential dieser Technik nur mit gesunder Skepsis betrachtet werden." [Kacsóh 1999]

(As long as only laboratory experiments are performed with respect to the feasibility of transmutation – and this is the actual state of research – the theoretical potential of this technology can only be considered with sound skepticism.)

A representative of the OECD's Nuclear Energy Agency, at the DisTec 2004 conference, has recently confirmed this assessment. This representative pointed out that there are still open questions; he also emphasized that even after transmutation, a final repository would be needed, although for smaller quantities of waste [Shimomura 2004].

4.4 Recent International Developments and Trends

Steps backward and problems, in many countries, characterize the international development of the last years.

In Germany, the final disposal projects have reached a standstill. The former (red/green) Federal Government initiated the development of a new procedure for site selection with public participation, which is to start without any advance decisions or assumptions, from a “white map” (a blank map of all of Germany), so to speak. At the same time, the old repository projects of Gorleben and Konrad were not given up, in spite of them being both politically controversial and scientifically questionable. The newly developed site selection procedure was effectively blocked by this lack of consistency, as well as by resistance from the waste producers’ prospective (NPP operators), right from the beginning.

The Federal Minister for the Environment under the former government was considering a new legal regulation, which would transfer responsibility for final disposal from the Federal Government to a corporation founded by the NPP operators. The former government, however, could not get the site selection procedures for final disposal out of their deadlock [Nies 2004]. Since the change of Federal Government in Germany in 2005, increasing pressure is building up to disregard the new procedure for site selection altogether and go back to the Gorleben and Konrad projects as only options. The concept of the present Minister for the Environment so far, on the other hand, has been to initiate a new site selection process and compare new sites to the Gorleben and Konrad sites. To date (September 2006), the issue is unresolved.

In the United States, scientific doubt concerning the final disposal project Yucca Mountain is persisting. In the last years, it has been questioned whether the quality control regarding the scientific work performed during site investigation was adequate. Problems which have not been sufficiently explored include, for example, the possibility of groundwater intrusion and the effects of earthquakes.

Furthermore, there has been a far-reaching change in the basic premises for the project. In July 2004, the U.S. Appeals Court (Washington) rescinded the isolation period of 10,000 years, which has so far been required for Yucca Mountain. Corresponding to a recommendation of the U.S. National Academy of Sciences, the Court demanded a longer isolation period (up to 1 million years). [Platts 2004]. Consequently, the U.S. Environmental Protection Agency and Nuclear Regulatory Commission both have proposed changes in the safety standards. According to these proposals, the period to be considered in safety analyses is to extend to the time of peak dose, but for no more than 1.000,000 years. For the first 10,000 years, the individual protection standard shall be 0,15 mSv/year. For the remainder of the period under consideration, it is to be 3.5 mSv/year [NWTRB 2006]. The latter number is significantly higher than the value set in IAEA Safety Requirements – 0.3 mSv/year [IAEA 2006].

In the last report of the U.S. Nuclear Waste Technical Review Board, it is also pointed out that additional work is needed concerning the capability of natural barriers to isolate radio nuclides; work concerning processes and phenomena that could significantly affect the rate of radio nuclide transport. Although seven performance assessments have already been carried out, there is still lack of fundamental understanding. This is to be bridged by conservative approaches. However, the degree of conservatism is often difficult to assess [NWTRB 2006]. The license application for Yucca Mountain is now being prepared; but many open questions remain.

In many countries, among them Japan, site selection for a final repository is impeded not only by scientific problems, but also by lack of acceptance by the populace. In Finland, which is sometimes mentioned a positive example for progress regarding final disposal, site selection could be carried through only because a site in the immediate neighbourhood of a nuclear power plant was chosen. In the region concerned, intense public relations work for the nuclear installations had been ongoing for decades [Ryhänen 2004].

On June 18, 2001, the Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management has entered into play. Without doubt, this constitutes a step forward in the international development. This convention is the first instrument which regulates aspects of final disposal in an international context and establishes basic principles regarding the legal and regulatory framework as well as safety.

Significant problems remain in connection with this convention. At the time of the First Review Conference in November 2003, important countries like, for example, Russia or China had not yet consented to the agreement. Furthermore, an IAEA representative criticised the reports and the discussion at the First Review Conference in November 2003 for not being altogether satisfactory. Reporting was not always characterized by the frankness which is to be desired [Metcalf 2004].

At the time of the Second Review Conference in May 2006, positive developments were to be noted. There was progress in the scope of membership and the quality of national reports was improved, according to participants. The Joint Convention now includes all major nuclear power producing countries except India. However, no consensus on waste safety standards could be reached at the Conference. Regarding this crucial issue, “tooth-and-nail” fighting was reported. Whereas many countries are following IAEA recommendations, others, most notably the US, refused the establishment of IAEA documents as standard or benchmark [Nuclear Fuel 2006a].

An important finding of the Second Review Conference was that siting of disposal facilities, in particular geological repositories, is very difficult world-wide, and there is little progress [JC 2006].

4.5 Conclusion

Even the first steps of radioactive waste management – transport, intermediate storage, reprocessing – generate significant environmental pollution and include accident risks.

The most severe and unique problems appear during final disposal.

From today’s point of view none of the options for final disposal fulfills the requirements of safety and social compatibility.

- In case of transmutation there are open questions concerning the safety of the required partitioning procedures, as well as the operation of the reactor or accelerator systems. There are additional doubts with respect to the basic feasibility and the costs.

- For the two other options (geological repositories and temporally unlimited controlled surface disposal), due to the long time periods that would have to be covered by safety assessments it is hardly conceivable that sufficient safety can be guaranteed.

- In case of the disposal in geological repositories the natural sciences reach their predictive limits, considering that analyses are required to cover many thousands, and even millions of years. In case of unlimited controlled surface or near-surface disposal, on the other hand, the predictive limits with respect to social development will already be reached within a short period of time. Thus the further production of high-level radioactive wastes is not acceptable and should be stopped as soon as possible.

In the long-term there is a convergence of the problems of radioactive wastes and chemotoxic heavy metals. In both cases the hazardous potential is high even after millions of years. This means that the final disposal of chemotoxic wastes is also very problematic and the amounts generated have to be reduced significantly.

For the already existing radioactive wastes the solution with the smallest disadvantages has to be found within a social consensus. Nuclear phase out favors the minimization of disadvantages. The limitation of the produced waste streams possibly allows options that would not be possible for continuously increasing waste volumes (for example geological disposal in few mines that could be selected regionally according to the most favorable geological conditions, but have limited capacity; or concepts that could not be financed for larger amounts of waste).

The limitation of waste amounts would also reduce the temporal pressure, since the waste volumes that have to be transported and intermediately stored are smaller and thus the risks of intermediate storage and transport are reduced.

4.6 References

BFE (2006): Entsorgung hochaktiver Abfälle in der Schweiz technisch machbar; Schweizerische Eidgenossenschaft, Bundesamt für Energie, press release of June 18, 2006-09-12

COGEMA and BNFL (1990): "Specifications des Déchets Technologiques Cimentés" from zones 2/3 and zone 4, 2. series, COGEMA, January 1990

Damveld, H. and R.J. van den Berg: Nuclear Waste and Nuclear Ethics; Studie im Auftrag der Niederländischen Kommission für die Endlagerung radioaktiver Abfälle (CORA), Groningen/Wageningen, January 2000

Deppe, U. et al. (1992): Transporte gefährlicher Güter auf dem Stadtgebiet von Hannover unter Berücksichtigung möglicher Gefahren und Auswirkungen durch radioaktive Stoffe; Landeshauptstadt Hannover, Amt für Umweltschutz, Schriftenreihe kommunaler Umweltschutz Nr. 1/1992

DisTec (2004): DisTec 2004, International Conference on Radioactive Waste Disposal, Berlin, April 26-28, 2004 (insb. aus den Sektionen "Endlagerung hochaktiver Abfälle", "Endlagerung schwach- und mittelaktiver Abfälle" sowie "Sicherheit von Endlagern")

Endlager-Hearing (1998): Endlager-Hearing des Niedersächsischen Umweltministeriums; Zusammenfassender Bericht der Arbeitsgruppe ‚Eignungsnachweis', Braunschweig, 21.-23. September 1993

Erklärung der deutschen Bundesregierung (2000): Erklärung der deutschen Bundesregierung zur Erkundung des Salzstockes in Gorleben; Anlage 4 der ‚Vereinbarung zwischen der Bundesregierung und den Energieversorgungsunternehmen', 14. Juni 2000

Fukada, K. et al. (2003): IAEA Overview of global spent fuel storage; IAEA-CN-102/60, Vienna 2003

FZK (1998): Förderkonzept zur Entsorgung gefährlicher Abfälle in tiefen geologischen Formationen (1997-2001); Forschungszentrum Karlsruhe GmbH, April 1998

Gonzalez, A.J. (1998): The Future of Radioactive Waste Disposal; DisTec '98, International Conference on Radioactive Waste Disposal, Hamburg, September 9-11, 1998, 19-29

Gonzalez, A.J. (2004): DisTec '98, International Conference on Radioactive Waste Disposal, Berlin, April 26-28, 2004

Hirsch, H. et al. (2005): Expertise zum Entsorgungsnachweis für ein Schweizer Endlager für abgebrannte Brennelemente, hochradioaktive Abfälle und langlebige mittelaktive Abfälle – Mögliche Betroffenheit Österreichs; on behalf of Umweltbundesamt, Vienna, November 2005

IAEA (2003): International Atomic Energy Agency: Scientific and Technical Basis of the Geological Disposition of Radioactive Wastes; Technical Report Series No. 413, IAEA, Vienna, 2003

IAEA (2006): Geological Disposal of Radioactive Waste; Safety Requirements No. WS-R-4, jointly sponsored by International Atomic Energy Agency and OECD Nuclear Energy Agency, Vienna, May 2006

JC (2006): Summary Report – Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management, Second Review Meeting of the Contracting Parties, 15 to 24 May 2006, Vienna, Austria (JC/RM.2/03/Rev.1, 23 May 2006)

JC/FRA (2003): Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management, First Review Meeting, 3-14 November 2003 (National Report von Frankreich)

JC/NL (2003): Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management, First Review Meeting, 3-14 November 2003 (National Report der Niederlande)

Kacsóh, L. (1999): Isotopentransmutation – Aus- oder Irrweg der Atomtechnik?; Energiewirtschaftliche Tagesfragen, 49. Jg., Heft 3, 1999, 170-176

Kromp, W. and R. Lahodynsky (2006): Die Suche nach dem Endlager – “Make things small!“, in: “Wohin mit dem radioaktiven Abfall – Perspektiven für eine sozialwissenschaftliche Endlagerforschung“, Hrsg. v. Peter Hocke u. Armin Grunwald, Berlin, Edition Sigma, 2006

Lowson, R.T. and Browon (1995): Geochemistry Contributing to the Rehabilitation of the Wismut Uranium Mines, Germany; ICEM ’95, Fifth International Conference on Radioacative Waste Management and Environmental Remediation, Berlin, September 3-7, 1995, 1397-1403

Macy J. (2005): Nuclear Guardianship - responsible care for radioactive materials, http: //www.joannamacy.net/html/nuclear2.html and An Ethic of Nuclear Guardianship - Values to Guide Decision-Making on the Management of Radioactive Materials,
[http: //www.nonukes.org/r02ethic.htm]

Metcalf, P.E. (2004): The Joint Convention – Main Results from the first Review Meeting; Vortrag mit Diskussion auf der Tagung DisTec 2004 International Conference on Radioactive Waste Disposal, Berlin, April 26-28, 2004

NAS (1996): National Academy of Sciences, 1996
[http: //www.nap.edu/books/0309052262/html/]

Nies, A. (2004): The Plan for the Implementation of the AkEnd Recommendations; Vortrag mit Diskussion auf der Tagung DisTec 2004 International Conference on Radioactive Waste Disposal, Berlin, April 26-28, 2004

Nuclear Fuel (2003): Nuclear Fuel Vol. 28, No. 12, July 7, 2003

Nuclear Fuel (2006a): Nuclear Fuel, Vol. 31, No. 12, June 5, 2006

Nuclear Fuel (2006b): Nuclear Fuel Vol. 31, No. 13, June 19, 2006

NWTRB (2006): Report to The U.S. Congress and The Secretary of Energy – January 1, 2005, to February 28, 2006; U.S. Nuclear Waste Technical Review Board, Arlington, VA, June 2006

OECD (2004): OECD Nuclear Energy Agency: Die Sicherheit der geologischen Tiefenlagerung von BE, HAA und LMA in der Schweiz – Eine internationale Expertenprüfung der radiologischen Langzeitsicherheitsanalyse der Tiefenlagerung im Opalinuston des Zürcher Weinlands; OECD/NEA, Paris 2004

OSPAR (2000): OSPAR Decision 2000/1 on Substantial Reductions and Elimination of Discharges, Emissions and Losses of Radioactive Substances, with Special Emphasis on Nuclear Reprocessing; Meeting of the OSPAR Commission, Copenhagen, 26-30 June 2000

Pather, T (2005): Session summary "The Safety Case and Confidence Building"; International Conference on the Safety of Radioactive Waste Disposal, Tokyo, 3-7 October 2005 [http: //www-ns.iaea.org/meetings/rw-summaries/tokyo-2005-rad-waste-safety-disposal.htm]

Platts (2004): Nuclear News Flashes, Friday, July 7, 2004; and: Nucleonics Week, Vol 45, No. 33, August 12, 2004

Ryhänen, V: (2004): Progress of the Finnish Deep Repository Program towards Implentation; DisTec 2004 International Conference on Radioactive Waste Disposal, Berlin, April 26-28, 2004

Shimomura (2004): DisTec 2004, International Conference on Radioactive Waste Disposal, Berlin, April 26-28, 2004

van den Berg, R.J. and H. Damveld (2000): Discussions on Nuclear Waste; Studie im Auftrag der Niederländischen Kommission für die Endlagerung radioaktiver Abfälle (CORA), Wageningen/Groningen, Januar 2000

Vrijen, J. (1999): Reversibility/Retrievability – Issues and Implications; Euradwaste 1999, Fifth European Conference on Radioactive Waste Management and Disposal and Decommissioning, Luxembourg, 15 – 18 November 1999

Warwick, P. et al. (1999): Partitioning and Transmutation – Summary of the Discussions; Euradwaste 1999, Fifth European Conference on Radioactive Waste Management and Disposal and Decommissioning, Luxembourg, 15 – 18 November 1999

Warwick, P. et al. (1999): Role of Colloids and Organic Substances in Radionuclide Transport: State of the Art; Euradwaste 1999, Fifth European Conference on Radioactive Waste Management and Disposal and Decommissioning, Luxembourg, 15 – 18 November 1999

5 Terrorism and War*

Helmut Hirsch
With contributions by Oda Becker
September 2006

Editors comment:

An assessment of the nuclear option would be incomplete without consideration of possible effects of terrorism and war. A comprehensive paper on this topic was prepared and submitted to the Austrian government. However, many things are known or should be discussed in this context, that prudence forbids to publish. For the purposes of the published edition of the assessment, such sensitive passages were deleted and a shortened version of the comprehensive paper was produced. Even so, the relevance of terrorism and war for the nuclear option remains obvious.

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5 Terrorism and War*

5.1 Introduction

In the course of the 20th century, numerous deliberate acts of terrorism have occurred. Long before September 11th 2001, terrorist groups demonstrated their determination and ability to attack exposed targets. The suicide attack by Hezbollah against U.S. barracks in Beirut, which took place October 23, 1983 can serve as an example. A highly developed car bomb exploded, destroying the building and killing 241 soldiers. Another suicide car bomb attack with a high number of casualties occurred in Colombo, Sri Lanka, on June 21, 1991 when the Liberation Tigers of Tamil Eelam killed 51 people. The list goes on.

Considering the present global situation, the terrorist threat appears to be particularly great in the early 21st century. This overall situation, which is determined by economic, military, ideological and political factors, will not be discussed and evaluated here. It is important, however, to take note of the following fact: Although, at the moment, general attention is focussed on the threat from a certain direction (Islamic fundamentalism), there are, worldwide, many different ideological positions and organisations from which potential terrorists could be recruited. For example, the bombing of a building of the U.S. federal government in Oklahoma on April 19, 1995, which killed 169 people and injured more than 500, was committed by right wing American extremists [Thompson 1995]. The bombing attacks by ETA in Spain in the last years can serve as another example for the diversity of the terrorist threat.

There are numerous potential targets for terrorist attacks. Industrial installations, office buildings in city centers or sports stadiums filled with spectators can appear “attractive”, if a terrorist group plans to kill as many human beings as possible in one attack. A nuclear power plant, on the other hand, could be selected as target for one of the following reasons, or a combination of those reasons:

- Because of the symbolic character – nuclear power can be seen as the epitome of technological development, as typically “high-tech”. Furthermore, it is a technology of an ambiguous civilian/military nature. Many people therefore regard it as potentially very hazardous. Therefore, attacks against nuclear power plants can have a particularly strong psychological impact.

- Because of the long-term effects – an attack can lead to far-reaching radioactive contamination with long-lived radio-nuclides. The region which is being attacked will bear the mark of destruction for a long time. Furthermore, there will be economic damage for decades.

- Because of the immediate effects on the electricity generation in the region – nuclear power plants are, wherever they are operated, important components of the electricity supply system. They feed into the grid with a high capacity. The sudden shutdown of such a large plant can lead to a collapse of the electricity grid.

- Because of the longer-term effects on electricity generation, not only in the affected region, but also in other regions (possibly even in all countries where nuclear power plants are operated) – a successful attack against a nuclear power plant in one country is also an attack against all

* Short version of a more comprehensive report to the Austrian government

nuclear power plants in the world [Braun et al. 2002]. After such an attack has demonstrated the vulnerability of an NPP, it is possible that other NPPs will be shut down in the country affected, but also in other countries. This leads to world-wide attention.

If nuclear plants other than NPPs or nuclear transports are attacked, there is no direct consequence for electricity production. However, the symbolic character as well as the possibility of long-term land contamination also applies in this case.

Terror attacks against nuclear plants can be performed through large variety of means. It is not possible to list all conceivable scenarios since it is absolutely impossible to anticipate all products of human fantasy.

In principle, attacks can vary with respect to the means being used, the concrete target, the organisation, number and effort of the attackers as well as other factors. For each of those variables, there are many possibilities of implementation. Even the attempt to completely list what is foreseeable would, therefore, lead to a matrix with a large number of different scenarios.

Terror attacks against nuclear plants are no hypothetical risk. In the past, a number of such attacks have already taken place. Luckily, they have not, so far, led to a catastrophic radioactive release.

For example, in February 1993, a man forced his station wagon through the main gate into the turbine building of Three Mile Island 1 NPP in the United States [Thompson 1995, USNRC 1993]. In November 1994, there was a bomb threat at Ignalina NPP, Lithuania. Fortunately, the deadline passed without an explosion and no bomb was found in the power plant [Nucleonics Week 1994]. In December 1995, the U.S. government warned the Russian Federation and other members of the Commonwealth of Independent States of the possibility of terrorist attacks by Chechnyan commandoes against power reactors on their territory. This warning was based on a psychological profile of Chechnyan leader Dzhokar Dudayev [Nucleonics Week 1995].

Acts of war against nuclear installations constitute another danger deserving special attention in the present global situation – in spite of the fact that the 1st Protocol to the Geneva Conventions forbids attacks against nuclear plants. Since the fall of the Iron Curtain, there is an increasing tendency towards “small”, regionally restricted wars of long duration. Those wars are connected occasionally with the falling apart of a large state; or with efforts of groups in a population to achieve independence from such a large state [Münkler 2003]. The reasons for terror attacks listed above could, in such a war, motivate one of the conflict parties to attack a nuclear plant.

Wars of intervention constitute another form of conflict. They can occur as a consequence of a regional war of long duration, as mentioned above. In the course of such wars, western countries attack a state from which emanates a real or alleged threat. The political goals and interests of the attacking states usually play an important role in such cases. If there are nuclear plants in the attacked country, there is the hazard that they will be damaged unintentionally during the fighting. Furthermore, an intervening power might attack power plants in order to paralyse electricity supply in the attacked country. If there were efforts to avoid radioactive releases; such attacks probably would concentrate on the conventional parts of an NPP (turbine hall, transformer station). Because of the compact layout of the individual parts of a nuclear power plant, however, safety relevant parts of the installation might nevertheless be damaged. Furthermore, it must be considered, that damages to the conventional part of the plant would lead to radioactive releases, for example through failure of cooling systems or of the connection to the grid. Also, in times of war, the electrical supply system might collapse without direct attacks against power plants. In combination with further destruction of infrastructure, this, too, could in the end, lead to incidents or accidents in nuclear power plants, with consequences for the surroundings.

It is also conceivable that nuclear plants, which serve military purposes or are feared to serve such purposes, will be deliberately destroyed. In this case, the release of radioactive materials might not be intended by the attacker, but the attacker will accept the risk. The Israeli air raid of June 7, 1981, destroying the Iraqi research reactor at Tuwaitha, can serve as an example for such attacks. The reactor was not yet in operation, and no radioactive release took place. Nevertheless, this attack demonstrates that such considerations are by no means purely theoretical [Thompson 1995].

Threats through acts of war cannot be excluded in any region, not even in Europe. During the Balkan conflicts in the early 90s, the Slovenian nuclear power plant Krško was endangered several times. In June 1991, three fighter bombers of the Yugoslavian air force flew over the plant. There was no attack; however, this act clearly constituted a warning. In September 1991, war again approached the Slovenian border. There was fighting in the surroundings of Zagreb, which could easily have spread to Slovenian territory [Hirsch et al. 1997].

In case of a military conflict, terror attacks might occur in combination with acts of war.

This danger is particularly high in case of an asymmetric war – in case an enemy attacks a much weaker country, for example during a war of intervention. Scruples about actions mostly directed against the enemy's civilian population might be drastically reduced if the attacked country has no other options of hitting back at an all-powerful enemy, and/or has already suffered severe civilian losses itself.

The special case of the use of weapons of mass destruction, particularly of nuclear weapons, against nuclear power plants (through terrorist or military attack) will not be discussed here.

5.2 Targets and their Vulnerability

Of all commercial nuclear plants, nuclear power plants are probably the most "attractive" targets for terrorist or military attacks. They are most numerous of all nuclear plants, contain a considerable radioactive inventory and are, as already pointed out, important components of the electricity supply system. Furthermore, they are large buildings with a typical structure, well visible even over large distances. Therefore, this contribution focuses on nuclear power plants as possible targets of attacks.

The nuclear power plant area consists of several tens of thousands of square meters. The core piece of the buildings in this area is the reactor building, which, as the name indicates, contains the reactor with the highly radioactive nuclear fuel (in the order of magnitude of 100 tonnes), as well as important cooling and safety installations.

It is likely that the reactor building would be the primary target in case of an attack. If the reactor is in operation when the attack occurs, and the cooling is interrupted, a core melt can result within a very short time (about 1 hour). Even if the reactor is shut down, the decay heat is still considerable, and the fuel will also melt – although somewhat slower.

In case of destruction of the reactor building with failure of the cooling systems, a core melt accident of the most hazardous category results: rapid melting with open containment. The resulting radioactive releases will be particularly high and occur particularly early.

The spent fuel storage pool is another vulnerable component with considerable radioactive inventory. In some plants, it can contain more fuel (and thus more long-lived radioactive substances) than the reactor itself. In some nuclear power plants, this pool is located inside the containment and is protected against external impacts by a concrete hull (for example in German pressurized water reactors). In many cases, however, the pool is installed in a separate building with less protection.

Apart from the reactor building and, if applicable, the building with the spent fuel pool, there are further buildings and installation of varying safety significance. So far, not all nuclear power plants have been specially designed against external, human-made impacts (for example aircraft crashes). In the case of those that have been, an impact in one spot only has been assumed (corresponding, for example, to the crash of a small military aircraft, and not a large commercial airliner). Spatial separation of safety relevant installations was the most important counter measure. This should guarantee that only one installation vital for safety could be destroyed by an impact – a situation where recovery is possible.

For example, in case of failure of the auxiliary power supply via the corresponding transformer, the emergency power supply with diesel generators can be activated. If the control room is destroyed, the emergency feed building or the emergency standby building should be able to guarantee the safety functions which are absolutely necessary (i.e. cooling of the reactor).

Even if the reactor building remains intact in the case of an attack, the situation is still likely to get out of control, if more than one safety relevant installation of the plant is destroyed. This can happen even in case of spatial separation of important components.

Apart from nuclear power plants, all those nuclear plants containing large radioactive inventories could be “interesting” targets for attacks leading to large-scale radioactive contamination. An important example is intermediate storage facilities, which can be co-located with other nuclear plants (in particular, NPPs or nuclear reprocessing plants).

An analysis of the relative probabilities of attacks against nuclear power plants on the one hand and other nuclear plants on the other, cannot be performed here. Only the technical hazard potential will be discussed.

At the site of reprocessing plants highly active liquid waste and other radiologically important and long-lived waste is stored in quantities much larger than the amounts in the core of a large pressurized water reactor [Thompson 2003]. Reactor intermediate storage facilities for spent fuel in combined transport and storage casks, can have capacities of more than 1,500 t. The potential for large releases from those facilities, although smaller than for storage pools, is still considerable [Meister et al. 2002].

In the sector of nuclear fuel supply, stores of uranium hexafluoride are particularly in danger. In order to be enriched, uranium has to be converted into this chemical form. The depleted uranium which is also produced during enrichment, is not required for fuel production, but is stored for possible later use – usually as hexafluoride.

Uranium hexafluoride is a volatile substance. If it is released, it reacts with the humidity of the air, resulting among others in highly toxic hydrofluoric acid (HF).

At present, in the USA, about 57,000 steel containers with almost 700,000 t of depleted uranium hexafluoride are stored at three different sites[1].

A further potential target for terrorists is the transport of radioactive substances. Most important are the following:

- Spent fuel elements and highly active wastes from reprocessing (high specific inventory of radioactive substances)

- Plutonium (high radiotoxicity, particularly if released as aerosol)

- Uranium hexafluoride (high chemical toxicity of released substances, resulting in immediate damaging effects (lung damage))

Since the amounts transported, at most, are about several tonnes, the expected releases will be smaller than those which result from attack on a storage facility – even if the transport containers are severely damaged. On the other hand, the place where the release occurs cannot be foreseen, as attacks can occur, in principle, everywhere along the transport routes (for example, during handling at seaports; during rail transport through large cities). Thus, releases can take place in urban areas, leading to severe damage to many people, even if the area affected is comparatively small.

5.3 Possible Attack Scenarios

Since September 11, 2001, the public debate tends to concentrate on suicide attacks with a commercial airliner. In fact, the threat is much more diverse and complex.

In the following, various possibilities for terror attacks are listed as examples. Almost all of them could also take place in times of war, committed by commando troops or a fifth column. Some of the scenarios could be implemented, with minor changes, in the course of military operations.

Scenarios for fixed nuclear installations (nuclear power plants and others) could include [Hirsch et al. 2005]:

- Attack from the air

- Firing on plant from a distance

- Intrusion of attackers onto plant area

- Attacks involving insiders

- Attacks against installations located outside the plant perimeter

[1] http: //web.ead.anl.gov/uranium/faq/storage/faq16.cfm; seen on September 15, 2006

Furthermore, transports of radioactive materials, particularly with high inventory, high radiotoxicity and/or chemical toxicity, could be the target of an attack.

Not all nuclear plants and nuclear transports are vulnerable to the same extent. Most attack options listed here can lead, in the worst case, to very severe releases. Some will have rather limited effects. Different parts of a plant can be varyingly vulnerable to different modes of attack.

5.4 Consequences of Terror or Military Attacks on Nuclear Facilities

From the long list of possible scenarios, three will be discussed in more detail here – shelling of a nuclear power plant, bombing of an intermediate storage facility for spent fuel and attack on a uranium hexafluoride transport. These examples are intended to illustrate the great variety of conceivable targets and scenarios.

5.4.1 Shelling of a Nuclear Power Plant

Attacking a nuclear power plant can lead to a reactor accident of the most severe category: Core meltdown with early containment failure.

A possible scenario would be shelling with a 15.5 cm-howitzer, transported by road, as part of military operations or as terrorist attack. Almost every army of the world today possess such weapons; it is conceivable that terrorists are also able to acquire them.

If high-explosive shells are used, which belong to the standard munitions for howitzers, the reactor building will be destroyed. Severe damage will occur inside. A large part of the plant personnel will be killed or injured. At the site area, shots which are slightly off-target will create further devastation. It is extremely difficult to implement effective and rapid counter measures.

Within a few hours, core meltdown will occur, with severe releases of radioactivity. The amount released to the atmosphere can be 50 – 90 % of the radioactive inventory of volatile nuclides like iodine and cesium, plus a few percents of further nuclides like strontium-90. In case of a nuclear power plant with 1000 MW electric power, this corresponds, among others, to several 100,000 Tera-Becquerel (TBq) of Cs-137. (During the Chernobyl accident, about 85,000 TBq Cs-137 were released [OECD NEA 1996].)

According to the assessment of L. Hahn, chairman of the German Reactor Safety Commission (Reaktor-Sicherheitskommission, RSK) at that time, the consequences would amount to a national catastrophe [Hahn 1999]: Up to 10,000 km^2 would have to be evacuated in a short amount of time. There could be up to 15,000 acute radiation deaths and up to 1 million cancer deaths, as well as uncounted cases of genetic damage. An area of up to 100,000 km^2 could be contaminated in the long term to a degree such as to necessitate the relocation of the population. This is an area larger than Portugal. The economic damage has been estimated at about 6 trillion Euros.

For many reactors, the probability of destruction or severe damage of the spent fuel pool is high. In this case, releases can be several times those given above, with correspondingly more severe consequences.

5.4.2 Bombing of an Intermediate Storage Facility

An attack of this kind is conceivable, primarily as an act of war. However, it also cannot be excluded that a terrorist organisation kidnaps an armed military plane or recruits the pilot of an air force to perform an attack of this kind – be it through bribery, blackmail or ideological conviction.

For the example considered here, it is assumed that the spent fuel in the facility is stored in casks. This storage concept is increasingly used in Germany as well as in some of the new EU member states. It is less vulnerable to attacks than pool storage, which is still the favoured concept worldwide (for example, there are storage pools with very large capacity at La Hague, France).

For the attack, a bomb of the type BLU-109 (908 kg) could be employed. This bomb is widely used by air forces.

If the bomb is well aimed, it will pass through the roof of the storage building and hit a spent fuel cask. The cask will be severely damaged; air can flow into in its interior. The material of the fuel element hulls (an alloy, based on zirconium) will be, to some extent, fragmented and will start burning. From one cask of the German type CASTOR V/19, about 10,000 TBq Cs-137 could be released. If several casks are destroyed or severely damaged, the release would be higher.

A release of this order of magnitude could necessitate long-term relocation of the population in distances up to 10 km. Even further away, there will be significant radioactive ground contamination which requires drastic restrictions in agricultural use. There would possibly be no acute radiation deaths. The number of resulting cancer cases would depend on population density and on the timeliness and efficiency of emergency measures.

5.4.3 Attack of an Uranium Hexafluoride Transport

Uranium hexafluoride is transported in containers of the type 48”Y, if it is material yet to be enriched or depleted uranium. These steel containers have a wall thickness of merely 16 mm; they can be loaded with up to 12.5 t UF_6. On a truck one container can be transported, in case of rail transport, there are up to three on a wagon [URENCO 2001]. A tanker with petrol or liquid gas could be used as a “weapon” to attack a road transport of uranium hexafluoride. After a violent collision with the uranium hexafluoride transport, the tanker will be severely damaged. At the site of the accident, a hot fire lasting several hours would result.

A container of the type 48”Y fails after about 50 minutes in a fire with a flame temperature of 800 °C. Failure will occur earlier in case of higher flame temperatures (1000 °C and more could in fact be reached). The steel cylinder would burst. Part of the UF_6 would be ejected high in the air, the remainder would be thrown piecewise in the nearer surroundings. Chemical reaction with the humidity of the air produces, among others, HF (hydrofluoric acid). HF is a very effective respiratory as well as contact poison.

In the immediate vicinity of the site of the accident (up to about 100 m distance), there is acute mortal danger. In a distance of up to 500 m, people could suffer severe poisoning and burning from HF. In case of longer exposure times, there is mortal danger also in this region. Even in distances of more than 1 km, there is the risk for health damage for sensitive people [Albrecht et al. 1988].

The short-term consequences of such an attack, regarding health effects and deaths caused by HF, can be drastic – in particular, if the attack takes place in a densely populated region. It is possible that thousands of people would be killed or injured. Additional effects would result from uranium contamination. Uranium is a metal of relatively low specific activity, but considerable chemical toxicity. If it is the product of reprocessing, it could contain further toxic radio-nuclides.

If the attack takes place in a rural area, there would be severe damage to plant and animal life.

5.5 Protective and Countermeasures and their Limits

Several measures are conceivable which could possibly provide a certain degree of protection for nuclear plants against acts of war and terror attacks. Regarding terror attacks, such measures are at present under examination by NPP operators and supervisory authorities. Some have already been implemented or are at least in a concrete planning stage.

The most important options are the following, which are, to some extent, also subject of public debate:

1. Preventive shut-down of nuclear power plants

2. Structural backfitting against deliberate aircraft crash and other hazards

3. Covering buildings with a smoke screen as protection against deliberate aircraft crashes

4. Additional personnel (and equipment) at the site, for the mitigation of the consequences of an attack

5. Strengthening the guard force

6. Implementing additional measures for accident management

Issues 2 to 5 can be relevant for all kinds of nuclear plants.

The protective measures mentioned in most cases do not correspond directly with a particular mode of attack; generally, their potential effects are directed against several kinds of attacks.

Potentially, all measures mentioned can also increase protection against acts of war. Smokescreens e.g. could be effective against military air raids as well as against suicide attacks with airliners. However, most will be of little use against a military attack, supported by heavy weapons.

In connection with terror attacks, further measures are also under consideration, which belong to the military, police or administrative sector.

5.5.1 Preventive Shut-Down

Preventive shut-down of a nuclear power plant in case of a threat can increase safety margins against all types of attacks. In particular, it can increase the time span available for counter measures after the attack.

However, the thermal power of the fuel elements (decay heat) decreases rather slowly in the shut-down reactor. In order to achieve a significant safety gain, intervention times of about one day should be available (in case the barriers around the fuel remain intact). This would require shutting down of a nuclear power plant (pressurized or boiling water reactor) several months before the attack, at the latest.

If barriers are compromised, in particular, if the reactor pressure vessel and/or the cooling circuit are damaged, even preventive shut-down cannot guarantee appropriate intervention times. Even in this case, however, it will give some slight advantages; core melt will occur somewhat later.

The potential advantages of preventive shut-down are mostly irrelevant if the spent fuel pool is in an exposed position in the reactor building – as is the case in many nuclear power plants.

5.5.2 Structural Backfitting Against Deliberate Aircraft Crash and Other Hazards

In principle, structural backfitting could be a protective measure against attacks of all kind from the air, but also against shelling and the use of explosives. The following options are conceivable:

- Strengthening of buildings against all kinds of impacts
- Protective buildings against air attacks (e.g. towers)
- Obstacles on the ground against car bomb attacks

Strengthening of the structures of nuclear plant buildings, however, is hardly feasible and has not been seriously discussed so far.

The construction of protective buildings around the reactor buildings, on the other hand, has been seriously considered. In Germany, the erection of towers was originally proposed [BMU 2002], as well as the building protective ramparts of reinforced concrete, to block approach paths for aircraft [Financial Times Deutschland 2004]. However, those concepts are not in the focus of public debate any more.

The construction of protective buildings, whatever the concept, would create specific new problems: If the buildings are placed at a greater distance from the reactor building, their height would have to be considerable. In a distance of over 200 m, it would have to reach 200 m and more. Thus, the buildings would be visible from a large distance. They could serve as orientation points in case of other attacks, for example, shelling. If the protective structures were placed close to the reactor building, on the other hand, they would create hindrances for traffic on the site.

The erection of massive reinforced concrete structures leads to another problem. The destruction of such a structure, be it tower or rampart, by aircraft attack leads to the formation of heavy concrete pieces which can create damage to the site.

Thus, such protective structures could be an effective measure, only in case of low buildings – for example nuclear waste or plutonium stores. In this case, no large height would be required.

The situation is different regarding the intrusion of attackers with vehicles on the ground. If such intrusion onto the site is effectively prevented, the options for terrorist are reduced. In particular, the use of car bombs in the vicinity of a nuclear plant can be blocked. Even a military attacker could be hindered by such obstacles. Furthermore, the expenditure for the erection of such barriers can be expected to be small. However, the traffic level is usually high in the surroundings of nuclear plants, and to some extent also on the site itself. This, in practice, creates limits to the implementation of this measure.

Measures like strengthening of the fence which is to prevent the intrusion of attackers, too, can result in a certain improvement of protection at low costs.

5.5.3 Covering Buildings with a Smoke Screen

Concepts for covering nuclear power plants with smokescreens, mainly for the protection against deliberate crash of an aircraft, constitute the central element of the protective concept in Germany, according to an agreement reached by the NPP operators and the German Government. This measure is to be supplemented by jamming the global positioning system (GPS) in the surroundings of the nuclear power plant concerned. It is to be introduced first, as a pilot project, at Grohnde NPP in Lower Saxony [BMU 2005]. In April 2006, however, the assessment of the measure was not yet completed [Deutsche Bundesregierung 2006].

Adaptation of military concepts is envisaged. However, military smokescreens usually are used under completely different circumstances. Military smokescreens are used for example to protect warships against attack by automatic, target-seeking missiles. Under cover of the smokescreen, the ships will withdraw. In case of an attack against a nuclear power plant, the target is not movable. Furthermore, a human pilot who can circle for some time over the target since no immediate counter attack is to be feared would guide the aircraft. Also, it will probably be more difficult to mislead a human pilot than an automated system.

The timely triggering of this measure constitutes a further problem. Europe is densely populated – all nuclear power plants, more or less, are located close to large airports and air traffic routes. Thus, it is possible that a possible attack would not be recognised early enough. Furthermore, even if a smokescreen is successfully created, it would be relatively easy to find the target nevertheless – for example with the aid of flares triggered by accomplices on the ground.

If, in times of peace air attacks at low height, by helicopter or military aircraft occur, the smokescreen system would be completely useless. In this case, the attack would only be recognised as such when it is too late to put the smoke screen in place.

An extensive smokescreen furthermore reduces visibility on the site and thus can hinder the personnel as well as counter measures like fire fighting. If the smokescreen is small, this aspect is less relevant. In this case, buildings on the site will still be visible, helping the orientation of the attacker and thus reducing the protection.

The deliberate triggering of the smokescreen by terrorists (faking of an air attack) can not be excluded. Subsequently, a ground attack could be launched under cover of the smoke.

The accompanying jamming of GPS has been criticised as problematic for the safety of air traffic. Also, it is possible that an airplane can navigate without GPS [Becker et al. 2006].

In times of war, smokescreens probably give better protection as it is more likely that approaching enemies will be recognised in time because of a higher alert level. For the protection of an immovable target, the position of which is well known, however, a smokescreen alone will nevertheless not be sufficient.

5.5.4 Additional Personnel (and Equipment) at the Site

In order to mitigate the consequences of all kinds of attack, experts in various fields are needed on the site. The possibilities and chances for mitigation will no doubt be improved if the number of knowledgeable personnel is increased – be it personnel directly located at the site, or in installations in the vicinity.

This concerns medical personnel, fire fighters and clearance workers, specialists for de-activating explosives, nuclear personnel and health physics experts. The corresponding equipment and materials could also be stored at the site.

5.5.5 Strengthening the Guard Force

In principle, strengthening of the guard force at the site is a suitable measure to improve protection against a terrorist attack on the ground. The task of the guard force consists of repelling the attacks of small groups, as well as in delaying larger attacks at least until police and/or military forces arrive.

Strengthening of the guard force, however, can lead to other risks:

- Members of the guard force could be blackmailed or bribed into supporting attacks.
- Protective installations on the site (in particular, weapons) could be taken over by terrorists.
- In case of private guard services, there is also the issue of sufficient quality control and vetting of guards.

In a recently published report on the U.S.-firm Wackenhut, which is, among others, responsible for security at nearly half the nuclear reactors in the U.S. many shortcomings are listed. This concerns, for example, poorly maintained weapons' inventories, inappropriate storage of explosives, inadequate control over access badges and improperly positioned guards [Service Employees International Union 2004].

Another investigation concludes that guard forces frequently are under-manned, under-equipped, under-trained, under-paid and unsure about the use of deadly force in case of a terrorist attack. Furthermore, in case of a stronger attack, the guard force is to use delaying tactics, while calling for reinforcements from outside. However, a terrorist attack is likely to be "successfully" concluded within three to ten minutes, and will not necessarily be noticed immediately. On the other hand, help from outside the site (for example a SWAT-team) will need one or two hours to reach the nuclear power plant. At best, local police forces could arrive within about twenty minutes [Project on Government Oversight 2002].

The adequacy of exercises testing the security of nuclear power plants is also questioned in the U.S.. It was criticised by NGOs that the same firm which provides guard services at many reactors (Wackenhut, mentioned above) was also training the teams which would act as “attackers” in these exercises [Nucleonics Week 2004].

Problems with ineffective exercises, deficient security equipment, improper access controls and other shortcomings appear to persist in mid-2006 [Nucleonics Week 2006].

In case of military attacks on large units, in particular those equipped with heavy weapons, the guard force is still less likely to be able to mount an effective defence.

5.5.6 Additional Measures of Accident Management

Measures of accident management are available in most nuclear power plants worldwide, to control severe accidents or to at least mitigate the effects of such an accident. In connection with the protection against terrorist attacks, there have been new considerations since September 11, 2001, to further improve accident management. For example, the German technical support organisation GRS claims that the protection of NPPs could be enhanced by accident management methods [BMU 2002].

The corresponding concepts have not yet been published. However, it is questionable to which extent the measures already planned could be expanded further. It is not possible to backfit a significant number of additional diverse installations; there are limits regarding the available space, as well as regarding the increasing complexity of the whole system, which could reduce clarity in case of an emergency.

5.5.7 Remark on Military, Police and Administrative Measures Against Terror Attacks

Concerning military, police, secret services and administration, the following measures, among others, are conceivable:

1. Protection of plants by military (including anti-aircraft defence and control of neighbouring waterways)

2. Measures to prevent hijacking of airplanes, for example improving control of passengers and military airplanes

3. Measures for the early recognition of a skyjacking, for example by improved control of air traffic

4. Measures against a skyjacked plane

5. Intensifying measures for vetting and control of plant employees (including sub-contractors); screening of previous career, constant surveillance – leading to better protection against insiders

The first measure mentioned clearly could also improve protection against acts of war.

Steps for an improvement of the control of flight passengers as well as preparing the possible use of military planes against hijacked airliners have already been taken in Germany [Deutsche Bundesregierung 2004].

It has to be kept in mind that measures like the "militarization" of the energy economy or extensive control of flight passengers as well as intensified vetting and surveillance of plant personnel are limited, in particular in times of peace, in an open and democratic society.

In a remarkable decision, the German Federal Constitutional Court stopped a law, introduced by the German Government, which would have permitted shooting down of a skyjacked plane as a last resort to avoid a sensitive target being hit [FR 2006].

If plants are protected by military units, the protection measures themselves can lead to new risks, just as in the case of private guard services. Military personnel, too, could be recruited by terrorists using bribes or blackmail. Furthermore, military installations at the site could be taken over by terrorists.

Furthermore, some experts fear that increased military protection of nuclear installations will lead to an escalation of violence. The reaction to such protection could be that terrorists will consider the use of weapons of mass destruction [Braun et al. 2002].

Military installations located directly at the plant site alone will be largely useless against certain kinds of attacks, if there is no timely warning – for example in case of an attack with business jets or helicopters. In particular, a helicopter attack can be performed at treetop height unnoticed by radar.

The insider problem is of particular complexity. Generally, at present, qualified personnel for nuclear plants is scarce. Sub-contractors are extensively used, for example for maintenance work during the regular plant stand-stills. This considerably increases the "chances" for terror organisations to recruit insiders. The efficiency of the internal surveillance of the personnel depends on the internal work organisation as well as on the concrete measures which are being used by the employer.

5.6 Conclusions

The threats to nuclear plants form terror attacks and acts of war can be summarized as follows:

- Because of their importance for the electricity supply system, nuclear power plants are "attractive" targets for terrorist as well as for military attacks.

- Various kinds of nuclear plants as well as nuclear transports could become targets of terrorist attacks, because of their symbolic character as well as the severe consequences of radioactive releases.

- All kinds of nuclear plants are vulnerable against terrorist and military attacks.

- An attack on a nuclear power plant can lead to radioactive releases equivalent to several times the release during the accident at the NPP Chernobyl in 1986. Relocation of the population can become necessary for large areas (up to 100,000 km^2). The number of cancer deaths can reach 1 million and more.

- Attacks on other nuclear plants, for example intermediate storage facilities, can also lead to severe releases with catastrophic consequences.

- Transports of various substances being used in large amounts within the nuclear energy system are also vulnerable to terror attacks. For example, an attack against a transport of uranium hexafluoride taking place in an urban area can lead to thousands of deaths and injuries within a short time.

- Protective measures against terror attacks are of very limited use. Furthermore, a number of conceivable measures (for example military protection of plants, increased surveillance and control of all suspect persons) cannot be implemented in an open and democratic society.

- There is no protection against military attacks, in particular if heavy weapons are used.

Thus, nuclear plants are and will remain vulnerable to terrorist and military attacks, no matter what protective measures are being taken. The only effective protection is the phasing out of nuclear power.

An ideal society that has eliminated the root causes of instability, war and terrorism on the global scale could operate nuclear power plants without significant risks of the type described above. Present day society, however, is far from being ideal. Indeed, global development seems to be heading the opposite direction: The gap between rich and poor nations as well as people is widening, the number of clashes is increasing, the dividing line between terrorism and acts of war is becoming blurred, thus international treaties protecting nuclear power plants are losing effectiveness, etc..

A central question to be asked is: Which industrial and energy systems can this kind of society afford from a safety point of view?

Obviously large, centralised installations that are essential for the economy of a society make this society vulnerable. If – as is the case with nuclear plants – societies must not only deal with loss of the services of the installation in case of attack, but also with substantial health and environmental problems, the acceptability of the risk incurred by the operation of such an installation must be questioned. It is not only legitimate to pose this question; in view of recent global developments it is indeed increasingly necessary to give it serious thought. In the energy field alternative solutions are available. The "soft" energy path, with maximum efficiency of energy use and reliance on renewables implies the production of energy in many small decentralized plants. Thus there is little dependence on any one plant. The system as a whole is less vulnerable to attacks than "hard" systems, such as the nuclear option. "Soft", sustainable energy systems are therefore also less attractive targets for attacks. Should, nevertheless, an attack occur the destruction of a renewable energy plant will generally not lead to dramatic consequences for people and for the environment. Thus, such systems could meet sustainability criteria also in the face of terrorist and military attacks, while the nuclear option clearly does not.

Finally, it should be noted that a “soft” energy system which does not include dual-use (civilian/military) technology, which does not present targets which can be “tempting” to terrorists and military attackers, and hence does not give rise to the need for extensive protective measures, could also contribute to the lessening of international and societal tensions.

5.7 References

Albrecht, I. et al. (1988): Gutachten über die Gefährdung durch den Transport radioaktiver Güter auf dem Gebiet der Hansestadt Lübeck; erstellt von der Gruppe Ökologie Hannover im Auftrag der Hansestadt Lübeck, Juni 1988

Becker, O. und H. Hirsch (2006): Schwere Unfälle im AKW Esenshamm und ihre Folgen – Schwerpunkt Terrorgefahren; Studie im Auftrag des Landesverbandes Niedersachsen und des Kreisverbandes Wesermarsch von Bündnis 90/Die Grünen, Hannover, April 2006

BMU (2002): Schutz der deutschen Kernkraftwerke vor dem Hintergrund der terroristischen Anschläge in den USA vom 11. September 2001 – Ergebnisse der GRS-Untersuchungen aus dem Vorhaben "Gutachterliche Untersuchungen zu terroristischen Flugzeugabstürzen auf deutsche Kernkraftwerke"; Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit (BMU), Bonn, 27.11.2002

BMU (2005): Schreiben von Staatssekretär R. Baake Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit (BMU) an W. Hohlefelder, E.ON Energie AG, mit Anlage, Bonn, 07. September 2005

Braun, Ch., F. Steinhäusler and L. Zaitseva (2002): International Terrorists' Threat to Nuclear Facilities; Presentation at the American Nuclear Society 2002 Winter Meeting, Washington D.C., November 19, 2002

Deutsche Bundesregierung (2004): Sicherheit von kerntechnischen Anlagen; Antwort der Bundesregierung auf die Kleine Anfrage der FDP, Drucksache 15/2829, 31.03.2004

Deutsche Bundesregierung (2006): Gefahren der Atomenergie; Antwort der Deutschen Bundesregierung auf eine Kleine Anfrage der Fraktion Bündnis 90/Die Grünen, Drucksache 16/724, 13.04.2006

Financial Times Deutschland (2004): Trittin rügt Lücken im Terrorschutz für AKW; Financial Times Deutschland, 27.07.2004

FR (2006): Karlsruhe kippt Gesetz zu Flugzeug-Abschuss; article in Frankfurter Rundschau, February 16, 2006

Hahn, L. (1999): Kernkraftwerke der Welt – Bestand, Funktionsweise, Sicherheitsprobleme; in: Gefahren der Atomkraft; Ministerium für Finanzen und Energie des Landes Schleswig-Holstein, 2. aktualisierte Auflage, Kiel, Mai 1999

Hirsch, H. et al. (1997): Extended Safety Review for Krsko NPP; Institute of Risk Rresearch of the Academic Senate of the University of Vienna, Risk Research Report Nr. 9, Vienna, November 1997

Hirsch, H. und O. Becker (2005): : Vulnerability of Nuclear Power Plants to Terror Attacks – An Overview; Proceedings of the Conference "Nuclear Energy and Security" (NUSEC), University of Salzburg (Austria), July 20-23, 2005

Meister, F. et al. (2002): Grenzüberschreitende UVP gemäß Art. 7 UVP-RL zum Standortzwischenlager Biblis; Bericht an das Österreichische Bundesministerium für Land- und Forstwirtschaft, Umwelt und Wasserwirtschaft, sowie an die Landesregierungen von Oberösterreich und Vorarlberg, Umweltbundesamt, Wien, Februar 2002

Münkler, H. (2003): Die neuen Kriege; Büchergilde Gutenberg, Frankfurt/Main, Wien und Zürich, 2003

Nucleonics Week (1995): U.S. Intelligence Warns Against Chechnyan Attacks on Reactors; newsletter article, Nucleonics Week, Washington, DC, December 22, 1995

Nucleonics Week (1994): Ignalina Sabotage Deadline Passes Without Blow-Up, Bomb Not Found; newsletter article, Nucleonics Week, Washington, DC, November 17, 1994

Nucleonics Week (2004): Nucleonics Week Vol. 45, No. 32, August 5, 2004

Nucleonics Week (2006): Nucleonics Week Vol 47, No. 36, September 7, 2006

OECD NEA (1996): Chernobyl – Ten Years On: Radiological and Health Impact; OECD Nuclear Energy Agency, Paris 1996

Project on Government Oversight (2002): Nuclear Power Plant Security – Voices from Inside the Fences; Washington, revised October 2, 2002

Service Employees International Union (2002): Homeland Insecurity – How the Wackenhut Corporation is Compromising America's Nuclear Security; Service Employees International Union, Washington, April 2004

Thompson, G. (1995): War, terrorism and nuclear power plants; study commissioned by Greenpeace Germany, Institute for Resource and Security Studies, Cambridge/Mass., USA, Dezember 1995

Thompson, G. (2003): Sellafield – a Safe Future?; Presentation to a Working Group of the European Parliament, Brussels, 26.03.2003

URENCO (2001): Uranhexafluorid-Transporte; URENCO Deutschland, 1. Auflage, Gronau/Jülich, März 2001

USNRC (1993): Status Report from NRC Incident Investigating Team; U.S. Nuclear Regulatory Commission Washington, DC, February 10, 1993

6 Emergency Planning

Helmut Hirsch
September 2006

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6 Emergency Planning

6.1 Introduction

The reactor of a nuclear power plant contains a large amount of highly toxic radioactive materials. A severe accident can cause the release of a significant part of these materials into the atmosphere.

The emissions of Chernobyl demonstrate this fact: the total inventory of radioactive inert gases was released (6.5 billion GBq [1 Gigabequerel GBq is one billion Becquerel], 50-60 % of the radioactive iodine (1.76 billion GBq), 25-60 % of tellurium-132 (1.15 billion GBq), 20-40 % of radioactive cesium (140 million Gbq), 4-6 % of strontium-90 and about 3,5 % of the inventory of plutonium, one of the most hazardous radioactive substances [OECD NEA 2002].

A PWR melt-down accident in connection with an early containment failure or containment bypass occurring in Western Europe, the United States or another country could release comparable radioactive emissions or even higher. This could arise due to a hydrogen explosion or be caused by a melt ejection from the reactor pressure vessel at high internal pressure. In that case 50-90 % of the radioactive iodine, cesium, tellurium could be released into the environment [Ministerium für Finanzen und Energie des Landes Schleswig-Holstein 1999].

Especially in cases were the release is very high, the radioactive cloud reaches the atmosphere after only few hours. The warning time to take emergency measures can, therefore be very short. This is also true for larger distances. With wind speeds of only 20 km/hour – rather frequent in Europe – the radioactive cloud can travel about 500 km per day and thus cross, for example, Austria completely.

The exposure of the population to radioactive material could cause death from acute radiation diseases after few weeks. In any case millions of human beings could be affected by long-term effects, like cancer or genetic changes (mutations).

Severe accidents with radioactive emissions are not unique to nuclear power plants; large releases can also occur in other nuclear installations, like reprocessing plants or fuel manufacturing plants. The transport of nuclear materials can also cause radioactive releases that in case of an accident could require counter measures even within several km distance [Deppe et al. 1992]. The particular problem with these accidents is the fact that they can occur at any point of the transport route, which very often has a length of several hundreds of kilometers.

These points already prove that nuclear power is neither environmentally sound nor socially compatible.

During the last few years, the situation has become more and more critical, and this trend is likely to continue in the future. The risk of terror attacks and acts of war against nuclear installations is increasing – and with it, the risk of catastrophic radioactive releases with very little warning beforehand. Furthermore, the likelihood of natural catastrophes is increasing, because of the anthropogenic climate change under way. Floods, tornadoes and extreme temperatures also heighten the risk of nuclear accidents.

On the other hand, it should to be pointed out that the discussion here is based on the reactor types which are presently in operation worldwide. The assessment does not concern possible future generations of reactors with qualitative improvements compared to present-day plants.

6.2 Emergency Planning

A variety of different measures is required to be prepared for the case of a nuclear emergency. Expenditures related to these measures have to be covered not only by the countries that operate nuclear power plants, as there may be transboundary effects.

It is generally acknowledged, esp. in countries with nuclear power plants, that the threat of nuclear power plants in neighbouring countries is identical to that of national plants. This is demonstrated by a quotation from the German recommendations for the emergency planning (Deutsche Rahmenempfehlungen für den Katastrophenschutz):

"Bei ausländischen kerntechnischen Anlagen, die sich in der Nähe der deutschen Grenze befinden, müssen die gleichen Maßnahmen zum Schutz der Bevölkerung durchgeführt werden können wie bei deutschen Anlagen." [Länderausschuss für Atomkernenergie 1999].

(It must be possible to take the same measures of protection of the population for foreign nuclear installations near the German border as for German installations.)

A complete presentation of required emergency measures is not possible here, but as an example several topics will be named which show the enormous efforts that have to be taken:

- Preparation of shelters, planning of protection measures outside of these rooms (in apartments, working places, schools, etc.)
- Installation of an early-warning system with sufficient measuring sites, connected to the respective systems of other countries
- Development of a warning and alarm systems for the population, including an information system
- Planning for the distribution and administration of prophylactic stable iodine
- Planning for the decontamination of equipment
- Planning of installations for medical treatment of radiation exposure victims (including possibly contaminated victims)
- Planning of evacuation and other countermeasures: preparation of the legal basis, evaluation of specific plans, education of the public and emergency workers

All of these measures and plans have to be updated continuously taking into account the most recent state of population distribution and structure, the traffic routing, the medical state-of-the-art, technical possibilities etc. The start-up of a new nuclear installation can require extensive supplementary activities and revisions.

Emergency planning is also necessary for countries that do not operate nuclear power plants. It is not a singular expenditure, but requires a continuous effort. It is a kind of infrastructure that has to be maintained and possibly modified and extended – especially in case of a world wide extension of nuclear power.

The financial expenditures are paid by the public, an expense generally not taken into account in the electricity costs from nuclear power plants.

6.3 In Case of Emergency

Even in case of optimum emergency planning, it is doubtful that due to the short pre-warning times the required measures can be realized in time, in the most endangered areas. These are areas that will be reached by the radioactive cloud within several hours, and can enclose several hundreds of square kilometers.

With the incoming information about an accident in a nuclear power plant the first questions arise: At which time are radioactive releases expected? Which emission is to be expected? In which direction is the radioactive cloud going to move?

These predictions can be very difficult and will always include large uncertainties. Nevertheless, decisions are required. In the first place, the public has to be informed. The advantages of spreading information quickly to reduce the radiation exposure in a population in the case of an emergency has to be weighed with the consequences of having an unnecessary alarm that might cause panic within a population.

Immediate decisions on the implementation of measures have to be taken. Should the public be asked to stay in their houses or move into shelters? Is it necessary to start preparations for an evacuation? Shall stable iodine tablets be distributed?

These considerations will take place while the situation within the power plant could be very complicated. The conditions within the reactor building are presumably not exactly known. Measuring devices for monitoring and surveillance of the spreading of radioactive materials might fail or deliver unreliable or contradictory data.

Even a short-term prediction of wind direction and the resulting path of the radioactive cloud is difficult. In France, an extensive emergency system was developed that is supposed to allow the prediction of radiological consequences. Even under such circumstances – that certainly are not at all existing in every country – there are still significant uncertainties:

"...tests performed on some of the French nuclear sites have shown that the prediction [of wind direction] could be done with an uncertainty of + 30° with a confidence level lower than 70 percent on rather complex terrains." [Herviou & Winter 1999]

The identification of a sector with an opening angle of 60° with less than 70 % reliability is not a good basis for the implementation of emergency measures.

The situation is aggravated due to the known fact that radioactivity is not perceptible by human senses. Therefore it is not astonishing that stress, panic, and irrational behavior of people has to be expected – including official personnel and emergency management workers.

Besides these problems it could be very difficult to realize the planned measures in case of emergency, due to the pressure of time and other factors.

This could concern the distribution of iodine tablets since the thyroid gland has to be saturated with iodine in order to block the intake of radioactive iodine. This should happen before or just at the time the radioactive cloud passes inhabited areas.

"Der Schutz ist dann am wirksamsten, wenn die Jodtabletten kurz vor oder praktisch gleichzeitig mit dem Einatmen von radioaktivem Jod eingenommen werden. Aber auch wenige Stunden nach dem Einatmen von radioaktivem Jod wird noch ein gewisser Schutz erzielt. Später als ein Tag nach der Aufnahme des radioaktiven Jods schützt die Einnahme von Jodtabletten nicht mehr; sie ist dann eher schädlich." [Strahlenschutzkommission 2004]

(Protection is most effective, if the iodine tablets are taken immediately before of or at the same time than the inhalation of radioactive iodine. However, some protection is also achieved a few hours after the inhalation of radioactive iodine. More than a day after the uptake of radioactive iodine, taking iodine tablets provides no protection any more; rather, it can be harmful.)

In Germany, the distribution of tablets to households in an area of up to 25 km around the nuclear power plant is supposed to be completed within 2-4 hours, in the endangered regions up to 100 km distance within 12 hours after the decision for the distribution has been taken [Länderausschuss für Atomkernenergie 1999]. It is more than doubtful that this can be realized.

Moreover, in the worst case the radioactive cloud could reach communities within 25 km of the respective nuclear power plant within 3 hours after the accident has been initiated, since core melting and containment failure can occur within two hours. Depending on wind velocity and the path of the cloud, radioactivity can reach places within 100 km after only a few hours.

Taking iodine tablets can actually be harmful to susceptible persons (for example by triggering hyperactivity of the thyroid). Thus, if taken too late, the negative effects of iodine tablets could outweigh the positive ones.

Nevertheless, the quantity of tablets which is stored by the German state (Länder) authorities recently was increased, as a precautionary measure. This decision is likely to have been influenced by the threat of terror attacks. However, in case of such attacks, it is feared that the advance warning time will be very short, and hence, that preconditions are particularly unfavorable for the timely taking of iodine tablets [Strahlentelex 2004].

Sheltering is supposed to protect, in case of emergency, against external exposure to the radiation from the cloud and against inhalation of radioactive pollutants. The best protection will be to stay in cellars. However, even this mode of protection is limited as the air within the shelter will eventually become contaminated. Sheltering is meant to be used until the cloud passes, and is then to be followed by relocation as needed from excessively contaminated areas.

This yields problematic conflicts: It is simultaneously necessary that the population can be reached by broadcasting or public-address systems, which is not always possible in cellars. Moreover, it might be that within the most critical time period many people are on the way to pick up the iodine tablets. Accordingly, the German recommendations state:

"Der Aufenthalt in Gebäuden ist eine einfache und effektive Katastrophenschutzmaßnahme, die jedoch nur über kurze Zeit aufrechterhalten werden kann." [Länderausschuss für Atomkernenergie 1999]

(Staying in buildings is a simple and effective protective measure, however this can only be maintained for a short time)

In case of the feared severe radioactive exposure, evacuation is the strongest protective measure (provided that it can be accomplished before plume arrival). Also in this case the timely action is decisive. The German recommendations state laconically:

"Die Evakuierung ist besonders dann eine wirkungsvolle Maßnahme, wenn sie vor Durchzug der radioaktiven Wolke erfolgt." [Länderausschuss für Atomkernenergie 1999]

(Evacuation is an efficient measure especially if performed before the crossing of the radioactive cloud)

It is not clear how the evacuation shall be realized in time, especially in large cities. The problem of finding citizens in need of help (disabled, old and sick persons) in a city and being able to transport them in an appropriate way is presumably unsolvable. It is also almost impossible to avoid the total collapse of traffic, especially on main roads.

Also, it has to be considered that evacuations, in case they can be performed, will cause additional grave problems for the persons concerned. They will presumably have to live for long time periods in emergency lodgings, with possible psychological stress and social tensions. Working places will be lost; education and schools will be hampered. Whole cities as functioning social units will be destroyed, neighborhoods and even families disrupted.

The fast and efficient implementation of emergency measures is further hindered by the fact that plans and guidelines in different countries are varying, sometimes to a considerable extent. Even inside the European Union, there are significant differences. This point is of great importance, since nuclear accidents generally will have cross-border consequences.

For example, regarding the iodine tablets already mentioned, the radioactive dose above which children are to receive such tablets is different in Belgium, France, Germany and Luxembourg. They vary by a factor of ten. Also, there are differences regarding the zones of distribution. The regulations are different in all those four neighboring countries. It cannot be expected in the short or medium term that they will be harmonized [Feider 2004].

It is not surprising that a German state government, the highest level emergency protection authority in case of an nuclear accident, has summarized:

"Die schleswig-holsteinische Landesregierung ist jedoch der festen Überzeugung, dass die bestmögliche Vorsorge gegen den Unfall eines Atomreaktors darin besteht, diesen Reaktor gar nicht erst zu betreiben. Die Folgen einer nuklearen Katastrophe wären so unermesslich, dass

ein Verzicht auf diese Form der Energiebereitstellung das Ziel staatlichen Handelns sein muss." [Ministerium für Finanzen und Energie des Landes Schleswig-Holstein 1999]

(The government of Schleswig-Holstein is convinced that the best precaution against a nuclear power plant accident is not to operate the power plant. The consequences of a nuclear catastrophe would be so immense that the renunciation of this form of energy production has to be a governmental aim.)

6.4 International Efforts – a Considerable Helplessness Remains

In order to improve decision making and planning of measures in case of a nuclear catastrophe, the system RODOS (Real-time On-line Decision Support system for off-site emergency management in Europe) was developed as a common effort by 20 countries of the European Union, Eastern Europe and the former Soviet Union. This System is to provide information on the present and future radiological situation, information for the evaluation of counter measures as well as methodical support for decision making.

In principle, this approach has the potential to improve emergency management. However, the system is very complex, and its development and introduction are very time-consuming. The project started in 1989. At present, the installation of the RODOS-System is still under way in East European Countries. Until 2004, it has been implemented in Hungary, Poland, the Slovak Republic, Slovenia and Ukraine. Installation in Bulgaria, the Czech Republic, Romania and Russia is still under way [Forschungszentrum Karlsruhe 2003]. An assessment of the strengths and shortcomings of this system will not be possible before the installation is completed and comprehensive tests and exercises have been performed. Even then, it will remain open how it will prove itself in case of a real emergency. Furthermore, the RODOS-System also relies on extensive prognostic models, for example for the meteorological situation. The prediction accuracy of those models is limited. All the information and decision support which RODOS is providing can only be as accurate and reliable as the models on which they are based.

The IAEA, together with six other international organizations, published a new report in the "Safety Standards Series" in November 2002, which determines the requirements for advance planning and reaction in case of a nuclear emergency. This is the first report, in an international framework, of a comprehensive and summarizing character. It is to support the responsible national authorities by better enabling them to see questions of emergency planning in their entirety – on a rather general level [IAEA 2002].

This effort towards harmonizing the requirements for emergency planning can, in principle, only be welcomed. However, the helplessness which, to a large degree, remains in the face of a nuclear catastrophe in spite of all planning and preparation is also mirrored in the wording of this report.

This can be seen, for example, in the requirement that first responders, when saving human life, should ignore signs indicating the presence of radioactive material – and thus, could be exposed to very high doses of radiation. Furthermore, it is stated that precautionary urgent action should be taken before a release of radioactive material occurs or shortly after. It has already been pointed out that this requirement will be very difficult to fulfill in practice – particularly in case of terror attacks or acts of war, but also in a situation in which the plant personnel at first assumes that a release can still be avoided.

The doses received shall be communicated to the workers involved when an intervention has ended; however, the reconstruction of those doses will not always be possible. In addition, the general impossibility to set obligatory dose limits for the first responders becomes manifest. Their dose shall be kept below twice the maximum single year dose limit, unless for life saving actions – in the latter case, a limit of ten times the maximum single year dose applies. However, in certain circumstances, even this limit can be exceeded.

And the list of examples goes on. By no means, is it to be understood as a criticism of the document which was compiled by IAEA and the other international organizations. It is simply not possible to formulate requirements for the case of a nuclear catastrophe which can be reliable fulfilled in all possible situations. Even the use of practical exercises, as were performed in the framework of emergency planning, is limited.

Chapter 5 of the document lays down the requirements for the infrastructure. Again, it becomes clear how substantial the efforts and expenditures are, which have to be performed well in advance. Because of the far-reaching consequences of nuclear accidents, countries without nuclear power plants are also concerned.

All in all, many open problems still remain in mid-2006; even regarding those measures which could, in principle, be implemented to somewhat mitigate the effects of a nuclear catastrophe. An IAEA representative comes to the following conclusions:

"Many member states are currently not adequately prepared to respond to such [radiological] emergency situations. Moreover, without standard procedures and common approaches, protective actions can differ between countries, resulting in confusion and mistrust among the public, interfering with recovery operations and possible leading to severe socioeconomic and political consequences. Many of the lessons from past accidents, including even the Three Mile Island and Chernobyl accidents, have still not been completely incorporated into emergency plans in all States. Furthermore, there is a heightened awareness of the need to strengthen arrangements to respond to emergencies that could arise from criminal or terrorist activities involving nuclear and other radioactive materials." [de Oliveira 2006]

6.5 Experiences: Harrisburg, Chernobyl, Tokai Mura

6.5.1 Three Mile Islands – "Blind Men" Decide

The accident in the NPP Three Mile Islands on March 28, 1979 caused significant emissions of radioactive materials, compared to emissions in normal operation. Fortunately, the containment was not significantly challenged and a catastrophic release of radioactivity was avoided.

The Three Mile Island accident illustrates how in case of a nuclear accident a completely unclear situation can arise.

On March 30 the confusion was culminating. There was no definite information from the plant. While the temperature of the reactor core was increasing several measuring points failed and radioactivity was released. The further development was not predictable (at least as far as the operating crew was concerned). The emergency protection management therefore received the recommendation to consider evacuation [Innenausschuss des Deutschen Bundestages 1979].

On that day the chairmen of the upper nuclear regulation authority NRC Joseph Hendrie stated with respect to himself and the governor of Pennsylvania Richard Thornburgh:

"We were almost completely fumbling in the dark. His knowledge was not existent and mine not sufficient. It was, like a few blind old men stumbling around were making decisions." [May 1989]

The monitoring devices in the off-gas stacks had failed. Radiation monitoring in the surroundings was full of gaps; there were not enough measuring instruments available.

Especially due to the fact that on March 30 a hydrogen explosion was threatening, about 3.500 children and pregnant women were evacuated from the 8 km-radius of the power plant. In total up to 200.000 people voluntarily left the area.

In the next week, the situation gradually cleared up. The closed schools were re-opened and the public was asked to return to their homes. It was not possible, however, to determine the extent of the radioactive releases which had taken place.

The health effects of the accident have only been investigated to a small extent. There are indications for an increase of cancer incidence in the surroundings of the plant, which were discussed controversially. Many questions remain open until today [Mangano 2004].

Since this accident, the emergency planning in the USA was revised and extended, and major shortcomings were eliminated.

Still, for the basic problem, that in case of a nuclear accident the information can be incomplete and confusing and thus for days no reliable basis for the planning of protective measures might be available, no completely satisfying solution will be possible.

6.5.2 Chernobyl – Accident Consequences over Thousands of Kilometers and Many Decades

Seven years after the Three Mile Island accident a catastrophe occurred in a Soviet nuclear power plant. The accident of Chernobyl on April 26, 1986 has dramatically changed the lives of millions of people. Hundred of thousands of square kilometers of soil were contaminated. The officially stated economic losses are in the order of a billion US dollars [Hille et al. 1996].

What are the lessons to be learned for emergency planning?

The early days after the accident were characterized by a very hesitant information policy of the Soviet authorities – with respect to their own public and foreign countries. The community Pripyat in the immediate neighborhood of the nuclear power plant was warned only 36 hours after the accident [UNOCHA 2000]. The radioactive cloud reached many European countries earlier than reliable information on the accident. Indeed, the first hint of trouble outside the Soviet sphere of influence was an increase of radiation monitoring instrumentation at the Forsmark NPP in Sweden.

These problems are, to some extent, avoidable. After the Chernobyl accident two international conventions were agreed on that offer an improved basis for international cooperation with respect to early information in case of accidents and for mutual help [IAEA 1986a,b]. Beyond that many bilateral agreements arose and in many countries improvements were achieved with respect to early-warning systems and the planning of protective measures.

Chernobyl also shows that a considerable part of the consequences of a severe nuclear accident cannot be avoided by any optimized planning. A quarter million people were evacuated, millions still live in heavily contaminated areas. It would be extremely difficult to find living areas for all of them in uncontaminated regions.

New cities had to be built within a short time for the evacuated people. These cities became focal points of social stresses. Economic life does not function without friction – unemployment is high and the cities depend on subsidies.

In the best case, emergency planning can reduce radiation exposure of the public, but is less useful with respect to the social consequences of a large accident.

Moreover, Chernobyl has shown the size of the area that can be affected by a reactor accident. Countermeasures due to contamination were found to be necessary in distances of thousands of kilometers from Chernobyl.

Even in recent years, high values of cesium contamination are found in game meat in Bavaria. Up to 40,000 Bq/kg were measured in the meat of wild pigs in 2004, far above the German limit of 600 Bq/kg [BFS 2006].

In Nordic countries, cesium levels remain high in mushrooms and freshwater fish, frequently showing levels 10 to 20 times the limit of 1,500 Bq/kg. Reindeer meat also was highly contaminated, but is reported to be “mostly within limits” by 2006 [Nucleonics Week 2006]. Possibly restrictions concerning the consumption of food will have to be maintained in Great Britain until 2010 or 2015 [Smith et al. 2000].

Finally the Chernobyl accident demonstrates the long-term consequences of a nuclear catastrophe. This does not only concern the long-term restrictions of food consumption in large distances from the accident site but also the accumulating number of diseases and deaths.

Due to the lack of systematic studies and documentation, especially during the first years after 1986, part of the consequences cannot be recorded in detail anymore. And most of the consequences with respect to lifetime and health of the population will happen in the future.

A comprehensive study of the Chernobyl health effects, compiled by 50 Russian and Ukrainian scientists and published at the occasion of the 20*th* anniversary comes to the conclusion:

“Complete evaluation of the human health consequences of the Chernobyl accident is therefore likely to remain an almost impossible task, such that the true extent of morbidity and mortality resulting may never be fully appreciated.” [Yablakov 2006]

In this study, various estimates of the number of victims of cancer and other illnesses are reported. The highest values go up in the millions. In view of the available evidence, it seems plausible that the number of deaths will be in the six-figure range. Clearly, the countries most severely concerned are Belarus, the Ukraine and Russia. A significant amount of morbidity and mortality also has been caused across other European countries.

Even today the consequences of the accident can still be aggravated if already released radioactive materials are further distributed into the environment, by plant growth or fire in contaminated woods, or if more of the radioactive inventory is released from the site – for example, from the waste trenches which have been hastily dug there, or from the severely damaged reactor building.

In order to be efficient, emergency planning should therefore include long-term considerations (over decades).

6.5.3 Tokai Mura – an Accident in a Densely Populated Area

The criticality accident in the uranium conversion plant of JCO (Japan Nuclear Fuel Conversion Company Ltd.) on September-30 and October-01, 1999 did not have far-reaching consequences. Other countries were not concerned.

But still this accident demonstrates the difficulties of taking timely protective emergency measures in a densely populated region. It also demonstrated that nuclear threats are not unique to nuclear power plants.

The uncontrolled chain reaction in the uranium conversion plant started on September 30 at 10:35. The operation management realized within a few minutes that criticality occurred. Nevertheless the respective authority, the Science and Technology Agency, was not notified until 40 minutes later, and the municipality of Tokai Mura only at 11:34. [Nucleonics Week 1999]

Only four to five hours after the start of criticality were 150 persons within a 150-meter-radius around the plant were evacuated. At about the same time the 310,000 inhabitants within a 10-km surrounding got the information to stay in their houses [Nuclear Fuel 1999].

In the early morning of October 1st, further evacuations were considered. Finally, the authorities did not evacuate because it was raining and panic was expected. At that time the chain reaction was still going. Due to the direct neutron radiation the radiation exposure in 400 meters distance was one milli-Sievert [WISE 1999].

At 6:30 in the morning of October 1st criticality was stopped and the protective measures were cancelled.

Since the ventilation system in the plant was still operating, radioactive iodine was still released. These emissions lasted for at least one week [Nucleonics Week 1999a]. Later on the system was shut down, and leakage through windows of the respective building was reduced.

The accident was characterized by delays in information distribution and by slow implementation of protective measures – and that happened in an industrialized country with a highly developed infrastructure. It is also clear that the continuing iodine release was stopped far too late.

Besides, it cannot be judged whether the protective measures were optimal. The exact radiation exposure in the environment cannot be reconstructed anymore – only rough estimates are possible and they are not very reliable for the short-living iodine isotopes. Therefore it will not be possible to get exact information on the radiological long-term consequences.

Such uncertainties during nuclear accidents can most likely not be completely avoided, even in case of better organization and faster reaction.

6.6 Conclusions

The reactor of a nuclear power plant contains large amounts of radioactive materials. During a severe accident a significant part of these hazardous substances can be released into the atmosphere. This is valid for all reactor types that are presently in commercial use or in concrete planning.

In case of accidents with very severe releases – like terrorist attacks or acts of war leading to the destruction of a reactor building, or internally initiated accidents with early containment failure – the radioactive cloud reaches the atmosphere after a few hours. The warning time for protective measures can be very short. Depending on the wind velocity the cloud can travel several hundreds of kilometers during the first day.

The radioactive exposure of the population due to a severe accident can cause acute radiation diseases. In any case millions of persons could experience long-term consequences like cancer or other diseases, and genetic changes (mutations).

In order to be prepared for an emergency a large variety of protective measures is required. Expenditures for such measures are also necessary for countries that do not operate nuclear power plants or other nuclear facilities due to transboundary effects.

Extensive measures have to be taken, early-warning systems have to be implemented, stock-piling and evacuation plans have to be worked out, installations for decontamination and medical care for the contaminated victims have to be provided, and so on.

This will be a continuous task as long nuclear power plants are operated: The plans and protective measures have to be continuously revised and actualized, even extended in case of a world wide continuation of nuclear power generation.

Even in case of optimum emergency planning it has to be assumed that the implementation of protective measures in the near surroundings of the accidental plant cannot be realized in time, due to the limited warning times. Depending on wind speed the extension of the “near surroundings” can comprise hundred kilometers.

It is doubtful that protective measures like the distribution of iodine tablets and especially the evacuation of the endangered population is possible within appropriate time periods. The evacuation of large cities is certainly impossible within several hours.

Finally, it has to be considered that evacuations, as far as they can be realized, will cause further burden on the concerned persons. They might have to live for long time periods in emergency lodgings, were psychological stress and social tensions have to be expected. Working places will be lost, education and schools might be compromised. Cities as functioning social units will be destroyed; neighborhoods and even families will be disrupted.

In the last few years, there have been international efforts to strengthen emergency planning. The endeavors are aiming, on the one hand, at the development of prognostic methods and other tools for decision support in case of severe releases. On the other hand, basic requirements of general validity are to be established. Without doubt, those international efforts are going in the right direction. However, they cannot provide a sound and reliable solution. A closer look reveals that they, too, only demonstrate the far-reaching helplessness in the face of a nuclear catastrophe.

Three examples from the last three decades show that the basic problems of emergency planning exist even today and are very likely unsolvable.

During the Three Mile Island accident in 1979 the responsible authorities were unable to take adequate decisions for days due to incomplete and confusing information from the plant.

The Chernobyl catastrophe in 1986 showed drastic consequences requiring the resettlement of the population. Moreover it was demonstrated that a severe accident can concern whole continents, even after decades counter measures are still necessary thousands of kilometers away from the incident.

During the criticality accident in Tokai Mura it was remarkable that the responsible management and the authorities reacted very slowly in spite of early information - and that occurred in a modern industrial country with very good infrastructure.

Efficient emergency planning has to consider the large spatial distribution and the long-term character of the consequences. Furthermore, the possibility of incomplete information and hesitation on the part of responsible persons has to be taken into account.

Besides technical and medical aspects, the social, psychological and economic aspects have to be considered – and the fact that a large number of different countries could be concerned and an international exchange and coordination of information is required.

All this is valid not only for countries that operate nuclear power plants but also for those that do not to use nuclear power.

It seems impossible that all the needed requirements can be fulfilled. The challenges seem to be too overwhelming.

6.7 References

BFS (2006): Pilze und Wildbret im süddeutschen Raum noch immer belastet; report on website of the Federal Office for Radiation Protection (Bundesamt für Strahlenschutz, BfS) dated May 18, 2006;
[www.bfs.de], consulted September 14, 2006

Convention on Assistance in Case of Nuclear Accident or Radiological Emergency (1987): in Kraft getreten 1987, und Convention on Early Notification of a Nuclear Accident, in Kraft getreten 1986

Deppe, U. et al (1992): Transporte gefährlicher Güter auf dem Stadtgebiet von Hannover unter Berücksichtigung möglicher Gefahren und Auswirkungen durch radioaktive Stoffe; Landeshauptstadt Hannover, Amt für Umweltschutz, Schriftenreihe kommunaler Umweltschutz Nr. 1/1992

Energy News (2004): 16.05.2004

Feider, M. (2004) : L'harmonisation de la sureté nucléaire en Europe : le point de vue d'un pays ne possédant pas de centrale nucléaire ; CONTROLE, La Revue de l'Autorité de Sureté Nucléaire, Paris, No. 159, Juillet 2004, p. 69-72

Forschungszentrum Karlsruhe (2003): Presentation of RODOS, 21.05.2003; for further developments, see as of September 14, 2006:
[www.rodos.fzk.de]

Herviou, K. & Winter D. (1999): Organisation and Operation of the IPSN crisis centre in case of accident in a French PWR; EUROSAFE, Paris, November 18 & 19 1999

Hille, P. et al. (1996): Die Folgen des Reaktorunfalls von Tschernobyl für Mensch und Umwelt; Forum für Atomfragen, Wien, Dezember 1996

IAEA (1986a): Convention on Early Notification of a Nuclear Accident. 18.11.1986 INFCIRC/335
[http: //www.iaea.org/Publications/Documents/Infcircs/Others/inf335.shtml]

IAEA (1986b): Convention on Assistance in the Case of Nuclear Accident or Radiological Emergency. 8.11.1986 INFCIRC/336
[http: //www.iaea.org/Publications/Documents/Infcircs/Others/inf336.shtml]

IAEA (2002): International Atomic Energy Agency: Preparedness and Response for a Nuclear or Radiological Emergency; IAEA Safety Standards Series, Requirements No. GS-R-2, jointly sponsored by FAO, IAEA, ILO, OECD/NEA, PAHO, OCHA & WHO, Vienna, November 2002

Innenausschuss des Deutschen Bundestages (1979): Harrisburg-Bericht – Bewertung des Störfalles im Kernkraftwerk Harrisburg; 2. Zwischenbericht für den Innenausschuss des Deutschen Bundestages, der Bundesminister des Innern, Bonn, 01.06.1979

Länderausschuss für Atomkernenergie (1999): Rahmenempfehlungen für den Katastrophenschutz in der Umgebung kerntechnischer Anlagen; Beschlüsse des Länderausschusses für

Atomkernenergie – Hauptausschuss – vom 06.04.1999 und der Innenministerkonferenz vom 11.06.1999

Mangano, J. (2004): Three Mile Island: Health Study Meltdown; Bulletin of the Atomic Scientists Vol. 60, No. 5, September/October 2004, p. 30-35

May, J. (1989): Das Greenpeace-Handbuch des Atomzeitalters; deutsche Ausgabe, Knaur, München 1989

Ministerium für Finanzen und Energie des Landes Schleswig-Holstein (1999): Gefahren der Atomkraft; 2. aktualisierte Auflage, Kiel, Mai 1999

de Oliveira, N. (2006): Renforcer les standards internationaux pour la préparation et la réponse en cas de situation d'urgence; CONTROLE, La Revue de l'Autorité de Sûreté Nucléaire (ASN), No. 171, Juillet 2006

Nuclear Fuel (1999): Nuclear Fuel Vol. 24, No. 20, October 4, 1999

Nucleonics Week (2006): Nucleonics Week Vol. 47, No. 17, April 27, 2006

Nucleonics Week (1999): Nucleonics Week Vol. 40, No. 40, October 7, 1999

Nucleonics Week (1999a): Nucleonics Week, Vol 40, No. 41, October 14, 1999

OECD NEA (2002): Chernobyl – Assessment of Radiological and Health Impact; NEA Committee on Radiation Protection and Public Health, OECD Nuclear Energy Agency, Paris 2002

Smith, J.T. et al.(2000): Pollution: Chernobyl's legacy in food and water; Nature 405, 141, 2000

Strahlenschutzkommission (2004): Verwendung von Jodtabletten zur Jodblockade der Schilddrüse bei einem kerntechnischen Unfall – Empfehlung der Strahlenschutzkommission; verabschiedet in der 192. Sitzung der Strahlenschutzkommission, 24./25. Juni 2004

Strahlentelex (2004): Nr. 410-411, 2004

UNOCHA (2000): United Nations Office for the Coordination of Humanitarian Affairs (UNOCHA): Chernobyl – A Continuing Catastrophe; United Nations, New York and Geneva, April 2000

WISE news communiqué (1999): WISE news communiqué, No. 520, October 29, 1999

Yablokov (2006): A. Yablokov (editor) et al.: The Chernobyl Catastrophe – Consequences on Human Health; Greenpeace, Amsterdam, April 2006

7 Nuclear Proliferation Issues Associated with the Commercial Nuclear Fuel Cycle

Steven Sholly
March 2006

Editors comment:

From the start development of nuclear energy was strongly linked with military interests. The nuclear proliferation debate stood at the beginning of the discussions on commercial use of nuclear energy and has been a part of the debate through-out. The international dispute about the Iranian Nuclear Program is just one recent example of this.

An assessment of the Nuclear Option would therefore be incomplete without consideration of possible misuse of nuclear material for non-peaceful purposes. A comprehensive paper on the possibilities of states that do not have nuclear weapons at present to proliferate from the commercial nuclear fuel cycle was prepared and submitted to the Austrian government. However, many things are known or should be discussed in this context that prudence forbids to publish. For the purposes of the published edition of the assessment, such sensitive passages were deleted and a shortened version of the comprehensive paper was produced. Even this "cleaned" version makes the relevance of proliferation for the nuclear option obvious.

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7.1 Introduction

7.1.1 Purpose

The purpose of this report is to provide a perspective on the potential nuclear weapons proliferation pathways available from a commercial nuclear (fission) power plant fuel cycle, considering all the steps from mining to final waste disposal (including reprocessing and recycling). For the purpose of this document, proliferation is defined as "*the spread of nuclear weapons, nuclear weapons materials, and nuclear weapons technology*" [DOE 1998].

This report does not address, except in passing, proliferation arising from other pathways (such as research reactors, accelerators, fusion power concepts, etc.). Finally, this report also does not address weapons other than nuclear weapons (e.g., radiological dispersal devices, so-called "dirty bombs") [Carafano][1].

7.1.2 Background

As part of the Kyoto Protocol to the UN's Framework Convention on Climate Change, adopted in December 1997, a "*clean development mechanism*" (CDM) has been defined for the purpose of supporting - in developing countries - the development and deployment of energy production facilities that do not release greenhouse gases. Some organisations have advocated the expansion of the CDM to include nuclear power projects although this proposal has not been accepted to date. Certain aspects or characteristics of nuclear power bear on its potential inclusion within the CDM. The purpose of the current report is to address one of these matters - the potential to use the commercial nuclear (fission) fuel cycle to obtain nuclear weapons.

Specifically, this report assesses the proliferation potential of the nuclear fuel cycle for nations which are not already "nuclear weapon states"[2]. This focus arises from the Kyoto Protocol scope, parties to which are nations (rather than subnational or multinational groups). The scope limitation to the commercial nuclear fuel cycle arises from the need to assess whether the commercial nuclear fuel cycle is sustainable. Thus, this report does not look at other aspects of nuclear energy, nor at issues dealing with sabotage, terrorism or military actions which are addressed by other authors.

In addition, this report focuses on horizontal proliferation. Vertical proliferation is possible – that is, "nuclear weapon states" can use the commercial nuclear fuel cycle to produce additional

[1] Readers interested in the subject of radiological dispersal weapons may wish to consult other reports which discuss radiological dispersal devices (RDDs), several of which are easily available (Carafano 2004; Ferguson 2003; Ford 1998).

[2] The phrase "nuclear weapon states" as used in this report does not have the same meaning as that phrase is used in the Nonproliferation Treaty (NPT). The NPT recognizes only five "nuclear weapon states": China (the People's Republic of China, PRC), France, the Russian Federation, the United Kingdom and the United States of America. The NPT definition ignores the very evident possession of nuclear weapons by, for example, India and Pakistan (both of which have conducted multiple nuclear tests).

nuclear weapons, enhance the capabilities of existing nuclear weapons, or maintain the yield strength of existing nuclear weapons. Such a concern is not merely theoretical – the United States of America is using the Watts Bar nuclear power plant (operated by the Tennessee Valley Authority and licensed by the US Nuclear Regulatory Commission) to produce tritium for use in its nuclear weapons program. Such vertical proliferation is not further addressed in this report because the focus of the current report is on the potential for non nuclear weapon states to proliferate from the commercial nuclear fuel cycle.

The commercial nuclear fuel cycle[3] is inherently associated with a risk that nuclear explosive devices or nuclear weapons can be produced if internationally agreed safeguards arrangements are not followed. It can be argued how easy or difficult it is to proliferate from various steps in the nuclear fuel cycle, but a potential for the nuclear fuel cycle to be used to produce nuclear weapons cannot be avoided. The risk of nuclear weapons proliferation among current methods of producing electricity or process heat is unique to the commercial nuclear (fission) power fuel cycle. This risk can be minimized, but it cannot be eliminated.

With the scope of the current report as defined above, the first task is to identify those nations which are already nuclear weapon states. The main attempt to control risk of proliferation from the commercial nuclear fuel cycle on an international level is the Treaty on the Non-Proliferation of Nuclear Weapons, most often referred to as the "Nonproliferation Treaty" or simply the NPT [IAEA 1970]. The NPT entered into force on 5 March 1970, and includes as signatories nearly all of the nations on earth. The four nations not belonging (or no longer belonging) to the NPT are (note that all four are identified as "nuclear weapon states" below):

- India
- Israel
- North Korea (DPRK)
- Pakistan

Secondarily, there are a variety of multi-lateral arrangements by which transfers of so-called "dual use" equipment (i.e., equipment with legitimate uses apart from nuclear weapons production) are controlled. These multi-lateral dual use arrangements include the following:

- The Nuclear Suppliers Group (NSG), http: //www.nsg-online.org/.
- The Zangger Committee, http: //www.zanggercommittee.org/Zangger/default.htm.

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[3] The nuclear fuel cycle comprises the following steps:
- Mining and milling of uranium ore, and its conversion to yellowcake.
- Production of either natural uranium metal or uranium hexafluoride (UF6) as a prelude to enrichment.
- Enrichment of the uranium-235 fraction from the natural state (0.7 % U-235) to 3 %-5 %.
- Production of nuclear fuel and its "burnup" in a power reactor.
- Removal of "spent" fuel from the reactor and cooling in a spent fuel storage facility.
- Transport of the spent fuel to a reprocessing facility (if used) for separation of plutonium for recycling in mixed oxide (MOX) fuel, and vitrification of the resulting high level waste.
- Preparation of spent fuel and/or vitrified waste for disposal.
- Disposal of the spent fuel and/or vitrified waste in a geological repository.
- Preparation of spent fuel and/or vitrified waste for disposal.

There are also a variety of additional bilateral and multilateral arrangements and agreements by which proliferation of nuclear weapons is sought to be controlled. These arrangements are widely described and need not be enumerated here [Federation of American Scientists][4].

For the purposes of this report, "nuclear weapon states" are identified based on the following four criteria:

1. The state is known to have nuclear weapons by virtue of its own admission and by the conduct of one or more nuclear tests.

2. The state has publicly declared that it has nuclear weapons, and this claim is widely acknowledged to be correct despite the absence of a nuclear test.

3. The state is strongly suspected of having nuclear weapons, and this suspicion is widely held to be correct notwithstanding the silence or contrary statements of the government.

4. The state previously had nuclear weapons, but has since decommissioned these weapons (the decommissioning having been verified).

Based on these criteria, there are ten nuclear weapon states:

- China (criterion 1; also an NPT Nuclear Weapon State).

- France (criterion 1; also an NPT Nuclear Weapon State).

- India (criterion 1).

- Israel[5] (criterion 3).

- North Korea (DPRK)[6] (criterion 2)[7].

- Pakistan (criterion 1).

- Russian Federation (criterion 1; also an NPT Nuclear Weapon State).

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[4] See, for example:
- Federation of American Scientists on "Arms Control Agreements" [http: //www.fas.org/nuke/control/index.html]
- Arms Control Association's Web page on "Treaties" [http: //www.armscontrol.org/treaties]
- Center for Nonproliferation Studies, http: //cns.miis.edu/pubs/inven/index.htm, Monterey Institute of International Studies.

[5] Israel refuses to comment concerning speculation that it has a large number of nuclear weapons. Nonetheless, Israel is widely suspected of having 75-200 (or more) nuclear weapons of various types (Cirincione 2003; Farr 1999; Hersh 1993; Norris 2002; Sublette 2001; UIC 2004; WP 1996).

[6] North Korea claims to have nuclear weapons. Although this has not been independently verified, and North Korea has not conducted a nuclear test, there is no substantial reason to suspect that their claim is not correct. The US Central Intelligence Agency has concluded that North Korea has a small number of nuclear weapons (Niksch 2003, Shea 2004).

[7] Editor's Note: North Korea conducted an underground nuclear test on 09 October 2006.

- South Africa[8] (criterion 4).

- United Kingdom of Great Britain and Northern Ireland (criterion 1; also an NPT Nuclear Weapon State).

- United States of America (criterion 1; also an NPT Nuclear Weapon State).

Not included in this list are nations which were formerly part of the Soviet Union and which, upon independence, returned the Soviet nuclear weapons to the Russian Federation (Belarus, Kazakhstan and Ukraine). Also not included in this list are nations in which nuclear weapons were based but which did not belong to the country in question (this was a relatively long list of countries during the era of the "Cold War", and still includes a number of countries).

The rest of this report addresses the potential for the commercial nuclear (fission) fuel cycle to be used to produce nuclear weapons in countries other than the ten nuclear weapon states identified above. Readers interested in the details of nuclear weapons programmes of the ten nuclear weapon states will have no difficulty in finding an abundance of publicly available documentation on this subject.

It should be noted that notwithstanding the risk of proliferation from the commercial nuclear fuel cycle, in the main the ten nuclear weapon states listed above have dedicated facilities and programs (China, France, Pakistan, the Russian Federation, South Africa, the United Kingdom, and the United States) or high power research reactors (India, Israel & North Korea) to produce nuclear weapons materials. There are however some cases that have crossed the boundary and for which some would argue represent cases of proliferation from the commercial nuclear fuel cycle[9].

7.1.3 A Note Regarding Uniform Resource Locator (URL) Addresses in the References

Many of the references to this report (enumerated in Chapter 8) include Uniform Resource Locator (URL) addresses which – at the time the report was written – contained the reference in question. No doubt most readers are well aware of the transient nature of URLs – URLs frequently change. For all references, as complete a citation as is feasible has been provided to aid the reader in locating the document in question. URL addresses are provided where applicable, subject to the proviso that these World Wide Web addresses frequently change.

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[8] South Africa developed six gun-type highly enriched uranium (HEU) nuclear weapons (as well as parts for a seventh) before dismantling these devices and acceding to the Nonproliferation Treaty as a non-nuclear weapon state (Albright 1994; Albright 2001; Horton 1999; NTI 2004a; Von Baeckmann 1995).

[9] The United States is currently using special assemblies in the core of the Watts Bar Nuclear Power Plant to produce tritium for the nuclear weapons program. In addition, the United States produced electric power for grid distribution at the Hanford "N-Reactor", which was a production reactor. The United Kingdom also used production reactors to produce electrical power for the power grid. In addition, both the United States and India have each conducted at least one nuclear test using "reactor-grade" plutonium.

7.1.4 Document Organization

The remainder of the document is organized as follows:

- Section 2 discusses in more detail the potential proliferation vulnerabilities of different parts of the nuclear fuel cycle, and highlights some specific proliferation vulnerabilities.

- Section 3 delves into the issue of how difficult it is (or is not) to design, develop, deploy and deliver nuclear weapons, addressing along the way how far a potential proliferator could go and remain undetected before fielding nuclear weapons.

- Section 4 identifies countries that can be considered to be "nuclear capable" and provides the rationale for this designation.

- Section 5 provides a summary, conclusions and recommendations.

- Section 6 consists of the references for the report (along with, where available, URL addresses for the documents).

For an abbreviated primer on nuclear weapons and proliferation see [Sholly, St. 2006].

7.2 Potential Proliferation Vulnerabilities of the Commercial Nuclear Fuel Cycle

Numerous books have been written on the subject of proliferation vulnerabilities of the commercial nuclear (fission) fuel cycle. Readers wishing a full treatment of this subject should consult one of these books. The object here is to simply identify the principal potential proliferation vulnerabilities of the commercial nuclear fuel cycle.

In order to produce and deploy nuclear weapons, one must: (a) have a workable design and be able to fabricate it; (b) have the required nuclear material; and (c) have the means to deliver the weapon to the target. The picture that emerges from the literature is that items (a) and (c) are relatively easy - the hard part of producing nuclear weapons is obtaining the necessary nuclear material. In order to produce a nuclear weapon, one needs highly enriched uranium (HEU; either U-235 or U-233), "weapons-usable" plutonium, or Neptunium-237 in order to produce a nuclear weapon[10].

Production of a nuclear weapon design can proceed quite separately from the availability of nuclear materials, however the design must of course consider the nuclear materials that are being sought or are planned to be produced. A nuclear weapon design, while of course representing a precondition to producing a weapon, is independent of the nuclear fuel cycle and

[10] There is a great deal of dispute and misunderstanding about the weapons usability of Neptunium-237. Neptunium-237 is a fissile material, and is identified as such in US DOE (e.g., DOE Order 5480.3, Safety Requirements for the Packaging and Transportation of Hazardous Materials, Hazardous Substances and Hazardous Wastes, 9 July 1985; http: //packages.llnl.gov/doe_ord/054803.pdf and IAEA standards. Neptunium-237 is recognized as fissile in other literature as well (Rothstein 1999; Albright 1999), and the experiment at Los Alamos National Laboratory in September 2002 which established the base critical mass of Neptunium-237 has definitively settled the issue (LANL 2002).

can be embarked on without yet having the nuclear fuel cycle stages in place upon which one would ultimately rely to produce the needed nuclear material for the weapon.

Similarly, the means of transporting a nuclear weapon to the intended target also are independent of the nuclear fuel cycle. Studies and production of the means of weapon delivery can proceed apart from the nuclear fuel cycle (with the proviso that the means of delivery must match up with the design in terms of size and weight limits).

This Chapter then focuses on the vulnerabilities of the commercial nuclear fuel cycle from which one could proliferate the nuclear material(s) desired to produce nuclear weapons. Bearing in mind that this report focuses only on the commercial nuclear fuel cycle (dedicated nuclear weapon material production facilities and research reactors are excluded from the scope of the report), the following are the principal points of vulnerability for nuclear weapons proliferation [May][11]:

- Direct enrichment of uranium hexafluoride (UF_6) to HEU.

- Processing fresh LWR fuel (already enriched to 3 % to 5 % Uranium-235), production of uranium hexafluoride and completion of enrichment to HEU level.

- Reprocessing of spent fuel to recover weapons-usable plutonium and/or Neptunium-237.

- Retrieval of spent fuel from a high level waste repository and recovery of weapons-usable plutonium and/or Neptunium-237.

In the first case above, UF_6 feedstock nominally intended for the commercial nuclear fuel cycle can be enriched to HEU instead of stopping enrichment at low enriched uranium (LEU) intended for reactor fuel. In the latter three cases above, these actions can result from diversion of materials from the commercial fuel cycle or from theft.

The first and third cases above are relatively straightforward. Direct enrichment of UF_6 feedstock to HEU requires more time and more energy than stopping enrichment at levels typical of commercial reactor fuel (three to five percent Uranium-235). Reprocessing of spent fuel to recover weapons-usable plutonium and/or Neptunium-237 is also a straightforward manner. Retrieval of spent fuel from a repository and reprocessing it to recover weapons-usable plutonium and/or Neptunium-237 is just a variation on the case of taking the spent fuel from storage. Some further remarks on all four cases will illuminate the relative difficulties involved.

7.2.1 Direct Enrichment of Uranium Hexafluoride to HEU

When uranium enrichment was performed with gaseous diffusion plants and electromagnetic isotope separation (EMIS), enrichment facilities were so expensive to construct and so expensive (in terms of electricity supply) to operate that only a few countries operated uranium enrichment plants and these were already countries which had nuclear weapons. (This did not, however,

[11] The abuse of a Light Water Reactor for proliferation purposes for plutonium production is well described in Diversion and Misuse Scenarios for Light-Water Reactors, Chapter 5 in (May 2001). However, this work assumes that the plutonium route is the most important vulnerability. Considering the discussion below, it is far from evident that this is the case.

prevent Iraq from attempting to enrich uranium using EMIS technology [Albright 1991; Gsponer 1995; Gsponer 2001][12].)

With the advent of other methods of enrichment, however, this restriction no longer applied and it became feasible for other countries with lesser resources and infrastructure to pursue uranium enrichment. In particular, gas centrifuge technology [Oelrich][13] has been spread around the world[14]. Other uranium enrichment technologies that have been used include atomic and molecular laser isotope separation and aerodynamic separation using a vortex tube (successfully used in the South African nuclear weapons program; but this also requires large amounts of electricity).

It no longer requires billions of dollars of investment and hundreds or thousands of megawatts of electric power to accomplish uranium enrichment on a scale that enables a small nuclear weapons program to proceed. The change in scope and scale of uranium enrichment, and the change to making HEU available for weapon design together with the effect of this on the ease of producing nuclear weapons is well explained by Oelrich [Oelrich 2004]:

"A proliferator has two routes leading to a bomb, one exploiting plutonium, the other uranium. Plutonium does not occur naturally and has to be created in a nuclear reactor but, once made, it is easy to separate. But the bombs that use plutonium are much harder to design and manufacture. On the other hand, the simplest uranium bomb, in which one slug of uranium is shot into another, thus called a "gun-assembled" bomb, is quite simple indeed. But the required bomb-grade uranium has been very difficult to prepare, requiring huge, energy-hungry gaseous diffusion plants. Thus, either route presented a would-be proliferator with at least one big technical hurdle, either the bomb or the material. Moreover, the production of either nuclear material required plants that are distinctive and difficult to conceal.

Modern gas centrifuges change this picture. They make the separation of the fissionable uranium-235 much easier and cheaper than it would be using gas diffusion, even potentially easier than producing plutonium, so the easiest route to getting bomb material has become aligned with the simplest gun-assembled bomb design. Modern centrifuges open up a nuclear option for a new group of proliferators with only moderate technical sophistication, such as Iraq, Iran or North Korea. Moreover, centrifuge enrichment plants are modular, much smaller than gas diffusion plants and use potentially just five percent[15] of the electrical power of a gas diffusion plant. Thus, they not only make the development of nuclear weapons easier, they make more difficult both the monitoring of supposedly peaceful uranium enrichment for nuclear power and the detection of clandestine bomb-making programs".

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[12] The lesson to be learned from this experience is not to get blinded by high technology means of accomplishing nuclear weapons proliferation when lower technology means exist. The means of proliferation do not have to be efficient and state-of-the-art to work - they merely have to work at a cost and rate which matches the means and patience of a potential proliferator.

[13] Gas centrifuges work by introducing UF_6 gas into an evacuated chamber with a high speed, "frictionless" rotor. The heavier U-238 bearing gas is more concentrated at the edge whereas the lighter U-235 bearing gas is more concentrated at the center. See, for example, Institute for Science and International Security, "What is a Gas Centrifuge", 2003; http: //www.exportcontrols.org/centrifuges.html; and Federation of American Scientists (Oelrich 2004).

[14] Including Germany, Iran, Iraq, Japan, Libya, Netherlands, North Korea, Pakistan, the Russian Federation, the United Kingdom and soon in the United States (Boureston 2004; CIA 2003; CIA 2004; FAS 2000; Green 2003; DOD 1998).

[15] The Federation of American Scientists estimates that the difference is as little as 2.5 % - they estimate that the electricity requirement for a "separative work unit" (SWU) of uranium enrichment using gaseous diffusion is round 2,400 kWh, while the same requirement for a gas centrifuge plant is only 60 kWh (FAS 2000; DOD 1998).

7.2.2 Processing Fresh LWR Fuel to Uranium Hexafluoride and Completion of Enrichment to HEU

Although it is evidently well known within the confines of the industry, it is not generally known that once uranium has been enriched to the levels typical of light water reactor fuel (that is, enriched in Uranium-235 fraction in the range of 3.5, more than 80 % of the total enrichment work needed to HEU from natural uranium has already been accomplished [Sokolski 2003]. Based on estimates from the Non-Proliferation Education Center [NPEC 2003; Sokolski 2003], a country could start with the initial fuel load for a 1000 MWe LWR and use this as feedstock for further enrichment.

Assuming a 20-kilogram HEU core for an implosion weapon, 50 nuclear weapons could be produced at a rate of one per week with 11,000 centrifuges or a rate of one every two days with about 44,000 centrifuges. Assuming rejection of "tails" from the process at 2 % Uranium-235 content, there would be an additional 1700 kg of Uranium-235 in the tails, much of which could be recovered at a slower rate through continued enrichment and rejection at a lower tails concentration.

This calculation provides some indication of how further enrichment of LEU reactor fuel could be used to produce nuclear weapons. If the process is started with a higher enrichment level (e.g., 5 % enriched LEU for a longer fuel cycle), the rate of production of weapons would be somewhat faster. Obviously, if a smaller or greater number of centrifuges were used, the rate of production of weapons would vary accordingly.

7.2.3 Reprocessing Spent Fuel to Recover Weapons-Usable Plutonium and/or Neptunium-237

The reprocessing of spent fuel to recover weapons-usable plutonium and/or Neptunium-237 is well addressed in the literature in terms of a dedicated, engineered reprocessing facility. The extraction technologies are matters of public record (the PUREX process for plutonium, and a variant thereof for the Neptunium-237).

But how hard would it be for a subnational group to accomplish this? The answer is provided in a special proliferation vulnerability team study performed for the US Department of Energy by experts from four national laboratories (Sandia, Lawrence Livermore, Los Alamos and Savannah River). In short, the pertinent facts and opinions of this group are as follows [Hinton 1996: 9,15, 4-3, 4-4, 4-6]:

- The threat of unauthorized parties attempting to illicitly acquire plutonium-bearing material, whether by overt forcible theft or covert diversion, and to recover plutonium metal sufficient for nuclear explosive devices was considered to be "*quite credible*".
- The technology for extracting plutonium from spent fuel is in the open literature.
- The technology required to extract the plutonium represents a "*rather simple process*" that can be operated by an adversary group in a makeshift or temporary facility, such as a warehouse or small industrial plant.
- The resources required for extracting a significant quantity of plutonium from spent fuel using this technology are relatively modest.

- A small, well-prepared group could recover enough plutonium from spent fuel for a nuclear device within four to eight weeks.

- Four persons with appropriate qualifications would be required for the operation to extract plutonium from spent fuel.

7.3 How Difficult is it to Make a Nuclear Weapon?

7.3.1 General Considerations

During World War II, the United States "Manhattan Project" developed four nuclear weapons and the related plutonium production and uranium enrichment technologies in a three-year period with the expenditure of \$ 2 billion (1945 dollars) and the work of thousands of scientists and engineers. About forty years later, South Africa produced six nuclear weapons at a cost of about \$ 1 billion (1980 dollars) with the work of 400 people and indigenous technology. Clearly, it does not require the replication of the "Manhattan Project" in order to produce nuclear weapons [O'Shei 1976; Stumpf 1995].

The following statements from experts in the field are taken as illustrative concerning the difficulty of producing nuclear weapons:

- *"The relevant technology is increasingly available. In the nuclear domain, much information about the production, fabrication and behaviour at high temperatures and pressures of such materials as uranium, plutonium and beryllium is now in the open literature. Continuing advances in such areas as computers, explosives and precision machining make the task of reinventing nuclear weapons easier. If it is not essential to minimize the weapons' size and weight and to predict its yield, the computational power available in today's personal computers should suffice to develop weapons of all levels of technical sophistication, including thermonuclear ones, with only minimal full-scale nuclear testing. Relatively unsophisticated fission weapons might be stockpiled under such conditions without any nuclear testing, especially if a range of non-nuclear testing methods is available."* [Cohen 1991]

- "*Once adequate quantities of enriched uranium or plutonium are available, the problem of fabricating a simple fission weapon should not prove too difficult for any state that has developed even a modest level of competence in the nuclear field. The basic design features of first generation fission weapons are now widely known. A small number of scientists and engineers whose experience was derived from a peaceful nuclear power program could develop a workable design. The actual fabrication of a device would require a small team of fairly qualified experts in a number of fields with access to laboratory and fabrication facilities using easily obtainable equipment.*" [Goldberger 1985: 229]

- *"Once weapons-usable material has been acquired, actually designing and manufacturing weapons is the next issue. Compared to the problem of manufacturing fissile material, this is comparatively easy however. The fundamental technologies to actually build a weapon is possessed by any nation with a significant arms industry (that is, virtually any country with a significant military). The technologies used to actually build the weapons employed by the US in WWII are crude by today's standards, and are widely available. ... Virtually any* *industrialized nation today has the technical capability to develop nuclear weapons within several years if the decision to do so where made. Nations already possessing substantial nuclear technology and arms industries could do so in no more than a year or two. The larger industrial nations (Japan and Germany for example) could, within several years of deciding to do so, build arsenals rivalling those planned by Russia and the U.S. for the turn of the millenium following the implementation of START II. It is also very likely that most any country with advanced military capabilities system will have undertaken design work in nuclear weapons to some extent. This is almost mandatory for national security reasons, if only to provide indigenous expertise in evaluating intelligence and projecting the capabilities of possible foes.*" [Sublette 2001]

- "*...[T]here are very simple nuclear weapon designs available to a potential proliferator. Weapons based on these designs would bear little resemblance to the more advanced weapons deployed by today's nuclear powers, but that is beside the point, since even simple weapons could reliably produce an explosion equal to hundreds or thousands of tons of TNT. That is a much easier task than most people think; the main obstacle has been the difficulty of securing an adequate supply of fissile material.*" [Coté 1996]

- "*A significant point is that a simple fission design would not require testing to prove that it would work. The only debate would be about the yield.*" [Hinton 1996: 4-7]

- "*Although weapons-grade plutonium is preferable for the development and fabrication of nuclear weapons and nuclear explosive devices, reactor grade plutonium can be used. The technology for recovering plutonium from spent fuel is in the open literature and can be easily adapted for the material forms within the alternatives. The resources required for the recovery of a significant quantity of plutonium are estimated to be relatively modest. The presence of a radiation barrier sufficient to require shielding and the need for chemical processing during recovery provide the greatest discrimination among the material forms. However, a small, well-prepared group could recover sufficient plutonium for a device within perhaps two months. Keeping plutonium inaccessible is the key to proliferation resistance.*" [Hinton 1996: 4-7]

- "*Nuclear weapons testing is not essential now for proliferating nations, as it once was, because information related to nuclear weapons is now widespread. The technological hurdles faced by US weapon designers in the 1940s are long gone. Universities teach courses in physics, engineering, metallurgy and chemistry that can provide a sound basis for a nuclear weapons program. The information superhighway enables researchers in remote locations to access thousands of relevant articles and reports, as well as to seek assistance from experts who, prior to the invention of the Internet, were inaccessible. Advanced computers, although not a prerequisite, are readily available and make weapons design easier. The state of knowledge has also advanced with regard to materials, which makes it easier for a nation to design lighter, less bulky weapons than those built at the outset of the US nuclear weapons program. When combined, these variables make feasible for a nation to design with high confidence a nuclear weapon that, in the not-so-distant past, would have considered relatively sophisticated.*" [Bailey 1998]

It could be that knowledge of the lack of difficulty in fabricating simple fission weapons was a factor in the military strikes against nuclear facilities in Iraq on at least three occasions (by Israel and the United States) and Iraqi airstrikes on the reactor construction site in Iran on seven occasions [Vandenbroucke 1984].

7.3.2 The Nth Country Experiment

In the middle 1960ies, Lawrence Radiation Laboratory (later Lawrence Livermore National Laboratory) conducted what was called the "Nth Country Experiment". This experiment was intended to evaluate whether a non-nuclear country would be able to develop a successful nuclear weapons design from publicly available sources *then* available (i.e., in the middle 1960s).

The three-person team, all with Bachelor's degrees, deliberated selected a spherically symmetric plutonium implosion design because it was more difficult. One of the three members of the team quit and was replaced by an Army Lieutenant with a PhD [Stober 2003][16].

A total of three person-years of effort was expended on the design [Frank 1967]. Their design was characterized as too big for a missile, but small enough to be carried on an airplane or a truck. The design was never tested in nuclear detonation, but it was evaluated using the nuclear weapon codes in use at the time, and it was concluded that it was a viable design [Stober 2003].

According to one published report, the Nth Country experiment was successful in that a viable design was produced [Pethokoukis 2003][17]. As that author observed [Sublette 2001]:

"In the years since, much more information has entered the public domain so that the level of effort required has obviously dropped further. This experiment established an upper limit on the required level of effort that is so low that the hope at lack of information may provide even a small degree of protection from proliferation is clearly a futile one."

7.4 Nuclear Capable Countries

This Section of the report identifies "nuclear capable" countries. It also identifies countries with "breakout capability". For the purposes of this report, a country is considered to be nuclear capable if it possesses the requisite technical knowledge and industrial capacity to produce nuclear weapons, as well as a source of weapons usable nuclear material. It should be observed that since nearly all nations (with four exceptions, all of which are already nuclear weapon states) belong to the NPT, transitioning from a nuclear-capable country to a nuclear weapon state would require either breaking treaty commitments (which has occurred on several occasions), or opting out of the NPT with 90 days notice as North Korea recently did (the first country to do so).

A designation of a country as nuclear capable in this report is not a statement of the intention of that country to produce nuclear weapons. The purpose here to assess the capability but not the intent of non nuclear weapon states to produce nuclear weapons from the commercial nuclear fuel cycle. No inference of intentions is either intended or can reasonably be inferred from this report. Nonetheless, some of the states designated as nuclear capable in this report have had political or military experts, or organizations, which have in the past expressed an interest or desire that their country produce nuclear weapons, or in some cases the nations have had nuclear weapon programs which have since been terminated.

[16] The group of three initially consisted of David Dobson, David Pipkorn (who left after a few months) and Robert Selden (Stober 2003). Selden was later to become part of the Nuclear Emergency Search Team (NEST), working at Lawrence Livermore National Laboratory and later at Los Alamos National Laboratory.

[17] A story which ran in US News & World Report indicated an estimated yield of 15 kilotons (Pethokoukis 2003).

It should be noted, in viewing the list of "nuclear capable" states, that simply possessing an operating nuclear power plant in most cases confers "nuclear capable" status on a state. Spent fuel from light water reactors (PWRs, BWRs, RBMKs and VVERs) and pressurized heavy water reactors (PHWRs) can be reprocessed using *ad hoc* methods to recover plutonium to be used in the fabrication of nuclear weapons [Hinton 1996]. Factors which further affect nuclear capability include the following:

- Presence of a national nuclear research institute or institutes.
- Presence of a large nuclear infrastructure (e.g., nuclear-related equipment suppliers, nuclear utility engineering staff, consulting nuclear engineering industrial companies, nuclear services organizations, etc.), especially a reactor vendor.
- Presence of nuclear fuel cycle facilities, especially uranium enrichment facilities.
- A reprocessing facility foremost, or at least prior or current experience or research programs in spent fuel reprocessing, or in partitioning and transmutation. The presence of existing hot cells could facilitate reprocessing activities on an ad hoc basis.
- University departments or national science academies in nuclear physics and/or nuclear engineering.
- Presence of defence industries, especially in the areas of high explosives.
- Previous or current experience as a nuclear weapon host state, providing storage or basing of nuclear weapons from another country.

A summary list of "nuclear capable" states is provided below in Table 4.1. Note that this list is based on the potential to proliferate solely from the commercial nuclear fuel cycle. There are other states that are capable of proliferating from large research reactors [Cordesman 2003][18], as India, Israel and North Korea have done. This list was created considering a large number of references[19] as well as interpretations of these references by the author of the current report. Twenty-six "nuclear capable" states are identified, of which fourteen are considered to have "breakout" capability.

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[18] One current suspect for such a proliferation route is Algeria (Cordesman 2003; WP 2004; SIPRI 2004).

[19] Among the key references are the following: CEIP 2004; DOD 2001; NTI 2004b; Sublette 2001. In addition, in cases where they were readily available, the National Reports filed by the countries for the Convention on Nuclear Safety and the Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management were used as primary factual resources.

Tab. 7-1 **NUCLEAR WEAPONS CAPABLE STATES**

Argentina	Finland	Lithuania	**Spain**
Armenia	**Germany**	Mexico	**Sweden**
Belgium	Hungary	**Netherlands**	**Switzerland**
Brazil	**Iran**	Romania	**Taiwan**
Bulgaria	**Italy**	Slovak Republic	Ukraine
Canada	**Japan**	Slovenia	
Czech Republic	Kazakhstan	South Korea	

Some of these states have „breakout" capability; that is, the capability to produce a large number of nuclear weapons (of the order of dozens or more) in a very short period of time. Those states which are considered to have such breakout capability are shown in bold text in the table above. As with the designation of a state as nuclear capable, the designation of a state having breakout capability does not reflect an intention - merely the capability to do so.

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7.5 Summary and Conclusions

The purpose of this report is to provide a perspective on the potential nuclear weapons proliferation pathways available from a commercial nuclear (fission) power plant fuel cycle, considering all the steps from mining to final waste disposal (including reprocessing and recycling). For the purpose of this document, proliferation is defined as "*the spread of nuclear weapons, nuclear weapons materials and nuclear weapons technology*".

This report does not address, except in passing, proliferation arising from other aspects of nuclear sciences (such as research reactors, accelerators, etc.). Proliferation pathways potentially arising from fusion power concepts are also not addressed. Finally, this report also does not address radiological dispersal devices (so-called "dirty bombs").

The commercial nuclear fuel cycle is inherently associated with a risk that nuclear explosive devices or nuclear weapons can be produced if internationally agreed safeguards arrangements are not followed. It can be argued how easy or difficult it is to proliferate from various steps in the nuclear fuel cycle, but a potential for the nuclear fuel cycle to be used to produce nuclear weapons cannot be avoided. The risk of nuclear weapons proliferation among methods of producing electricity or process heat is unique to the commercial nuclear (fission) power fuel cycle. The risk can be minimized, but it cannot be made to "go away".

There are ten nuclear weapon states: China, France, India, Israel, North Korea (DPRK), Pakistan, the Russian Federation, South Africa (which has decommissioned its weapons and joined the NPT as a non-nuclear weapon state), the United Kingdom and the United States. The question here is whether there is a potential for the commercial nuclear (fission) fuel cycle to be used to produce nuclear weapons in countries other than the ten nuclear weapon states identified above.

The answer to this question is clearly yes. Limited solely to consideration of the nuclear fuel cycle, this report identifies twenty-six other countries which are "nuclear capable" - that is, possessing sufficient technical and industrial capacity along with a source of weapons usable nuclear material (spent reactor fuel or separated civil plutonium, or the enrichment capability to produce highly enriched uranium) such that they could (if a decision were taken) produce nuclear weapons. Fourteen of these twenty-six states (nearly half) are considered to have "breakout" capability – the capability to produce a large number of nuclear weapons very rapidly if a decision were taken to do so.

Nuclear weapons, especially first generation nuclear weapons of the type used by the United States in the Second World War (and developed by several countries since then), are not as difficult to produce as is commonly believed. Indeed, this is so much so that it is broadly believed within the non-proliferation community that the only thing standing between a country and nuclear weapons is the need for weapons usable material.

It is true that none of the ten existing nuclear weapon states have achieved this status based on a commercial nuclear power program. Rather, they have used dedicated weapon material production facilities or (in a two cases) research reactors for this purpose. As this report has pointed out, however, the commercial nuclear fuel cycle provides two principal means of proliferation – from enrichment facilities (by means of HEU), and from reactor spent fuel (by means of reactor grade but weapons usable plutonium). In addition, Neptunium-237 (which can also be recovered by reprocessing) is also weapons usable.

As this report has highlighted, diversion of fresh low enriched reactor fuel (about 3.5 %) to further enrichment can provide a very fast enrichment path to HEU because at 3.5 % enrichment, over 80 % of the total enrichment work required to get from natural uranium to 90 % enriched HEU is already accomplished by the time the fuel is enriched to 3.5 %. Obviously, at higher enrichment levels typical of reactors with long fuel cycles (18-24 months instead of 12-15 months), the figure is even greater than 80 % complete.

Weapons made from reactor grade plutonium, unless adapted by tritium boosting and other modifications to the design, would be expected to have a greater potential than weapons made from weapons grade plutonium to predetonate and result in less than full yields – even so-called "fizzle" yields are possible. However, fizzle yields are not trivial and certainly not a "dud". The minimum expected fizzle yield for an implosion weapon fabricated from reactor grade plutonium is of the order of one kiloton. A one kiloton yield is still 4000 times larger than the explosion of a typical 500-pound military bomb, and if detonated in a large city would have devastating consequences.

It is clear that there is a proliferation potential associated with the commercial nuclear fuel cycle that is unavoidable with current and near-term technology. Even in the best cases of future technology, the proponents of the technology call it "proliferation resistant" – not "proliferation-proof".

7.6 References

Albright (1991): D. Albright & M. Hibbs, *Iraq's Nuclear Hide-and-Seek*, Bulletin of the Atomic Scientists 47 September 1991
[http: //www.thebulletin.org/print.php?art_ofn=sep91albright]

Albright (1994): D. Albright, South Africa's Secret Nuclear Weapons, Institute for Science and International Security (ISIS) (Washington, DC), May 1994
[http: //www.isis-online.org/publications/southafrica/ir0594.html]

Albright (1999): D. Albright & K. O'Neill (eds.), Challenges of Fissile Material Control, Institute for Science and International Security Press (Washington, DC), March 1999 [http: //www.isis-online.org/publications/fmct/book/index.html]

Albright (2001): D. Albright & C. Hinderstein, South Africa's Nuclear Weaponization Efforts: Success on a Small Scale, Institute for Science and International Security (ISIS) (Washington, DC), September 13, 2001
[http: //www.isis-online.org/publications/terrorism/safrica.pdf]

ASNO (2004): Australian Safeguards and Non-Proliferation Office, Annual Report 2003-2004, Commonwealth of Australia (Canberra), 2004
[http: //www.asno.dfat.gov.au/annual_report_0304/ASNO_2004_AR.pdf]

Bailey (1998): K. Bailey, Statement by Dr. Kathleen C. Bailey, Lawrence Livermore National Laboratory (Livermore CA USA), Testimony before the US Senate Committee on Governmental Affairs, Subcommittee on International Security, Proliferation, and Federal Services, March 18 1998
[http: //www.fas.org/spp/starwars/congress/1998_h/31898testbanbailey.html]

Barletta (1999): M. Barletta & C. Ellington, South Africa's Nuclear Weapons Program: An Annotated Chronology, 1969-1994, Center for Nonproliferation Studies, Monterey Institute of International Studies (Monterey, CA), March 1999
[http: //cns.miis.edu/research/safrica/chron.htm]

Bergeron (2002): K. Bergeron, Tritium On Ice: The Dangerous New Alliance of Nuclear Weapons and Nuclear Power, MIT Press (Cambridge, MA USA), October 2002

Bergeron (2004): K. Bergeron, *Nuclear Weapons: The Death of No-Dual-Use*, Bulletin of the Atomic Scientists 60 January-February 2004
[http: //www.thebulletin.org/article.php?art_ofn=jf04bergeron]

Boureston (2004): J. Boureston, *Tracking the Technology*, Nuclear Engineering International 49 31 August 2004
[http: //www.neimagazine.com/story.asp?sectioncode=76&storyCode=2024442]

Carafano (2004): J. Carafano & J. Spencer, Dealing With Dirty Bombs: Plain Facts, Practical Solutions, Backgrounder No. 1723, The Heritage Foundation (Washington, DC), January 27, 2004
[http://www.heritage.org/Research/HomelandDefense/loader.cfm?url=/commonspot/security/getfile.cfm&PageID=55037]

CEIP (2004): Carnegie Endowment for International Peace, Nuclear Status, Web Site, as of November 26, 2004
[http: //www.ceip.org/files/nonprolif/map/default.asp]

CIA (2003): US Central Intelligence Agency (CIA), Unclassified Report to Congress on the Acquisition of Technology Relating to Weapons of Mass Destruction and Advanced Conventional Munitions, January 1, 2003 Through June 30, 2003 (Washington, DC), November 2003
[http: //www.cia.gov/cia/reports/721_reports/pdfs/jan_jun2003.pdf]

CIA (2004): US Central Intelligence Agency (CIA), Unclassified Report to Congress on the Acquisition of Technology Relating to Weapons of Mass Destruction and Advanced Conventional Munitions, July 1, 2003 Through December 31, 2003 (Washington, DC), November 2004
[http: //www.cia.gov/cia/reports/721_reports/pdfs/721report_july_dec2003.pdf]

Cirincione (2003): J. Circincione, *Mr. Bush and Israel's Nuclear Weapons*, The Globalist (Washington, DC), May 27, 2003
[http://www.theglobalist.com/DBWeb/StoryId.aspx?StoryId=3217]
[http: //www.iraqwatch.org/perspectives/bas-iraq-rules-nuke-8-91.htm]

Cohen (1991): A. Cohen & M. Miller, *Iraq and the Rules of the Nuclear Game*, Bulletin of the Atomic Scientists 47 July/August 1991

Cordesman (2003): A. Cordesman, Weapons of Mass Destruction in the Middle East: Regional Trends, National Forces, Warfighting Capabilities, Delivery Options, and Weapons Effects, Center for Strategic and International Studies (Washington, DC USA), April 15, 2003
[http: //www.csis.org/burke/mb/me_wmd_mideast.pdf]

Coté (1996): O. Coté, Jr., *A Primer on Fissile Materials and Nuclear Weapon Design*, Appendix B in G.T. Allison, et al., Avoiding Nuclear Anarchy: Containing the Threat of Loose Russian Nuclear Weapons and Fissile Material, CSIA Studies in International Security, John F. Kennedy School of Government, Harvard University (Cambridge, MA USA), 1996
[http: //www.pbs.org/wgbh/pages/frontline/shows/nukes/readings/appendixb.html]

DOD (1998): US Department of Defense, Militarily Critical Technologies List, Section V, "*Nuclear Weapons Technology*" (Washington, DC), 1998

DOD (2001): US Department of Defense, Proliferation: Threat and Response, (Washington, DC), January 2001
[http: //www.defenselink.mil/pubs/ptr20010110.pdf]

DOE (1998): US Department of Energy (DOE), Glossary, (Washington, DC), December 2 1998

Farr (1999): Lt. Col. W. Farr (US Army), The Third Temple's Holy of Holies: Israel's Nuclear Weapons, Counterproliferation Papers, Future Warfare Series No. 2, US Air Force Counterproliferation Center, Air War College, Maxwell Air Force Base (Alabama), September 1999
[http: //www.au.af.mil/au/awc/awcgate/cpc-pubs/farr.htm]

FAS (2000): Federation of American Scientists, *Uranium Production*, part of the Special Weapons Primer, Nuclear Weapons web site (Washington, DC) June 24, 2000
[http: //www.fas.org/nuke/intro/nuke/uranium.htm]

Ferguson (2003): C. Ferguson, T. Kazi & J. Perera, Commercial Radioactive Sources: Surveying the Security Risks, Occasional Paper No. 11, Center for Nonproliferation Studies, Monterey Institute of International Studies (Monterey, CA USA), January 2003
[http: //www.cns.miis.edu/pubs/opapers/op11/op11.pdf]

Ford (1998): James L. Ford, Radiological Dispersal Devices: Assessing the Transnational Threat, National Defense University, Strategic Forum, Fort McNair (Washington, DC), Number 136, March 1998
[http: //www.ndu.edu/inss/strforum/SF136/forum136.html]

Frank (1967): W. Frank (ed.), Summary Report of the Nth Country Experiment, UCRL-50249, Lawrence Radiation Laboratory (Livermore, CA USA), March 1967; original document is Secret/ Restricted Data (i.e., Classified); this version was declassified in 1995 in response to a Freedom of Information Act request from George Washington University's National Security Archive

Garwin (1996): R. Garwin & V. Simonenko, Nuclear Weapon Development Without Nuclear Testing?, Pugwash Workshop on Problems in Achieving a Nuclear-Weapon-Free World (London), October 25-27 1996
[http: //www.fas.org/rlg/dev_no_test.htm]

Goldberger (1985): M. Goldberger, et al., Nuclear Arms Control: Background and Issues, Committee on International Security and Arms Control, National Academy of Sciences (National Academy Press: Washington, DC USA), 1985
[http: //books.nap.edu/catalog/11.html]

Green (2003): R. Green, *Back to the Future*, Nuclear Engineering International, September 2003
[http: //www.usec.com/v2001_02/Content/AboutUSEC/NEIAmericanCentrifugeArticle-09-03.pdf]

Gsponer (1995): A. Gsponer & J-P. Hurni, Iraq's Calutrons: Electromagnetic Isotope Separation, Beam Technology, and Nuclear Weapon Proliferation, ISRI-95-03, Independent Scientific Research Institute (Geneva), October 19, 1995
[http: //nuclearweaponarchive.org/Iraq/andre/ISRI-95-03.pdf]

Gsponer (2001): A. Gsponer, *Iraq's Calutrons: 1991-2001*, Independent Scientific Research Institute (Geneva), July 31, 2001
[http: //nuclearweaponarchive.org/Iraq/Calutron.html]

Hersh (1993): S. Hersh, The Samson Option: Israel's Nuclear Arsenal and American Foreign Policy, Vintage Books (New York), 1993

Hinton (1996): J. Hinton, R. Barnard, D. Bennett, R. Crocker, M. Davis, E. Groh, E. Hakkila, G. Harms, W. Hawkins, E. Hill, L. Kruse, J. Milloy, W. Swansiger & K. Ystesund, Proliferation Vulnerability Red Team Report, SAND97-8203, Sandia National Laboratories (Albuquerque, NM USA), October 1996
[http: //infoserve.sandia.gov/sand_doc/1997/978203.pdf]

Horton (1999): Lt. Col. R. Horton, Out of (South) Africa: Pretoria's Nuclear Weapons Experience, Occasional Paper #27, US Air Force Institute for National Security Studies (Colorado Springs), August 1999
[http://www.usafa.af.mil/inss/OCP/ocp27.pdf]
[http: //www.fas.org/nuke/guide/rsa/nuke/ocp27.htm]

IAEA (1970): International Atomic Energy Agency, Treaty on the Non-Proliferation of Nuclear Weapons, INFCIRC/140 (Vienna), April 22 1970
[http: //www.iaea.org/Publications/Documents/Infcircs/Others/infcirc140.pdf]

LANL (2002): Los Alamos National Laboratory, *Neptunium criticality achieved*, Press Release 02-118 (Los Alamos, NM USA), October 17, 2002
[http: //www.lanl.gov/worldview/news/releases/archive/02-118.shtml;
images at http: //www.lanl.gov/orgs/pa/News/neptunium.html]

Mark (1990): J.C. Mark, *Reactor-Grade Plutonium's Explosive Properties*, Nuclear Control Institute (Washington, DC), August 1990
[http: //www.nci.org/NEW/NT/rgpu-mark-90.pdf]

Mark (1996): C. Mark, T. Taylor, E. Eyster, W. Maraman & J. Wechsler, *Can Terrorists Build Nuclear Weapons?*, Nuclear Control Institute (Washington, DC), in P. Levanthal & Y. Alexander (eds.), Preventing Nuclear Terrorism (Lexington Books, Lexington, MA USA), 1996
[http: //www.nci.org/k-m/makeab.htm]

May (2001): M. May (ed.), C. Braun, G. Bunn, Z. Davis, J. Hassburger, R. Lehman, W. Ruhter, W. Sailor, R. Schock & N. Suski, Verifying the Agreed Framework, UCRL-ID-142036, CGSR-2001-001, Center for Global Security Research, Lawrence Livermore National Laboratory, (Livermore, CA USA) and Center for International Security and Cooperation, Stanford University (Stanford, CA USA), April 2001
[http: //www.llnl.gov/tid/lof/documents/pdf/240048.pdf]
[http: //iis-db.stanford.edu/pubs/12020/VAF-June.pdf]

Niksch (2003): L. Niksch, North Korea's Nuclear Weapons Program, IB91141, Congressional Research Service (Washington, DC USA), updated August 27, 2003

Norris (2002): R. Norris, W. Arkin, H. Kristensen & J. Handler, *NRDC Nuclear Notebook: Israeli Nuclear Forces, 2002*, Bulletin of the Atomic Scientists 58 September-October 2002
[http: //69.36.186.201/print_nn.php?art_ofn=so02norris]

NPEC (2003): Non-Proliferation Education Center, Breaking Out Without Quite Breaking the Rules (Washington, DC), May 15, 2003
[http: //www.npec-web.org/pages/iranswu.htm]

NTI (2004a): Nuclear Threat Initiative (NTI), South Africa Profile - Nuclear, (Washington, DC), Updated April 2004
[http: //www.nti.org/e_research/profiles/SAfrica/Nuclear/][20]

[20] The cited URL is the "start page" for the South Africa Profile – Nuclear. Interested readers can follow the links provided there to additional sections of the country profile (Facilities, Chronology, Import/Export).

NTI (2004b): Nuclear Threat Initiative (NTI), Proliferation and Use of Nuclear Weapons (Washington, DC), Updated September 2004
[http: //www.nti.org/f_wmd411/f1a4_1.html]

Oelrich (2004): I. Oelrich, All Spun Up: A Tutorial on Gas Centrifuges' Role in Proliferation, Federation of American Scientists (Washington, DC), November 8, 2004
[http: //www.fas.org/main/content.jsp?formAction=297&contentId=319]

O'Shei (1976): Col. D. O'Shei (U.S. Army), Implications of Nuclear Proliferation, US Department of State, Senior Seminar in Foreign Policy, 18th Session 1975-1976. [Note: This document was recently declassified and released under the Freedom of Information Act in the United States.]
[http: //www.nautilus.org/foia/prolif.pdf]

Pethokoukis (2003): J. Pethakoukis, *Building the Bomb*, US News & World Report 2 September 2003
[http: //www.usnews.com/usnews/tech/nextnews/archive/next030902.htm]

Rothstein (1999): L. Rothstein, *Explosive Secrets*, Bulletin of the Atomic Scientists 55 March/April 1999
[http: //www.thebulletin.org/article.php?art_ofn=ma99rothstein]

Sessoms (1996): A. Sessoms, M. Kratzer, L. Lederman, A. MacLachlan, M. Miller, W. Panofsky, J. Taylor, F. von Hippel, Letter Report of the Task Force on the Nonproliferation and Arms Control Implications of Fissile Materials Disposition Alternatives, Secretary of Energy Advisory Board (SEAB), US Department of Energy (Washington, DC), 26 September 1996
[http: //www.seab.energy.gov/sub/fissmat.html]

Shea (2004): D. Shea, Radiological Dispersal Devices: Select Issues on Consequence Management, Report No. RS21766, Congressional Research Service (CRS), Library of Congress (Washington, DC), March 10, 2004
[http: //www.mipt.org/pdf/CRS_RS21766.pdf]

Sholly, St. (2006): Abbreviated primer on nuclear weapons and proliferation
[http: //www.univie.ac.at/irf]

SIPRI (2004): Stockholm Peace Research Institute (SIPRI), Countries of Nuclear Strategic Concern, Web Site (Stockholm), as of November 26, 2004
[http: //projects.sipri.se/nuclear/cnscindex.htm]

Sokolski (2003): H. Sokolski, Testimony before the United States House of Representatives, Committee on International Relations, pages 4-18 in House of Representatives, U.S. Nonproliferation Policy After Iraq, Serial Nr. 108-38 (Washington, DC), June 4, 2003
[http: //www.house.gov/international_relations/108/87494.pdf]

Stober (2003): D. Stober, *No Experience Necessary: The Nth Country Experiment Showed That Three Post-Docs With No Nuclear Knowledge Could Design a Working Atomic Bomb*, Bulletin of the Atomic Scientists 59 March/April 2003
[http: //www.thebulletin.org/article.php?art_ofn=ma03stober]

Stumpf (1995): W. Stumpf, *Birth and Death of the South African Nuclear Weapons Programme*, Atomic Energy Corporation of South Africa, Ltd. (Pretoria), presented at the conference 50 Years After Hiroshima (Castiglioncello, Italy), September 28 to October 2 1995
[http: //www.fas.org/nuke/guide/rsa/nuke/stumpf.htm]

Sublette (2001): C. Sublette, Nuclear Weapons Frequently Asked Questions, August 9, 2001
[http: //nuclearweaponarchive.org/Nwfaq/Nwfaq.zip]

Taylor (1996): T. Taylor, *Nuclear Power and Nuclear Weapons*, Nuclear Age Peace Foundation (Santa Barbara, CA USA), July 1996
[http: //www.wagingpeace.org/articles/1996/07/00_taylor_nuclear-power.htm]

UIC (2002): Uranium Information Center (UIC), Plutonium, Nuclear Issues Briefing Paper #18 (Melbourne), June 2002
[http: //www.uic.com.au/nip18.htm]

UIC (2004): Uranium Information Center (UIC), Iraq, North Korea & Iran - Implications for Safeguards (also South Africa, Israel and Libya), Nuclear Issues Briefing Paper #15 (Melbourne), January 2004
[http: //www.uic.com.au/nip15.htm]

Vandenbroucke (1984): L.S. Vandenbroucke, *The Israeli Strike Against Osiraq: The Dynamics of Fear and Proliferation in the Middle East*, Air University Review, Air University, U.S. Air Force, September-October 1984
[http: //www.airpower.maxwell.af.mil/airchronicles/aureview/1984/sep-oct/vanden.html]

Von Baeckmann (1995): A. Von Baeckmann, G. Dillon & D. Perricos, *Nuclear Verification in South Africa*, IAEA Bulletin, 37 January 1995, pages 42-48 [http://www.iaea.or.at/search97cgi/s97_cgi?action=View&VdkVgwKey=http %3A %2F %2Fwww %2Eiaea %2Eorg %2FPublications %2FMagazines %2FBulletin %2FBull371 %2Fbaeckmann %2Ehtml&QueryZip=nuclear+verification+in+south+africa&&viewTemplate=Iaea %2Fiaeacvw_smpl.hts&collection=IaeaSite]

WP (1996): The Wisconsin Project on Nuclear Arms Control, *Israel's Nuclear Weapon Capability: An Overview*, The Risk Report 2 July-August 1996
[http: //www.wisconsinproject.org/countries/israel/nuke.html]

8 Timeliness of the Nuclear Energy Option

Geert Weimann and Helga Kromp-Kolb
September 2006

Content

8 Timeliness of the Nuclear Energy Option

8.1 Introduction

The nuclear option is often hailed as a valuable contribution towards achieving the aims of the Kyoto Protocol: by replacing fossil fuel technologies greenhouse gas (GHG) emissions by the electric power industry could be reduced. Achieving a substantial contribution however implies a considerable growth of worldwide nuclear capacity.

Under the Kyoto Protocol, countries agreed to individualized reductions of GHG emissions to be met over the 2008 to 2012 period. The question is whether enough new nuclear capacity can be installed in time to contribute to the reductions targets in the short period remaining – not individual nuclear pilot projects, but nuclear capacities of Gigawatt dimensions.

However, it is not only the climate protection discussion that gives the nuclear industry hope for a revival. Some energy scenarios foresee a substantial increase in nuclear power for covering an expected increase in electricity demand caused by economic growth and also for closing the expected energy gap due to foreseeable shortages in fossil fuels (oil, gas). Here again the question is, whether the hoped for increase of nuclear power can be achieved within a reasonable timeframe.

A significant expansion of installed nuclear capacity will be possible only if nuclear energy can overcome the substantial disadvantages it is being charged with – mainly the extraordinary risks involved and the problem of nuclear waste. Of course, it is fair to require that fossil fuels should be replaced with environmentally friendly and sustainable technologies. Contrary to what the nuclear industry sometimes claims, it has not yet demonstrated how the nuclear option will fulfill these requirements.

This paper focuses on the question of timeliness. It examines whether nuclear energy can expand quickly enough to contribute to the solution of the above mentioned challenges. The question of timeliness cannot be treated without at least briefly touching upon nuclear safety, fuel availability and the nuclear waste problem, even though these topics are treated in other papers in this publication. These aspects are very relevant for the question of timeliness, because they strongly influence the time needed for the development of new reactor types before entering commercial operation.

To clarify the question of timeliness would require an examination of the entire fuel cycle from the mining activities to the final repositories of radioactive waste and the complete system of facilities, equipment and operational structures. Needless to say, each step in the chain of production would have to multiply its efforts, accompanied by far-reaching technological improvements, to make a timely growth of nuclear possible. This raises a number of questions:

- How large a share of the total energy demand should and can nuclear power deliver in the time period until 2020? What will the necessary framework look like in this period? Which direction of development would the nuclear industry have to embark on?

- Are the optimistic assumptions promising a revival and a significant expansion of existing nuclear capacities in the near future justified or overoptimistic when looking at the potential for growth of the involved industry branches and of the work force of trained personnel?

- Are the mentioned increases for this period realistic or will there be delays in the implementation, the market introduction and testing of new reactor concepts? Will uncertainties dominate planning and expectations not be fulfilled?

- Is it possible for the financial markets to provide the exorbitant investments needed? Are the high initial investments still an effective deterrent?

It is not possible here to conduct a thorough analysis of these questions, however, some substantial aspects critical to timeliness will be discussed. If the discussion of these issues casts doubts concerning the timeliness of the nuclear option, it is not necessary to examine the other aspects.

Lastly, we need to point out that most of the data cited is of high uncertainty due to discrepancies between the sources used and to the inherent uncertainty of forecasts for extended time periods.

8.2 Requirements

8.2.1 Size of Capacity

To answer the question what the potential demand for nuclear energy will be in the future, three basic factors are considered:

- the emission reductions needed to combat climate change,

- the increase in electricity demand and,

- the expected energy gap as a consequence of a gas and oil shortage.

The number of nuclear power plants that will be taken from the grid within the time period considered after having reached the end of their service life and that therefore need to be replaced is an additional factor.

The emission reductions necessary to mitigate climate change are not limited to the 5 % Kyoto Protocol aim for the first commitment period (2008-2012) because an increased contribution by nuclear in the remaining 6 years is no longer possible. Rather, the reductions decided upon for the post-Kyoto period must be considered, even if the final numbers are still being negotiated. Climatologists claim that at least 30 % reductions of Greenhouse Gas emissions compared to 1990 are necessary by 2030 and 60 - 80 % worldwide by 2050 to make a global temperature rise of more than 2 °C unlikely. When these percentages are applied to CO_2-emissions from electricity generation this implies that CO_2-emissions in 2030 must be about 2,100 kt lower than 1990. Based on present emission factors[1] and the assumption, that the reductions are achieved by replacing fossil fuels solely by nuclear energy this implies that in 2030 about 3.000,000 GWh must be produced additionally in nuclear plants or at least 435 more NPPs[2] must be in operation than today. Assuming optimistically that the first new power plants could begin operation in 5 years,

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1 For the present mix of fossil fuels in Germany this is 0.73 kt CO_2/GWh and for nuclear power plants 0.025 kg CO_2/kWh is assumed.
2 For an 80 % load factor and 1GWe installed capacity per NPP. Reserve requirements for peak loads are not included in the calculations.

i.e. 2012, then 24 NPPs would have to start operation per year. This also would result in almost a doubling of the present number of power plants, but with a higher capacity for most of them. These calculations do not take account of shut downs of existing plants nor of demand increase.

Currently, around 2 billion people do not have access to electricity, a situation which, according to international declarations of intent, should be rectified as soon as possible. Accordingly, electricity demand will increase much quicker than total energy consumption: projections vary considerably, but a doubling of demand by about 2030 is frequently assumed. The IEA [IEA 2004] estimates an additional demand of around 1400 to 1700 GWe of power generation capacity for the period 2000 to 2020, and a further 1000 to 1300 GWe by 2030. If the current share of nuclear, around 16 %, is to be maintained, an additional 480 to 600 new NPPs need to be put in operation by 2030[2]. Assuming again optimistically that the first new power plants could begin operation in 5 years then 27 to 34 NPPs would have to start operation per year – that is one ever 10 to 14 days – most of these in the developing world. In these calculations nuclear does not contribute to the reduction of CO_2 by replacing fossil fuels nor are compensations for shut downs of nuclear power plants taken into account.

If nuclear power is to contribute a larger share (more than 16 %) towards demand growth or towards closing the energy gap due to foreseeable oil and gas scarcities, e.g. through nuclear production of hydrogen, correspondingly higher capacities would be needed.

Assuming NPP service lives of 40 years[3] and a 5-years construction time for all plants presently under construction the installed capacity would drop under 100 GWe by 2030 [Zittel 2006]. This means that just to sustain the present production level about 260 GWe are required, that is 18 new NPPs per year.

To simultaneously compensate the shut down of older power plants, support future electricity demand growth – with the current 16 % share – and decrease CO_2-emissions through boosting the nuclear contribution to a significantly higher level than 16 %, on the order of 70 nuclear plants would have to go into operation per year in the near future – keeping in mind that a simple addition of the above numbers is not permissible. In order to implement nuclear in new fields, such as e.g. hydrogen production for the transport sector, the requirements would be even higher.

One of the scenarios of the Intergovernmental Panel on Climate Change (IPCC) assumes that nuclear power will supply 50 % of worldwide electricity production in 2075 (3000 GWe installed capacity) and 75 % in 2100 (6500 GWe installed capacity). With an assumed lifetime of 50 years it would be necessary to put around 70 reactors into operation per year [Feiverson 2003].

Obviously, it cannot be expected that nuclear energy covers all these needs: energy efficiency increases and alternative energies will supply the largest contribution, and hopefully the projections of demand prove to be overestimations as a consequence of the development of completely new energy policies. These upper bound calculations only serve to demonstrate the size of the problem and to dampen any hopes that nuclear could make a significant and timely contribution to the energy problems in the near future.

[3] The average life time of decommissioned nuclear power plants, including some very short lived prototypes, is presently 22 years.

8.2.2 Timeframe

For the climate discussion there are two periods that have to be viewed separately: first the initial Kyoto Protocol commitment period (2008-2012), binding under international law; second, the period consisting of the Post-Kyoto-Measures, which is still under discussion. According to a European Union proposal, this would be the periods until 2020 or 2030, until 2050 respectively, during which emission reductions of not yet decided extent should be attained. In other words, for a contribution of nuclear energy to become relevant in the first commitment period, nuclear has to start playing a bigger role in the energy mix in the next 2 to 6 years. For the Post-Kyoto Process, it has another 10 to 40 years.

The time frame resulting from the looming energy gap is of a very similar order of magnitude. The increase in electricity consumption in itself is quite a challenge for the next 20 years, independent of climate protection and possible shortages of fossil fuels.

Thus the question is whether nuclear will be able to contribute substantially in the next one or two, or at the most four decades.

8.2.3 Options

To achieve a larger contribution to energy production, the yield from nuclear power plants must be increased. In the present period of declining yield due to power plants being taken off the grid after having reached the end of their service life, increase means compensation of these lost capacities and additional new capacity.

The decline in yield can be reduced or delayed through life time extensions of presently operating nuclear power plants. This is of importance because the number of nuclear power plants approaching their end of life within the next years is such that a decrease is inevitable in spite of the implementation of new plants. Life-time extensions are the only way to influence the nuclear contribution in the short term defined by the Kyoto agreement. Because of the long construction time for nuclear power plants no nuclear plant that is not yet under construction will feed electricity into the grid within the next 6 years – thus, it must be clear that at most the loss of yield can be delayed.

Market analyses have spurred technological development of new power plant types into two directions:

- “Inherently safe” concepts for up to 1.5 GWe power output and

- Autonomous small installations with outputs in the range of 10 to 100 (300) MWe, [President’s Council 2005] allowing largely automatic operation [IAEA/NEA/IEA (2002)].

Research and development on “inherently safe” reactors has been going on for about a decade. They are part of the so-called third and fourth generation nuclear power reactors. Their concepts, their strengths and weaknesses are briefly described in the paper on safety of nuclear power plants. Some Generation III reactors are already in operation, the first Generation IV reactor is not expected to be put into operation before 2020.

The autonomous small stations (comparable with an energy container) will be centrally maintained in a maintenance facility, where they are brought for recharging. The first demonstration plants are scheduled to be ready and licensed by 2015. Commercial introduction will take place after 2020.

Both of these technical developments need time to mature, even if it is likely that there may be synergies from parallel development of new technologies and the operational modes. However, first experience can only be gained after introduction and application.

Apart from the technical challenges, the economic conditions of a liberalized electricity market must be taken into account. Pressure is high to reduce investment and operating costs, even though the increase of fossil fuel prices have brought some relief. The nuclear industry is looking at a range of measures to reduce high investments costs:

- Capturing economics-of-scale;
- Streamlining construction methods;
- Shortening construction schedule;
- Standardization, and construction in series;
- Multiple unit construction;
- Simplifying plant design, improving plant arrangement, and use of modeling;
- Efficient procurement and contracting;
- Cost and quality control;
- Efficient project management; and
- Working closely and co-operating with relevant regulatory authorities.

In this context, it is necessary to mention that of course there are efforts to influence the political conditions in favor of the nuclear option.

These conditions are hoped to produce a climate inductive to investments: attractive conditions to finance high investment costs and avoidance of financial bottlenecks due to exceeding financing needs. It remains to be seen whether the monetary market can accept these conditions under strained financial markets.

8.3 Plant Life Time Extension

In view of the difficulties in licensing new plants due to a lack of public acceptance and because of the investments involved, there is a tendency to extend the life time of existing nuclear power plants. This means that the operation of a nuclear power plant is prolonged beyond the originally licensed or planned operational time frame, towards the technical life expectancy. A wave of applications for licensing renewals for plants facing shutdown in the near future has been handed in.

If all applications are approved, the forecasted decline of nuclear power to 50 % installed capacity could be reduced significantly. Such a development would allow for an additional reconciliation period and – according to nuclear promotion groups – a possibility to achieve both, better design concepts and improved acceptance.

Logically, life time extension will also influence the development of production costs and consumer prices. Continued operation of an old nuclear power plant is usually very profitable because it has been amortized a long time ago.

It should be pointed out that life time extension should be accompanied with special and stricter safety controls since, in general, the probability of failure of components and materials increases with aging. Logically, those plants that are ready for closure are older plants (Generation I and older Generation II plants), which according to Probabilistic Safety Assessments (PSA) have probabilities of severe accidents of a factor of 10 to 100 above the general safety level (see also paper on Nuclear Safety).

In view of timeliness of the nuclear option life time extension of existing power plants represents only a minor relief.

8.4 New Power Plants

At present, the construction period for a standard nuclear power plant (start of construction until start-up of operations) is considered to be in the range of 6 to 8 years as compared to 10 years at the beginning of the construction of the present generation of power plants. However, a substantial expansion of nuclear power can only be considered based on the next or the following generation of reactors (Generation III and IV, today's reactors are generally considered to be Generation II). But for these reactor concepts are available only partly, and for those Generation III reactors that are under construction or running, there is still a lack of experience with design, construction and operation.

Early nuclear energy development showed that safety requirements in some cases demand the application of already tested technology. It is therefore necessary to have gathered operational experience not only with components but also with the system prototypes and with complete plants. It is not possible to allow commercial operation of improved Pressurized Water Reactors (PWR: e.g. EPR) or Boiling Water Reactors (BWR), or "inherently safe" reactor concepts (ISR) before having tested the prototypes in-depth to present them from the very beginning as a sufficiently "tested" technology.

These periods of development and testing have to be added to the construction period, and this can cause a lead time of 15-20 years. Taking into account the extensive know-how regarding design and the operation of nuclear power plants already acquired, it is probably possible to reduce the above mentioned time periods for prototype design, planning and testing of the most advanced prototypes of the NPP concepts now being developed to 8 to 14 years. If those projects were engaged in right now, the start of operation of the first plant would be expected to be in 2020, that is, in the post-Kyoto period.

The timetable laid out here does not allow much space for the further development of the "inherently safe" reactor (ISR), which is meant to be failure tolerant and have advanced passive features for accident consequences mitigation and improved intervention possibilities for accident management. The features protective against severe accidents will require extensive demonstration and appropriate testing. Even after successful plant vintage licensing, a host of prototype tests and evaluations still have to be completed, adding another 7 to 10 years to the schedule. “Inherently safe” reactors can therefore be expected to arrive at the earliest between 2030 and 2040. Only this generation of nuclear power plants can be expected to increase public acceptance for the nuclear energy option.

The timetable for reactors based on completely new physical concepts (e.g. the accelerator-driven high temperature reactor concept) foresees only feasibility tests of separate subsystems in the next few years. These reactors will most likely not be available before 2018, i.e. near the end of the above mentioned time period of 8 to 14 years.

8.5 General Framework

8.5.1 Capacity Development Until Now

Nuclear power reached its maximum increase in 1985 when 31 GWe/y were added. Since then, the growth rate has decreased to between 2 and 9 GWe/y in the past few years.

Currently, the share of nuclear in the total energy production is shrinking and this process is likely to accelerate until about 2020. The reason for this is that the first plants were commissioned in the sixties and average plant life is limited to about 35 years of operation. Very few nuclear plants have been ordered in the last few years and therefore new plants only minimally influence this development.

Until now only 20 % of the 537 nuclear power plants have been retired, and out of these many were prototypes. Their operational lifetime was on average only 7 years. As of October 21, 2004, there were 440 nuclear power plants in operation and 25 nuclear power plants under construction. The installed nuclear electrical capacity was 365.5 GWe, and this would – according to forecasts – drop to 180 GWe around 2024. Embarking on a 2 %/y increase ratio scenario would mean that the initiated decline should lead to a minimum of 294 GWe by 2021, followed by an increase.

Facing this development, it is necessary to ask the question whether it is realistic that the above mentioned need for more than 70 new nuclear power plants per year – even without reference to climate protection policies - can be satisfied. And in fact, the ratio of increase of nuclear capacity starting at the time the new power plants are available, is estimated at about 1-2 %/y [EIA 2004, EIA 2005]. This is significantly below the level necessary to maintain the 16 % contribution to global electricity production, if the EIA growth scenario is assumed.

8.5.2 Know-How and Qualified Workforce

The attractiveness of the nuclear industry, which was once very high, has all but disappeared today, after more realistic estimation of its possibilities have been made and due to the continued lack of orders for nuclear new-builds. The economic development – the quest for a higher shareholders´ value and higher profits – caused many producers and operators to reduce the number of employees. Some experienced professionals have retired and some have switched to other sectors. There has been a noticeable reduction of output of nuclear engineering graduates from American and European university courses; many university have substantially reduced their nuclear programs, a number of nuclear research centers have been largely dismantled or reorganized to conduct research into other areas. The attempt to halt this development by starting work on new concepts was successful only to a minor extent. This is a worrisome development for nuclear industry and many IAEA and NEA conferences have addressed the gap of experienced and well trained professionals.

The indispensable contributions made by specialized TSOs (Technical Support Organizations) have – in many instances – been lost because these small companies had to adapt to the market situation and to emerging markets. In many instances they had to abandon former core competence areas in nuclear for new, more profitable ones.

Mergers between various vendors and the realignment of co-operating consortia have alleviated the immediate threat of unavailability of suitable and experienced professionals to the industry, but it has also left some fields of knowledge abandoned, particularly in design.

Modular designs of nuclear power plants, which would be service free for several years of operation, could help to improve the difficult situation regarding trained personnel. Especially, in the context of construction of new plants in developing countries the modular concepts could become important. Increased energy demand and the economic structure could make the construction of nuclear power plants profitable to vendors. The limited availability of a skilled workforce and the low mobility of experienced personnel could, however, become a major problem for conventional nuclear stations.

In a rough estimate it can be assumed that each new power plant project will absorb a skilled workforce of roughly 10,000 over a ten-year period. The operational staff and personnel now used for recurrent maintenance are not the resources needed for the new projects, this aside from the fact that they are needed for the operation of the existing plants. The Technical Support Organizations (TSOs) are also already drawn on by the industry putting them in charge of some plants operations.

Thus, a new generation of skilled and later on experienced personnel must be trained: Basic courses take at least five years; learning to develop new equipment and technologies requires at least another five to ten years of job-oriented training and training on the job. A switch of pre-skilled people from other sectors, where similar skills are required, is made more difficult by the high requirements of the nuclear energy sector concerning safety and durability, which is less developed in other sectors.

The attempt to embark on an enhanced nuclear program immediately, or in the very near future, would therefore most likely fail due to the limited availability of a skilled workforce and the limited mobility of experienced personnel. Timeliness of a substantial nuclear energy expansion can be achieved only with sufficient numbers of experienced staff. However, the current development in the nuclear sector still indicates a loss in proficiency in the nuclear sector.

8.5.3 Economic and Structural Conditions

Technological development depends to a large extent on economic and structural conditions. These changed dramatically in the last few years and will continue to change in the future: a more favorable and quiet climate for the development of nuclear energy is not in sight.

The expansion of large technology companies into global players is not so much a consequence of inner growth, but of mergers with and takeovers of other companies. The primary goal is more efficient production and therefore the focus is on re-structuring and optimization of processes and less on technological development. The relocation of clearly defined technological sub areas to serve corporate strategy aspects, is part of the process that keeps key functions of strategic management in one hand.

At the same time, a counter-current development can be observed, namely the concentration on core competencies and the outsourcing of marginal and specialized sub areas. The number of companies with high reliance on external sources for technology and technological development has for this reason increased over the past decade.

It could be expected that the resulting larger structures have a stabilizing effect enabling a fruitful coexistence between corporations and smaller, more specialized suppliers. It has turned out, however, that the corporations themselves are subject to continuous change, partly due to a widely spread management structure. This in turn leads to a rapid change of partners with highly specialized know-how. Similar to a stormy sea, where small ships cannot dock on huge ships, the small specialized suppliers cannot really benefit from the ever changing big corporations.

These developments can also be observed in the nuclear supply sector. Already in the 1990s, a decrease in the number of manufacturers and technical support organizations (TSO) through mergers could be observed. This was driven by the shrinking market, which was partly caused by a lack of public acceptance for nuclear technology.

This structure is not supportive of a long lived advance of nuclear energy: neither can a stable development of the important TSOs be expected, nor an early consolidation of the large suppliers of nuclear technology.

8.5.4 Market Development

In order to supply timely replacement for existing nuclear power plants, soon reaching their end of life, the ordering of new technologically advanced nuclear power plants would have been necessary many years ago. A number of factors did not encourage this further development: the general lack of orders, the shrinking of the market, the life extension programs for plants in operation, and the financial cutbacks in research and engineering programs sponsored fully or in part by public means.

The situation has since changed, with some markets for nuclear power plants picking up again. However, these are buyer markets, and therefore of limited interest to the nuclear industry, and they are regarded more as confidence-building activities than commercially interesting undertakings.

The question remains, can a market that first has to re-establish itself resurrect a technology, and with it technological know-how? Further, can it be re-established at a quality level necessary for an advanced technology? Above all, can the market accomplish all of this within a short time frame?

8.5.5 Public Acceptance

In some European countries a nuclear critical climate has led to political guidelines (like the act prohibiting nuclear installations in Austria), which were unfavorable to the further development of nuclear power. The critical viewing of nuclear power has not changed substantially until now: An opinion poll by the EU in 2003 (Table 8-1) showed that even under the assumption that nuclear waste could be stored safely, the acceptance of nuclear power as an electricity generation option is under 50 % in 7 out of 15 states, the EU-average is a slim 50 %.

Tab. 8-1 **SHOULD NUCLEAR POWER REMAIN AN OPTION FOR ELECTRICITY PRODUCTION**

	Strongly Agree	Tend to Agree	Tend to Disagree	Strongly Disagree	Average	Don´t know	Nuclear Option
Country	Attitude poll results in [%]						
A	8.0	16.6	23.2	38.6	1.93	13.6	5
B	13.1	46.9	11.01	5.9	2.87	23.1	11
DK	29.5	24.7	13.4	25.3	2.63	7.1	4
D-W	12.7	33.3	21.7	14.0	2.55	18.3	16
D-E	11.9	42.1	16.7	9.6	2.70	19.7	19
D	12.5	35.1	20.7	13.1	2.58	18.6	17
GR	19.0	29.4	13.9	8.1	2.84	29.6	2
E	9.0	22.6	17.9	10.0	2.52	40.6	4
F	15.8	43.4	13.6	8.7	2.81	18.6	8
IRL	7.2	30.3	14.8	10.7	2.54	37.0	7
I	13.7	40.8	11.4	6.6	2.85	27.5	13
L	14.9	40.5	18.8	12.9	2.66	12.9	7
NL	30.8	29.4	10.0	14.6	2.90	15.2	14
P	5.7	32.5	12.4	7.6	2.62	41.8	5
FIN	26.5	38.5	14.7	9.5	2.92	10.8	27
S	47.3	26.3	9.9	8.0	3.23	8.5	32
UK	14.0	38.6	13.0	7.9	2.80	26.5	18
EU 15	**14.9**	**35.6**	**15.1**	**10.4**	**2.72**	**24.0**	**12**
EU 25							**12**

Public Opinion Poll in Europe in response to the question:
„If the waste is managed safely, should nuclear power remain an option for electricity production in the European Union". [Ann Bisconti Research 2003] and the result of a Eurobarometer poll 2006: Which of the following should the (national) Government mainly focus on the years to come to reduce our dependence on imported energy resources?" (last column)

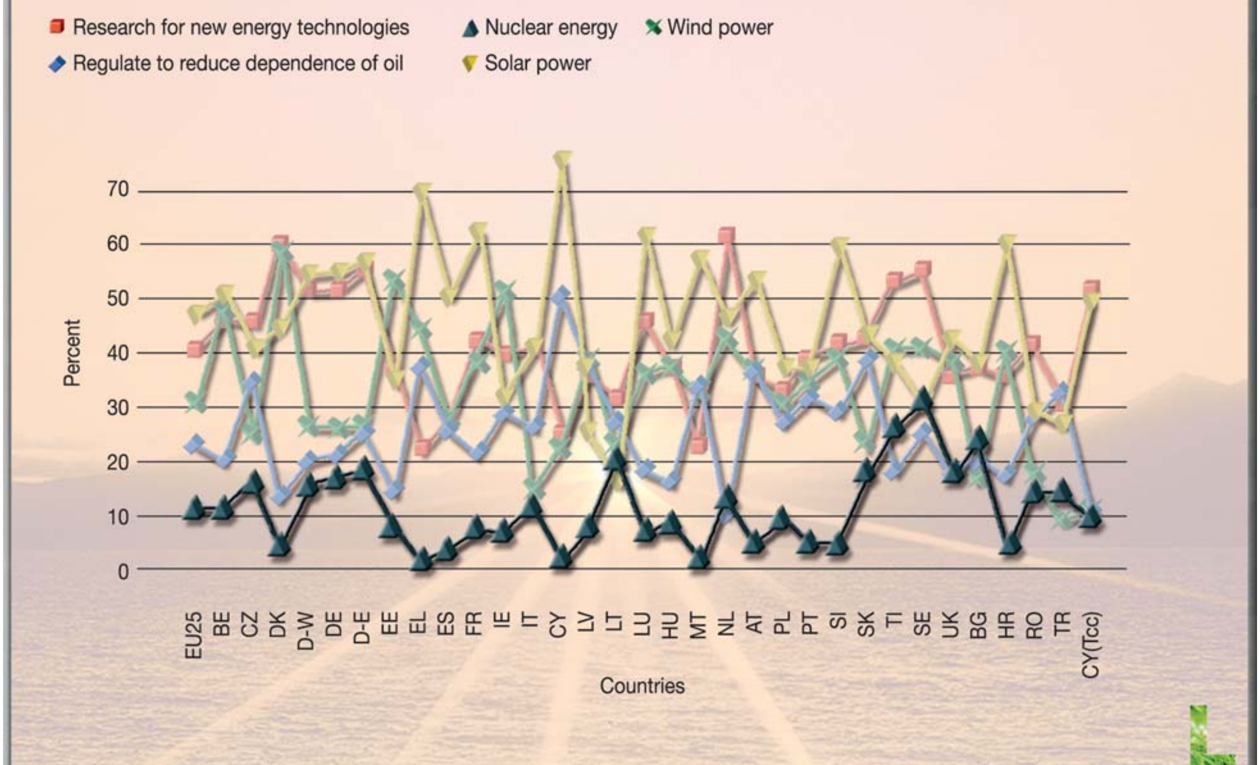
Quelle: Ann Bisconti Research 2003 / EBS 2006

lebensministerium.at

An opinion poll in winter 2005 [EBS 2006] showed that only 12 % of those questioned named enhanced reliance on nuclear energy as an option to reduce dependence on energy imports, even though only five options were offered (solar energy, advanced research on new technologies such as hydrogen, wind energy, nuclear energy and regulatory measures to decrease dependence on oil), and two could be selected. The nuclear option ranged clearly behind all other options in almost all countries (Figure 8-1).

Fig. 8-1 **EUROBAROMETER POLL ON THE DEVELOPMENT OF NUCLEAR ENERGY**

Result of a Eurobarometer poll on the development of nuclear energy as one of five options to reduce dependence on energy imports, two nominations possible



Source: EBS 2006

However, climate change and energy shortages could lead to a rethinking about nuclear. A rise in acceptance seems to have taken place among politicians and media in the last months. This could grow stronger and the population may also latch on. However, one has to keep in mind that, especially in the past few years, a number of "almost-accidents" ("near-misses") and cover-up affairs have occurred that have shattered the belief in safety and partly also in the integrity of nuclear power plant operators. Moreover, it must also be assumed that the next larger accident will with quite some probability be the final "out" for nuclear power, at least in Europe.

It is therefore currently not possible to give a reliable prediction on the attitude of the public – it is very likely that the strong geographical differences will remain against a background basically critical of nuclear.

8.5.6 Political Conditions

Politicians can support the revival of nuclear energy in multitude of ways, although most of these are not in line with free market economy nor with the liberalized energy market: guaranteeing nuclear its share of electricity production, subsidies, tax concessions, state steps in with liability against delayed start-up, relaxed safety requirements and licensing procedures, cutback of citizens rights, cutback of provisions for waste disposal, discrimination of competing technologies, etc. Some of these and other measures are now being offered in the USA as incentives for the construction of new nuclear power plants. In Europe, some claim that the financing conditions for the construction of the Olkiluoto nuclear power plant in Finland were modified to include some alleviating measures not generally applied.

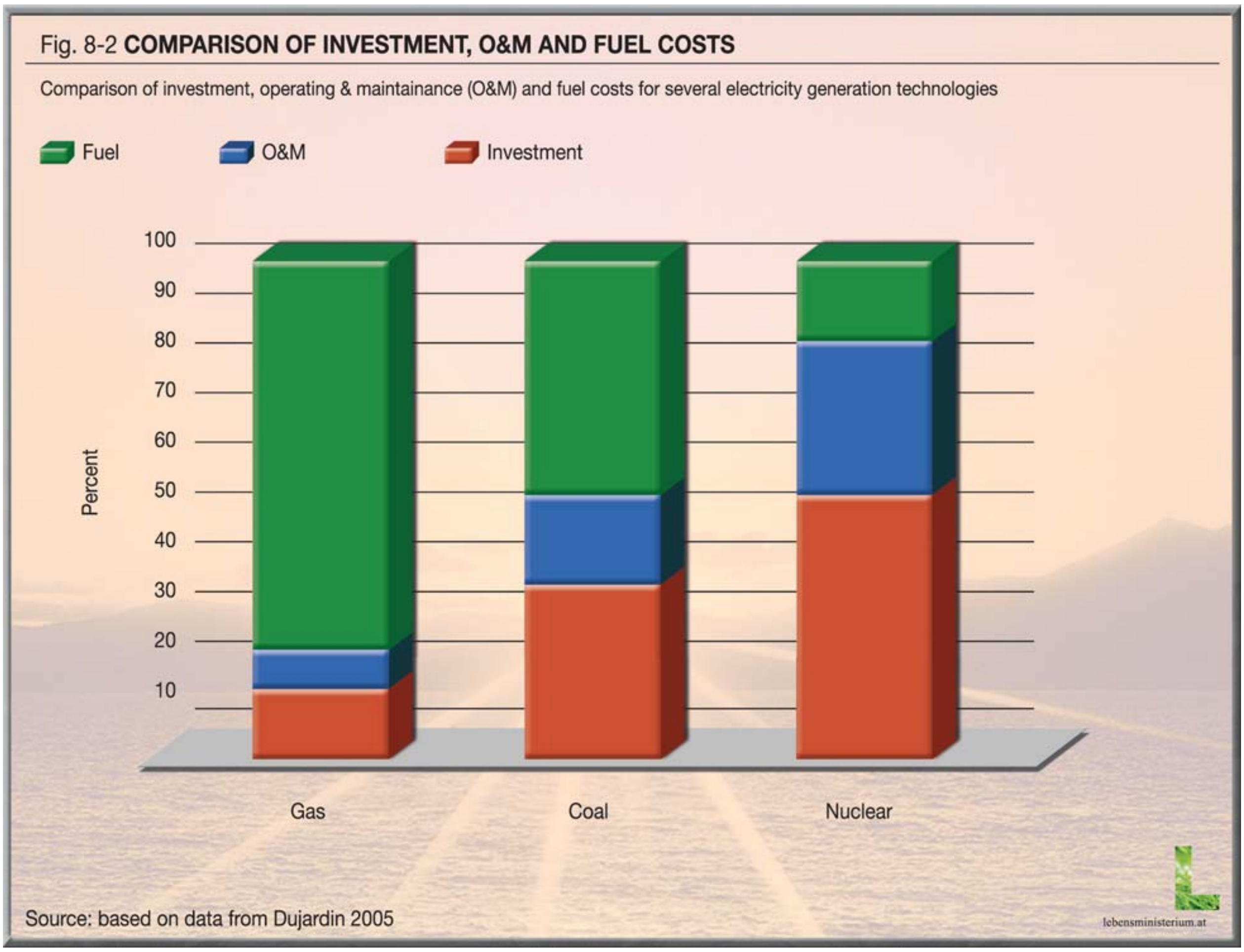
There are indications that policies towards nuclear might change under the impact of shrinking resources, and that this might be supported not only by the operators but also by the licensing authorities and possibly also a certain part of the population. This could ease and speed up the commissioning of nuclear power plants and contribute to timeliness. However, the licensing authorities would have to make sure that any easing of requirements does not entail a lowering of safety.

Designers and operators understand the need to reduce production costs and operating expenses, and to face the scarcity of resources: risk informed maintenance is an example of more efficient use of the available know-how, personnel, resources, time, etc. This can also be used as a solution to “important things first”, when the available maintenance support is insufficient. The extension of refueling periods, maintenance during operation, etc. are other measures taken to lower production costs and use diminishing resources sparingly. In this manner, the personnel need is reduced, which could allow the operation of additional installations with qualified personnel.

However, more favorable political conditions will not alone be able to substantially speed up the expansion of nuclear energy because they are subject to quick changes. However, at the present crossroad for the future of European energy, politics could create a more favorable climate for nuclear power.

8.5.7 Financial Markets and Investments

The initial investments needed for nuclear power are much higher than for other technologies. According to OECD (Dujardin 2005) the investment costs surpass the sum of operating and fuel costs in nuclear (Fig.8-2). Even though this comparison is strongly dependent on assumptions, mainly concerning fuel prices, and the figures quoted by different sources vary widely, the tendency regarding the relation between investment costs and operating and fuel costs is valid. The rise of fossil fuels costs during the last months reduce the portion of investment costs in non nuclear technologies even farther.



The problem of high investment costs is aggravated by the high risk potential of nuclear technology and the acceptance problem that nuclear energy is facing. Due to high initial costs, the installation has to stay in operation for a certain, rather long minimum period to provide investors with a return of investment (ROI). The statistics of nuclear power plants built and operated up to now show that a high percentage of plants were shut down long before reaching the end of planned life time – medium life time is currently 22 years, planned life time is 30 to 40 years. The most extreme case is the nuclear power plant on Long Island in the US, which was shut down for good by the authorities a few days after start-up. It is has to be pointed out, however, that the share of very early shut-downs has decreased and that average life time of nuclear power plants has increased in the past years.

With regard to the enormous damage potential and to the critical public, authorities and operators are forced to take very restrictive measures, e.g. to close down a plant for apparently slight reasons, sometimes only because a similar station is having problems (case in point: in August 2006 four Swedish Nuclear Power Plants were shut-down after an incident on July 25*th* in NPP Forsmark). When power plants repeatedly have to be taken off the grid because of occurring problems, attracting high media attention, attractiveness as an investment option is lost.

One could get the impression that politicians and media are talking about the revival of nuclear energy while energy utilities are much more cautious and investors are still rather disinterested. According to an analysis made by Standard and Poors 2006, the development of a new generation of nuclear power plants in a de-regulated energy market is a highly risky undertaking because of long development times and high capital costs. Siting is nowadays seen as much more sensitive than in the 1970s and 1980s when most plants were built. The political support will remain unreliable and dependent on safety performance worldwide. Basic matters, such as solving the nuclear waste storage and achieving far-reaching social consensus are still viewed as necessary before a wide-ranging nuclear power revival is possible. [Standard and Poors 2006]

For Europe alone the "Business-as-usual" Scenario forecasts a need of investment in the order of USD 2 trillion in the energy sector until 2030, and more than a half of it for electricity (IEA 2003). With such investment offers and investment demands it is hard to believe that the enormously high capital investment needed on short term for a timely expansion of nuclear would be placed in the most insecure of all investment options, nuclear power.

8.6 Nuclear Waste Problem

A substantial expansion of nuclear energy – whether with conventional reactors or fast reactors – will in any case cause a substantial increase of highly radioactive waste. Even though efforts are being made to intensify work on this most controversial topic, it is still far from being solved. There is no solution in sight that the public would approve of.

The problem is of a different quality than the operation of nuclear power plants: is it dominated by incomprehensibly long periods of time during which high-level radioactive nuclear waste (HLW) needs to be taken care of and is therefore a burden on society. German authorities currently demand a verifiably safe storage for one million years. Near surface, retrievable storage is not a solution, but hands over the problem to future generations. Irretrievable repositories in deep geological formations also put the burden on future generations, only with a time delay and the uncertainty whether some future generation, confronted with a resurfacing of nuclear waste will be in a position to handle radioactive materials in these large quantities.

Some other potentially promising concepts to handle HLW would have to be further examined and should – if proven to be feasible – be implemented while nuclear power plants are still in operation. Transmutation of actinides (the fraction of the waste with the most extensive half lives of its isotopes) or "burning" some of the waste will only be considered if there is a financially sound enterprise (a nuclear power plant) to make this profitable. At the same time, the solution must not use up substantial parts of the energy produced in the nuclear power plant. Thus, the solution for HLW must also be considered a time critical process: What quantities of HLW with which properties can be processed depends on reactor technology employed and its further development.

For many years the "wait-and-see" approach has been officially implemented. The lack of clear political guidelines and the lack of understanding of responsibilities has caused systematic delay of promising attempts to solve the problem. If new nuclear power plants are to be developed and built on a larger scale, waste strategies and technologies should be developed and implemented in parallel. To achieve this, it would be necessary to enlarge the development tasks of the nuclear industry and to clearly define the requirements for a solution of the waste problem. The necessary direction for policy guidelines must be derived from the goal to reach public acceptance and from the necessity to develop financing models for the storage or disposal of spent fuel and radioactive waste.

Without convincing proposals for a real solution, available in time, rather than a re-allocation of the problem in time or space, the waste problem poses a real hurdle to the timely expansion of nuclear power.

8.7 Summary and Conclusions

Although nuclear is frequently advocated as a potentially significant contributor towards the achievement of the Kyoto Protocol goals and towards the global energy demand, it is obvious that the nuclear option will not be able to fulfill these expectations in the short or midterm.

The reduction of greenhouse gases needed to attain the Kyoto aims or the Post-Kyoto proposals of the EU in electricity production necessitates compensation for about 70 GWe by 2010 and 380 GWe by 2030 produced from fossil fuels so far. If these capacities were supplied exclusively from nuclear energy about 14 nuclear power plants of 1 GWe per year would have to be built till 2030, some 425 in total. To maintain the present share of nuclear (16 %) in the rising world electricity production about 15 plants per year would need to be built without consideration of necessary emission reductions. To simultaneously attain both aims, nuclear must grow considerably faster than the sum of both numbers indicates. In any case, the losses through shut downs of plants reaching the end of their life time must be compensated additionally.

Feasible growth rate of nuclear capacity is estimated at 1-2 % per year from the moment new reactors are available. This is substantially lower than the level needed to maintain the nuclear share of 16 % of the global electricity generation according to the IEA growth scenario.

The nominal nuclear capacity reached its peak in 1985 and has since declined. All scenarios expect a further reduction until about 2020 due to an increasing number of plants shutting down at the end of their service life. Thus no significant contribution can be expected from nuclear power in the first commitment period (2008-2012) of the Kyoto agreement, and probably beyond (2020). Life time extensions that are being sought by many plant operators can delay the reduction – but the price is the operation of older, less safe plants of the first and second generation for a longer period of time.

In view of the risks of the present generation of nuclear power plants and due to the lack of acceptance of nuclear energy by the public a significant increase in nuclear power plants can only be expected if improved versions of the present Pressurized Water Reactors and Boiling Water Reactors or – more likely – a new generation of "inherently safe" reactors is available for commercial electricity production. The estimates are that prototypes of the new generations will be available between 2015 and 2020. The penetration of the market will take another decade.

At present a shortage of qualified and experienced personnel is experienced in the nuclear industry, particularly in the development sector: universities and research institutions do not supply enough graduates. While this also has an impact on the plants in operation, it poses a much larger problem for the development of new technologies and additional nuclear capacities. The recruitment and training of needed skilled employees takes some 5 to 10 years. This could be a strong limitation to the timely availability of a higher contribution of nuclear energy to the global energy production.

The economic and structural conditions – considerable movement amongst the large nuclear technology suppliers and loss of specialized Technical Support Organisations (TSO) – are not conducive to a long lasting rise of nuclear power. Neither a stable development of the important TSOs nor a rapid consolidation of the large nuclear suppliers is in sight and the market at present is not strong enough to push these issues.

No significant change in public acceptance of nuclear has taken place, considerable reservations are documented in practically every opinion poll in Europe, though there are regional differences. Whether climate change and problems with energy security will cause a change of attitude remains to be seen, especially in view of the repeated safety relevant incidents in nuclear installations all over the world.

In some countries special incentives for investments in nuclear are offered through political measures, however the high initial investments, the unsolved problems of safety and waste disposal as well as the lack of public acceptance especially in western democracies are a considerable obstacle for the expansion of nuclear energy.

The problem of high-level nuclear waste storage has not yet been solved either. The public will not accept any significant increase in nuclear capacities unless there is a realistic concept for the disposal of nuclear waste. The more sophisticated disposal concepts, such as “burning” and transmutation of actinides, are closely linked to the operation of nuclear power plants for technological and economic reasons. Thus, future nuclear power plants should make arrangements to include waste disposal facilities. These would need to be developed in parallel with the nuclear power plants. The waste disposal could, however, turn out to be a more difficult and time consuming problem than expected and could also challenge the timely availability of the nuclear option.

To sum up, the vision that the nuclear energy option can be available in time to contribute significantly to the big challenges – climate change, increase of energy demand and energy gap due to scarcity of oil and gas – must for multiple reasons be viewed with ample skepticism. In the short and medium term no contribution above the present contribution can be expected. Under conditions favourable for nuclear an important increase in nuclear energy could possibly be achieved in the second half of this century.

8.8 References

ACUS (1999): An Appropriate Role for Nuclear Power in meeting Global Energy Needs, The Atlantic Council of the United States, (February 1999)

AIE (1998): Electricity Market Competition and Nuclear Power, 23ème AIE Symposium, 9-11 Paris, France, (September 1998)

AIE (2004): AIE, Competition in Electricity Markets, AIE, Paris, France, (2004)

AIE (2005): World Energy Consumption, AIE, Paris, France, (2005)

Bermingham, J. R. (2006): PeakOil (World-Watch Institute) Commented, Denver, 2006

Boardman, C. E., C. E. Walter, M. L. Thompson and Ch. S. Ehrman (2002): The Separations Technology and Transmutation Systems (STATS) Report: Implications for Nuclear Power Growth and Energy Sufficiency, National Policy Analysis, 2002

CCICED (2005): Recommendations to the Chinese Government on the Formulation of China's Eleventh Five-Year Plan, China Council for International Cooperation on Environment and Development, Beijing 2005

De Sampaio Nunes, P. (2001): Strategies for a Sustainable Development of the Energy Supply, ILK Symposium "Opportunities and Risks of Nuclear Power" 26./27.04.01

Dujardin, Th. (2005): Nuclear Energy, Climate Change and Economics. Lecture given at the COP 11 in Montreal, Canada

EBS (2006): Attitudes towards Energy. Special Eurobarometer 247 / Wave 64.2 - TNS Opinion & Social [http: //europa.eu.int/comm/public_opinion/index_en.htm]

EIA (2005): Energy Information Administration, 2005: International Energy Outlook 2004. DOE/EIA-0484(2006), www.eia.doe.gov/oiaf/ieo/index.html. U.S. Department of Energy. Washington, DC 20585

EPRI (2006): Nuclear Plant Deployment, Electric Power Research Institute (EPRI) 2006 Portfolio, Palo Alto 2006

EU 2000: Green Paper – Towards a European strategy for the security of energy supply COM(2000) 769, November 2000

EU 2006: EK GREEN PAPER – A European Strategy for Sustainable, Competitive and Secure Energy, SEC(2006) 317
[http: //europa.eu.int/comm/energy_transport/library/livre-vert-en.pdf]

Feiverson, H. A. (2003): Nuclear Power, Nuclear Proliferation and Global Warming, Forum on Physics and Society of the America Physical Society, January 2003

Foulke, L. R. (2004): A Perspective: Status and Future of Nuclear Power in the United States, ANS LaGrange Park, IL, 2004

Holdren, John P. (1997): “Federal Energy Research and Development for the Challenges of the 21st Century: The 1997 PCAST Study and its Relevance to Provisions of S.597: .” July 18, 2001

IAEA (1991): INSAG-4 Safety Culture IAEA, Vienna 1991

IAEA (2002): Improving Economics And Safety Of Water Cooled Reactors: Proven Means And New Approaches, IAEA-TECDOC-1290, ISSN 1011–4289, IAEA, (May 2002)

IAEA (2003): Comparison of energy sources in terms of their full-energy-chain emission factors of greenhouse gases, IAEA-TECDOC-892, International Atomic Energy Agency, Vienna (2003)

IAEA (2004a): Status of Advanced LWR Designs, IAEA Light Water Cooled Reactor Project, Nuclear Power Technology Development Section, TECDOC-1391, Vienna, (2004)

IAEA (2004b): Improving Economics and safety of water-Cooled Reactors: Proven Means and New Approaches. IAEA Light Water Cooled Reactor Project, Nuclear Power Technology Development Section, TECDOC-1290, Vienna, (2004)

IAEA (2005a): IAEA 8th Scientific Forum 2005, Vienna, Austria (September 2005)

IAEA (2005b): INSAG-15 Key Practical Issues in Strengthening Safety Culture IAEA, Vienna 2005

IAEA/NEA/IEA (2002): IAEA, OECD/NEA, IEA, Eds., Innovative Nuclear Reactor Development, Opportunities for International Co-operation, “Three-Agency Study”: Available through: IAEA Nuclear Power Technology Development Section, Vienna, Paris, (2002) [http: //www.iea.org/textbase/nppdf/free/2000/innovativenuclear2002.pdf]

IEA (2003): International Energy Agency, 2003: Energy to 2050 Scenarios for a Sustainable Future. Paris, France

IEA (2004): International Energy Agency, 2004: World Energy Outlook 2004. Paris, France [http: //www.iea.org/Textbase/publications/free_new_Desc.asp?PUBS_ID=1266]

IEE (2004): The Energy Portfolio, 2 years on, IEE, London 2004

IEE (2005): The Energy White Paper, Two Years On Challenges for the UK Energy Policy, IEE, London 2005

INPO (2004): Principles for a Strong Nuclear Safety Culture, INPO, Washington 2004

Kubel, Ed Jr. (2005): Editorial: Nuclear-Energy Bus Picking Up Speed, October 7, 2005

Lackner, K.S., R. Wilson, H-J. Ziock (2000): Free-Market Approaches to Controlling Carbon Dioxide Emissions to the Atmosphere: a discussion of the Scientific Basis “Global Foundation Conference on Global Warming and Energy Policy”, Eds.: Kursunuglu, Mintz and Perlmutter, Kluwer Academic/Plenum Press New York, Boston, Dortrecht, London and Moscow, (2000) Makhijani, A. and A. Seth (1997): The Use of Weapons Plutonium as Reactor Fuel, IEER 1997

Meier, P.J. (2002): Life-Cycle Assessment of Electricity Generation Systems and Applications for Climate Change Policy Analysis, University of Wisconsin Report UWFDM-1181, (August 2002)

MIT (2003): The Future of Nuclear Power, An interdisciplinary MIT study, (July 2003)

Moniz, E. J. (2005): MIT Tech Talk, Energy, MIT, Boston 2005

Moniz, E.J. and M. A. Kenderdine (2003): Meeting Energy Challenges: Technology and Policy, Physics Today, 2003

NERI (2005): NERI – 2004 Annual Report, Washington D.C. 2005

OECD (1998): Nuclear Power and Climate Change, Organization for Economic Co-operation Development (OECD) report, OECD, (April 1998)

OECD (2004): Collective Statement Concerning Nuclear Safety Research, Capabilities and Expertise in Support of Efficient and Effective Regulation of Nuclear Power Plants, Paris © OECD 2004

OLGA (2004): Science and Technology to Meet our Energy Needs, American Chemical Society – Office of Legislative and Government Affairs, Washington D.C. 2004

Orbach, R. L. and W. D. Magwood (2004): Advanced Computational Materials Science: Application to Fusion and Generation – IV Fission Reactors, Conference Proc. Washington 2004

President's Council (2005): President's Council of Advisors on Science and Technology S&T Collaboration: Ideas for Enhancing European-American Cooperation, October 5, 2004, Dr. James DeCorpo, Technical Director

Rothwell, Geoffrey (2003): Can Nuclear Power Compete? Center for Economic Policy, Washington D.C. 2003

Shlyakhter, A., K. Stadie, R. Wilson (2001): Constraints limiting the expansion of nuclear energy, World Strategy Council, Washington D.C., (2001)

TOPS / NERAC (2001): Research Stanford University Report by the Tops Task Force of the Nuclear Energy Research Advisory Committee (NERAC): Technological Opportunities to Increase the Proliferation Resistance of Global Civilian Nuclear Power Systems (TOPS) Final Report 2001, Washington D.C. 2001

University of Chicago (2004): "Nuclear Power Competitive With Coal & Natural Gas" September 20, 2004

Voß, A. (2001): The Ability of the Various Types of Power Generation to Compete on the Liberalized Market, VGB Power Tech 4/2001

WBCSD (2005): Energy & Climate Change: Sharpening the focus for action - a business perspective, Business & Sustainable Development News, Energy & Climate WBCSD, 2005

Wilson, R. (2000): The Changing Need for A Breeder Reactor, in Proceedings of the Annual Symposium, Uranium and Nuclear Energy: 1997-1999, The Uranium Institute, London, Nuclear Energy 39, 99-106, (2000)

9 Nuclear Energy and the Kyoto Protocol in Perspective*

Anthony Froggatt
September 2006

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* This paper was based on “Nuclear Energy and Kyoto Protocol in Perspective” by Peter Biermayr, Manfred Heindler, Reinhard Haas, Brigitte Sebesta. Unpublished, November 2004

9 Nuclear Energy and the Kyoto Protocol in Perspective*

9.1 *Predicted Global Energy Consumption*

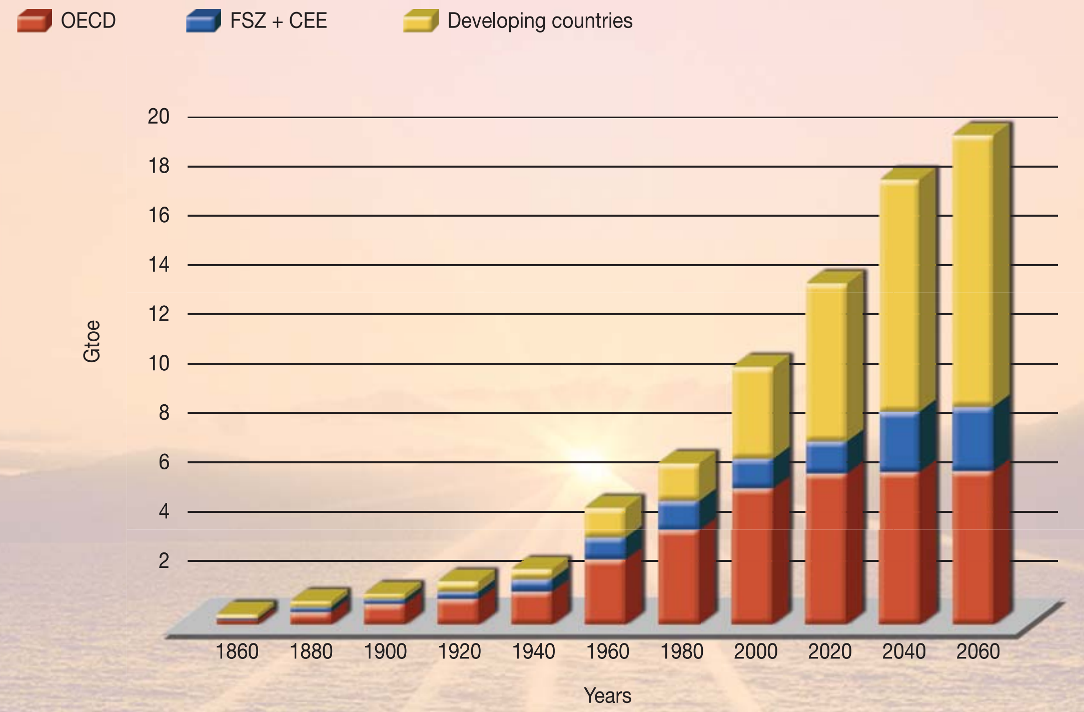
Global energy consumption is increasing year on year. In 2004 the global average was 4.3 %, with the highest growth level in Asia-Pacific, 8.9 %, continental Europe, 1.9 % and North America 1.6 % (BP 2005). Growth therefore is not just in developing countries, as they try to reach parity with northern countries, but globally. The graphic below (Figure 9-1) demonstrates the extent to which global energy consumption is expected to increase over the next 50 years.

In 2004 global commercial energy consumption is around 10 G tonnes of oil equivalent, which under this scenario would double in the next 50 years.

The reference case projection of the International Energy Agency (IEA) foresees a significant increase in CO_2-emissions, 62 % increase between 2002-2030. This is in the main as a result of this increased energy demand. Of this, the increase of CO_2-emissions from North America would amount to 33 %, in Western Europe to 20 %, in the OECD countries in Asia and Pacific regions to 20 %. The largest increase is forecast to be seen in economies in transition, 40 %, and from the larger developing countries, China, India, Indonesia and Brazil, 120 – 160 %.

Fig. 9-1 **GLOBAL ENERGY CONSUMPTION**

Global Energy Consumption since 1860 and forecasts. The graph for the period 2000 to 2060 shows a scenario of future energy consumption based on the current trends



Source: World Energy Council, World Bank

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Half of the projected emissions growth in the period of 2002 to 2030 originates from the power sector, and about one-third from coal-based power generation. The second key sector is transport that causes about 26 % of the emissions growth.

9.2 Is a Low Carbon Economy Achievable?

According to the IEA's business as usual scenario over the next three decades the projected annual increase in energy demand is thought to be 1.7 %. This will require a massive $ 16 trillion in global investment consuming around 4.5 % of the total investment between 2001-30. OECD Europe is expected to require around $ 2 trillion of energy related investment during this period. Globally and in Europe, most of the investment will be required in the electricity sector, with a total investment requirement of $ 10 trillion, while in the EU this will be around $ 1.1 trillion. This is forecast to result in the construction of 650 GW of new capacity (of which 330 GW will be the replacement of existing capacity) [IEA 2003].

The scale of the investment required highlights the importance of the next decade in determining the global direction of the energy sector. With power plants and infrastructure set to last for around 50 years, decisions about the fuel types used in the power sector will determine emissions levels for decades to come.

However, in addition to the reference scenario the IEA analysed the impact of energy policy measures currently under consideration that were targeted towards curbing CO_2-emissions and reducing import dependency. This alternative scenario did not lead to an increase in nuclear power, but rather an increase in the use of renewable energy, combined heat and power and energy efficiency. The alternative scenario led to a 30 % decrease in investment requirement, through lower development costs for the transmission and distribution sectors [IEA 2003].

If the alternative scenario were adopted it would lead to a stabilisation of CO_2-emissions from the energy sector at 2000 levels by 2030. The IEA conclude that "*The alternative policy scenario illustrates that if existing policies were strengthened and new policies adopted to curb emissions and reduce electricity consumption, the reduction in CO_2 would be considerable*".

9.3 European Union: Dynamics of Energy Demand

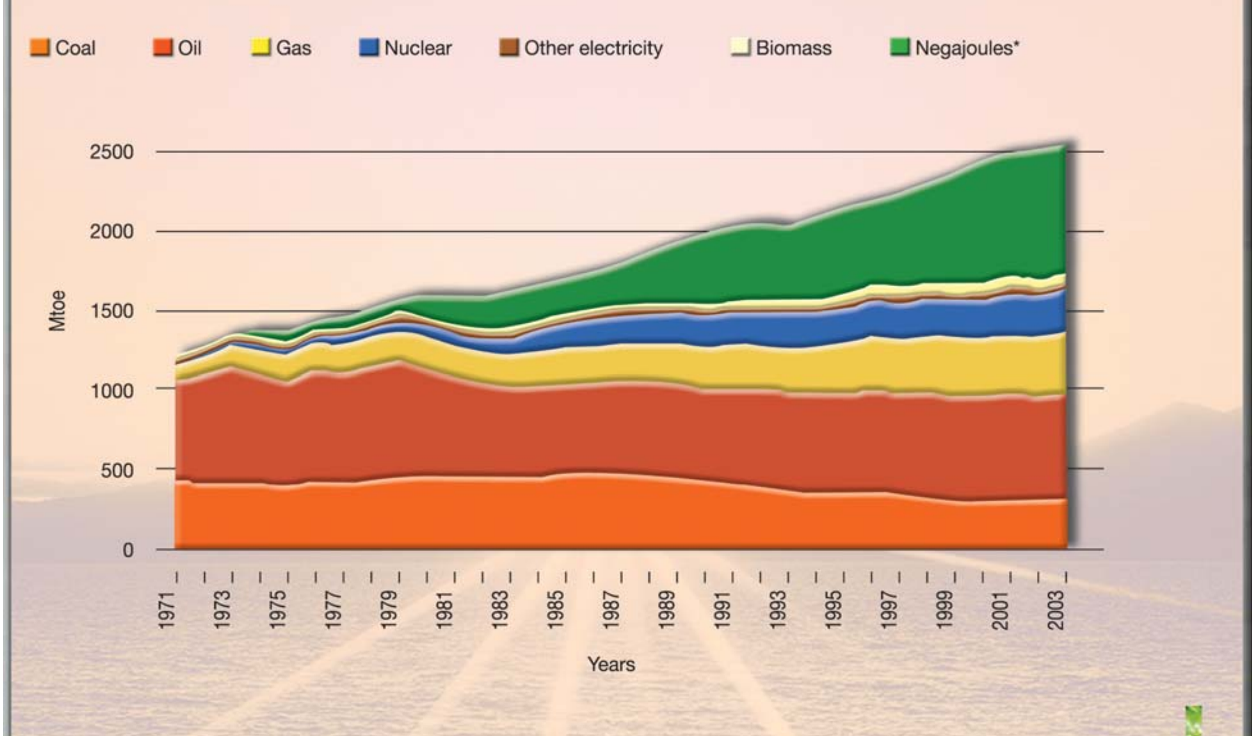
The European Union, with about 15 % of global primary energy consumption and with more than a third of its electricity produced in nuclear power plants, is of particular interest in the context of the question what role nuclear energy can play in the attempt to meet the Kyoto target. Current energy demand in the EU-25 is increasing by 1.3 % per year.

The European Commission state that the energy savings potential is considerable and that using existing measures and technologies 20 % of the EU's energy could be saved with a saving of € 60 billion a year. [European Commission 2005]

The phenomenon of economic growth with essentially constant energy demand, which had been referred to as "decoupling of the economic growth from energy demand", has been observed in the industrial sector of EU, and was also true for the entire economy as a whole during the 1970s and 1980s. However, this has been a passing phenomenon, linked to particularly higher energy prices at a particular time and, unfortunately, not to an efficiency policy aimed at lasting impact. Recently, energy demand and GDP have increased at about the same rate, a result of low energy prices and the absence of policy measures that would appropriately guide the market forces, in spite of low prices. The consequences of the recent, substantial, rises in energy prices remain to be seen.

Figure 9-2 below shows that (a) fossil energy increased slightly while its mix shifted to natural gas, (b) the increased energy demand was essentially met by nuclear energy, and, most importantly, (c) even in the European context – i.e. starting from an already relatively high level of energy efficiency, as compared to countries in development or with economies in transition – more than half of the GDP growth was "powered" by decreased energy intensity.

Fig. 9-2 **DEVELOPMENT OF THE PRIMARY ENERGY DEMAND AND OF "NEGAJOULES"* – EU25**



* "negajoules": energy savings calculated on the basis of 1971 energy intensity
Source: Biermayer et al. 2004

Within the last three decades, the contribution of energy efficiency and structural change to GDP growth was about 2.4 times that of nuclear energy. Had the energy intensity decreased at a slightly higher rate (30 %) than it actually did this could have "replaced" the contribution of nuclear energy.

9.4 *Nuclear Power Plants are a Comparatively Expensive Measure to Reduce CO_2-Emissions*

Extensive analysis has been undertaken to assess the role of nuclear power in helping to reduce CO_2-emissions. Nuclear power is only CO_2-free during operation, not throughout the fuel cycle, and there are other technologies or programmes that also have very low or zero CO_2-emissions connected with their operation. This means that Governments or utilities have a range of options available to them to reduce CO_2-emissions.

There have been a number of studies that have compared the opportunity cost of different technologies, these have included:

Bill Keepin and Gregory Kats: They compared the economic cost of investing in nuclear power or energy efficiency measures and concluded: "*Even if the most optimistic aspirations for the future economics of nuclear power were realized today, efficiency would still displace between 2.5 and 10 times more CO_2 per unit investment. We conclude that revitalizing nuclear power would be a relatively expensive and ineffective response to greenhouse warming, and that the key to reducing future CO_2-emissions is to improve the energy efficiency of the global economy"* [Keepin and Kats 1988]

Florentin Krause: A study published by the International Project for Sustainable Energy Paths (IPSEP) [Krause 2000] shows that it is possible to achieve the Kyoto target EU-wide at the same time as increasing economic efficiency and opting out of nuclear energy by 2020. The key results of the study are:

- Assuming plausibly imperfect policies starting in 2000 that will mobilize no more than 50 % to 65 % of Europe's efficiency and other low carbon resource potentials, it will be possible to reduce EU emissions in 2010 to 8 % below 1990 levels, and thus meet the Kyoto target.

- The above CO_2-reductions can be achieved assuming an accelerated phase-out of nuclear energy by 2020. Thus, according to this study, the EU has a technological choice in meeting global environmental goals, rather than having to trade off nuclear and climate risks to achieve the Kyoto target.

- Measures to reduce CO_2 normally go hand in hand with an increase in productivity, which means that investments in climate protection measures do not only lead to a reduction of CO_2 but also to an increase in economic productivity.

Three studies in 2006 also highlight the expense of using nuclear power as a mechanism to reduce CO_2-emissions.

Amory Lovins: Analysis from the Rocky Mountain Institute in the US estimates that *"nuclear power saves as little as half as much carbon per dollar as windpower and traditional cogeneration, half to a ninth as much as innovative cogeneration, and a little as a tenth as much carbon per dollar as end-use efficiency".* [Lovins 2006]

Uwe Fritsche: *"If we are optimistic and use the low range of nuclear GHG abatement costs to compare with the fossil alternatives (cogeneration) and renewable energy (biomass and off-shore wind) as well as some electricity efficiency, the alternative mix offers GHG abatement costs three to four times lower than that those of nuclear power".* [OKO 2006]

UK Sustainable Development Commission: "*Nuclear power is not the answer to tackling climate change or security of supply."* In response the Government's current energy review, the SDC nuclear report draws together the most comprehensive evidence base available, to find that there is not justification for bringing forward a new nuclear power programme at present. [SDC 2006]

9.5 Nuclear Energy in Countries with Emerging/Developing Economies

There is huge inequality in the use of energy in the world. An individual in a developed country will use around five times more energy than someone from a developing country. There are currently 2.4 billion who lack access to modern energy services [Canrea 2005]. Cooking and heating with solid fuels on open fires results in high levels of indoor pollution, which is said to be responsible for 1.6 million deaths per year, most of which are under five, making it one of the most lethal activities [WHO 2005].

In 2000 the United Nations adopted the Millennium Development Goals which included the objective of reducing by half the proportion of people living on less than $ 1 per day by 2015. There is a clear and recognised link between giving access to energy services and achieving this objective. Despite this, the number of people lacking access to modern energy services is forecast by the International Energy Agency (IEA) to increase to 2.63 billion by 2030.

The future of global energy demand will significantly result from what will happen in developing countries and in emerging economies, in particular China and India. There energy demand is expected to double or treble within the next 30 years, the share of global energy demand will exceed that of OECD countries shortly after the turn of the century, and incremental energy demand is expected to be supplied almost exclusively by fossil fuel.

Nuclear power is currently deployed in 10 countries outside Europe and North America. Apart from South Korea (38 %), Japan (23 %) and Taiwan (23 %) it only plays a minor role in electricity production in these countries: Argentina (8.2 %); South Africa (6.6 %); Mexico (5.2 %); Brazil (3 %); India (2.8 %); Pakistan (2.4 %); and China (2.2 %). This means that nuclear power contributes less than 1 % of the commercial energy consumed in the regions concerned, compared to global average of 6.2 %.

It is suggested that the current growth in nuclear power will be seen outside the OECD. This is reflected by the fact that of the 28 reactors under construction, only two, in Finland and Japan are in OECD countries as can be seen in the graphic below (Figure 9-3).

Fig. 9-3 **REACTORS UNDER CONSTRUCTION**

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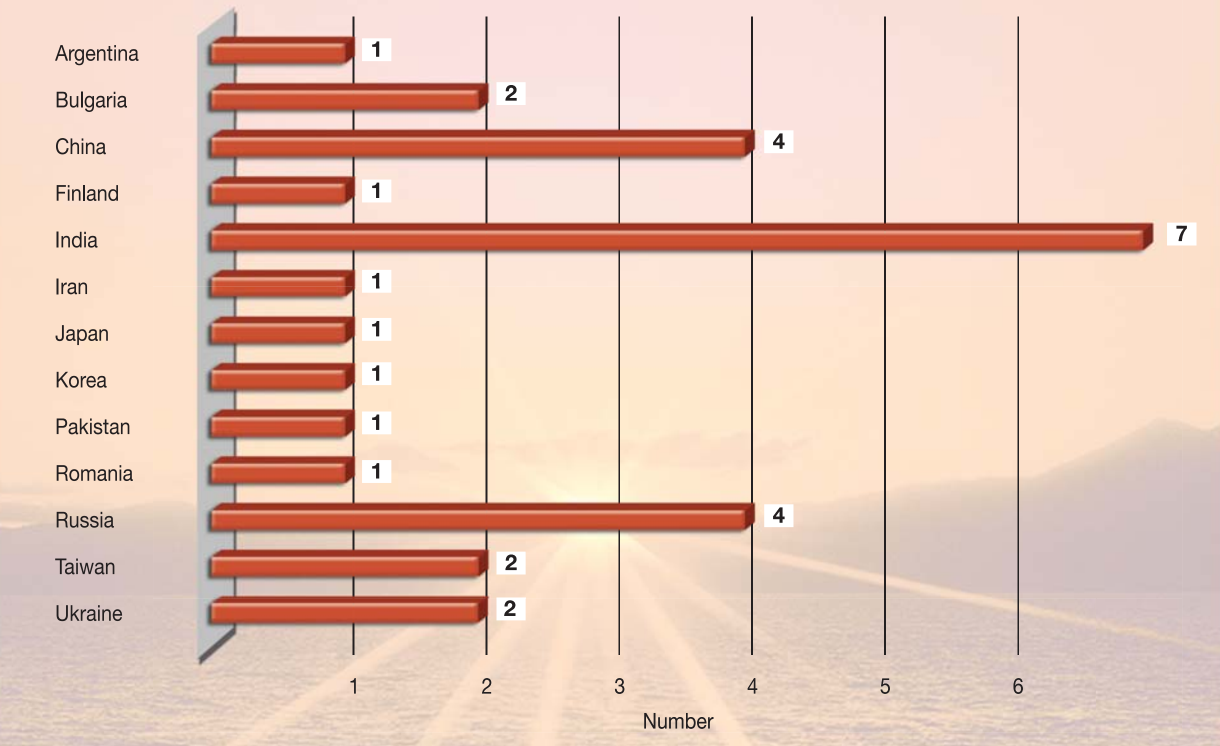

Source: It should be noted IAEO PRIS Databasis[1]

[1] It should be noted that this data is based on official reports from Governments and may not reflect the continuation of physical construction. For example in Bulgaria the completion contracts for Belene are still subject to tender.

Over the next decades there will be unparalleled levels of investments necessary for the Chinese energy sector. Most of this is expected to go into the power sector, with nearly $ 2 trillion in investment in the next 30 years. In total nearly 500 GW of new generation capacity is expected to be build, with around one tenth of this being nuclear. This would increase nuclear's share of electricity generation from around 2 % to around 6 %.

In view of this, nuclear energy can only play an essential role in mitigating CO_2-emissions if it addresses the markets in these countries, i.e. if the nuclear technology can be made compatible to the respective social, economic and legal structures and safety cultures. The present generation of nuclear power plants does not fulfill this requirement: Present nuclear power technology requires safety culture, infrastructure and specialized education which are at the limit of what the industrialized world is able to provide. Nuclear power technology is therefore not adapted to countries with emerging/developing economies.

There are several mismatches between nuclear technology as developed in and for industrialized countries, and the needs of developing countries:

Dimensional incompatibility: Due to the economy of scale, the "economic" size of the current reactor generation is of one GW(e) and more, designed for base load, whereas the need is for small, adaptable, load following plants.

Infrastructure incompatibility: If the prerequisite of implementing the present nuclear power technology was to modify a society - its industry, its labor force, its regulatory processes – to make it suit the needs of present nuclear power technology, this could hardly be called a sustainable approach. If these countries were to be reduced to vendors of sites for nuclear power plants to be operated by companies and crews from highly industrialized countries, this could not be called an ”adapted technology”, and would not be acceptable.

9.6 Widespread Deployment of Nuclear

Nuclear power is operated in 32 countries around the world with a total of 443 nuclear reactors. In 2004 nuclear generated electricity provided 16 % of the global total and around 6 % of the world’s commercial energy. If non-commercial energy is included – e.g. the using of solar thermal and biomass (collected by individuals for personal use), then the nuclear contribution provides even less of the total energy consumed. Over the last decades the construction of new nuclear power plants around the world has slowed significantly and there are now only 28 reactors being built anywhere in the world. Furthermore in 2005 construction only began on two new reactors in the world, at Chasnupp 2 in Pakistan and Olkiluoto 3 in Finland.

If an operational life of 40 years is assumed for modern reactors, which is relatively optimistic given the average age of reactors closed to date is 22 years, but which seems possible given the progress that has been achieved on the current generation of plants compared to the previous one, then just to maintain the current contribution of nuclear power to the global energy mix over the next 10 years, 82 new reactors would have to start up operation within a decade [Schneider 2004]. This alone would require a rapid upturn in the global view of nuclear power and is highly unlikely given the long lead times required for nuclear power (from ordering to power production).

Nuclear power uses uranium fuel, which along with fossil fuels, is limited in its use by the earth´s reserves. Currently, there are a variety of estimates for the extent of the global reserves. These estimates are dependent on both exploration techniques, exploitation costs as well as the current price of fuel. As the price of fuel increases, so exploration and exploitation of reserves tends to increase. The World Energy Assessment has reviewed both the current expected reserves, but also gives the larger figure for the total resources – i.e. the expected total availability of a resource, regardless of cost of extracting the material – of the various fuels. A table summarising their findings can be seen below (Table 9-1). This indicated that fossil fuel reserves are currently thought to be sufficient for between 80-229 years of consumption at 1998 levels, compared to uranium reserves of 47 years.

Tab. 9-1 **EXPECTED ENERGY RESERVES AND RESOURCES**

	Consumption in 1998 (10^3 Exajoules)	Reserves (10^3 Exajoules)	Reserves last (yrs)	Resources (10^3 Exajoules)	Resource last (yrs)
Oil	0.14	11.11	80	21.31	152
Gas	0.08	14.88	186	34.93	436
Coal	0.09	20.67	229	179.00	1988
Uranium	0.04	1.89	47	3.52	88

Source: WEA 2004

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Other authorities give slightly different figures, especially for the level of resources. The joint International Atomic Energy Agency/Nuclear Energy Agency assessment – known as the “red book” – estimates that the total reserves at extraction prices of less than $ 80/kg (about double the current world market price) is around 3.5 million tonnes, and resources are estimated to be around 9.7 million tonnes[1]. They assess that uranium consumption in 2003 was 68,815 tonnes per year, therefore the reserves will last around 50 years with total resources lasting around 140 years. [IAEA/NEA 2003]

If a global nuclear power programme is to be expanded then the rate at which the world’s uranium reserves are depleted will increase (see also Sholly, St. “Nuclear Generated Hydrogen Economy - A Sustainable Option?“, in this volume).

To exploit lower grade uranium ores requires energy which itself results in CO_2-emissions. Using current uranium ore grades – around 2 % concentration – results in around 33 g of CO_2 equivalent per kWh of nuclear electricity in Germany. Other estimates cited in the study by the Ökologie Institut [ÖKO 2006] suggest that the international norm is in the range of 30-60 g CO_2 /kWh. However, the World Nuclear Association operators suggest that the range should be lower, at 6-26 g CO_2 /kWh [WNA 2005]. The Ökologie Institut study also cites the estimated emissions using lower grade ores (0.1-1 % concentration) might increase the CO_2-emissions up to 120 g CO_2 /kWh. These resulting emissions are on a par with the most efficient combined heat and power combined cycle gas turbines. [ÖKO 2006]

If nuclear power is to play a major role in meeting global energy needs, then there will need to be a massive scaling up of the current programmes. Nuclear power currently produces around 6 % of commercial primary energy production and 16 % of electricity consumed. The Intergovernmental Program on Climate Change (IPCC) put forward a scenario in which nuclear power plays a more central role in reducing CO_2-emissions and increases to 3000 GW of installed capacity in 2075 (providing 50 % of the world’s electricity) and then to 6500 GW in 2100 (75 % of electricity). Under this scenario it would reduce by one fourth the CO_2-emission predicted by 2100. Even assuming an operating life of around 50 years (a compromise date between current and future expected operating lives and certainly very optimistic), it would require the construction of around 7000 reactors in the next century, or 70 reactors per year. Given that, at the peak of the global nuclear industry in the 1980s, the highest number of reactors connected to the grid in a year was 33 and that in 2005 only 5 were connected, this scenario is extremely optimistic from a nuclear point of view. If only uranium fuelled reactor were used, this would result in 600 tonnes of plutonium being produced annually and if plutonium fuelled reactors were deployed, which is likely given the current reserves of uranium and the favoured designs of the Generation IV reactors, around 4000 tonnes of plutonium being per year [Feiverson 2003].

The use of plutonium fuels in reactors has the advantage that it increases the potential energy resource available from uranium sixty fold. Thus hugely increases the longevity of the uranium resource. However, experience with plutonium fuelled fast breeder reactors (FBR), has not been successful. In Europe reactors planned or in operation in France, Germany and UK have all been closed, leaving only one research reactor – Phenix in France. In the rest of the world there are only operational reactors of this type in Japan and Russia and one under construction in India.

[1] As the price of uranium increases less economically viable (lower grade) ores may be used.

Used fuel from conventional reactors is partly reprocessed, which separates the plutonium to allow it to be made into fuel. In the 1970s and 1980s reprocessing plants were ordered and subsequently built in France and UK. Reprocessing is a technically complex process which creates, by volume, far more waste than the original spent fuel. The factors given vary significantly. The failure of the FBR has resulted in a stockpile of over 200 tonnes of separated plutonium.

A revival of the plutonium fuel cycle, even if it became technologically and economically viable significantly increases the proliferation risks associated with civilian nuclear power. This is because only a relatively small amount of plutonium, around 5 kg, is necessary to make a nuclear bomb.

9.7 Conclusion

There needs to be a global effort to reduce CO_2-emissions in order to reduce the impacts of climate change. Globally, emphasis must be placed on safe, sustainable and secure technologies that have wide-spread applicability.

The arguments presented in this paper strongly suggest that the reduction of energy intensity, i.e. the increase of the efficiency of conversion and use of energy needed to meet the increasing demand for goods and services is the only way in which CO_2-emissions can be reduced significantly.

Relying on nuclear energy to mitigate CO_2-emissions therefore seems to imply forgoing the much larger potential of reducing the energy intensity of our economies at a much faster pace than in the past. Furthermore, the limited availability of uranium at sufficient ore concentrations make the larger use of nuclear power even less acceptable, as the only longer term large scale nuclear programme will have to depend on plutonium fuelled reactors, which vastly increase the waste and proliferation dangers of nuclear power.

For efficiency alternatives to become the choice of the market, higher energy price strategies may be necessary, but are certainly not sufficient. The reasons for the energy intensity decrease of past decades would have to be carefully analysed: What part was technology driven, what part policy driven? Transaction costs, legal, social and technical barriers would have to be identified and overcome by appropriate strategies, often yet to be developed. Past (negative and positive) experience would also have to be carefully analysed with respect to driving and opposing factors. This is probably more difficult to organize than to launch a new nuclear initiative, but it would certainly be more appropriate for solving the climate problem (rather than the problem of the stagnating nuclear industry).

9.8 Summary

This paper concludes that using nuclear energy is no favourable option for CO_2-reduction. The major arguments for this conclusion are:

If nuclear energy is to play a non-marginal role in reducing CO_2-emissions, its rate of use would have to be increased to a level at which it would essentially compensate the anticipated increase in fossil fuel consumption. This would require a rate of commissioning of nuclear power plants, which is about an order of magnitude above that experienced in the ”golden” decades of nuclear energy, i.e. in the 1970s and 1980s. However, there is no basis for such a rate of deployment, neither regarding production capacity nor regarding the ability of host countries to absorb such a growth.

In the past decades, the increase of global CO_2-emissions would have been about two times higher than it actually was, that is to say about twice as much additional fossil energy would have been consumed, if the growth of our economies had not been associated with an important reduction of their energy intensities. In comparison, all CO_2-lean energy sources, among them nuclear, have had a much more modest contribution to the reduction of the rate at which CO_2-emissions have actually grown. That is, the contribution of nuclear and renewable energy has been outweighed by far by the increase of efficiency and structural changes in energy conversion and use.

The rate at which total world energy intensity decreases (historically about 1 % per year) can be substantially influenced. Had this rate been slightly higher, for example 1.2 % instead of 1 %, this additional "production of negajoules" would have equalled the actual production of nuclear energy. A doubling of the rate (2 % instead of 1 %) would have roughly led to a world wide decoupling of economic growth and energy demand. That means economic growth can be provided without an increase in energy demand. Through appropriate policies, such as minimum efficiency standards for buildings or appliances, this would be feasible.

Additional energy demand is increasingly shifting from industrialized to developing countries and emerging economies, in particular China and India. Therefore, nuclear energy can only be expected to play an essential role in mitigating CO_2-emissions if it is marketed in a form which matches with the respective social, economic and legal structures and safety cultures of these countries. The present generation of nuclear power plants does not fulfil these requirements. This seems to suggest that present nuclear power technology would have to be substantially adapted to these requirements. No such development is in sight, which would suggest that nuclear energy in developing countries and in emerging economies could or should be implemented at a rate that would make it significant for climate protection.

A global increase in the use of nuclear power as a technological tool to reduce CO_2-emissions would bring its own environmental and security problems. The lack of high grade uranium ores would require the deployment of plutonium reactors which would significantly increase the nuclear waste and proliferation problems already associated with the current, relatively limited, nuclear energy programme.

9.9 References

Biermayr Peter, Manfred Heindler, Reinhard Haas und Brigitte Sebesta (2004): Nuclear Energy and Kyoto Protocol in Perspective, unpublished, November 2004

BP (2005): Beyond Petroleum Statistical Review of World Energy, June 2005

Canrea (2005): Renewable Solutions. Options for moving the global transition to renewable energy forward. Canadian Renewable Energy Alliance. December 2005

European Commission (2003): Annual Energy Review, Energy in Europe, Special Issue January 2000, European Commission; see also European Union Energy Outlook to 2000, Energy in Europe, Special Issue November 1999

European Commission (2005): 20 % Energy Saving by 2020. Memo based on Green Paper on Energy Efficiency, European Commission, June 2005

Feiverson (2003): Nuclear Power, Nuclear Proliferation and Global Warming, H.A. Feiverson, Forum on Physics and Society of the America Physical Society, January 2003

IAEA/NEA (2003): Uranium 2003 resources, production and demand. International Atomic Energy Agency, Nuclear Energy Agency, 2003

IEA (2003): World Energy Investment Outlook 2003. International Energy Agency, 2003

IEA (2004): World Energy Outlook, International Energy Agency, 2004

IEA (2005): World Energy Outlook 2005, Middle East and North America Insight, International Energy Agency, November 2005

Keepin and Kats (1988): Greenhouse warming; Comparative Analysis of Nuclear and Efficiency Abatement Strategies. Bill Keepin and Gregory Kats, Energy Policy, December 1988

Krause (2000): F. Krause, J. Koomey, D. Olivier (2000): Cutting Carbon Emissions While Making Money, California 2000

Lovins (2006): Nuclear power: Economics and climate-protection potential. Amory B. Lovins CEO, Rocky Mountain Institute, January 6th 2006

Öko (2006): Comparison of Greenhouse Gas Emissions and Abatement Cost of Nuclear and Alternative Energy Options from a Life-Cycle Perspective – updated Version. Uwe R Fritsche, Susi-San Lim, January 2006

Schneider (2004): The World Nuclear Industry Status Report 2004, Mycle Schneider and Antony Froggatt, Green-EFA Group in European Parliament, December 2004

WEA (2004): World Energy Assessment: Energy and the Challenge of Sustainability, Chapter 5, Energy Resources, 2004 update

WHO (2005): Multiple links between household energy and the Millennium Development Goals, World Health Organisation
[http: //www.who.int/indoorair/mdg/energymdg/en/]

WNA (2005): Energy Balances and CO_2 Implications. World Nuclear Association, November 2005
[http: //www.world-nuclear.org/info/inf100.htm]

10 Nuclear Energy – The Economic Perspective

Antony Froggatt

September 2006

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10 Nuclear Energy – The Economic Perspective

10.1 Introduction

Most energy policies, such as that in the EU, have three pillars: sustainability, security of supply and economic competitiveness. Over the last decades, in particular following the introduction of the liberalised energy market, the key issue for nuclear power has been its economic performance. Until recently, it has been largely accepted that nuclear power was more expensive than its mainstream alternatives. This was due to increased transparency with the introduction of the liberalised market coupled with significantly higher construction costs than for natural gas and coal power stations, and, relative to current day prices, low fuel prices for oil and gas. Nuclear industry observers described the situation as "*Deregulation of the European markets could represent an even bigger threat to the future of nuclear power than anti-nuclear ideologues*" [NUKEM 1997].

Analysis released by the Nuclear Energy Agency in 1998 shows that in virtually all OCED countries, electricity from nuclear power was more expensive than conventional thermal power plants such as gas and oil. In only three countries (France, Japan and Russia) was nuclear power cheaper than coal or gas fired power stations – when using a 10 % discount rate[1] (the interest rate applied during construction and a key factor in the economics of nuclear power). Taking a global average, nuclear power was 15 % more expensive than gas and 6 % more expensive than coal generated electricity. [IEA/NEA 1998]

However, higher fuel costs of the main alternative, natural gas, are leading some to now claim that nuclear power is now comparatively cheaper than the mainstream alternatives. In particular the NEA, in its revised forecast in 2005 concluded that using a 10 % discount rate the cost of electricity from coal power stations was in the range of $ 35-60/MWh, natural gas $ 40-63/MWh and nuclear at $ 30-50/MWh. [IEA/NEA 2005]

Many other economic reports and indicators do not fully support the conclusions of the recent NEA report and point to a number of issues that will impact upon the economic attractiveness of nuclear power. This report will look briefly at these issues.

1. Are the assumptions being taken for the costs of new build justifiable?

2. Are there financial risks associated with new build programmes?

3. Do new nuclear power plants require additional Government support or subsidies to compete i in a liberalised market?

4. Is there a need to consider the full environmental costs of different energy options?

5. What are the costs of nuclear power compared to other CO_2-reduction technologies?

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[1] The choice of discount rate influences the result of these types of calculations significantly.

10.2 Are the Assumptions Being Taken for the Costs of New Build Justifiable?

In recent years there have been numerous economic analyses undertaken which have reviewed the predicted cost of building more nuclear power plants. Table 10-2 (at the end of this section) compares and details some of these studies, showing the main parameters which affect the final electricity cost from nuclear power plants.

Construction Times:

The nuclear industry, as do other large construction projects, has not historically had a good reputation of building to time. The paper-studies reviewed estimate that construction times will be significantly reduced to around 5 years (60 months). However, Table 10-1 highlights how data from the countries with the two largest nuclear power programmes suggest that the optimistic timetable for new construction will be difficult to meet.

Recent experience is available from Finland, where the only nuclear power plant under construction in the European Union is being built at Olkiluoto: construction is now thought to be a year behind schedule, after less than two years of construction.

Tab. 10-1 **MONTHS ELAPSED FROM CONSTRUCTION START TO COMMERCIAL**

as of Dec 31, 2001

	Average (months)	Minimum	Maximum	Standard Deviation	Last Plant Begun
U.S nuclear plants connected to grid	111	40	280	44	1977
French nuclear plants connected to grid	79	51	195	24	1985

Source: IAEA 2002

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Construction Costs:

The forecasts for construction costs show considerable variation, from € 810 to € 3,650/installed kW. However, an even greater range can be seen when comparing the theoretical costs with those of actual construction. As only a few reactors have been built in recent years little data is available on actual construction costs. In the UK the last reactor to be completed was in the 1990s at Sizewell B and it is thought that the cost of completion was around € 5,110/kW. While in Japan General Electric estimated that the new 1300 MW Advanced Boiling Water Reactor could be constructed at a cost of $ 1,528 per kilowatt. However, when the units were built for Tokyo Electric Power Company the construction costs were $ 3,236/kW for the first unit and $ 2,800/kW for the second. [CRS 2001]

Cost of Capital:

The cost of borrowing is one of the most important variables, as due to the large construction cost, small changes in the interest rate can have a significant impact on the final electricity price. The studies reviewed give a range of between 5-12 % discount rate for their analysis. The cost of capital is affected by the risk associated with the project.

Load Factor:

Over recent years the average load factor for reactors has increased. This is in part as a result of the efforts by the operators to reduce outages to increase profits and in part due to the average age of the reactors. Over the life-time of a reactor, the capacity factor tends to start poorly – teething troubles – then have a good period, when the reactor should operate efficiently, before age related problems set in – sometimes at 20, increasingly at round 30-40 years. The average age of reactors globally is now 22 years and therefore on average in their optimum operational period. Despite this the average capacity factor globally is 77,8 %. The estimates for over 85 % life-time lead factor are seen by some to be optimistic.

Operating Life:

As noted the average operating life of current reactors is 22 years, while the average age of reactors closed is also 22 years. However, plans in some countries – such as the US – are now being implemented to operate the existing reactors for 60 years. Consequently, some of the economic analysis now being undertaken are suggesting that economic life of the reactors are 40 years and above. This may be optimistic given the lack of technical and economic experience of trying to operate light water reactors for forty years.

10.3 What are the Financial Risks Associated with New Build Programmes?

The economic uncertainties over the viability of nuclear power have given rise to concerns in the financial community over investing in nuclear power. In particular, there is recognition that oil and gas prices are volatile and as such can once again decrease. Nuclear power has such large fixed costs – for construction and decommissioning – and long construction times. On average the price per installed kW of constructing a nuclear power plant is around double that of coal and four times that of a gas plant. Furthermore, the times it takes to build a nuclear power plant is between 5-10 years, while a gas plant is built in 3 years and a wind farm around 6 months. This means that from a financial perspective there are both significantly larger upfront costs and a longer time before any revenue can be generated. This as well as projected operating times – now 40-60 years – is why investment in new nuclear power plants have been described by the consultancy UBS as "*a potentially courageous 60-year bet on fuel prices, discount rates and promised efficiency gains…*" [UBS 2005].

The report also notes that for nuclear to be competitive the price of oil must be above $ 28/barrel, which it currently is. However, as the graph below demonstrates this has not always been the case in the last fifty years, with it only meeting these conditions in less than 40 % of the time. However, declining oil reserves and increasing demand will tend to lead to higher oil prices in future.

Tab. 10-2 **ELECTRICITY GENERATION COSTS OF NUCLEAR POWER PLANTS**

Comparison of assumptions in recent forecasts of generation costs from nuclear power plants

Forecast	Construction cost (€/kW)	Construction time (months)	Cost of capital (% real)	Load factor (%)	Operating life (years)	Generating cost (€ c/kWh)
Canadian Nuclear Ass. [1]	1,557	72	10	90	30	4.82
Chicago University [2]	810 1,216 1,460	84	12.5	85	40	4.23 4.96 5.69
IEA/NEA [3]	1,606-3,650	60-120	5 10	85	40	1.75-3.94 2.6-5.5
Lappeenranta Univ [4]	1,748		5	91	40	2.23
OXERA [5]	2,372 first plant 1,679 later unit			95	40	
Massachusetts Institute of Technology [6]	1,622	60	11.5	85 75	40 25	5.4 6.4
Performance & Innovation Unit [7]	<1,226	-	8 8 15	>80	30 15 15	3.37 4.13 5.53
UBS [8]	2,044	60		91	45	3.06
EPR [9]	2,031	60	8	90.3	60	3.00

1) Canadian Energy Research Institute, August 2004, Levelised Unit Electricity Cost Comparison. Ontario
2) University of Chicago, August 2004, The Economic Future of Nuclear Power
3) OECD/ IEA NEA 2005, Projected Costs of Generating Electricity-update, 2005
4) Nuclear Power: Least-Cost Option for Baseload Electricity in Finland and RistoTarjanne & Sauli Rissanen, Uranium Institute, 2000.
5) Financing the nuclear option: modelling the costs of new build, Oxera Agenda, August 2005
6) "The Future of Nuclear Power: An Interdisciplinary MIT study" (The MIT O&M cost includes fuel.) available at http://www.mit.edu/afs/athena/org/n/nuclearpower
7) The Energy Review, Performance and Innovation Unit, February 2002
8) "More a question of politics than economics", Q Series: The Future of Nuclear, UBS Investment Research, March 2005
9) EPR Background and its Role in Continental Europe, Didier Beutier, Areva, Westminster Energy Forum, 23rd June 2005

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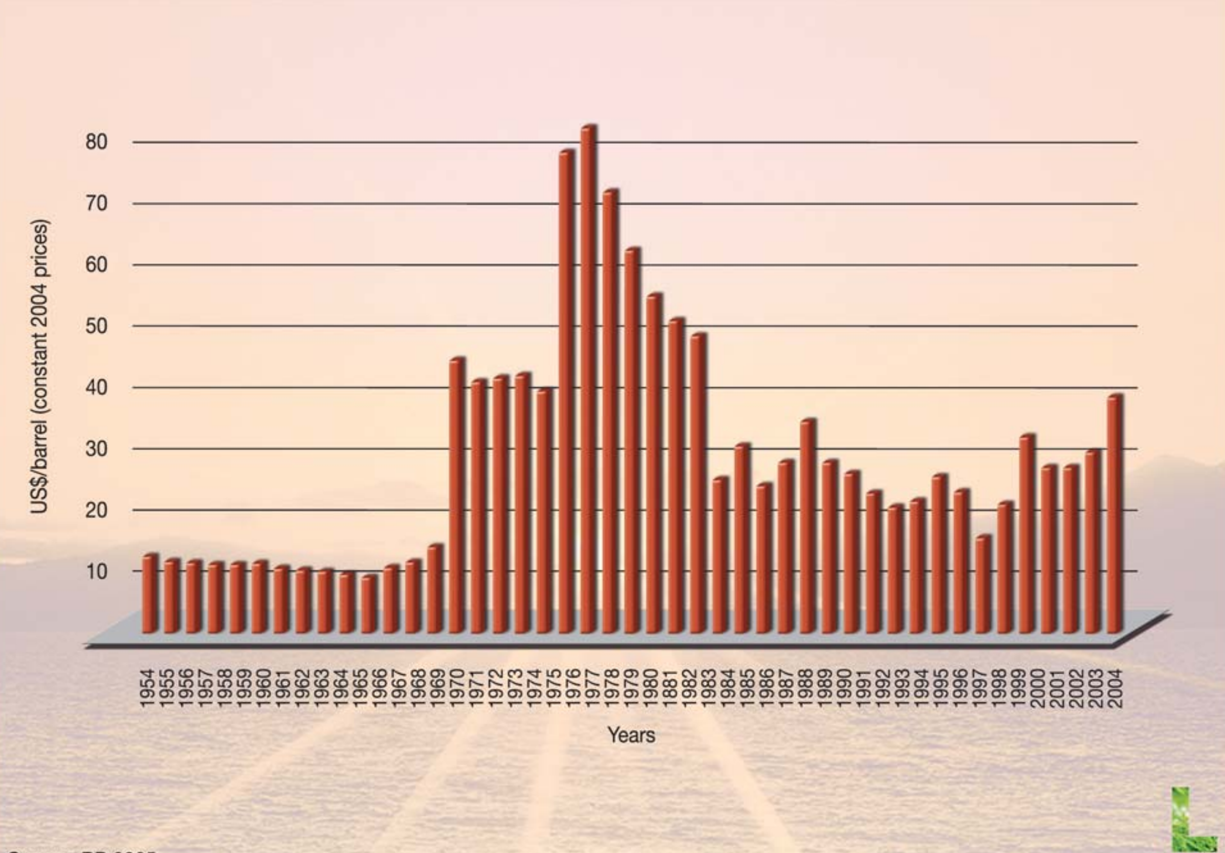
Another report by the Bank HSBC also highlights the risks associated with investment in new nuclear when it said: (HSBC 2005) "*Hence this financial risk [*new build*] coupled with unforeseen construction delays, the risk of cumbersome political and regulatory oversight, nuclear waste concerns and public opposition could make new nuclear a difficult pill to swallow for equity investors.*"

Fig. 10-1 **DEVELOPMENT OF OIL PRICE**



Source: BP 2005

Other financial institutions highlight the high risk of investing in nuclear power and look at other issues that will impact upon the technology's ability to give secure investments. In particular Standard&Poors, point to problems of nuclear accidents, nuclear waste storage and public acceptance as key factors.

Developing new nuclear generation in the deregulated European market environment is a high-risk venture, given the long construction times and high capital costs. Siting issues are likely to be more sensitive today than in the 1970s and 1980s when most reactors were built. Furthermore, political support will remain fragile to nuclear safety performance worldwide. Another Chernobyl-like accident can rapidly cool the current cordial sentiments. Fundamental issues, such as the final storage of nuclear waste and far-reaching social consensus, are still likely to be required before a potential large-scale renaissance can happen [S&P2006].

10.4 Will New Nuclear Power Plants Require Additional Government Support or Subsidies to Compete in a Liberalised Market?

As has been stated the nuclear sector and its advocates believe that the industry is now economic. The World Nuclear Association is so confident that they now claim that *"nuclear power in the 21st Century will be economically competitive even without attaching economic weight to the global environmental virtues of nuclear power or to national advantages in price stability and security of energy supply*". [WNA 2005]

However, this view is not shared by non-industry observers, who see that Government support and subsidies will be needed. In December 2005, Standard&Poor's stated on the potential for new investment that: *"If new construction of nuclear power is to become a reality in the U.K., Standard&Poor's has significant concerns over the future structure of the generating industry. In particular, the potential for increased regulation of the liberalized generating industry, a higher level of political interference in the market structure, and the ongoing prospects for nuclear power in a competitive power market. Standard&Poor's expects that investment in nuclear power will rely on the long-term sustainability of high electricity prices in the U.K. energy market." [S&P 2005]*

If Governments are to create the necessary market for nuclear power then there are a number of subsidy routes that might be considered, these include:

- Nuclear Obligation: This would require any electricity supplier to ensure that a percentage of their electricity came from nuclear sources. The Government could then fix the amount of nuclear electricity that had to be in the energy mix.

- Capital Grants: The Government could award capital grants for new construction.

- Cost Over-Run Guarantees: Utilities may seek Government assurances that they will compensate for any time or cost over-runs resulting from extended licensing processes. This could be in the form of the Government paying the interest on any loan extensions.

- Tax Breaks: The nuclear industry could become tax exempt, deferred or have reduced rates. This could be on a local level, through adjusted business rates or on a national level.

- Licensing: The nuclear industry would like to see a streamlining of the licensing process. This would ensure that a number of questions (energy justification, nuclear safety, economic etc.) were dealt with on a national level and therefore the planning inquiry was primarily to assess local environmental issues.

- Carbon Price Guarantees: The nuclear industry is looking for additional financing and guarantees on the price of carbon. Some proposals would like nuclear to gain additional financing from the fact that no CO_2 is emitted during the production of electricity from nuclear (although it is produced during the construction of facilities and the mining and fabrication of uranium fuel). Furthermore, proposals are being considered that would result in Governments giving a long term guarantee – maybe up to 30 years – for the price of carbon.

The need for additional support has been highlighted by plans and actions in some of OECD countries. In early 2005 construction began on the first European Pressurized Water Reactor (EPR) in Finland. When ordered the reactor was said to cost in the range of € 1,500-1,800/installed kW [AREVA 2005]. However, this price was artificially low due to the financing package available (which included, highly unusual for intra EU projects, Government Export Credit Guarantees from France and Sweden [Nucleonics Week 2005a] and an unrealistically low turn-key contract construction price - this appeared to be a “loss leader” from the constructors). This was further highlighted by the fact that the price for a similar reactor in France is reported to be about 25 % higher per installed kilowatt [Nucleonics Week 2005b].

In the US, where there hasn’t been a new reactors order for over the 30 years, the Government has announced a subsidy programme in an attempt to start a nuclear construction programme. This package includes [ICF Consulting 2005]:

- a tax credit of 1.8 cents/kWh for the first 8 years of generation for the first six units;
- a federal loan guarantee of up to 80 % of the cost of innovative technologies;
- a support framework against regulatory or judicial delays, worth up to $ 500 million for the first two reactors and $ 250 million for the next four;
- further research and development funding worth $ 850 million; and
- assistance with historic decommissioning costs (up to $ 1.3 billion).

It is estimated that this series of deals will cost the US taxpayer $ 13 billion [Lovins 2006].

10.5 The Need to Include the Full Environmental Costs of Different Energy Options

Energy producers and users do not pay the full environmental costs, e.g. the economic costs of pollution, such as CO_2, SO_2 or nuclear waste and other emissions. This is a subsidy to the polluting energy sources, like coal, gas and nuclear power and disadvantages clean technologies such as renewable energy. In fact analysis from Germany has suggested that the environmental costs of energy are greater than the more obvious direct support given to renewable energy. Work undertaken by the DLR suggested that in 2003 the support schemes for renewable energy in Germany cost a little over € 1 billion. However, if there was no support scheme and instead the same amount of energy was produced by conventional energy then the environmental cost would be over € 1.2 billion [DLR 2004].

Calculating the costs of the different pollutants and potential risks is extremely complex. A large study, part funded by the European Commission, is ongoing. In July 2001 the European Commission issued a press release on the findings of the first phase of the study. This concluded the “*cost of producing electricity from coal or oil would double and the cost of electricity production from gas would increase by 30 % if external costs such as damage to the environment and to health were taken into account. It is estimated that these costs amount up to 1-2 % of the EU’s Gross Domestic Product (GDP), …They have to be covered by society at large, since they are not included in the bills which electricity consumers pay”.*

The report has been criticised for failing to fully consider the costs associated with nuclear power, its potential impacts and the full environmental impact of global warming. On nuclear power the report states that it "*involves relatively low external costs due to its low influence on global warming and its low probability of accidents in the EU power plants".* However there are a number of statements in the report text that qualifies – to some extent – the conclusion of the report regarding nuclear power. These include: *"Reliable values of accident, high level wastes impacts, nuclear proliferation and impacts of terrorism have not been developed in ExternE. These omissions may well be significant and therefore should be clearly noted in any assessment"* [Externe 1998]. The 2005 update of the ExternE study continues to not include estimates for the full costs of nuclear power [Externe 2005].

Regarding nuclear power there are two key areas in which the industry is affectively subsidised or given favourable conditions relating to its environmental costs these are:

A) Decommissioning and Waste Management Costs

After a nuclear facility has been closed significant additional work is needed to make it environmentally secure and to manage the radioactive waste that has been produced. Many of these processes are untried and therefore their final cost cannot be estimated with a high degree of certainty. In Europe it is thought that the work necessary to dismantle and dispose or store the Union's radioactive waste are likely to cost in excess of € 200 billion. Citigroup estimated that the global waste and decommissioning market is likely to be in the order of € 1 trillion [Citigroup 2006].

As noted funds are supposed to be set aside during the operational life of a facility so that future clean-up work can be financed. If sufficient funds are not put aside then there are two consequences. Firstly, the electricity being sold is not reflecting the true environmental cost and thus this is an unfair advantage to nuclear power over other non-nuclear generating sources. Secondly, the clean-up with will still have to be done and therefore it is more than likely that this will be funded by future taxpayers, probably from another generation.

In Europe the issue is not new but is acute due to the differences between polices in Member States and the introduction of common EU energy market rules. Subsequently, European Commission has noted that "*this situation [lack of uniformity of decommissioning policies] could lead to distortion and discrimination between now competing nuclear electricity producers from different Member States. Decommissioning costs are clearly seen as part of the electricity production costs. They may not be cross-subsidised from the transmission activity nor be directly subsidised via state aid."* [European Commission 1998]

As a result of these concerns the Commission proposed legislation that would introduce new requirements for Member States to ensure that adequate reserves were put aside in segregated funds. A requirement for a segregated or separate fund is to stop utilities using these funds for their own, potentially high risk, purposes – such as market acquisitions. However, this was rejected by Member States, and in particular from France and Germany, who currently do not require segregated funds, therefore their utilities are not barred from accessing their decommissioning funds.

On the EU level the Commission is now drafting a new recommendation for Member States. This is non-binding legislation that would suggest best practice for utilities across the Union. It is not thought that this will fulfil either the legislative requirements or require sufficient transparency and guarantees to improve the current situation.

B) Nuclear Insurance

There are international agreements that create a framework for insurance cover for nuclear installations; one of them is the so called Vienna Convention on Civil Liability for Nuclear Damage. This convention creates a three tiered system, whereby part is covered by the operator, part by the State in which the facility is located and part by member states of the international convention. However, even these three tiers do not cover the full cost of a severe accident and there is a fixed ceiling for nuclear damage compensation. In February 2004 it was agreed that the current ceiling should be increased from $ 350 million to $ 1.5 billion. A nuclear operator will be required to have $ 700 million minimal liability cover, the nation State will cover a minimum of $ 500 million and the public funds from the international tier will cover $ 300 million. However, even this increase in costs both allows restrictions on the level of insurance that a utility is required to take out in the event of an accident and the total compensation that can be claimed following a nuclear accident. Were a nuclear generator required to fully cover the potential cost of a nuclear accident would significantly increase the cost of generating nuclear electricity. It has been estimated that if Europe's largest nuclear utility, Electricité de France (EdF), were required to fully insure their power plants with private insurance but using a limit on liabilities of approximately € 420 million, it would increase EdF's insurance premiums from 0.0017 c€/kWh, to 0.019 c€/kWh, thus adding around 8 % to the cost of generation. However, if there was no ceiling in place and an operator had to cover the full cost of a worst cost scenario accident it would increase the insurance premiums to 5 c€/kWh, thus increasing the cost of generation by around 200 % [European Commission 2003].

10.6 Can Costs for Nuclear be Expected to Go Down?

The cost problems that nuclear power face are further demonstrated by looking forward. The costs of renewable energy are expected to fall, due to improved technologies and economies of scale. As a rule of thumb it is said that for a doubling in production, the price of renewables falls by 20 %. Table 10-3 highlights the historical "learning rate" whereby the price of technologies have fallen. What can be seen is that the prices of nuclear power have not fallen significantly.

Renewable energies are being actively developed all over the world and are suitable for a range of activities including for transport, heating and cooling and electricity production. Furthermore, their versatility means that they can be rapidly introduced at a size that it suitable for every application. In 2004 about $ 30 billion was invested in renewable energy capacity and installations [REPN 2005].

Tab. 10-3 **HISTORICAL IMPACT OF LEARNING RATES ON DIFFERENT TECHNOLOGIES**

Technology	Period	Learning Rate %
Wind – OECD	1981-95	17
Solar PV – EU	1985-95	32
Compact Florescent Lamps (US)	1992-98	16
Gas Turbine – OECD	1984-94	34
Gas Pipelines – onland	1984-97	4
Nuclear Power – OECD	1976-93	6
Electric Power Production	1926-70	35

Source: McDonald und Schrattenholger 2001

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Figures from the UK Government's Department of Trade and Industry in Table 10-4 highlight how the price of electricity from some renewable energy is expected to fall considerably in the next decade, but remain relatively constant for nuclear power.

Consequently, the economic arguments that favour renewables over nuclear power today are forecast to get stronger over time.

Tab. 10-4 **AVERAGE COSTS OF RENEWABLE ENERGY AND NUCLEAR POWER**

Technology	Current cost (US Cents/kWh	Projected future costs beyond 2020 as the technology matures (US Cents/kWh)
Biomass Energy:		
Electricity	5-15	4-10
Heat	1-5	1-5
Ethanol for vehicle fuels	3-9	2-4
(c.f. petrol and diesel)	(1.5-2.2)	(1.5-2.2)
Wind Electricity		
onshore	3-5	2-3
offshore	6-10	2-5
Solar Thermal Electricity (insolation of 2500kWh/m² per year)	12-18	4-10
Hydro-electricityt		
Large scale	2-8	2-8
Small scale	4-10	3-10
Geothermal Energy:		
Electricity	2-10	1-8
Heat	0.5-5.0	0.5-5.0
Marine Energy:		
Tidal Barrage (e.g. the proposed Severn Barrage)	12	12
Tidal Stream	8-15	8-15
Wave	8-20	5-7
Grid connected photovoltaics, according to incident solar energy („insolation"):		
1000 kWh/m² per year (e.g. UK)	50-80	~8
1500 kWh/m² per year (e.g. southern Europe)	30-50	~5
2000 kWh/m² per year (most developing countries)	20-40	~4
Stand alone systems (incl. Batteries), 2500 kWh/m² per year	40-60	~10
Nuclear Power	5-7	3-5
Electricity Grid supplies from fossil fuels (incl. Transmission and distribution)		Capital costs will come down with technical progress, but many technologies largely mature and may be offset by risiing fuel costs
Off peak	2-3	
Peak	15-25	
Average	8-10	
Rural electrification	25-80	

Source: DTI 2005

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10.7 Conclusion

In recent months and years there has been renewed optimism from the nuclear industry that new nuclear power stations will be ordered within liberalised energy markets. This optimism is largely based on the increasing cost of oil and gas, which is causing electricity from nuclear power's main competitor, gas fired power stations, to be more expensive, and thus improving the relative economics of nuclear power.

As a result the nuclear industry is now arguing that it is fully competitive with conventional electricity generation options. However, despite this, the financial community is sceptical of the longer term economic viability of nuclear power. In particular they point to unresolved financial and public issues, such as siting, nuclear waste management and the dangers of nuclear accidents. Furthermore, some in the financial community note that the large fixed costs of nuclear power increase the financial risk of nuclear investments.

Despite claims that nuclear power is economically viable the countries in the OECD that are considering embarking again on nuclear power construction programme, Finland and the US, have all proposed direct or indirect financial support programme for their 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.

As a mechanism to reduce CO_2-emissions nuclear power cannot compete with a variety of already available alternatives. In particular energy efficiency, in addition to its overall environmental advantage has a clear economic benefit but also brings additional security of supply improvements. Furthermore, analysis on the projects costs of other low or zero CO_2-emitting technologies demonstrate that renewable energies will becoming increasingly price competitive with nuclear power due to low prices from economies of scale.

10.8 Literature

AREVA (2005): EPR Background and its Role in Europe. Didier Bueter, Areva, speaking at the Westminster Energy Forum, Nuclear New Build: Key Investment Issues and Implications for Strategic UK Energy Policy. 23rd June 2005

BP (2005): Statistical Review of World Energy, BP June 2005
[http: //www.bp.com/genericsection.do?categoryId=92&contentId=7005893]

Citigroup (2006): Nuclear Decommissioning Out with the Old and In with the New. Citigroup, Industry report, 27th January 2006

CRS (2001): Nuclear Power: Prospects for Commercial Reactors: CRS Report for Congress. 27th July 2001

DLR (2004): Wolfram Krewitt, Joachim Nitsch German Aerospace Center (DLR) Institute of Technical Thermodynamics, System Analysis and Technology Assessment Stuttgart, Germany Workshop on Long Term Energy Prospects and the Role of Renewable Energies Brussels, European Parliament 18th March 2004, Forecast Scenarios for the Potential Role of Renewable Energies

DTI (2005): Occasional Paper No1. Options for a Low Carbon Future: Review of Modelling Activities and an Update. Department of Trade and Industry, UK Government September 2005.

European Commission (1998): Nuclear Safety and the Environment, Decommissioning of nuclear installations in the European Union. Supporting document for the preparation of an EC Communication on the subject of decommissioning nuclear installations in the EU, EUR 18860 1998, page 30

European Commission (2001): European Commission: 20th July 2001, New Research Reveals The Real Costs Of Electricity In Europe
[http: //europa.eu.int/comm/research/press/2001/pr2007en.html]

European Commission (2003): CE, Solutions for Environment, Economy and Technology, Report for DG Environment January 2003 Environmentally harmful support measures in EU Member States, page 132

Externe (1998): ExternE: 1998 update; Aggregation of Externalities, page 497, Volume 7

Externe (2005): Rainer Freiderich, IER, University of Stuttgart. Externe: Methodology and Results. December 2005

OKO (2006): Comparison of Greenhouse-Gas Emissions and Abatement Cost of Nuclear and Alternative Energy Options from a Life-Cycle Perspective – updated version, Uwe R Fritsche Oko Institute, January 2006

HSBC (2005): Nuclear Cleanup Costs: 2020 Fission? Financial Analysis of Nuclear Decommissioning Costs, HSBC September 2005

IAEA (2002): Country Nuclear Power Profiles
[http: //www.pub.iaea.org/MTCD/publications/PDF/cnpp2002/index.htm]

IEA/NEA (1998): Projected Costs of Generating Electricity – Update 1998, October 1998, ISBN 92 64 161 62-1, Table 9b

IEA/NEA (2005): Projected Costs of Generating Electricity – 2005 Update, ICF Consulting 2005: 2005 Energy Bill: The Impacts on Nuclear Power, ICF Consulting

Keepin and Kats (1988): Greenhouse warming; Comparative Analysis of Nuclear and Efficiency Abatement Strategies. Bill Keepin and Gregory Kats, Energy Policy, December 1988

Krause (2000): F. Krause, J. Koomey, D. Olivier (2000): Cutting Carbon Emissions While Making Money, California 2000

Lovins (2006): Nuclear power: Economics and climate-protection potential. Amory B. Lovins CEO, Rocky Mountain Institute, 6th January 2006

Mc Donald and Schrattenholger (2001): Learning Rates for Energy Technologies, Energy Policy 2001

Nucleonics Week (2005a): EC will investigate "green power" complaint of state aid to TVO EPR, Nucleonics Week Volume 46 / Issue 2 / January 13, 2005

Nucleonics Week (2005b): German utilities nearer decision to invest in Flamanville-3 Nucleonics Week Volume 46 / Issue 46 / November 17, 2005

NUKEM (1997): Is there Life After 40 for Western Europe's Nuclear Plants? Plant Life Extension – Nukem Market Report, August 1997

REPN (2005): Renewables 2005, Global Status Report, Paper prepared for the Renewable Energy Policy Network for the 21st Century, by the Worldwatch Institute

SDC (2006): Nuclear Power Won't Fix It: Press Release for " The role of Nuclear Power in a Low Carbon Economy". Sustainable Development Commission
[http: //www.sd-commission.org.uk/pages/060306.htmlMarch 2006]

S&P (2005): Standard and Poor's: UK Security of Supply Fears Spark Renewed Interest in Nuclear Energy, Standard and Poor's 8th December 2005

S&P (2006): Standard and Poor's: Credit Aspects Of North American And European Nuclear Power, Standard and Poor's 9th January 2006

UBS (2005): More a question of politics than economics, Q Series: The Future of Nuclear, UBS Investment Research, March 2005

WNA (2005): The New Economics of Nuclear Power. World Nuclear Association, December 2005

11 Nuclear Generated Hydrogen Economy – A Sustainable Option?

Steven C. Sholly
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11 Nuclear Generated Hydrogen Economy – A Sustainable Option?

11.1 Rationale: Why a Hydrogen Economy?

Nuclear power is frequently identified as an important element of a coming hydrogen economy, which in turn is hailed by some as the solution to both the climate change and "Peak Oil" issues. The discussion of some aspects of sustainability of both the nuclear production of hydrogen and the hydrogen economy itself are the subjects of this report.

The generally cited rationale for a hydrogen economy (i.e., the replacement of fossil fuels by hydrogen for transportation) is in principle straightforward:

- Transportation worldwide is currently strongly linked to the availability of petroleum-based fuels.

- Fossil fuels are also used for electric power generation and heating.

- Petroleum discoveries peaked in the early 1960ies, and the general trend since then is downward. Petroleum production has already peaked in many areas and is expected to peak in all current production areas within the next decade and then decline[1]. As economic development proceeds in Asia and elsewhere, there will be a growing disparity in fossil fuel supplies and demand, and thus a growing competition for the available supplies.

- Coal, which has a longer expected supply lifetime than petroleum, is currently cost effective only for electrical generation and, to a lesser extent, heating. The environmental impacts of coal burning are not yet reflected in the price paid for coal or for electrical power generated using coal. Unless carbon sequestration[2] is incorporated in proposed additional uses of coal (e.g., as a source of methane for steam reformer production of hydrogen), larger releases of CO_2 will result from wider use of coal.

- Imported fossil fuels represent, for a number of countries and areas (including the European Union) a significant economic and national security dependence owing to the expense involved in maintaining more than a 60-90 day supply and the ease with which imports can be interrupted.

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1 Notwithstanding this conclusion, which has very broad support in the technical community (including OECD's International Energy Agency), the EU-funded "European Hydrogen and Fuel Cell Technology Platform" blithely assumes that oil production will increase from the current 80 million barrels per day to 120 million barrels per day in 2030 [HFP 2005]. No supporting analysis is provided.

2 Carbon sequestration describes processes that remove carbon from the atmosphere and store it either in depleted oil or gas wells or – in future possibly - in the deep ocean. The viability and sustainability (in terms of the permanence of sequestration) of carbon sequestration is not addressed here. In addition, the environmental impacts of carbon sequestration (both the environmental impacts from the sequestration technologies themselves, as well as the environmental impacts that would arise from problems with the permanence of sequestration technologies) are also not addressed here. It is well recognized, however, that proof of the permanence of sequestration is essential to the strategy [IEA 2004b]. The significance of the issue of permanence of sequestration is easily seen in a 2005 report from IEA examining the legal implications of carbon sequestration [IEA 2005b].

There is thus an incentive to replace fossil fuels with another energy source if an economically feasible source with less of a security vulnerability can be identified for particular uses[3].

- Climate change is linked to greenhouse gas emissions from fossil fuel use as the main anthropogenic factor by most scientists. One means of limiting greenhouse gas emissions is, of course, to replace current uses of fossil fuels by other power sources that are not associated with greenhouse gas emissions.

- Provided that hydrogen can be produced, distributed or stored, and used economically and with minimal environmental impact, it is a "clean" fuel with emissions mainly consisting of water vapour (plus nitrogen oxides in case hydrogen is used for high temperature combustion). It might therefore qualify as one contributor to the replacement of fossil fuels – especially in the transportation sector.

One fuel replacement strategy that is being suggested is to use nuclear power plants (initially from fission power plants and, later – after commercial demonstration - from fusion power plants[4]) to produce hydrogen. Many of those who consider nuclear energy to meet the criteria mentioned above – i.e., economic production and minimal environmental impact – see a hydrogen economy based on nuclear production as a viable and sustainable option to meet the energy demands of the future. This claim in part triggered the present study.

Of the various facets of a possible hydrogen economy, the current study focuses on nuclear produced hydrogen as a vehicle fuel for light duty vehicles (passenger cars, pickup trucks, sport utility vehicles, etc.).

11.2 The Energy Carrier Hydrogen

11.2.1 Introduction

Hydrogen is not a primary energy source as a result of its chemical affinity for other elements such as oxygen (forming water). There is very little hydrogen found free in nature. As a result, in order for hydrogen to be used as a fuel, it must first be chemically liberated from a source material. Chemical liberation of hydrogen from a source material is a process which itself requires energy.

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[3] Note that it is assumed and asserted by many that nuclear power is such a source. The fact is, however, that for the European Union uranium represents an imported fuel. While it is easier (in terms of storage space) to store a supply of uranium as a hedge against supply disruptions, the supply can nonetheless be cut off. In 2004, 99 % of the uranium purchased by the EU came from 10 countries outside the EU (75 % from only four countries: Australia, Canada, Niger and the Russian Federation). Only about 1 % came from sources within the EU [Euratom 2004]. Developing another source of supply is not a simple matter since identifying suitable uranium deposits and constructing necessary facilities to extract the ore, convert the ore to yellowcake, and converting the yellowcake to uranium hexafluoride for use in uranium enrichment all take years to accomplish.

[4] Fusion power plants based on tokamak concepts are in the planning stage of feasibility demonstration (the ITER tokamak experimental fusion reactor has been designed but not yet built). If current concepts prove to be workable, it seems likely that rather large unit sizes would be required in order to make the process an economic source of power, and very large units (in the range from 2000-5000 MWe) could be necessary in order to compete in a liberalized market [IRF 2004]. At such large unit sizes, off-peak capacity will be considerable, and it could be used to produce bulk hydrogen which could then be consumed in power plants to support load levelling with peak load power generation units.

Thus, hydrogen is best thought of as an "energy carrier". Bulk hydrogen production can support the use of hydrogen as a fuel for producing electricity in fuel cells for stationary and transportation use.

Ultimately, one needs to question whether it makes sense (from the standpoint of efficiency, primary energy source consumption, environmental impact, etc.) to use a primary energy source to produce hydrogen instead of using it directly. But hydrogen production from off-peak electricity could supplement hydrogen production from other sources. Hydrogen could also be produced from intermittent power sources - such as solar or wind power – and be stored for later use when the intermittent power source is not available. [IEA 2003b]

Hydrogen can be stored, distributed and transported as a compressed gas or liquid. In order for a major "hydrogen economy" to be developed and used, there are fundamental requirements for an economic source of hydrogen production and for the development and deployment of the infrastructure needed to support its use.

Hydrogen can be produced from many sources, including water[5] and natural gas (the source of most current hydrogen production). Using hydrocarbon feedstock to produce hydrogen has the same detriments as burning the hydrocarbon fuels directly – this reduces the hydrocarbon feedstock available for production of petrochemicals, and unless it is accompanied by carbon sequestration (which has consequences for the economics and the sustainability of the process) it also releases greenhouse gases (carbon dioxide, primarily). Even if vastly expanded production of hydrogen from natural gas were pursued together with carbon sequestration as a means of reducing greenhouse gas emissions, and if there were no sustainability problems involved in sequestration, the process would not be sustainable due to the limited natural gas resources. Using natural gas as a feedstock to produce hydrogen could at most be a transitional strategy in reducing greenhouse gas emissions[6] until other non-fossil sources of hydrogen could be developed and brought into commercial operation.

11.2.2 Current General Situation

Hydrogen is currently mainly used in the production of ammonia to make fertilizer and in hydrocracking of petroleum, with minor percentages also used for diverse high-purity chemical and industrial uses, as vehicle fuel (fuel cells), as fuel for fuel cell-based peaking power stations and as missile fuel.

Current world hydrogen production amounts to about 50 million metric tonnes annually[7], consuming 1.5 % of the total world energy consumption [ACIL 2003]. Current annual hydrogen production in the United States is about 11 million metric tonnes, while in Europe it is about 8. Because hydrogen storage and distribution are currently expensive, most hydrogen is currently produced where it is used. Where hydrogen is transported, this is done by pipeline or by road

[5] It is clear that there are regions of the earth where (relatively) clean water in abundance is a problem. Such regions would not be expected to be used for hydrogen production, and would be better suited to use available energy resources in a primary form such as electricity generated by wind or solar facilities. If hydrogen is needed as a vehicle fuel in such areas, it could prove to be more sensible to produce the hydrogen elsewhere and transport it to areas where it is needed.

[6] Methane could be produced from biogas sources, and then used to produce hydrogen. Such a procedure would be inefficient - and it would probably make more sense to simply use the methane directly rather than take the extra step of using it as feedstock to produce hydrogen.

[7] If all of this hydrogen were burned to produce electricity, the net electrical generation would amount to about 200 GW of capacity [Forsberg 2002]. The total world electrical generating capacity is about 3,600 GW (of which about 370 GW is nuclear capacity) [EIA 2005].

via cylinders, tube trailers and cryogenic tankers, with a small amount shipped by rail or barge. Transport of high-pressure cylinders and tube trailers is normally done over distances of 160-320 kilometres from the production facility. For distances up to 1600 kilometres, hydrogen is transported as a liquid in cryogenic tankers, railcars or barges. In the US, hydrogen pipelines are used in few areas where large hydrogen refineries and chemical plants are located (mostly in California, Indiana, Louisiana and Texas). Hydrogen pipelines also exist in Europe.

The current sources of hydrogen production are as follows:

- 48 % from natural gas
- 30 % from petroleum
- 18 % from coal
- 4 % from electrolysis of water[8]

It should be noted from this that 96 % of current production of hydrogen comes from fossil fuel sources, predominantly (78 %) combined from natural gas and oil involving greenhouse gas emissions. If a hydrogen economy is to develop, these sources of hydrogen will have to be nearly completely replaced or accompanied by carbon sequestration.

Projected demand for hydrogen for industry in 2030 is expected to be five to six times greater than current production levels [Buckner 2002]. Note that this projected increase is for industrial demand alone and is separate from any demand that might occur due to a hydrogen economy for vehicle fuel or other purposes[9].

11.2.3 Advantages and Disadvantages of Hydrogen

Hydrogen has certain advantages as a fuel. Hydrogen is non-toxic and it is not a carcinogen or a mutagen. Hydrogen is odorless, colourless and tasteless. The combustion product of hydrogen is water vapour. Hydrogen in its gaseous and compressed gaseous forms is much lighter than air and thus quickly disperses when released. (The same is not true of liquefied hydrogen, which when initially released is heavier than air.)

Hydrogen also has disadvantages as a fuel. Hydrogen is extremely combustible and it is subject to the same hazardous combustion regime (Boiling Liquid Expanding Vapour Explosion or BLEVE) as Liquefied Petroleum Gas (LPG) and Liquefied Natural Gas (LNG). Hydrogen must be significantly compressed or liquefied to be useful as a fuel. Due to its very small molecular size, hydrogen migrates rapidly through very small openings, thus the requirements for leak tightness of piping and container systems are much more stringent for hydrogen than for hydrocarbon-based fuels.

8 This source of hydrogen is mostly a byproduct of bulk chlorine production.

9 This increase (from 50 million tonnes to 250-300 million tonnes) is far larger than is estimated to be required to support a hydrogen economy for vehicle fuels (23 million tonnes per year for the EU). Industry will have to come up with a way to produce this hydrogen irrespective of a hydrogen economy for vehicle fuels, and it is clear that the sources will not be able to continue to be principally natural gas and oil.

11.2.4 Hydrogen Storage

If hydrogen is produced in bulk, it must either be used at the source or liquefied and stored as a cryogenic liquid. If it is produced in distributed fashion as a gas, it must again be used at the source or be compressed and stored for distribution. Both compression and liquefaction are energy intensive processes, which – independently of the means and expense of producing the hydrogen in the first place – reduce the overall efficiency of the hydrogen economy and increase its cost.

For use as a vehicle fuel, more recent studies are based on concepts where hydrogen is produced by electrolysis at the point of delivery (i.e., at vehicle fuelling stations). This avoids the costs and impacts associated with bulk production, storage and transport and makes the whole process more of a "just-in-time" nature. (Of course, if the electrical grid goes down, hydrogen cannot be produced or distributed. But this is no different from the existing gasoline- and diesel-based passenger transportation systems, since when power is not available, gasoline or diesel fuel cannot be pumped.)

The longer hydrogen is in storage or distribution, the more of it is lost to the environment. A "just-in-time" hydrogen electrolysis system for vehicle fuelling stations appears to be both more efficient and more cost-effective in the long run than a centralized bulk hydrogen production, storage and distribution to vehicle fuelling station concept.

Hydrogen storage from bulk production would either be short-term storage as a compressed gas prior to distribution via hydrogen pipeline to end users, or more likely as a cryogenic liquid awaiting use or distribution. Cryogenic hydrogen storage and distribution has risks associated with it that require careful consideration (see Section 2.3, and see also Section 7 for more detail).

11.2.5 Hydrogen Distribution

For bulk hydrogen production that is not used at the point of production, in addition to a storage system a hydrogen distribution system would have to be created to deliver the hydrogen to end users. Two possibilities for hydrogen distribution to end users are cryogenic tanks (either by truck or rail) and compressed hydrogen gas pipelines.

Cryogenic hydrogen distribution trucks in Europe typically carry 3.35 metric tonnes of liquid hydrogen. Cryogenic hydrogen railcars carry 2.3-9.1 metric tonnes of liquid hydrogen, depending on their size. Boil-off liquid hydrogen loss rates from cryogenic truck and rail tank cars are 0.3-0.6 % per day. Losses during transfer of cryogenic hydrogen from a tank truck to a storage tank at the end user are 10-20 % of the total shipment [Amos 1998]. The effects of such losses on atmospheric chemistry are not well understood, particularly on the scale that such losses could occur in a full-blown hydrogen economy. This is something that requires further investigation.

Compressed hydrogen gas pipelines are in use in a number of areas of the world (including Belgium, Canada, France, Germany, Netherlands, United Kingdom and United States), the longest of which is nearly 900 km long (an Air Liquide network in France, Belgium & Netherlands) [Vinjamuri 2004].

Owing to the expense involved with hydrogen storage and distribution (resulting from hydrogen's low density, even in a liquid state), more and more frequently the literature indicates a focus for hydrogen fuelled vehicles on distributed production using electrolysis and other production methods rather than centralized bulk production. This entirely shifts the nature of the hydrogen economy from a traditionally large industry focus to local focal points, where hydrogen is produced "just-in-time" in necessary quantities without resorting to centralized bulk production facilities requiring massive storage and distribution infrastructure.

11.3 Hydrogen Production Methods

11.3.1 Overview

There are basically only three types of hydrogen production and all of the other "methods" of hydrogen production are variations on a theme. These three methods are:

- Electrolysis;
- Steam reforming of methane;
- Thermo-chemical water-splitting:

Of the above processes, electrolysis and steam reforming of methane are well understood and currently in use. Steam reforming of fossil fuel methane, in the context of the hydrogen economy, requires the sequestration of carbon from the process, otherwise it makes no sense because it releases huge quantities of greenhouse gases.

Thermo-chemical water-splitting, despite for decades of discussion and research, remains demonstrated only in laboratory scale[10]. The scale-up from laboratory scale to the commercial scale anticipated by the advocates of nuclear thermo-chemical water-splitting is of the order of a factor of ten millions. There appear to be rather significant materials problems involved with the two main thermo-chemical water-splitting cycles (I-S, and Ca-Br) due to high temperature (800 °C) processes involving extremely corrosive sulfuric or hydrobromic acid (respectively). In addition, there seems to have been little serious consideration given to the chemical accident hazards attendant on thermo-chemical water-splitting schemes.

Unfortunately, neither the proponents of nuclear production of hydrogen nor its critics have produced convincing economic arguments. What is needed is a thorough life cycle cost analysis - with all costs, economic, environmental and others included - in order to place the comparison between nuclear-produced hydrogen and hydrogen produced by other processes.

11.3.2 Processes for Nuclear-Generated Hydrogen

11.3.2.1 Introduction

Although any nuclear power plant technology can be used for production of hydrogen through electrolysis or thermo-chemical water-splitting, more efficient technologies will be required in order to achieve economically competitive hydrogen costs. Several technology choices are highlighted

[10] The peak production cited to date has been 0.031 m^3/hour for one week at bench scale in 2004 (Shiozawa 2006). This is a factor of 3 million smaller than the industrial scale facility envisioned by the Japanese (Shimizu 2001).

in the following as exemplary of those currently being discussed. Using nuclear power as an energy source to produce hydrogen is not currently being done except on an experimental scale[11].

11.3.2.2 Electrolysis

Any nuclear power plant that produces electricity could be used to produce hydrogen in an electrolytic process. In this case, the electrolytic production facility could be located at any convenient place with a sufficiently large grid connection and would not necessarily have to be close to the nuclear power plant. (Of course, the closer the electrolytic production facility is located to the power plant, the lower the transmission line losses would be. This would result in a modest increase in overall efficiency of the use of electricity for electrolytic hydrogen production.)

Electrolytic production of hydrogen is currently too expensive for bulk hydrogen production and is mostly used in applications where very high purity hydrogen is required (which hydrogen is too expensive to use as a vehicle fuel). The difficulty with electrolytic hydrogen production is the relative inefficiency of the process (the efficiency is around 25-30 %) [Schultz 2002: 5]. An inexpensive source of electricity (e.g., cheap hydroelectric power) would be required for electrolysis to be economical for other uses.

An international coalition of countries has formed the Generation IV International Forum[12]. This coalition has identified six advanced reactor technologies for deployment in the 2030 time frame. Only one of these six designs – the Very High Temperature Reactor or VHTR – is identified with nuclear-generated hydrogen production. The current design concept is for a 600 MWt modular design cooled by helium [Park 2003]. The goal of the VHTR Nuclear Hydrogen Initiative is to commence operation of a demonstration nuclear powered hydrogen production facility in 2017 [Henderson 2004]. Hydrogen could be produced by two processes: First, the electrical output of the station could be used to produce hydrogen by electrolysis; second, the high temperature process heat (about 50 MWt of the 600 MWt output) could be used to produce hydrogen by a thermo-chemical process.

11.3.2.3 Thermo-Chemical Processes

Hydrogen could also be produced using nuclear power plant process heat in a thermo-chemical process. Direct use of process heat to support hydrogen production, however, requires a reactor with a very high coolant temperature. The efficiency of thermo-chemical production of hydrogen is estimated to be about 50 % [Schultz 2002: 5]. The coolant temperature of most currently operating reactors is far too low to make thermo-chemical hydrogen production economically feasible[13]. Future reactor designs using high temperature helium gas or liquid salt or liquid metal

[11] The High Temperature Test Reactor (HTTR) facility in Japan is being used on an experimental basis for producing hydrogen from nuclear power [Ryskamp 2003: 13].

[12] At the time this report was written, the Generation IV International Forum consisted of ten nations (Argentina, Brazil, Canada, France, Japan, the Republic of South Africa, the Republic of Korea, Switzerland, the United Kingdom and the United States) plus Euratom.

[13] The coolant temperature of currently operating LWRs is in the range of 320 °C. High temperature reactors intended for use in thermo-chemical production of hydrogen have primary coolant temperatures of 750 °C and higher. The higher the coolant temperature, the more efficient the thermo-chemical process is expected to be.

coolants (e.g., lead, lead-bismuth) are being investigated for possible use in thermo-chemical hydrogen production[14].

11.3.2.4 High-Temperature Hydrolysis

Finally, a hybrid process called high temperature hydrolysis has been suggested which uses both high temperature process heat (700-900 °C) and electricity [Forsberg & Pickard 2002: 7]. This process is estimated to be about 40 % efficient [Schultz 2002: 5], but the efficiency would depend on the temperature of the reactor coolant heat source used to power the process. Higher temperature reactors could be expected to yield some improvement in efficiency.

11.4 Hydrogen Economy

11.4.1 The Scale of the Hydrogen Economy

Bounding calculations indicate that the scale of production required is in the order of 23 million metric tonnes of hydrogen annually just to fuel the current light vehicle fleet in the 25 European Union countries. To illustrate what the production of this amount of hydrogen would mean in terms of effort and costs, rough estimates were made for different energy sources (IRF 2006):

a. Sixty-three EPR nuclear stations at a capital cost of € 159 billion for the nuclear stations.

b. Something over 5,000 km^2 of solar photovoltaic stations with capital costs of the order of € 1.08 trillion.

c. About 63,000 three megawatt wind turbines, requiring about 2,500 km^2 of land area; capital costs of the order of € 1-3 million per wind turbine, plus ancillary facilities and land costs.

d. One hundred and five H2-MHR modular nuclear stations (MHR: Modular Helium Reactor) with co-located thermo-chemical water splitting plants for bulk hydrogen production, at a capital cost of € 154 billion.

e. Hydrogen production from biomass using biogas production and steam-methane reforming technology for bulk hydrogen production, requiring 464 plants and a total acreage in biomass production 259,376 km^2 (6.5 % of the land area of the EU), with capital costs of € 175 billion for the biogas and the steam reforming plants alone. To this would have to be added cryogenic liquefaction facilities and cryogenic hydrogen distribution infrastructure.

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[14] Another nuclear generated hydrogen concept (called the Advanced High-Temperature Reactor or AHTR) has been proposed by Oak Ridge National Laboratory in which the fuel is cooled by molten fluoride salts. Coolant temperatures of 750 °C or even 850 °C are envisaged [Forsberg & Pickard 2002].
Argonne National Laboratory and Texas A&M University have proposed the STAR-H2 (Secure Transportable Autonomous Reactor for Hydrogen Production) design for hydrogen production. STAR-H2 is a 400 MWt lead-cooled fast reactor with a core outlet temperature projected at 780 °C. A helium-based intermediate cycle would take the process heat from the nuclear plant to a thermo-chemical hydrogen production plant. STAR-H2 is a Generation IV reactor, forecast to be deployable after 2030 [Wade, Doctor & Peddicord 2002].
The Japan Atomic Energy Research Institute (JAERI) is preparing to demonstrate nuclear production of hydrogen using its High-Temperature Engineering Test Reactor (HTTR). A thermo-chemical, iodine-sulfur-based process for hydrogen production is being developed to use the process heat output of HTTR to produce hydrogen [Forsberg & Pickard 2002].

In all cases above, hydrogen fuelling infrastructure (and in two cases a cryogenic hydrogen distribution system as well) and annual operations and maintenance (O&M) costs are additional. Hydrogen fuelling infrastructure for distributed production of hydrogen by electrolysis is estimated to be in the range of € 94.5 - € 202.5 billion for the EU 25. The infrastructure costs for a system based on cryogenic distribution for bulk hydrogen production and fuelling stations based on production of compressed gas from cryogenic fluid have not yet been estimated.

In short, the cost of transition to a hydrogen economy is clearly in the range of at least € 250 to € 500 billion just to fuel the current light vehicle fleet in the 25 European Union countries. For comparison, the Gross Domestic Product (GDP) of the EU for 2005 was estimated to be about € 10,000 billion [CIA 2006].

Apart from the costs, there are, of course, other constraints to the different options, such as availability of land (b,c,e), iodine (d) or acceptance by the population (a,c,d). The Iodine needed per year for the 105 H2-MHR modular nuclear stations e.g. amounts to 15 % of the worlds known iodine resources [Anzieu 2006].

11.4.2 Time-Scale Required for the Hydrogen Economy

If the hydrogen economy is expected to alleviate concerns over price, magnitude of supply and security-of-supply over oil as a vehicle fuel, the hydrogen economy will have to be established much sooner than current planning seems to envision. Many government-sponsored “road map“ documents suggest 2040 - 2050 for the hydrogen economy.

For example, the EU‘s high level hydrogen advisory panel – whose report serves in significant part as the impetus for current EU R&D plans regarding hydrogen – assumed that only about one-third of all the vehicles on the roads of Europe would be hydrogen powered by 2040, and that a little over one-third of the new vehicles sold in that same year would be hydrogen-powered [EC 2003]. This can be contrasted with IEA estimates for 2024 which show a disparity between supply and demand for oil as large as was the production of oil as recently as 1997.

Simply put, the oil supply crunch for which the hydrogen economy is being advertised is coming much faster than is being acknowledged. The hydrogen economy would have to be accelerated in terms of time scale, or it will likely come into being too late. At the same time, the hydrogen economy has to take account of the economic, security and environmental concerns about existing transportation fuels, and resist the temptation to resort to fossil fuel-based sources of hydrogen without engaging in carbon sequestration.

11.4.3 Limits to the Availability of Uranium

Due to the limited uranium resources it is clear that unless nuclear fission-based power sources resort to widespread use of fast breeder reactors and a plutonium recycle economy, nuclear produced hydrogen is not “sustainable“[15].

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[15] The concept that the nuclear industry is not sustainable is hardly a radical notion; see, for example, (Rothwell & Van der Zwaan 2002). However, this concept is in contradiction to what is almost an article of faith within the nuclear industry itself.

Numbers regarding the uranium reservoirs vary considerably with the source, but a total of about 4 million metric tonnes of uranium ore recoverable for € 108/kg or less available worldwide are a plausible estimate [WEC 2001]:

- 2.96 million metric tonnes of “Reasonably Assured Resources” of uranium ore and

- 0.99 million metric tonnes of “Estimated Additional Resources“ (EAR-I) of uranium ore.

The current demand for uranium is about 62,000 metric tonnes per year, and is expected to expand to 79,800 metric tonnes per year by 2015. Assuming a linear trend the uranium resources will last about 41 years. Additional speculative resources of about 10 million metric tonnes are thought to be available [WEC 2001]. This would extend the period of supply to 95 years.

Full recycling of plutonium in MOX fuel could extend the period by perhaps 30 %, but many current reactors are not able to use MOX fuel and the period of extension is not so remarkable since plutonium is already being recycled in some countries. The degree to which the fission reactor era could be extended by full plutonium recycle without resorting to fast breeder reactors is not significant enough for fission technology to escape the conclusion that it is not sustainable.

If however, nuclear power is more than doubled to account for an increased demand for electricity (demand for electricity worldwide is expected to double by 2030, and if nuclear power merely keeps pace with its current contribution it will also double) [Birol 2004] and to support a hydrogen economy, the fission era without fast breeder reactors and plutonium recycling will be over in half this time – that is, in about half a century. As above, this period could be stretches by about 30 % through plutonium recycling – i.e. about 65 years.

These figures are somewhat more optimistic than those given by IAEA [IAEA 1997] and DOE [DOE 2002b] based on slightly different shares of nuclear in the overall energy supply and energy demand increases. According to DOE without deployment of fast reactors, uranium identified resources would be depleted by 2030 and the (currently) speculative resources by 2060. Other sources [e.g. Matthes et al. 2005] are even more restrictive.

Whatever the real numbers are, they will likely meet very few peoples’ expectations for sustainability[16].

It is perhaps not widely appreciated outside the nuclear industry that demand for uranium actually outstripped supply in 1990, with the excess (about 40 %) coming from drawdown of reserves, recycling of highly enriched uranium formerly used in nuclear weapons programmes, enrichment of previous tails from the enrichment process and rejecting tails at a lower concentration of Uranium-235 and recycling and enrichment of uranium from reprocessing.

[16] One could resort to extraction of uranium from seawater for reactors other than fast breeders in order to extend the era of fission power, but the cost of doing so would take the cost of the resulting nuclear-generated hydrogen out of reach for all except critical uses (including perhaps defence, public protection, etc.). It is broadly assumed within the nuclear industry that extracting uranium from seawater would cost ten times more than recovery from uranium ore. This would double the cost of power from nuclear fission, and the cost of hydrogen produced from this power would also be doubled. Using uranium from seawater would extend the period of operation of fission power plants in a non-breeder mode by making available a resource estimated by the Uranium Information Center at 4000 million (4 billion) metric tonnes [UIC 2005]. Whether this is practical or not remains to be seen; it represents speculation only at the current time.

Fission technology is *only* sustainable in the sense of resource deployment if a relatively near-term (within 40-50 years) transition is made to fast breeder reactors. Given the performance to date of fast breeder reactors, there is little about which to be optimistic that fast breeder reactors could be commercialised and brought into widespread use in time support a hydrogen economy within the next two or three decades. The only nuclear alternative would be widespread deployment of fusion technology to power the hydrogen economy. If neither of these technologies proves to be feasible on a large scale, another (probably renewable) source of energy would be needed for the hydrogen economy.

11.4.4 Other Perspectives of the Hydrogen Economy

Whatever its potential as a vehicular fuel, hydrogen is in danger of being over-sold by its advocates seemingly as the answer to everything. Hydrogen will not be a major source of base load electrical generation. This conclusion derives from the fact that hydrogen must be produced from another energy source. For base load generation it makes far more sense (and is far cheaper and more efficient) to simply use the primary energy source to produce electricity directly. High temperature fission power plants and possibly future large fusion power plants (some 50 or more years in the future, if demonstrated to be feasible) may be able to economically produce bulk hydrogen during off-peak hours for use in load levelling during peak demand periods. In addition, hydrogen may be useful for electricity production on a small scale for remote sites, but if small, modular nuclear units prove to be feasible, even this use of hydrogen for power generation could be in question.

The burning or modification of a fuel, or using another power source (uranium, wind, solar or hydroelectric), to produce hydrogen is inefficient for electrical generation purposes. It is much more efficient to simply generate electricity directly from the original sources (fuel, uranium, wind, solar, biomass gas or hydroelectric). Hydrogen production and use only makes sense in the case of distributed uses (transportation, remote locations, etc.) and peaking power (load balancing). In the case of burning hydrogen for peaking power, however, it must be recognized that this use of hydrogen is not greenhouse gas-free because the high-temperature combustion process results in production of nitrous oxides (NO_x) which are greenhouse gases. It therefore seems more likely that use of hydrogen for peaking power will be by means of hydrogen fuel cell power plants.

11.5 Environmental Impacts from the Hydrogen Economy

In the explosion of articles, reports, papers and books about hydrogen in the past five years, the issue of environmental impacts from the hydrogen economy tends to get lost in the wake of dreams of a greenhouse-gas free energy economy. Production, storage, distribution and use of hydrogen all have environmental impacts that need to be systematically considered. In some cases, the environmental impacts are probably not going to be very different from those currently experienced with other fuels. In others, the environmental impacts are perhaps not as obvious as with existing fuels. Regardless, the environmental impacts of a hydrogen economy need to be identified and systematically assessed, as much as they are with any other energy technology.

Contrary to frequent and widespread statements, use of hydrogen is not entirely free of pollutants, depending on the energy source and chemical process used to produce the hydrogen, the nature of the storage and distribution system for the hydrogen and the end uses of the hydrogen. If hydrogen is burned in flame, for example, nitrous oxides (NO_x) will be formed due to hydrogen's flame temperature [Solomon & Banerjee 2004: 2; Bellona 2002].

In the case of nuclear power-related production of hydrogen, there is the usual suite of environmental issues associated with any nuclear power plant as well as those related to uranium mining and processing. The radioactive waste disposal issues also remain. Special attention must be paid to the hitherto little known environmental effects of the new generation of nuclear power plants and the plutonium economy. These issues are treated in other papers in this volume.

11.6 Safety and Risk Considerations for the Hydrogen Economy

11.6.1 Hydrogen BLEVEs and other Risks

Many of the discussions of the hydrogen economy assert a "low" risk. However, the risks posed by widespread adoption of a hydrogen economy have unfortunately not been systematically assessed and will undoubtedly vary depending on the concept at issue.

Bulk production, storage and distribution of liquid hydrogen have a particular risk that must be well understood – namely the occurrence of what is known in the industry as a "Boiling Liquid Expanding Vapour Explosion" or BLEVE.

BLEVE phenomena are applicable to any cryogenic liquid tank which fails due to fire. The tank pressurizes as the contents heat up, and a relief valve (if present) opens but – not being sized for such a pressure transient – the relief valve merely serves to maintain the pressure in the tank at the relief valve setpoint. As the fire progresses, if not extinguished soon enough, the tank wall will weaken and then structurally fail. The tank tends to fail catastrophically, blowing tank debris through a large area (upwards of about a kilometre or so). If the cryogenic fluid stored in the tank is combustible, the tank contents tend to explode, adding a shock wave and thermal pulse to the damage caused by the BLEVE[17].

From 1950 to 2004, there were nine BLEVE's recorded in Europe involving LPG transport (one involving rail transport, and the other eight involving truck transport) [Molag & Kruithof 2005]. BLEVEs are also applicable to cryogenic hydrogen transport and stationary cryogenic hydrogen storage tanks in case of fire.

There is apparently little publicly available data on liquid hydrogen BLEVEs. The limited data available on LPG BLEVE's suggest a frequency for tank farm BLEVEs of 4×10^{-4} per tank farm year. If such a frequency is also applicable to liquid hydrogen storage (this is unknown at present), it would pose a potential problem in the case of bulk hydrogen production using nuclear power. Considering the EU-25 example above, if 2,373 four-module H2-MHR hydrogen production stations were built, this would result in a BLEVE at a nuclear hydrogen production station on average about every year.

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[17] An indication of the recognition within governmental emergency response agencies of the hazards posed by cryogenic hydrogen transport and storage is provided the fact that the North American Emergency Response Guidelines (2004) recommend an immediate evacuation in all directions to a distance of 1600 meters whenever a cryogenic hydrogen tank is involved in a fire; see [DOT 2004].

Another potentially important risk that needs to be understood in the context of bulk hydrogen production is the potential for process or storage system failures which result in the release of large quantities of hydrogen to the air. Such a release can result in a confined vapour cloud explosion (but typically not in a well designed facility, which prevents confinement of releases) but more likely an unconfined vapour cloud explosion (UVCE). Such explosions have occurred in non-hydrogen facilities, causing extensive damage (e.g., Flixborough, United Kingdom, 1974)[18].

Non-fire related tank failures are not so uncommon. Statistics from the Loss Prevention Association of India indicate frequencies around 1.5×10^{-3}/a for low temperature vessels and up to 2.7×10^{-3}/a for process vessels [Viswanathan 2004].

The limited available statistics for cryogenic tanks (with and without fires) indicate that if bulk hydrogen production and large storage tanks are used for the hydrogen economy (which is clearly envisioned by advocates of using high temperature gas-cooled reactors for production purposes), there could be a non-negligible likelihood of large explosions. The effects of such explosions on structures, systems, components, and operating staff at the co-located nuclear facility will require very careful design and analysis to mitigate potential risks.

11.6.2 Hydrogen Infrastructure Vulnerability

An assessment of infrastructure vulnerability for the hydrogen economy requires a definition of how the hydrogen economy will be structured, requiring answers to questions such as:

- Will hydrogen production be centralized or distributed?

- If centralized, will the hydrogen be distributed via pipeline or bulk transport by rail and/or truck?

Consider possible security/terrorism implications of shipping liquid hydrogen – at about 17,500 shipments per day for the EU (350 per day for Austria), one would need a veritable army of guards solely to protect liquid hydrogen shipments. And how effective could the guards be against terrorists armed with assault weapons and Rocket-Propelled Grenades (RPGs) if their adversaries are attacking liquid hydrogen transport trucks? How many guards are needed for each truck?

If bulk production, storage and distribution are used in the hydrogen economy, a very careful assessment of infrastructure vulnerability will be required, if for no other reason than to understand the degree of difficulty (or simplicity as the case may be) with which significant disruptions could occur due to man-made and natural phenomena hazards, particularly extreme events such as earthquakes, high winds and incidents of sabotage and terrorism. In the latter regard, security vulnerability concerns are already being expressed for gasoline, LNG and LPG facilities

[18] This accident resulted in a release of cyclohexane which was subsequently ignited, resulting in an explosion with a yield equivalent variously estimated to the explosion of 9-280 tonnes (more commonly cited as 16 tonnes) of TNT. A variety of easily accessible sources provide additional information (http: //www.hse.gov.uk/comah/sragtech/caseflixboroug74.htm; http: //en.wikipedia.org/wiki/Flixborough_disaster; http: //www.icheme.org/about_icheme/medals/Venart2004.pdf).

and transport. The concerns for bulk cryogenic hydrogen storage facilities and liquid hydrogen transport are no less serious[19].

The environmental impact issue is not developed in detail here, but clearly it is one requiring detailed attention if a move is made to go to a hydrogen economy. The issue needs to be addressed up front and on a continuous basis so that consideration of environmental impact is one of the "drivers" of the technologies, instead of waiting until the last step (implementation) before concerning oneself with environmental impact.

11.6.3 Nuclear Risks

The safety (and risk) issues involved with nuclear power plant-based hydrogen production depend on the reactor type (and power level) selected, the hydrogen production method used, reactor site-related features and hazards and the proximity and type of hydrogen storage and/or transmission technologies employed. The nuclear risks of power plants and waste disposal sites are extensively treated in other contributions to this volume.

The nuclear industry is well aware of the necessity to ensure that the nuclear reactor and the hydrogen production facility are sufficiently isolated from one another that an "upset" in one facility does not impact the other [Forsberg & Pickard 2002]. If this aspect of the risk posed by nuclear production of hydrogen is satisfactorily addressed, there should be no additional radiological safety issues attendant on nuclear production of hydrogen compared with operating a nuclear power plant as a producer of electricity and/or process heat. However the larger number of plants increases the overall risk.

11.7 Conclusions

The following conclusions are suggested based on this paper:

- Hydrogen is not a primary energy source – it is an energy carrier and must be created by using some other primary energy source (nuclear, wind, photovoltaic, biomass, etc.). Energy is required to create hydrogen, compress or liquefy it for storage and distribute it. The overall efficiency of this centralized hydrogen economy is low.

- Hydrogen production methods are variations of three basic methods: (a) electrolysis, (b) steam reforming methane and (c) thermo-chemical water-splitting schemes. Of these, electrolysis and steam reforming methane are well developed. Thermo-chemical water-splitting is still at only laboratory scale despite four decades of research and in application involves what appear to be considerable problems with corrosion of materials as well as chemical hazards which have yet to be systematically assessed.

- Electrolysis and thermo-chemical water-splitting schemes could be powered by nuclear plants, but the use of present generation nuclear power plants would not be efficient.

[19] Clearly any security threat incident which involved catastrophic failure of a cryogenic hydrogen tank under pressure due to external fire would pose a BLEVE hazard. Note that security threats could include hijacking of a cryogenic hydrogen tank truck and driving it to a "high-value" target of choice. The US Army has warned brigade and battalion commanders, and staff officers, about such a hazard involving hijacked gasoline tank trucks since at least 1992 [US Army 1992].

- Centralized, bulk hydrogen production, storage and distribution carries with it risks of specific types of chemical accidents (BLEVEs & UVCEs) which require careful probabilistic and deterministic analysis on the scale of hydrogen production contemplated in current replacing passenger vehicle fuels with hydrogen.

- A decentralized, "just-in-time" hydrogen economy is only just beginning to be explored, but appears to more adaptable to diverse primary energy sources and eliminates risks associated with BLEVEs which are only possible in the case of bulk distribution of cryogenic liquid hydrogen[20].

- The amount of hydrogen needed to support a hydrogen economy for light duty vehicles in the 25 EU states is of the order of 23 million metric tonnes per year. This about half of the current world production.

- Production of such a quantity of hydrogen is a huge undertaking, the costs of which will run into the range of € 250-500 billion.

- The hydrogen needed annually just to fuel the current light vehicle fleet in the 25 European Union countries would appear to require of the order of sixty-three EPR nuclear stations, supporting distributed production of hydrogen via electrolysis or of the order of one hundred and five H2-MHR modular nuclear stations with co-located thermo-chemical water-splitting plants for bulk hydrogen production.

- The security and terrorism threat implications of a hydrogen economy have barely begun to be considered. But it would imply – in the case of a transportation system centred around bulk cryogenic hydrogen – providing security for 6.4 million shipments of liquid hydrogen per year. That's over 17,500 shipments per day in the EU (for Austria about 350 shipments per day) – each potentially requiring security.

- The environmental problems associated with the hydrogen economy are only beginning to be addressed. More research is needed before the impact of releasing gaseous hydrogen into the atmosphere on a scale attendant upon the hydrogen economy is adequately understood.

- At present it is difficult to see hydrogen – nuclear or non-nuclear - as a significant contribution towards the solution of either the climate problem or the emerging energy gap; it is certainly not one that can be rapidly deployed.

[20] The US Department of Energy has issued a draft hydrogen roadmap report indicating that distributed production is the most viable option for introducing hydrogen and building hydrogen infrastructure (DOE 2005b).

11.8 References

ACIL 2003: ACIL Tasman Pty. Ltd & Parsons Brinckerhoff, National Hydrogen Study, Australian Department of Industry, Tourism and Resources, 2003
[http: //www.industry.gov.au/assets/documents/itrinternet/Hydrogen_StudyOct20032003102112O716.pdf]

Alcock et al. 2001: J. Alcock, L. Shirvill & R. Cracknell, Compilation of Existing Safety Data on Hydrogen and Comparative Fuels, Shell Global Solutions, prepared for the EU EIHP2 5th Framework Research Program (1998-2002), Contract Nr. ENK6-CT2000-00442, May 2001
[http: //www.eihp.org/public/Reports/Final_Report/Sub-Task_Reports/ST5.1/CompilationExistingSafetyData_on_H2_and_ComparativeFuels_S.pdf]

Amos 1998: W. Amos, Costs of Storing and Transporting Hydrogen, NREL/TP-570-25106, National Renewable Energy Laboratory (Golden, CO USA), November 1998, page 33 [http: //www.eere.energy.gov/hydrogenandfuelcells/pdfs/25106.pdf]

Anzieu 2006: P. Anzieu, et al., Coupling a Hydrogen Production Process to a Nuclear Reactor, in Nuclear Production of Hydrogen: Third Information Exchange Meeting, Oarai, Japan, October 5-7, 2005, NEA-6112, OECD Nuclear Energy Agency (Paris), 2006

Areva 2003: Areva Press Release, December 18, 2003
[http: //www.areva.com/servlet/ContentServer?pagename=arevagroup_en %2FPressRelease %2FPressReleaseFullTemplate&cid=1069857874218]

Bellona 2002: B. Kruse, S. Grinna & C. Buch, Hydrogen: Status & Possibilities, Bellona Report Nr. 6: 2002, Bellona Foundation (Oslo), 2002
[http: //www.bellona.no/data/f/0/26/97/0_9811_1/Hydrogen_6-2002.pdf]

Birol 2004: F. Birol, *Power to the People: The Outlook for World Electricity Development*, IAEA Bulletin 46: 1 2004
[http: //www.iaea.org/Publications/Magazines/Bulletin/Bull461/article3.pdf]

Bossel et al 2005: U. Bossel, B. Eliasson & G. Taylor, The Future of the Hydrogen Economy: Bright or Bleak?, Final Report, Updated February 28, 2005
[http: //www.efcf.com/reports/E02_Hydrogen_Economy_Report.pdf]

Brundtland 1987: G. Brundtland (Chairman), Our Common Future: The Report of the World Commission on Environment and Development, Report to the United Nations General Assembly, 42nd Session (New York, NY USA), 4 August 1987 [http://www.are.admin.ch/imperia/md/content/are/nachhaltigeentwicklung/brundtland_bericht.pdf?PHPSESSID=d24d89a5655442184bf989036962464e]

Buckner 2002: M. Buckner, *Regional Nuclear Energy Parks for Hydrogen Production*, Savannah River Technology Center (Aiken, SC USA), presented at the “Technical Workshop on Large Scale Production of Hydrogen from Nuclear Power – Fission and Fusion” (San Diego, CA USA), May 14-15, 2002
[http: //web.gat.com/hydrogen/images/pdf %20files/buckner_energy_parks.pdf]

Cadwallader & Herring 1999: L.Cadwallader & J. Herring, Safety Issues with Hydrogen as a Vehicle Fuel, INEEL/EXT-99-00522, Idaho National Engineering and Environmental Laboratory (Idaho Falls, ID USA), September 1999
[http: //www.inl.gov/hydrogenfuels/projects/docs/h2safetyreport.pdf]

CIA 2006: US Central Intelligence Agency, The World Factbook, Online Version, updated 10 January 2006
[http: //www.odci.gov/cia/publications/factbook/geos/ee.html]

Cracknell & Shirvill 2002: R. Cracknell & L. Shirvill (Shell Hydrogen), *Safety Considerations in Retailing Hydrogen*, presented at the H2NET Meeting, November 12, 2002
[http: //www.h2net.org.uk/PDFs/Safety/H2NET %20Safety.pdf]

DOE 2002a: US Department of Energy, A National Vision of America's Transition to a Hydrogen Economy – To 2030 and Beyond, February 2002
[http: //www.eere.energy.gov/hydrogenandfuelcells/pdfs/vision_doc.pdf]

DOE-2002b: A Technology Roadmap for Generation IV Nuclear Energy Systems, December 2002, U.S. DOE Nuclear Energy Research Advisory Committee and the Generation IV International Forum

DOE 2005a: US Department of Energy, Basic Research Needs for the Hydrogen Economy, Report on the Basic Energy Sciences Workshop on Hydrogen Production, Storage, and Use, Argonne National Laboratory, May 13-15, 2005

DOE 2005b: US Department of Energy, Roadmap on Manufacturing R&D for the Hydrogen Economy, Draft (Washington, DC USA), December 2005.
[http: //www.hydrogen.energy.gov/pdfs/roadmap_manufacturing_hydrogen_economy.pdf]

DOT 2004: US Department of Transportation (DOT), Transport Canada, Secretariat of Transport and Communications of Mexico, and Centro de Inforación Química para Emergencias of Argentina, 2004 Emergency Response Guidebook: A Guidebook for First Responders During the Initial Phase of a Dangerous Goods/Hazardous Materials Incident, ERG2004, 2004
[http: //hazmat.dot.gov/pubs/erg/erg2004.pdf]

EC 2003: European Commission, Hydrogen Energy and Fuel Cells, A Vision of Our Future: Final Report of the High Level Group, EUR-20719-EN, Directorate-General for Research and Directorate-General for Energy and Transport (Brussels, Belgium), 2003
[https: //www.hfpeurope.org/uploads/678/688/hydrogen-vision-report_HLG_2003_en.pdf]

EIA 2005: US Energy Information Administration, Annual Energy Review 2004, DOE/EIA-0384(2004), US Department of Energy (Washington, DC USA), August 2005
[http: //www.eia.doe.gov/emeu/aer/pdf/aer.pdf]

Euratom 2004: Euratom Supply Agency, Annual Report 2004, European Commission (Luxembourg), 2005
[http: //europa.eu.int/comm/euratom/ar/ar2004.pdf]

EU 2005: European Union, Directorate-General Energy and Transport, Energy & Transport in Figures 2004, 2005

Forsberg 2002: C. Forsberg, *Nuclear Production of Hydrogen*, Oak Ridge National Laboratory (Oak Ridge, TN USA), presented at the "Technical Workshop on Large Scale Production of Hydrogen from Nuclear Power – Fission and Fusion" (San Diego, CA USA), May 14-15, 2002 [http: //web.gat.com/hydrogen/images/pdf %20files/forsberg_hydrogen.pdf]

Forsberg & Pickard 2002: C. Forsberg (Oak Ridge National Laboratory) & P. Pickard (Sandia National Laboratory), *The Advanced High Temperature Reactor: Matching Nuclear Energy Systems to Thermochemical Hydrogen Production*, presented at the American Institute of Chemical Engineers (AIChE) Spring Meeting, March 12, 2002
[http: //www.ornl.gov/~webworks/cppr/y2002/pres/113981.pdf]

Gross et al. 1994: R. Gross, W. Otto, A. Patzelt & M. Wanner, *Liquid Hydrogen for Europe – The Linde Plant at Ingolstadt*, Reports on Science and Technology 54 1994
[http: //www.linde-gas.com/international/web/lg/com/likelgcom30.nsf/repositorybyalias/pdf_report_ingoldstadt/$file/Bericht_54_g.pdf]

Henderson 2004: D. Henderson (Office of Nuclear Energy, Science & Technology, US Department of Energy), *Nuclear Hydrogen Initiative Overview*, DOE Hydrogen Program Review (Philadelphia), May 24, 2004
[http: //www.eere.energy.gov/hydrogenandfuelcells/pdfs/review04/3_nhi_overview_henderson.pdf]

HFP 2005: European Hydrogen and Fuel Cell Technology Platform (HFP), European Hydrogen & Fuel Cell Technology Platform Deployment Strategy, August 2005
[https: //www.hfpeurope.org/uploads/677/687/HFP_DS_Report_AUG2005.pdf]

HFP 2006: European Hydrogen and Fuel Cell Technology Platform (HFP), *Fossil Energy: World Energy Resources*, 2006
[http: //infotools.hfpeurope.org/energyinfos__e/energy/main05.html]

HSB PLC 2000: HSB Professional Loss Control (HSB PLC), Sphere Storage Risk Evaluation xxxxxx Refinery Co., 2000
[http: //www.cheric.org/ippage/g/ipdata/2000/07/file/ip2000-08.ppt]

HyNet 2004: HyNet, Towards a European Hydrogen Energy Roadmap, Executive Report, April 21, 2004
[http: //www.hynet.info/publications/docs/HYNET-Roadmap_Executive_Report_JUN2004pdf]

IAEA 1997: IAEA-TECDOC-1258, "Assessment of uranium, deposit types and resources — a worldwide perspective" Proceedings of a Technical Committee Meeting organized by the International Atomic Energy Agency and the OECD Nuclear Energy Agency and held in Vienna, June 10–13, 1997

IEA 2003a: International Energy Agency (IEA), Energy Technology: Facing the Climate Challenge, Meeting of the Governing Board at the Ministerial Level (Paris), April 28-29, 2003 [http: //www.iea.org/dbtw-wpd/textbase/papers/2003/challenge.pdf]

IEA 2003b: International Energy Agency, Energy to 2050: Scenarios for a Sustainable Future, Paris, 2003
[http: //www.iea.org/textbase/nppdf/free/2000/2050_2003.pdf]

IEA 2004a: International Energy Agency, Hydrogen and Fuel Cells. Review of National R&D Programs, Paris, 2004

IEA 2004b: International Energy Agency, Prospects for CO_2 Capture and Storage, Organisation for Economic Co-operation and Development (Paris), 2004
[http: //www.iea.org/textbase/nppdf/free/2004/prospects.pdf]

IEA 2005a: International Energy Agency, Prospects for Hydrogen and Fuel Cells. Energy Technology Analysis, Paris, 2005.

IEA 2005b: International Energy Agency, Legal Aspects of Storing CO_2, Organisation for Economic Co-operation and Development (Paris), 2005
[http: //www.iea.org/textbase/nppdf/free/2005/co2_legal.pdf]

Ingersoll et al. 2004: D. Ingersoll, et al., Status of Preconceptual Design of the Advanced High-Temperature Reactor (AHTR), ORNL/TM-2004/104, Oak Ridge National Laboratory (Oak Ridge, TN USA), May 2004
[http: //www.ornl.gov/~webworks/cppr/y2001/rpt/120370.pdf]

IRF 2004: Institut für Risikoforschung, Comparison of a Tokamak Fusion Power Plant With Possible Nuclear Fission and Nuclear Fusion Competitors in 2050, SERF-III Report, Task TW1-TRE/EFDA (Vienna, Austria), prepared for the European Fusion Development Association (EFDA), *in final editing*, planned for release in October 2004

IRF 2006: Institut für Risikoforschung, Visualizing the scale of a hydrogen economy for traffic in Europe, Internal Report
[http: //www.univie.ac.at/irf]

Ivy 2004: J. Ivy, Summary of Electrolytic Hydrogen Production: Milestone Completion Report, NREL/MP-560-36734, National Renewable Energy Laboratory, US Department of Energy (Golden, CO USA), September 2004
[http: //www.nrel.gov/docs/fy04osti/36734.pdf]

LaBar et al. 2003: M. LaBar, A. Shenoy, W. Simon & E. Campbell, *Status of the GT-MHR for Electricity Production*, General Atomics (San Diego, CA USA), presented at the World Nuclear Association Annual Symposium, London, England, September 3-5, 2003 [http: //www.world-nuclear.org/sym/2003/pdf/labar.pdf]

Ling Chan et al. 2001: Ling Chan & Partners Ltd., CH2M Hill (China) Ltd., Wong Pak Lam & Associates Ltd., Thomas Anderson & Partners Ltd., LLA Consultancy Ltd., MDA Hong Kong Ltd. & Edaw Earthasia Ltd., Environmental Impact Assessment for Proposed Headquarters and Bus Maintenance Depot in Chai Wan, prepared for the Hong Kong Special Administrative Region of The People's Republic of China – Government Information Centre, June 2001
[http: //www.epd.gov.hk/eia/register/report/eiareport/eia_0602001/html/eia.htm]

Lovins 2002: A. Lovins, *FreedomCAR, Hypercar®, and Hydrogen*, Rocky Mountain Institute, testimony before the US House of Representatives, Committee on Science, Subcommittee on Energy (Washington, DC USA), June 26, 2002
[http: //www.rmi.org/images/other/Trans/T02-06_FreedomCAR.pdf]

Lovins 2003: A. Lovins, *Twenty Hydrogen Myths*, White Paper #E03-05, Rocky Mountain Institute (Snowmass, CO), Updated, September 2, 2003
[http: //www.rmi.org/images/other/Energy/E03-05_20HydrogenMyths.pdf]

Lovins & Cramer 2004 A. Lovins & D. Cramer, *Hypercars®, hydrogen, and the automotive transition*, Int. J. Vehicle Design 35: 1/2 2004
[http: //www.rmi.org/images/other/Trans/T04-01_HypercarH2AutoTrans.pdf]

Matthes et al. 2005 : F. Ch. Matthes und H.-J. Ziesel 2005: Sicherheit der Rohstoffversorgung – eine politische Herausforderung ?! Kurzstudie für die Bundestagsfraktion Bündnis 90/Die Grünen. Berlin Februar 2005

Matzner 2004: D. Matzner, *PBMR Project Status and the Way Ahead*, PBMR Pty. Ltd., presented at the "2nd International Topical Meeting on High Temperature Reactor Technology" (Bejing, People's Republic of China), September 22-24, 2004
[http: //www.iaea.org/programmes/inis/aws/htgr/fulltext/htr2004_a04.pdf]

Molag & Kruithof 2005: M. Molag & A. Kruithof, BLEVE Prevention of a LPG Tank Vehicle or a LPG Tank Wagon, B&O-A R 2005/364, TNO (Nederlandse Organisatie voor toegepast-natuurwetenschappelijk onderzoek), Netherlands, prepared for the Ministry of Transport, Public Works and Water Management, The Hague, Netherlands, December 2005
[http: //www.unece.org/trans/doc/2006/wp15ac1/ECE-TRANS-WP15-AC1-06-BE-inf03e.pdf]

NAE 2004: National Academy of Engineering, The Hydrogen Economy: Opportunities, Costs, Barriers and R&D Needs, National Academies Press (Washington, DC USA), 2004
[http: //www.nap.edu/books/0309091632/html/228.html]

NEA 2001: Nuclear Production of Hydrogen: The First Information Exchange Meeting, Paris, France, October 2-3, 2000, OECD Nuclear Energy Agency (Paris, France), 2001

NEA 2004: Nuclear Production of Hydrogen: Second Information Exchange Meeting, Argonne, Illinois, USA, October 2-3, 2003, NEA-5308, OECD Nuclear Energy Agency (Paris), 2003

NEA 2006: Nuclear Production of Hydrogen: Third Information Exchange Meeting, Oarai, Japan, October 5-7, 2005, NEA-6112, OECD Nuclear Energy Agency (Paris), 2006

Park 2003: C.V. Park (Idaho National Engineering Laboratory), *Next Generation Nuclear Plant (NGNP) with Hydrogen Production*, High Temperature Heat Exchanger Project Kickoff Meeting, University of Nevada - Las Vegas, Nuclear Science and Technology Group, October 24, 2003
[http://nstg.nevada.edu/heatpresentations/Microsoft %20PowerPoint %20- %20Park.pdf]

Richards et al. 2005: M. Richards, et al. (General Atomics, Idaho National Laboratory, Texas A&M University, Fuji Electric & Toshiba), *H2-MHR Conceptual Designs Based on the SI Process and HTE*, presented at the "OECD Nuclear Energy Agency 3rd Information Exchange Meeting on the Nuclear Production of Hydrogen and Second HTTR Workshop on Hydrogen Production Technologies" (JAEA, Oari, Japan), October 5-7, 2005
[http: //www.nea.fr/html/science/hydro/iem3/papers/12_M_Richards_GA.pdf]

Rogner & Scott 2001: H. Rogner & D. Scott, Building Sustainable Energy Systems: The Role of Nuclear-Derived Hydrogen, in Nuclear Production of Hydrogen: The First Information Exchange Meeting, Paris, France, October 2-3, 2000, OECD Nuclear Energy Agency (Paris, France), 2001

Rothwell & Van der Zwaan 2002 G. Rothwell & B. Van der Zwaan, Is Light Water Reactor Technology Sustainable?, SIEPR Discussion Paper Nr. 02-11, Stanford Institute for Economic Policy Research, Stanford University (Stanford, CA USA), September 2002 [http: //siepr.stanford.edu/papers/pdf/02-11.pdf]

Ryskamp 2003: J. Ryskamp (Idaho National Engineering and Environmental Laboratory), *Hydrogen Production from Nuclear Energy*, presented at the IEEE Power Engineering Society meeting (Sun Valley, ID USA), April 28, 2003 [http: //nuclear.inel.gov/papers-presentations/nuclear_hydrogen_3-3-03.pdf]

Schultz 2002: K. Schultz (General Atomics), *Efficient Production of Hydrogen from Nuclear Energy*, Presentation to the California Hydrogen Business Council, June 27, 2002 [http: //www.ch2bc.org/General %20Atomics/NuclearH2-27June02.pdf]

Shimizu et al 2001: S. Shimizu, et al., A Study on the Thermo-Chemical IS Process, in Nuclear Production of Hydrogen: First Information Exchange Meeting, Paris, France, October 2-3, 2000, OECD Nuclear Energy Agency (Paris), 2001

Shiozawa et al 2006: S. Shiozawa, M. Ogawa & R. Hino, Future Plan on Environmentally Friendly Hydrogen Production by Nuclear Energy, in Nuclear Production of Hydrogen: Third Information Exchange Meeting, Oarai, Japan, October 5-7, 2005, NEA-6112, OECD Nuclear Energy Agency (Paris), 2006

Simbeck & Chang 2002: E. Simbeck & E. Chang, Hydrogen Supply: Cost Estimate for Hydrogen Pathways – Scoping Analysis, NREL/SR-540-32525, National Renewable Energy Laboratory (Golden, CO USA), November 2002
[http: //www.nrel.gov/docs/fy03osti/32525.pdf]

Solomon & Banerjee 2004: B.D. Solomon (Michigan Technological University) & A. Banerjee (University of Delaware), A Global Survey of Hydrogen Energy Research, Development and Policy, US Society for Ecological Economics (USSEE) Working Paper (Duluth, MN), draft manuscript, April 26, 2004
[http: //www.ussee.org/working_papers/4wpssolomonhydrogen.pdf]

UIC 2005: Uranium Information Center, *Supply of Uranium*, UIC Nuclear Issues Briefing Paper Nr. 75 (Melbourne, Australia), September 2005
[http: //www.uic.com.au/nip75.htm]

US Army 2002: US Army, Operations in a Low-Intensity Conflict, FM 7-98, October 19, 1992

Vinjamuri 2004: G. Vinjamuri, *Development of US-DOT Regulations for Hydrogen Transportation Systems*, Research & Special Programs Administration, US Department of Transportation (Washington, DC USA), presented at the "Panel Forum on Challenges of Hydrogen Pipeline Transmission, International Pipeline Conference and Exposition" (Calgary, Canada), October 5, 2004
[http: //www.fitness4service.com/news/pdf_downloads/h2forum_pdfs/Vinjamuri-DOT.pdf]

Viswanathan 2004: S. Viswanathan (Loss Prevention Association of India Ltd.), *Risk, Modeling and Society*, TIFAC-IIASA Meet at New Delhi, India, October 25-26, 2004
[http: //www.tifac.org.in/news/eviiasa/T %20V %20Vishwanathan.ppt]

WEC 2001: World Energy Council (WEC), Survey of Energy Resources, online version, 2001
[http: //www.worldenergy.org/wec-geis/publications/reports/ser/foreword.asp]

Wikipedia 2006: Wikipedia, Sustainability, March 7, 2006
[http: //en.wikipedia.org/wiki/Sustainability]

WNA 2005 World Nuclear Association, *Transport and the Hydrogen Economy*, Information Paper Nr. 70 (London, England), October 2005
[http: //www.world-nuclear.org/info/printable_information_papers/inf70print.htm]

Wurster 2001: R. Wurster, *Hydrogen Activities in the European Union and Germany*, H2NET Symposium, June 13, 2001
[http: //www.h2net.org.uk/PDFs/RN_2/Hydrogen_in_Europe&Germany-09JUL2001.pdf]

12 Sustainability and the Production of Electricity by Nuclear Power Stations – The Legal Dimension

Manfred Rotter
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12 Sustainability and the Production of Electricity by Nuclear Power Stations – The Legal Dimension

12.1 Avant Propos

This analysis is performed on three levels. To begin with the term “sustainability” the problem of its substantiation within extra-legal normative systems is considered. The second level is dedicated to the discussion of “sustainability” in the field of public international law and the law of the European Community. On the third level the intrinsic incompatibility of electricity production by nuclear power stations with the principle of sustainability is derived from some examples of legal provisions on the licensing, the operation and the dismantling of nuclear power stations and the management of radioactive waste.

12.2 Law and Other Normative Systems

12.2.1 Law and Society

The legal evaluation of segments of societal reality is reduced to the dichotomy of “legal” and “illegal”. Even the most complex legal systems consist of nothing else but a hierarchically structured system of formalised criteria for “yes - no” and “if - then” decisions. The result of these decisions is linked to certain societal consequences, which are legally determined. We speak of legal consequences. In this context, one has to bear in mind, that legal systems are self-contained formal systems providing their own creation and their own abolition [Walter 1974][1].

They are linked to societal reality by the law making processes on the one and law enforcement on the other hand. The law making procedure however is of special importance, as it is the exclusive way for rendering legal relevance to societal demands for regulations. Societal demands that do not pass the membrane of law making, remain without legal relevance, no matter what imperative character, they may have - according to whatever value systems.

Another important societal function of a legal system is its creating predictability and by that security. Legal systems are carried by the expectation of all their actors, that the respective other actors will shape their behaviour according to the guidelines provided for in their provisions. Thus legal systems may be seen as mutually conditioned sets of commonly shared behavioural expectations [Luhmann 1993][2]. Deviating behaviour (i.e. illegal) is met by standardized sanctions, the execution of which is reserved to special authorities, endowed with the exclusive right to use force as ultimate ratio. Due to this enforceable general validity of law, the societal values incorporated in legal norms carry an enhanced importance and stability as compared to other values.

[1] See Robert Walter, Der Aufbau der Rechtsordnung, 2. Aufl. (1974), p. 13 ff.
[2] Especially Niklas Luhmann, Das Recht der Gesellschaft, 1. Aufl. (1993); ibid., Rechtssoziologie, 3. Aufl. (1987), passim, with further references.

12.2.2 Extralegal Normative Systems

Yet behavioural expectations are also created by other normative systems as e.g. custom, morals and other social conventions. Among the latter we may list the principles of environmental protection, which are carried by increasing though not unlimited consensus. These extra legal normative systems comprise those societal demands for regulation which have not - or not yet - passed the membrane into the contents of legal systems.

It is important however to distinguish clearly between legal and extra legal normative systems. They differ in their creation and in the formal quality of the sanctions against deviating behaviour. Legal systems are created by specially legitimated authorities according to a particular, formalised procedure. Extra legal normative systems arise from unspecified societal processes in various ways, without any formalised procedure.

Legal systems standardise and formalise sanctions against deviating behaviour. Their application is reserved to especially legitimated authorities, in order to secure the binding character of law even by force as a last resort.

Extra legal normative systems are not generally binding. Their sanctions are not standardised and their application and execution are left to the discretion of the actors of the system. Their consequences, however, may be more severe than legal sanctions, as for instance social isolation within a society or economic embargoes on the international plane[3].

12.3 The Operationalization of Sustainability

12.3.1 The Brundtland – Formula

The term sustainability seems to have been used as early as in the 18th century in German forestry suggesting the utilisation of forests in perspective of the needs of future generations [Deutscher Bundestag][4]. The current version of sustainability was coined in the Brundtland Report: “Sustainable development is a development that meets the needs of the present without compromising the ability of future generations to meet their own needs” [Report of the World Commission on Environment and Development][5]. Although phrased in the indicative, this sentence clearly has the marks of a postulation, of an imperative that is to say of a norm. A norm that belongs to an extra legal normative system, yet with the capacity of creating predictability in the sense given above.

The broad consensus, which carries this understanding of sustainability to a great extent, was facilitated by the ambiguity of its phrasing. Contents and set-up of the Brundtland Report[6] however clearly indicate its designation as a master plan for shaping nearly all fields of societies. The EU Commission too, in a proposal to the European Council emphasised: “Sustainable

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[3] E.g. UN Charter Art. 41.

[4] Wissenschaftliche Dienste des Deutschen Bundestages, Fact Sheet 06/2004, [www.bundestag.de/bic/analysen] visited: 28.10.2004.

[5] “Our Common Future”, Report of the World Commission on Environment and Development (Independent Expert Commission founded by the UN 1983) under the chairmanship of Gro Harlem Brundtland, UN-Doc. A/42/427, August 4 ,1987, p. 54.

[6] 12 Chapters with 336 pages. The topics covered range from “New Approaches to Environment and Development“ to “Conflict as a Cause of Unsustainable Development”.

development should become the central objective of all sectors and policies."[7] The forthcoming reviews of Common Policies must look at how they can contribute more positively to sustainable development. The fields covered by this paper therefore reach from Common Fisheries Policy (especially fish stocks management and protection of the maritime ecosystems) to the improvement of law making procedure in the European Communities in view of assessing the potential economic, environmental and social benefits and costs of action.[8]

The demand for sustainable development has numerous dimensions. That entails the necessity of its specification not just in general but according to the needs of the respective fields of its application.[9] The above mentioned origin of sustainability from forestry hints better than any other reference, that sustainability basically is a question of distribution of resources between the present and future generations. The operationability of such an understanding of sustainability requires however a renewable amount of resources, as in forestry. To distribute a limited amount of non-renewable resources between the present and future generations in a sustainable way will pose an unsolvable enigma, as the somehow assessable size of the present generation has to be confronted with the (hopefully) infinite chain of future generations.

12.3.2 Sustainability as a Paradigm for Distribution

Yet in the context of producing electricity from nuclear power it does make sense to deal with sustainability in view of the issue of resources sharing. The main resource, we have to deal with here is global environment, which basically has a self healing and self renewing capacity, but is structurally consumed and impaired by the operation of nuclear power stations. This is due to the inevitable emission of radiation in normal operation and the still unsolved question of permanently reposing (disposal)[10] of spent nuclear fuel and nuclear waste. A potential consumption and impairment of the environment lies in the possibility of grave nuclear accidents.

The reality of nuclear industry, by the way, proves the European Commission to be quite right in adding the field of law making (as shown above) to those to be considered in the context of enhancing sustainability. A good deal of the lacking sustainability of nuclear industry lies in the fact that its regulatory need is met exclusively by national legislation without serious institutionalized international control or control by the European Communities, so as if the consequences of nuclear accidents would stop at national frontiers.

12.3.3 Sustainability as Rule of Proportionality

We may hold at this point that sustainability is widely accepted as a socio-ethical norm and thus could well serve as a guiding line for forming future societies. And yet we have to realise that in its generality sustainability is a norm, whose normative value has to be established in the concrete circumstances. There is no universally valid concept of sustainability. It has to be enhanced with additional values and aims in order to be applicable to specific situations. To this end we also need a convincing definition of the "needs" of the present generation and the "abilities" and "needs" of the future generations.

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[7] A Sustainable Europe for a Better World: A European Union Strategy for Sustainable Development, COM (2001) 264 final, p. 6.

[8] Ibid.

[9] This is also reflected in the Proceedings of the International Law Association attempting to furnish sustainability with an international law dimension. The International Law Association, Report of the Seventy-First Conference (Berlin 2004), Committee on International Law on Sustainable Development p. 566-620, report p. 566-586.

[10] Different sources use different terms.

In other words, we are confronted with problems with no convincing solutions in sight. All we can do is to search with the best of our *present* abilities for ways of *approximating* plausible solutions for practically infinite times to come. Never the less it is urgent to set the ground for conceiving convincing *methods* for at least developing eventually satisfying solutions.

The normative character of the principle of sustainability referred to above suggests an approach to the problem of its operationability with normative reasoning. Sustainability provides the inseparable dependence of the future generations on the existing present generations, yet without any standing for claiming whatever rights they may have. A truism of course, as only those who exist are in a position to lay claims. The principle of sustainability is a norm of self restraint with only virtual claimants. Yet in order to make sense, even such a unilateral social norm requires to be applicable to individual cases, which requires operationability.

This could be achieved by analogy to the principle of proportionality as laid down for instance in the Treaty on European Community (EC), which deals with a comparable situation, as it seems. Its aim is to prevent the EC from taking more legal competences from its Member States than is absolutely necessary for achieving the goals of the EC. The principle of sustainability on the other hand is to prevent the existing generations from consuming an excess of natural resources at the expense of the future generations.

Against this background the principle of sustainability in the field of energy production could be operationalized as follows:

The present generation's demand for energy is to be kept as moderate as possible and should be covered with the least possible expense of resources and at the least possible environmental costs. According to the principle of real cost assessment the burdens of energy production are to be met by those generations exclusively, which take advantage of it. [fn.58][11]

This solution of the dilemma of operationalizing the principle of sustainability would also easily fit into the range of the objectives of EC environmental policy.[12]

12.3.4 Sustainability as Global Conviction

Notwithstanding the difficulties of specifying the term sustainability it was introduced into two meanwhile historic final declarations of international UN conferences on environment. In the Rio Declaration on Environment and Development [Report of the UN Conference on Environment and Development][13] sustainability is understood as a human right to "a healthy and productive life in harmony with nature" (Principle 1) and environmental protection is considered the central element of sustainable development (Principle 4). In order to secure sustainable development: "States should reduce and eliminate unsustainable patterns of production and consumption and promote appropriate demographic policies" (Principle 8).

[11] See also below at fn. 58 and the Argumentarium of the German Federal Government about Sustainability in context with the so called "Ausstieg aus der Atomenergienutzung",
[http: //www.bmu.de/de/1024/js/download/b_nachhaltigkeit_kernenergie] (visited: 28.10.2004).

[12] Art. 174 EC Treaty.

[13] Annex I to the Report of the UN Conference on Environment and Development (Rio de Janeiro, June 3-14, 1992).

The next UN summit on development in Johannesburg (August 24 till September 4, 2002) was already named "World Summit on Sustainable Development".[14] The measures adopted during its course reveal a specification of the policy of sustainability towards the global raising of the lowest social levels of sanitation-, water-, health- and energy-supply. Commitments to combat desertification, to reduce biodiversity loss, activities to improve access to the markets for the Least Developed Countries and measures to improve their management of natural disasters round off the concept of sustainability of the Conference. Even there a definition of sustainability was avoided.

The final declarations of both Conferences are of national and international political significance though not legally binding. They reflect however the global consent over the indispensability of a policy of sustainability.

12.4 Sustainability as Legal Norm

12.4.1 The UN Framework Convention on Climate Change

The multilateral UN Framework Convention on Climate Change 1992[15] was concluded in the realm of the Conference of Rio. It is in force since March 1994[16]. The Framework Convention seems to be the first international treaty to contain "sustainability" in varying contexts as substantial part of international legal regulations. The measures to be taken by the parties to the Convention in order to prevent dangerous anthropogenic interference with the climate system for instance should allow for "the economic development to proceed in a sustainable manner"[17]. In the broad spectrum of the numerous commitments undertaken by the parties to the Convention sustainability repeatedly is referred to as decisive specification of the measures required by the Convention.[18] This is of special significance as the Convention contains various provisions on reviewing and controlling the implementation of the commitments undertaken by the parties[19] and on dispute settlement[20] including the possibility of submitting disputes to instances of arbitration or even the International Court of Justice. The parties to the Convention thus indicate their intention to accept sustainability in its respective specification at least as potential criterion for solving legal disputes.

The necessity of specifying sustainability for each individual case, as said above, still remains of course. The Convention however paved the way for eventually specifying "sustainability" by legal (in the sense of the Convention) authorities, with legal relevance for the given case before it. It is quite common that the legislator leaves the specification of substantially difficult or just controversial terms to the wisdom of the ensuing legal practice of administrative authorities or courts of justice. We speak of the so called "unbestimmte Gesetzesbegriffe" (indeterminate legal

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[14] Final Report (incl. Corrigendum) [http: //www.johannesburgsummit.org/html/documents/documents.html] (visited: 28.10.2004).

[15] United Nations Convention on Climate Change, (31 International Legal Materials (ILM) 1992, p. 851, [http: //unfccc.int/resource/docs/convkp/conveng.pdf] (visited 21.11.04).

[16] BGBl. 414/1994; BGBl. III 12/1999.

[17] Art. 2

[18] Art. 4

[19] Art. 7 - 10

[20] Art. 14

terms)[21]. As “sustainability” is also twice referred to in the preamble of the Convention it gains additional legal quality as guidance for interpreting its provisions in case of doubt, according to the international law of treaties.[22]

12.4.2 The Kyoto Protocol

The so called Kyoto Protocol[23] even more elaborates on sustainability. It is based on the above presented Framework Convention and was signed by the majority of its parties on December 11, 1997. The protocol is in force[24] since February 12, 2005, as it was approved by both houses of the Russian parliament on October 27, 2004.[25]

The Kyoto protocol provides the reduction of the carbon dioxide emission of its parties according to individually assessed quotas for each of them, with the possibility of trading the quotas. What interests here, is the fact that after its entering into force, those of its provisions referring to sustainability as legal criterion become applicable too. The whole amount of commitments listed in Art. 2 is intended “to promote sustainable development.” To this end we find in Para. 1, lit a ii “promotion of sustainable forest management practices, afforestation and reforestation” and in lit a iii “promotion of sustainable forms of agriculture in the light of climate considerations”. The control of the compliance with the various provisions of the Protocol including the application of the elements of sustainability is vested with the conference of the Parties to the Protocol[26]. Similar to the above mentioned Framework Convention the measures of dispute settlement under the Protocol may also comprise authorities or courts of arbitration or even the (UN) International Court of Arbitration. In other words, both international treaties, the Convention and the Protocol provide the legal norms as well as the procedure, to give sustainability a genuine legal quality.

12.4.3 Sustainability in the Law of the European Community

We find the term “sustainability” in the wide meaning, as shown above in the Treaty Establishing the European Community (TEC) in various places. Art. 2 lists “balanced and sustainable development of economic activities” and “sustainable and non-inflationary growth” among the other tasks of the Community.

In Art. 6 “the promoting of sustainable development” is made an integral aim of integrating environmental protection requirements into the definition and implementation of Community policies...”. Thus “sustainability” is made an integral part of common environmental protection, although it is neither expressively referred to among its objectives in Art. 174 nor in the operational regulations of Art. 175. As the requirements of environmental protection have to be observed in all other fields of Community tasks sustainability has, or at least will, become a key paradigm for

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[21] As for instance “Einbruch der Dunkelheit“ (beginning of darkness); Reinhold Zippelius, Juristische Methodenlehre, 6th Ed. (1994), p. 43 et seq.

[22] Vienna Convention on the Law of Treaties, Art. 31 Para 2. See Alfred Verdross - Bruno Simma, Universelles Völkerrecht, 3rd Ed. (1984), p. 492

[23] Kyoto Protocol to the United Nations Framework Convention on Climate Change (1997), 37 ILM 1998 p. 22.

[24] According to its Art. 25 the Kyoto Protocol enters into force after the ratification by at least 55 Signatories or more until the ratifying parties together account for more than 55,5 % of the global carbon dioxide emission.

[25] “Russisches Oberhaus verabschiedet Kyoto Protokoll“ [http: //www.welt.de] (visited: 27.10.2004).

[26] Art. 13. and additional institutional provisions Art. 14 to Art. 19.

Community policies. It is or will increasingly become part of what doctrine calls a cross-section matter.[27]

In the realm of third world politics and development co-operation "sustainability" is an explicit aim of common development policy. According to Art. 177, the Community fosters "the sustainable and social development of the developing countries, …".

Sustainability as part of environmental protection was also introduced into the "Charter of Fundamental Rights of the Union". Art. 37 reads: "A high level of environmental protection and the improvement of the quality of the environment must be integrated into the policies of the Union and ensured in accordance with the principle of sustainable development." The Charter of Fundamental Rights is not part of the existing Community law but it should be taken into consideration as guiding line for its enacting, administration and interpretation. It was increasingly referred to in the judgements of the European Court of Justice[28] and the Court of First Instance[29].

Meanwhile the Charter of Fundamental Rights was made part of the Draft Treaty establishing a Constitution for Europe, signed on October 29, 2004. If the European Constitution should ever enter into force against all odds,[30] the right to environmental protection in accordance with the principles of sustainable development Art. II-97 not only will become part of existing law but also an individual right of the European citizens, however only within the still weak competences of the EC in environmental policy. [31]

12.4.4 Provisionary Outlook

We may conclude this chapter with the following resumé: Sustainability is a practicable item for legal systems. As far as now, we have no convincing indicator though, that it has already become part of international customary law. The examples of the two international treaties show however, that sustainability may very well be litigable, once the respective authorities are established.

Under EC law "sustainability" is established without doubt as one of its numerous operational components. The necessary legal requirements are prepared. Only the facts for respective cases are lacking. That is the reason for the absence of administrative and judicial practice.

Both in international law as well as in Community law it will rest with the deciding administrative or judicial authorities to specify "sustainability" for each individual case.

It has to be warned however against too high expectations. All that can be said now[32] is that sustainability has been made part of legal norms. Whether a given situation, even if considered

[27] Rudolf Streinz, Europarecht, 7th Ed. (2003), RZ 1113 uses the term cross-section clause.

[28] See e.g. the opinions of Attorney-General Juliane Kokott of October 14th, 2004, Joint Case C-387/02, C403/02, Silvio Berlusconi et al., not yet in ECR.

[29] Case T-177/01, Jégo-Quéré/Kommission, ECR 2002, II-2365 (para. 47), Case T-54/99, max.mobil Telekommunikation Service GmbH/Kommission der Europäischen Gemeinschaften, ECR 2002, II-313 (para. 48).

[30] As a consequence of the negative referendums in France (May 29, 2005) and the Netherlands (June 1, 2005) the project of a European constitution failed, as its Art. IV-477 requires the constitutional assent of all member states.

[31] The present role of sustainability in existing Community law will remain unaltered under the new European Constitution with a good chance of even gaining importance.

[32] February 16, 2006.

to be a grave nuisance, can successfully be brought before administrative tribunals or courts of law, depends on its specification for the given circumstances. The many dimensions of sustainability leave the addressed legal authorities with a wide range of creative discretionary power for interpretation. In a legal dispute however, the interpretation of sustainability lies in the competence of the deciding authority exclusively. Sustainability as legal term is neither at the disposal of the parties to a dispute nor the general public. Outside legal systems “sustainability” is an object of public discourse either in general or focused on a given situation.

This is important to stress in application to the question of sustainability of nuclear power stations. If we are able to prove sustainability to be a substantial element of an existing legal norm with appropriate jurisdiction of administrative or judicial authorities, we have a chance of initiating legal procedure, provided we are able to present the necessary evidence for its violation.

As long as the question of sustainability of nuclear power stations remains on the societal, the political plane, we are in an endless chain of political arguments and disputes over the real, the ultimate concept of sustainability.

This structural dichotomy between the legal and the purely societal plane of dealing with the problems of nuclear politics accounts for the reluctance of the governments of nuclear power states to enter into binding legal agreements restricting their freedom of choice.

12.5 The Licensing of the Construction and the Control of the Operation of Nuclear Power Stations as Prerogative of the Individual State

12.5.1 The Convention on Nuclear Safety

1996, ten years after Chernobyl (!) the Convention on Nuclear Safety (1994) entered into force.[33]

Its paramount goal is “to achieve and maintain a high level of nuclear safety world wide”.[34] In the perspective of this analysis it is significant, that the Convention reaffirms “that responsibility for nuclear safety rests with the State having jurisdiction over a nuclear installation”.[35] Consequently almost every article begins with the stereotype “Each Contracting Party shall....”. The ensuing commitments are so common, trivial and unspecific, that 50 years after the construction of the first nuclear power stations they must have been fulfilled by the Parties before signing the Convention.[36] The accomplishment of the safety standards is left entirely to the Parties of the Convention. Occasionally the national safety standards are referred to. Art. 14 for instance amongst others provides that the surveillance of the operation of nuclear power stations ensures, that they continue “to be in accordance with its design, applicable national safety requirements, and operational limits and conditions. Even in the context of radiation protection of workers and the general public it is the “prescribed national dose” that is referred to as limits.[37] All these are

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[33] Text in [http: //www.iaea.org/Publications/Documents] Though the Convention was drafted and signed under the auspices of the IAEA, it is not an IAEA Convention in the strict sense of the word.

[34] Art. 1

[35] Preamble Pt. iii

[36] Otherwise the Convention certainly would not have been concluded at all.

[37] Art. 15

no editorial flaws but the expression of the clear will of the contracting Parties. The preamble makes clear, that "this convention entails a commitment to the application of fundamental safety *principles* for nuclear installations rather than of detailed safety *standards*"[38]. Maybe as a kind of relief this paragraph continues with the reference "to internationally formulated safety guidelines, which are updated from time to time". All this would be quite tolerable, if the Convention created a regulatory body in charge of specifying its rather general provisions in the individual cases. But that is not the case. The review of the compliance with the Convention is assigned to Review Meetings of the Contracting Parties, which decide by consensus[39].

The Convention of course had to deal with the possibilities of nuclear accidents. The Parties are aware, "that accidents at nuclear installations have the potential for transboundary impacts".[40] In Art. 18 they are just committed to ensure, that nuclear installations are designed and constructed "with a view to preventing the occurrence of accidents and to mitigating their radiological consequences, should they occur." As easy as that!

No doubt, the nuclear power states were quite successful in preserving the exclusiveness of their competence to regulate their nuclear economy according to their own interests.

12.5.2 The European Atomic Community (EAC)

An analysis of the law of the EAC results in a similar, yet slightly more differentiated picture. Still there is no community wide regulatory standard for the nuclear industry binding all 27 Member States equally. Only the new states had to accept a review of their all ready existing nuclear power stations by the EU Commission as a prerequisite for their admission to the Union. The enlargement procedure thus forced the question of nuclear safety to the Community plane, what was carefully avoided till then since the establishment of the EAC. After preparations under the Austrian Presidency[41] the Cologne summit for the first time considered to raise the safety standards of the nuclear power stations in the accession states to the European level: "The European Council emphasises the importance of high standards of nuclear safety in Central and Eastern Europe. It stresses the importance of this issue in the context of the Union's enlargement and calls on the Commission to examine this issue thoroughly in its next regular progress reports on the applicant countries, due in autumn 1999"[42]. From then on, the question of nuclear safety in the context of the enlargement of the Union gained separate dynamics. The dispute between the Czech Republic and Austria over the nuclear power station in Temelín too was and still is carried by that dynamics.

The European Council of Laeken extended the concern about nuclear safety beyond the acceding states over all nuclear installations in the EU: "The European Council undertakes to maintain a high level of nuclear safety in the Union. It stresses the need to monitor the security and safety of nuclear power stations. It calls for regular reports from Member States' atomic energy experts, who will maintain close contact with the Commission".[43]

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[38] Pt. vii

[39] Art. 22 - 25

[40] Preamble Pt. v

[41] See Council, 24 September 1998.

[42] European Council of Cologne, 3/4 June 1999, Presidency Conclusions; see also European Council of Helsinki, 10/11 December 1999, Presidency Conclusions, para. vii.

[43] European Council of Laeken, December 14/15, 2001, Presidency Conclusions, para. 59.

The Commission started extensive activities to introduce common standards for nuclear safety for all EU states[44] and presented two proposals for Directives dealing respectively with the safety of nuclear facilities and the management of spent fuel and radioactive waste. These initiatives failed. The "powerful nuclear industry"[45] could relax. Looking back, the substance of these two proposals did not warrant hopeful expectations. The proposal for a "Council Directive (Euratom) laying down basic obligations and general principles on the safety of nuclear installations"[46] in general does not exceed the standards of the Convention on Nuclear Safety, mentioned above. Still, two elements deserve attention.

First, the proposal also covered the implications of the closure and dismantling of nuclear power stations[47]. Of course the various concepts - legal or extra legal - of nuclear safety indirectly comprised these implications. Yet they were never dealt with as separate area for regulation. The necessity to do so, arose from the imperative need to close down and dismantle several sub-standard nuclear power stations in the acceding former communist states. One of the various practical tasks to be accomplished in this process was that of funding.[48] The total costs of closure, dismantling and reconditioning of the site are estimated to 15 % of the original investment. In absolute figures that may amount to 200 Millions to 1 Billion Euro.[49]

Second, the national regulatory bodies were to be submitted to the control by the Commission. To this end the Commission was to avail itself of an expert council the members of which were to be nominated by the member states. This had been a great procedural progress, although the main responsibility for securing the compliance of the nuclear industry with the still national safety regulations remained with the national regulatory bodies. The even greater advantage had lain in the fact, that questions of the safety of nuclear installations had become litigable before the European Court of Justice.

In 2004 the Commission again presented revised versions of the two proposals. The amended proposal for a "Council Directive (Euratom) laying down basic obligations and general principles on the safety of nuclear installations"[50] now is completely reduced to the low standard of the Convention on Nuclear Safety. The reference to the problems of closing down and dismantling outdated nuclear power stations was eliminated as well as the supervision of the national regulatory bodies by the Commission. What is left as a last trace of makeshift control is a Committee of Regulatory Authorities composed of *representatives* (!) of the national regulatory bodies for advising the Commission and among other things for summing up the annual reports to be sent in by the member states.[51] The Commission has no material authority what so ever over the

[44] With further references Manfred Rotter, Nukleare Sicherheit in der Europäischen Union, in Christian Callies (Hrsg.), Der Konventsentwurf für eine EU-Verfassung im Kontext der Erweiterung: Vorträge des Dritten Österreichischen Europarechtstages am 12./13. September in Graz, organised by the Institute for Community Law at Karl-Franzens-Universität Graz, 1. Ed. (2004).

[45] In line with the generally shared convictions of 1957, one of the aims of EAC Treaty was "to create the conditions required for the development of a powerful nuclear industry which will provide extensive supplies of energy, lead to the modernisation of technical processes and in addition have many other applications contributing to the well-being of their peoples,..." (Preamble, para. 4).

[46] COM (2003) 32. The proposal for a "Council Directive (Euratom) on the safe management of the spent nuclear fuel and radioactive waste" in the same document is mentioned here without further comment.

[47] Art. 4

[48] Art. 9, para. 2.

[49] COM (2002)605 final, p. 2 et seq.

[50] COM (2004)526 final.

[51] Art. 12

national regulatory bodies. There seems to remain a vague though possibility of jurisdiction of the European Court of Justice for matters of the safety of nuclear power stations if they amount to a breach of the directive.

In short, the nuclear power states preserved their exclusive authority over the nuclear industry under their jurisdiction. The security requirements in the Convention on Nuclear Safety are far too general to offer quantifiable or otherwise specified criterions for assessing the safety status of a given nuclear installation. The quite impressive first attempt of the Commission to bring the question of the safety of nuclear installations to the Community level failed. The chances of the second substantially milder attempt are open.

12.6 The Provisions for Permanent Repositories (disposal facilities)

Of course the chemical and physical requirements of the permanent reposition of the spent nuclear fuel and highly radioactive waste are known and recognised on the national, the international and the level of EU and its Communities. However, the gathering of the respective scientific findings is one thing, the preparation of the necessary legal regulations, the creation and funding of institutions for coping with their organisational consequences is quite another.

12.6.1 The Spent Fuel and Radioactive Waste Convention

This highly important aspect of the nuclear industry is covered by the Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management also drafted under the auspices of the IAEA[52]. The problems of spent fuel management are dealt with in Art. 4 to 10 and those of the safety of radioactive waste management are dealt with in Art. 11 to 17. Then follow regulations common to both parts and some rather weak provisions on compliance control[53]. Within these two main areas of regulations a difference is made between installations for spent fuel management and radioactive waste management respectively on the one side and permanent reposition (in terms of the Convention “disposal”) on the other. Installations for the management of spent fuel and radioactive waste are dealt with in more details than those for the permanent reposition. Clearly enough disposal[54] (permanent reposition) does not require specially elaborated rules for “operating” or “decommissioning”, once the installations are filled and closed[55]. Yet it is exactly the finality of the reposition that requires special regulations for siting and constructing the respective installations and the emplacement of nuclear waste. These requirements are not met at all, as will be shown below.

The Joint Convention like the Convention on Nuclear Safety follows the principle that every state itself has to provide all that is necessary for the management of spent fuel and radioactive waste of nuclear installations on its territory. That comprises the definition of safety standards

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[52] Text at [http: //www.iaea.org/Publications/Documents/Conventions] (visited: 28.10.04).

[53] They follow the pattern of the Convention on Nuclear Safety.

[54] According to Art. 2 lit. (d): “disposal means the emplacement of spent fuel or radioactive waste in an appropriate facility without the intention of retrieval; ” while according to lit. (t): “storage means the holding of spent fuel or radioactive waste in a facility for its containment, with the intention of retrieval“.

[55] According to Art. 2 lit. (g): “operating lifetime means the period during which a spent fuel or a radioactive waste management facility is used for its intended purpose. In the case of a disposal facility, the period begins when spent fuel or radioactive waste is first emplaced in the facility and ends upon closure of the facility“.

within its own legal system (Art. 18 and 19), to establish regulatory bodies entrusted with the implementation of these standards (Art. 20), to ensure the necessary human and financial resources (Art. 22) as well as radiation protection (Art. 24), to name the most important items only. Specific standards in terms of borderline limits are explicitly avoided. All that is required to "provide for effective protection of individuals and society and the environment by applying at the national level suitable protective methods…" with due regard to "internationally endorsed criteria and standards" (Art. 4, para. 2, lit. iv).

It certainly is a good idea that already at the design state of a disposal facility (permanent repository), the technical provisions for its closure must be prepared (Art.14, lit. iii) and that before its construction a systematic safety assessment and an environmental assessment for the period following closure shall be carried out according to the criteria established by the regulatory body (Art. 15, lit. ii).

The problem, however, is that the main intention of the authors of the Joint Convention was to leave the autonomy of its parties for dealing with spent fuel and radioactive waste including its disposal (permanent reposition) should remain untouched. That may easily be deduced from the fact, that the normative implications of the "closure" of a disposal facility practically are hidden in Art. 2, lit. (a), dealing with definitions. It reads: "*closure* means the completion of all operations at some time after the emplacement of spent fuel or radioactive waste in a disposal facility. This includes final engineering or other work required to bring the facility to a condition that will be safe in the long term."

What measures are to be taken in reality to meet these ends and for how long a term, is left open in the definition and elsewhere in the Joint Convention. And yet, Art. 22, lit iii prescribes that "financial provision is made, which will enable the appropriate institutional controls and monitoring arrangements to be continued for the period deemed necessary following the closure of a disposal facility".

With all these provisions the Joint Convention proves the predicament the nuclear power states moved themselves into rather than to offer practicable solutions on the international plane. It is one thing to realize that there is no alternative to permanent reposition (disposal), and quite another to find physically and societal suitable sites. The choice of reconditioning spent fuel only postpones the problem and generates new ones.[56]

The commitment – or just appeal (?) – to strive "to avoid actions that impose reasonably predictable impacts on future generations greater than those permitted for the current generations...and to avoid imposing undue burdens on future generations" [Art. 4; Art. 11][57] illustrates the dilemma even more. For this reference to sustainability[58], it makes sense only if there was a reasonable choice, which there is not. The somewhat unorganic introduction of "sustainability" into the context of the Joint Convention makes it difficult to avoid the impression, that it is primarily used as a lip service and not really taken seriously.

[56] Preamble, para. vii "Recognizing that the definition of a fuel cycle policy rests with the State, some States considering spent fuel as a valuable resource, that may be reprocessed, others electing to dispose of it."

[57] Art. 4, para. 2, lit. vi and vii and identical Art. 11, para. 2, lit. vi and vii.

[58] See above at fn. 11.

12.6.2 Proposal for a Council Directive 2004

The amended proposal for a Council Directive (Euratom) on the safe management of spent nuclear fuel and radioactive waste[59] does not go beyond the Joint Convention just dealt with. The Commission does not even try to conceive regulations of a higher complexity in accordance with the higher integrational density of the EAC with its 27 members as compared to the Joint Convention addressing an open number of State parties to it without institutionalising ties. That is to say that even within a highly integrated international organisation as the EAC the nuclear power states are left unimpaired in their splendidly exclusive autonomy of regulating the nuclear industry under their jurisdiction.

Also the Commission starts from the assumption that, on the basis of present knowledge, there is no conceivable alternative to "geological disposal" of "long-lived radioactive waste."[60] It is left to the Member States to study the possibility to give priority to the solution of deep geological disposal[61], considering their specific circumstances (Art. 4, para. 1, sub para. 2). The Member states are to ensure public information on the measures to be taken and the state of progress of the decision-making process, notably as regards the disposal sites (Art. 3, para. 5). Suitable timetables should be set up, to support the solution of the nuclear waste problem (Art. 5). As to the control system the Commission explicitly resorts to the system of the Joint Convention (Art. 7 and 8). It clearly was the firm intention of the Commission not to commit the EAC Members beyond the standards of the Joint Convention.

12.6.3 The 10,000 Years Limit and the Yucca-Mountain Case

The "Radioactive Waste Management Committee" of the Nuclear Energy Agency (NEA) of the OECD and the (German) Society for Installations and Reactor Safety (GRS) have issued collections of national regulations on the designing of permanent repositories (disposals)[62], which need not be dealt with here in greater detail. What does interest here however is the fact, that most of the national regulations prescribe a control period for permanent repositories of ten thousand years.[63] The EU Commission in a respective recommendation suggests the same period of time.[64]

On closer look this control period of ten thousand years is just an arbitrary assumption. Two elements among the materials to be deposited, the Neptunium-237 has a half life of more than 2 million years and the Iodine-129 a half life of 17 million years.

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59 COM (2004)526 final.

60 Reason 17.

61 The definitions correspond to those of the Joint Convention.

62 "The Regulatory Control of Radioactive Waste Management - Overview of 15 NEA Member Countries", NEA/RWM/RF(2004)1, 13.02.2004 [http: //www.nea.fr/html/rwm/docs/2004]; and "Zusammenstellung internationaler Kriterien zur Bewertung und Auswahl von Standorten für die Endlagerung von radioaktiven Abfällen in tiefen geologischen Formationen", GRS-A-2834, Jänner 2001.
[http: //www.akend.de/aktuell/berichte/berichte_an_akend.htm] (visited: 28.10.2004)

63 For instance France "Règle fondamentale de sûreté (RFS) III.2.f" der L' Autorité de sûreté nucléaire (ASN); or Sweden "The Swedish Nuclear Power Inspectorate's Regulations concerning Safety in connection with the Disposal of Nuclear Material and Nuclear Waste", SKIFS 2002: 1 [http: //www.ski.se/page/5/22.html?29044] (visited: 28.10.2004)

64 Endlagerung radioaktiver Abfälle – Empfohlene Kriterien für die Standortwahl eines Endlagers, Serie "Euradwaste" Nr. 6, EUR 14598, 1992.

All this has become notorious in the Yucca Mountain Dispute by the judgement of the US Court of Appeals for the District of Columbia Circuit of July 9, 04[65].The Yucca Mountains are in Nevada 150 odd km north west of Las Vegas. They are chosen as disposal site for the highly radioactive nuclear waste of the entire USA (till 2003 40 thousand tons). The central issue among the numerous legal questions before the Court was the decision of the Environmental Protection Agency (EPA), a Federal Authority, to limit the compliance time for the disposal site at 10 thousand years. According to the regulations[66] to be followed by the EPA it should have accepted an expertise by the National Academy of Science (NAS). The compliance time is that period for which the natural and organisational qualities of the disposal site warrant that virtual persons in a given perimeter around the site are exposed to acceptable radiation only. The NAS had demanded a compliance time beyond the peak of radiation of the materials disposed. The EPA however intentionally did overrule the NAS expertise, with the argument, that it could not see much sense in extending the horizon of institutional planning beyond 10 thousand years.

For these here highly simplified reasons the Court finally arrived at the decision: "In sum, because EPA's chosen compliance period sharply differs from NAS's findings and recommendations, it represents an unreasonable construction of section 801(a) of the Energy Policy Act".[67]

This judgement is a severe set back for the EPA and all the other federal authorities involved and above all for the nuclear industry. Nevertheless the original idea of submitting the case to the US Supreme Court[68] for final decision was dismissed. The judgement of the US court of Appeals for the district of Columbia Circuit of July 9, 2004 became final.

Still, the Yucca Mountain Judgement is of crucial importance for the sustainability issue. It reveals in contentious procedure before an independent court of the greatest nuclear power in world the central structural weakness of the nuclear industry: the unsolvable problem of the permanent reposition of highly radioactive nuclear waste.

Thinking of the fact, that the period of written human history covers about five thousand years, the requirement of disposing spent nuclear fuel and radioactive nuclear waste for several million years, ridicules all conceivable concepts of sustainability. This disproportion is even enhanced by the planned legislative measures for saving the Yucca Mountain permanent repository. The allowed maximum radiation emanating from the repository for persons at a distance of 11 miles is to be provided for the first ten thousand years with 15 millirem annually and for the next 990 thousand years with 350 millirem.[69] Legislation and administration for the next million of years! An ordinary case of strictly normal madness.

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[65] Opinion No. 01-1258
[http: //pacer.cadc.uscourts.gov/docs/common/opinions/200407/01-1258a.pdf]
(visited: 28.10.2004). The half lives given above are on p. 6 of the judgement.

[66] Mainly the Energy Policy Act of 1992, H.R.776, Pub. L. 102–486.

[67] Yucca Mountain-Judgement p. 31.

[68] For further information see
[http: //www.reviewjournal.com] of September 16, 2004 ("Yucca Mountain Project: U.S. Supreme Court intervention sought") and
[http: //www.yuccamountain.org/court/lawsuits.htm]

[69] Las Vegas Review Journal Oct. 12, 2005
[http: //reviewjournal.printthis.clickability.com]

12.7 Germany's Renunciation of Nuclear Energy

For all these reasons the Red - Green Coalition Government and the parliament of the Federal Republic of Germany have drawn the sole conceivable consequence that is to renounce the "Kernenergienutzung zur gewerblichen Erzeugung von Elektrizität"[70]. That of course does not relieve Germany from the necessity to provide permanent reposition (disposal) for the hitherto and still in the transitory period generated spent nuclear fuels and radioactive waste. From 2005 on, the criteria for the selection of the disposal site are to be enacted. Upon that the procedure of the actual selection is to be initiated. Meanwhile the deposit for covering possible damages was raised to 2.5 Billions Euro for each nuclear power station, that is ten times of the original amount [dt. Bundesumweltministerium][71]

Without further details, the Federal Republic of Germany is the first state[72], to draw the consequences from the evident incompatibility of nuclear industry with the principles of sustainability.

The general elections of September 18, 2005 did not lead to a substantial change of that line of energy policy, because the partners in the new coalition government were unable to reach agreement on a new concept for NPP policy.[73]

12.8 Conclusions

This analysis based on several key documents beyond any doubt shows that electricity production by nuclear power plants is in clear and indisputable conflict with the principles of sustainability. The economic use of nuclear energy entails risks, which in themselves create demands for legal regulations, which surmount the capacities of the individual national legal systems, which leaves the nuclear industry a comfortably wide range of autonomy. The nuclear power states therefore evade all efforts to enact legal provisions for the use of nuclear energy above the national level, be it on the plane of public international law or within the EAC, in order to supplement and control the national legal systems in this field. The presented international treaties and proposals for EAC Directives on purpose do not exceed general principles. The paramount object of the governments of nuclear power states is to preserve their exclusive regulatory authority for their nuclear industry under as tight as possible exclusion of foreign supervision. That line is also reflected in the very restrictive provisions in bilateral international treaties on the mutual

[70] "The use of nuclear energy for the industrial production of electricity" German BGBl. I 26/2002 (in force since. April 27, 2002).

[71] Information of the German Federal Ministry of Envoirment
[http: //www.bmu.de/de/1024/js/sachthemen/atomkraft/kurzinfo/] (visited: 28.10.2004)

[72] Earlier decisions by Sweden (1980) and Italy (1990) to renounce nuclear energy as source for the production of electricity were based on other arguments, not explicitly on the conflict with the principles of sustainability.

[73] "Gemeinsam für Deutschland. Mit Mut und Menschlichkeit. Koalitionsvertrag von CDU,CSU und SPD"
[http: //www.spd.de/servlet/PBIshow/1589444/1105_Koalitionsvertrag]

information of nuclear accidents[74] and also in the not yet successful attempts to limit the liability for nuclear accidents by international treaties.[75]

The inevitable dilemma of the regulatory deficit of nuclear industry is topped by the fact, that roughly 60 years after the first nuclear power stations were put into operation there still is no solution for the problem of permanently repositing nuclear waste. Its time dimension of more than one million years ultimately proves the inherent incompatibility of the production of electricity by nuclear power with the principles of sustainability.

12.9 Summary

- The term "sustainability" as used in the *Brundtland* formula needs concretion in order to be applicable to specific problA parties, when signing the agreement.

- The core of the applicability of the principle of sustainability lies in an extended redistribution syndrome in the context of the succession of generations. Thus, it is well suited for being resorted to in the field of producing electricity by nuclear power stations, which in fact is a question of distributing the asset "environment" and the burdens of nuclear energy production among the present and the coming generations.

- In the context of energy production the principle of sustainability could be read as: The present generations demand for energy is to be kept as moderate as possible and should be covered with the least possible expense of resources and at the least possible environmental costs. According to the principle of real cost assessment the burdens of energy production are to be met by those generations exclusively, which take advantage of it.

- Public International Law (especially international treaties) and Community Law show promising items with plausible procedural elements for giving the principle of sustainability legal relevance. Yet here too concretion is required for its applicability in individual cases. It must be warned however against exaggerated expectations and hopes.

- The (IAEA) Convention on Nuclear Safety entered into force ten years after Chernobyl and 40 years after the first nuclear power stations were put into operation. Its contents gives the impression of only those provisions being agreed upon, which were already fulfilled by its parties, when signing the agreement.

- Specific safety standards were intentionally avoided. Only security principles were accepted with vague references to unspecified safety standards, which are to be revised according to the scientific development.

[74] Not covered here. C.f. Manfred Rotter, Rechtsfragen eines künftigen Tschechisch-Österreichischen Abkommens betreffend gemeinsame Interessen im Bereich der nuklearen Sicherheit und des Strahlenschutzes (Final Report in 2 Volumes); Internal Publication (2002).

[75] Not covered here. C.f. Karl Arlamovsky, Sind Kernkraftwerke aus rechtswissenschaftlicher Sicht ein Beitrag zur nachhaltigen Entwicklung gemäß Art. 12 Kyoto-Protokoll?, in Kernenergie, Klimaschutz und Nachhaltigkeit, Ein Argumentarium zur Vorbereitung der COP6 (Manuscript).

- In the field of nuclear industry the legislative autonomy of the nuclear power states remains untouched. A supervision of the compliance even with the safety principles only is restricted to a system of tri-annual reports presented by the states to a tri-annual Review Meeting of the Member States.

- Impressive attempts by the EU Commission to establish Community wide safety standards for nuclear power stations failed, although they did not exceed the standards of the (IAEA) Agreement already accepted by the EU Member States. It contained however a lean but promising system of supervision and provisions for the dismantling of used nuclear power stations. The real advantage of this attempt had been the implicit establishment of the jurisdiction of the EAC and especially the European Court in matters of safety standards for nuclear power stations.

- The second, substantially milder attempt by the EU Commission again does not exceed the (IAEA) Agreement. The former promising provisions on a system of supervision, too, were reduced to the report standard of the (IAEA) Agreement. The provisions on the dismantling of nuclear power stations were completely omitted. A minimum competence of the EAC and the European Court may be preserved, if this Proposal for a Directive would ever be enacted.

- The costs of the dismantling of nuclear power stations, according to estimates by the EU Commission amount to 15 % of the total original investment, which equals in absolute numbers between 200 Million and 1 Billion Euro each. These costs arise after closing the power station, i.e. after producing electricity and after procuring income. Considering the originally planned life span of 40 years of nuclear power stations, we already now face the problem of cost shifting to generations, which are not benefiting from them.

- The security of permanent national repositories for spent nuclear fuel and high-level radioactive waste for the coming ten thousand years exceeds the capacity of all conceivable societal regulatory systems. In comparison: the written human history covers 5000 years. In other words, the political systems of the nuclear power states are forced to project highly complex decision making systems over a period twice the span of hitherto written human history.

- A closer look, however, reveals that the ten thousand years period is an arbitrary assumption. The half-life of just two elements concerned such as Neptunium-237 is more than 2 million and that of Iodine-129 even 17 million of years.

- For that reason the United States Court of Appeals for the District of Columbia Circuit in a (meanwhile final) judgment of July 9, 2004, vacated the decision of the competent federal US authority limiting the compliance period of the Yucca Mountain permanent repository for spent nuclear fuel and high-level radioactive waste to 10 thousand years. The ensuing legal consequence is US legislation providing the security standards for this repository for the next one million years. An ordinary case of strictly normal madness.

Putting it simple:
Frequently Asked Questions (FAQ)

January 2007

Putting it simple: Frequently Asked Questions (FAQ)

January 2007

General

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

Yes. Efficiency measures contributed more to the growing energy need in the past decades than nuclear power and the potential of efficiency increase is not exhausted by far. Nuclear power, due to its long lead periods, will not be able to make a significant contribution to climate policy in the foreseeable future.

2. Can we do without nuclear energy even after "Peak Oil" *?

Yes. Nuclear energy cannot replace the oil: in view of the number of power plants that would be needed, a technology with significantly lower risks would be mandatory. This technology is not yet available. In addition, fissile uranium is not accessible to the extent required to operate the large number of power plants. For the important sector of transport nuclear could supply energy only through the very inefficient production of hydrogen. Efficiency increase and structural changes will have to play the leading role in case of "Peak Oil" as well.

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

No. Nuclear energy 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 energy does not satisfy any of these criteria. Considering the complete fuel cycle, from uranium mining to final repositories, nuclear energy is certainly not CO_2-free.

Normal Operation

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

Yes. Experiments and the analyses of medical statistics show that there is no harmless dose - only the likelihood of damage is reduced at low radiation levels. Enhanced cancer frequencies were reported from areas near nuclear power plants in Germany, USA, Japan und Canada and from the environs of the reprocessing plants in Sellafied (UK) and La Hague (France). Some types of damage surface on a larger scale only after several generations.

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

Safety

5. **The safety of Nuclear Plants is continuously increasing. Has this not solved the safety problem?**

   No. The Chernobyl catastrophe has 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, a series of incidents in nuclear power plants over the last few years demonstrates that accidents still cannot be excluded. Besides, many nuclear power plant do not comply with all safety guidelines of the IAEA.

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

   No. “Inherent safety” has not yet been proven for any reactor. Besides, “inherent safety” only applies to design base accidents, not to external dangers and certainly not to acts of war or terrorism. Reactors of the next but one Generation (IV) are based on completely different concepts that raise new safety problems and imply a plutonium economy. Plutonium is not only radioactive but also highly toxic and enhances the danger of proliferation. It is not realistic to expect that new reactor and fuel cycle technologies willsimultaneously overcome the problems of cost, safety, waste, and proliferation.

7. **Why is the safety aspect focussed on so strongly in the case of nuclear energy? Are not chemical plants burdened with a similar risk?**

   Nuclear risk is special because the likelihood of a severe accident is very small, but the consequences if it does happen are 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. But of course the call to reduce disaster potentials is valid for other areas, e.g. the chemical industry, as well.

8. **Does the deregulation of the electricity market have impacts on the risk of accidents in nuclear power plants?**

   Yes. The need for cost reductions triggered by deregulation 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.

9. **Will many nuclear power plants not be shut down anyway due to their reaching the age limit?**

   Due to rising energy needs and lack of acceptance for new plants attempts are being made to extend the life time of plants. Unfortunately, however, the safety risk grows at a certain age*, mainly because some components suffer from material fatigue due to intense strain. The fact that this coincides with cost cuts due to the deregulation of the electricity market and a shortage of spare parts as well as of qualified staff in consequence of the stagnation of the nuclear industry causes serious concern also among proponents of nuclear energy.

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* 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.

Radioactive Waste

10 . 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. There are many knowledge gaps and unsolved details regarding final repositories in deep geological formations. Also, it is not possible to guarantee safe storage for the requested period of 1 million years.

11. Is controlled surface storage the only responsible procedure, as claimed by some?

It is impossible to foresee whether societies in some centuries or millennia will be able to maintain control over the repositories. As all other repository options it puts the burden of handling the waste on future generations. As compared to the deep geological repository the chances of keeping knowledge about the repository alive and of making use of possible advanced technologies to eliminate it are greater, but so is the short term risk of radioactivity being set free.

12. Can radioactive wastes be rendered harmless by transmutation?

Transmutation requires very expensive separation by reprocessing, a process that is connected with high environmental costs and accident risks. Even after transmutation, long term final repositories are needed. Besides, this technology is still far from applicable on a large scale. It must also be considered that low and medium active fractions of nuclear waste that make up by far the greater volume, cannot be treated in this manner. Thus, in spite of high costs, transmutation cannot solve the problem of radioactive waste.

13. 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 minimised. For the waste already accumulated a consensual solution must be sought in a wide and open public debate.

Terrorism and War

14. Are nuclear power plants “attractive“ targets for terrorist attacks?

Yes. Due to the long lasting impacts of such an attack, the effects on electricity supply and their symbolic character, nuclear power plants can be considered to be attractive targets from the point of view of terrorists. It is surmised that the airplane that crashed in Pennsylvania on September 11 in 2001 was aiming for a nuclear power plant.

15. 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. Countless deaths and contamination of large areas could be the consequence.

16. Are effective counter measures against terrorist attacks or military actions possible?

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. Here too, centralised, non sustainable technologies with inherent potential for catastrophe such as nuclear energy have obvious draw backs.

Emergency Management

17. Can an effective emergency management significantly reduce the consequences of a severe nuclear accident?

Under favourable circumstances accident consequences can be mitigated but they can not be eliminated. Timely intake of iodine tablets for instance blocks radioactive iodine from the glands, but they do not protect from other consequences of radiation. In case of severe accidents the radioactive cloud can be emitted into the atmosphere within a few hours and measures such as intake of iodine tablets or evacuation can hardly be taken in time.

18. What do past experiences of nuclear accidents show?

The accidents of Three Mile Island (USA) and Chernobyl (former SU) 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 less badly prepared for future nuclear accidents.

19. Do only states that operate nuclear power plants need 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 expensive protective action against the case of emergency.

Proliferation

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

No. While it is in principle possible to do so, proliferation from the commercial nuclear fuel cycle has not yet taken place. However, of the countries known or strongly suspected to have developed nuclear weapons, not all have used dedicated nuclear weapons production facilities to produce the nuclear material for their weapon programmes.

21. 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 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.

22. Can nuclear weapons be designed and built by “newcomers”?

Yes. Most aspects of first generation nuclear weapon design are public knowledge. It is, however, difficult to develop more sophisticated designs in which the physical size and weight are minimized. Weapons usable material is much more plentiful now, and much cheaper to produce than it was some decades ago, and non-nuclear testing provides sufficient confidence that an implosion weapon will work.

Timeliness

23. Can the development of Nuclear Energy be rapid enough to meet the needs of climate policy and diminishing cheap oil?

No. The new generation of so-called “inherently safe” reactors – a precondition for a generous expansion of Nuclear Energy – is only expected to be available in a decade. There are still no acceptable solutions for waste disposal. The expertise and work force needed for nuclear build up could not be made available in time. Even now there is a shortage of trained personnel in several countries. Many nuclear power plants will be taken from the grid in the coming years as they end their projected lifetime. The nuclear power plants that are under construction will not be able to compensate for that loss, and any additional new power plants would come too late.

Contribution to Climate Policy

24. Is not nuclear the cheapest way to reduce CO_2-emissions?

No. As a mechanism to reduce CO_2-emissions nuclear power cannot compete with a variety of already available alternatives. In particular energy efficiency, in addition to its overall environmental advantage, has a clear economic benefit and also brings additional security of supply. Furthermore, analyses on the projects costs of other low or zero CO_2 emitting technologies demonstrate that renewable energies will become increasingly price competitive as prices decline with growing production.

25. Can nuclear be viewed as a technology to bridge the energy gap on the longterm?

No. The reserves of fissile Uranium-235 are limited. At the present production rate the known reserves of uranium accessible at around € 100 per ton will last for somewhat less than one century. When doubling the production rate till 2030 the reserves will be used up within 4 to 5 decades. After that, present day concepts envisage reactor types that make use of the plentiful Uranium-238. This, however, would imply the embarkment on a plutonium economy with all its difficulties and risks.

26. Can the Kyoto goals be achieved without expansion of Nuclear Energy?

Yes. There are studies that show that even the long term aim of the European Union – the stabilisation of global temperature at +2 °C – can be achieved without Nuclear Energy, if either sequestration* of a significant amount of CO_2 or a reduction in growth rate of energy demand is assumed.

Economical Aspects

27. Does Nuclear Energy offer commercial advantages?

No. Those countries in the OECD that are considering embarking again on nuclear power construction programme, Finland and the US, have both proposed 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 costs of nuclear energy are not included in comparative price calculations, nuclear energy is not less costly than most alternative technologies. Efficiency improvement (reduction of energy intensity for the supply of goods, services and private end use) is more advantageous regarding costs as well as CO_2-reduction potential than any form of additional supply of energy.

28. Will the costs for nuclear energy drop?

Not substantially. A comparison of cost developments shows that costs for nuclear energy have dropped much less than those of alternative technologies. There is no reason to expect that this will change in the near future.

29. Is Nuclear Energy presently subsidised by public enterprise?

Yes. 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. CTBTO) on the international level are born by public enterprise. Research and development costs for nuclear are also covered to a much larger extent than for other energy technologies. Besides, nuclear does not bear the insurance burden other industries are compelled to bear.

30. Do insurances cover nuclear risks?

No. The international liability regime for nuclear damage 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. Would Europe's largest nuclear utility Electricité de France e.g. be required to fully insure the full cost of a severe accident it would increase the cost of electricity generation by around 200 %.

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* Binding or depositing CO_2 in reservoirs rather than emitting it into the atmosphere is called sequestration.

Nuclear produced Hydrogen

31. Is nuclear produced hydrogen a solution for the transport sector in view of climate change as well as “Peak Oil”?

No. Without resolution of the well known problems of Nuclear Energy the nuclear production of hydrogen is not viable in view of the large number of plants necessary to produce a relevant amount of hydrogen. This view is reinforced by the low overall efficiency of the complete transformation chain and will improve only little with new reactor types. The basic problems connected to a hydrogen economy – independent of the mode of hydrogen production – are also considerable. Encompassing assessments of possible environmental effects are still lacking.

Legal Dimension

32. Could the problems and risks of Nuclear Energy be solved at the international level?

The risks of Nuclear Energy are structurally inherent. At the international or the European level the risks could be reduced by multilateral cooperation, but it could not be fully abolished. All attempts in this direction are hindered by the nuclear industry that resists stringent international or European regulations and control mechanisms.

Abbreviations

Abbreviations

ABWR	Advanced Boiling Water Reactor (General Electric, GE) / boiling light water cooled & moderated
ACR-700	Advanced CANDU Reactor, 700 MWe class (Atomic Energy of Canada, Limited) / heavy water moderated, light water cooled, low enriched uranium fuelled
AECL	Atomic Energy of Canada, Limited
AGR	Advanced Gas-Cooled Reactor, carbon dioxide cooled, graphite moderated
AHTR	Advanced High Temperature Reactor
AP1000	Advanced Passive 1000 MWe class pressurized water reactor (Westinghouse)
AP600	Advanced Passive 600 MWe class pressurized water reactor (Westinghouse)
B	Barrel; 1 B about 159 l oil (see glossary)
BLEVE	Boiling Liquid Expanding Vapour Explosion
BWR	Boiling Water Reactor
CANDU	Canadian Deuterium-Uranium Reactor / heavy water cooled & moderated, natural uranium fuelled (Atomic Energy of Canada, Limited)
CDF	Core Damage Frequency
CO_2	Carbon Dioxide
COP	Conference of the Parties, e.g. in the framework of the UNFCCC
EURATOM	European Atomic Energy Community
EOP	Emergency Operating Procedures
EPR	European Pressurized Reactor (Areva NP) / pressurized light water cooled & moderated
ESBWR	Not an acronym; General Electric designation for an advanced boiling light water cooled & moderated reactor
ETA	Bask Separatist Movement
FBR	Fast Breeder reactor
Gb	Gigabarrel, 1 Gb = 1.000,000 Barrels

GCM	Global Climate Model or Global Circulation Model
GDP	Gross Domestic Product
GFR	Gas-cooled Fast Reactor
GHG	Greenhouse Gases
GT-MHR	Gas Turbine Modular Helium Reactor / a gas cooled, graphite moderated reactor (General Atomics)
Gtoe	Gigatons of Oil Equivalent (s. glossary)
GW	Giga-Watt: 1 GW = 1,000 megawatt
GWe	Giga-Watt electrical power
H2-MHR	Modular High temperature gas cooled Reactor / optimized for Hydrogen producton
HLW	High Level Radioactive Waste
HTTR	High-Temperature Engineering Test Reactor
IAEA	International Atomic Energy Agency
IEA	International Energy Agency
INES	International Nuclear Event Scale
INSAG	International Nuclear Safety Advisory Group of the IAEA
IPCC	Intergovernmental Panel on Climate Change
ISR	Inherently Safe Reactor concept
JAERI	Japan Atomic Energy Research Institute
LFR	Lead-cooled Fast Reactor
LNG	Liquefied Natural Gas
LPG	Liquefied Propane Gas
LWGR	IAEA PRIS abbreviation for RBMK Reactor
MAGNOX	Gas-cooled reactor
MOX	Mixed Oxide (nuclear fuel after reprocessing)

MSR	Molten Salt-cooled Reactor
MW	Megawatt: 1 MW = 1,000 watt
MWe	Megawatt (1000) electrical power
MWt	Megawatt (1000) thermal
NEA	Nuclear Energy Agency
NGL	Natural Gas Liquid
NPP	Nuclear Power Plant
OECD	Organisation for Economic Co-operation and Development
OPEC	Organisation of the Petroleum Exporting Countries
OSPAR	Oslo/Paris Convention (for the Protection of the Marine Environment of the North-East Atlantic)
PBMR	Pebble Bed Modular Reactor / a gas cooled, graphite moderated reactor using low enriched pebble bed fuel (PBMR Pty., Ltd., South Africa)
PHWR	Pressurized Heavy Water Reactor
PUREX	Plutonium and Uranium Recovery by EXtraction
RODOS	Real-time On-line DecisiOn Support system for off-site emergency management in Europe; Realtime Online Decision Support System for nuclear emergency management
ROI	Return of Investment
RPG	Rocket Propelled Grenades
PRIS	IAEA Power Reactor Information System
PSA	Probabilistic Safety Assessment
PWR	Pressurized Water Reactor
RBMK	Reactor Bolshoi Moschnosti Kanalynyi / boiling water cooled, graphite moderated, vertical pressure tube reactor (Russian acronym)
RSK	Reaktor Sicherheitskommission; Reactor Safety Commission
SCWR	Super Critical Water-cooled Reactor, a type of pressurized water reactor

SFR	Sodium-cooled Fast Reactor
STAR-H2	Secure Transportable Autonomous Reactor for Hydrogen Production
SWR-1000	Siedewasserreaktor (German: boiling water reactor), 1000 MWe class (Areva NP)
TSO	Technical Support Organization
UNFCCC	United Nations Framework Convention on Climate Change
UNGG	Natural Uranium fuelled, Gas cooled, Graphite moderated reactor
USD	US Dollar
UVCE	Unconfined Vapour Cloud Explosion
VHTR	Very High Temperature Reactor / a type of gas cooled, graphite moderated reactor
WBGU	Wissenschaftlicher Beirat für Globale Umweltfragen (Germany)
WEC	World Energy Council
WENRA	Western European Nuclear Regulators´ Association
WHO	World Health Organization
WNA	World Nuclear Association
WWER	pressurized light water cooled & moderated reactor / Russian acronym for type of pressurized water reactor, PWR (Voda-Vodyanoi Energetichesky Reaktor)

Glossary

Glossary

Anthropogenic

Anthropogenic effects or processes are such that are derived from human activities, as opposed to effects or processes that occur in the natural environment without human influences. The term is often used in the context of environmental externalities in the form of chemical or biological wastes that are produced as by-products of otherwise purposeful human activities. Anthropogenic sources include industry, agriculture, mining, transportation, construction and habitations.

Burnup

In the field of nuclear energy conversion the burnup is the amount of thermal energy that has been produced per mass unit of a fuel element. Usually it is expressed in gigawatt-days per ton of heavy-metal. In contrast to fossil fuel the fuel in nuclear reactors cannot be converted "in one go" since the fuel undergoes changes during its use in the reactor which require the fuel elements to be exchanged.

Barrel

The barrel (abbreviated bbl) is the name of several units of volume:

Oil barrel: 42 U.S. gallons (158.9873 litres), or approximately 35 Imperial (UK) gallons (34.97231575 UK gallons exactly). This is used for crude oil or other petroleum products. The measurement originated in the early Pennsylvania oil fields. Both the 42-gallon barrels (based on the old English wine measure, the tierce) and the 40-gallon (151.4 liters) whiskey barrels were used. The 40-gallon barrel was the most common size earlier, but companies often underfilled them with less. However, the Standard Oil Company shipped its oil in barrels that always contained exactly 42 gallons. Customers began to refuse to accept anything less and by 1866 the oil barrel was standardized at 42 gallons. Since Standard Oil painted its barrels blue, it was abbreviated "bbl" for "blue barrel". Oil has not been shipped in barrels for a very long time but the "blue barrel" is still the standard unit for measurement and pricing of oil.

Base-load

The share of the overall load in an electrical grid which remains constant for a given time frame (day, week, month or year).

Bentonite

Is an absorbent aluminium phyllosilicate generally impure clay consisting mostly of montmorillonite. Two types exist: swelling bentonite which is also called sodium bentonite and non-swelling bentonite or calcium bentonite. It forms from weathering of volcanic ash, most often in the presence of water.

Bequerel

The becquerel (symbol Bq) is the SI derived unit of radioactivity, defined as the activity of a quantity of radioactive material in which one nucleus decays per second. It is therefore equivalent to s^{-1}. The older unit of radioactivity was the curie (Ci), defined as 3.7×10^{10} becquerels or 37 GBq.

In a fixed mass of radioactive material, the number of becquerels changes with time. Sometimes, amounts of radioactive material are given after adjustment for some period of time. For example, one might quote a ten-day adjusted figure, that is, the amount of radioactivity that will still be present after ten days. This de-emphasizes short-lived isotopes.

SI uses the becquerel rather than its equivalent, the reciprocal second, for the unit of activity measure to eliminate any possible source of confusion regarding the meaning of the units, because errors in specifying the amount of radioactivity, no matter how far-fetched, could have such serious consequences.

BLEVE

Pronounced blevy, is an acronym for “boiling liquid expanding vapour explosion”. This is a type of explosion that can occur when a vessel containing a pressurized liquid is ruptured. Such explosions can be extremely hazardous. When the liquid is water, the explosion is usually called a steam explosion.

Business Rates

Business rates are a United Kingdom tax charged to businesses and other occupiers of non-domestic property. The proceeds of the tax are collected centrally and distributed to local authorities to contribute towards the costs of their services.

Carbon sequestration

Carbon sequestration is the term describing processes that remove carbon from the atmosphere. A variety of means of artificially capturing and storing carbon, as well as of enhancing natural sequestration processes, are being explored. This is intended to help mitigating global warming.

Carcinogen

In pathology, a carcinogen is any substance or agent that promotes cancer. Carcinogens are also often, but not necessarily, mutagens or teratogens. Carcinogens may cause cancer by altering cellular metabolism or damaging DNA directly in cells, which interferes with normal biological processes.

Colloids

In general, a colloid or colloidal dispersion is a substance with components of one or two phases, a type of mixture intermediate between a homogeneous mixture (also called a solution) and a heterogeneous mixture with properties also intermediate between the two. Typical membranes restrict the passage of dispersed colloidial particles more than they restrict the passage of dissolved ions or molecules; i.e. ions or molecules may diffuse through a membrane through which dispersed colloidal particles will not. The dispersed phase particles are largely affected by the surface chemistry existent in the colloid.

Combined Cycle Gas Turbines

Combined cycle is a term used when a power producing engine or plant employs more than one thermodynamic cycle. Heat engines are only able to use a portion of the energy their fuel generates (usually less than 30 %). The remaining heat from combustion is generally wasted. Combining two or more "cycles" such as the Brayton cycle and Rankine cycle results in improved overall efficiency.

In a combined cycle power plant (CCPP) or combined cycle gas turbine (CCGT) plant a gas turbine generator generates electricity and the waste heat from the gas turbine is used to make steam to generate additional electricity via a steam turbine; this last step enhances the efficiency of electricity generation. Most new gas power plants are of this type. In a thermal power plant, high-temperature heat as input to the power plant, usually from burning of fuel, is converted to electricity as one of the outputs and low-temperature heat as another output. As a rule, in order to achieve high efficiency, the temperature of the input heat should be as high as possible and the temperature of the output heat as low as possible (see Carnot efficiency). This is achieved by combining the Rankine (steam) and Brayton (gas) thermodynamic cycles. Such an arrangement used for marine propulsion is called COmbined Gas (turbine) And Steam (turbine) (COGAS).

Cogeneration

Cogeneration (also combined heat and power or CHP) is the use of a heat engine or a power station to simultaneously generate both electricity and useful heat.

Cryogenic

Cryogenics is a branch of physics (or engineering) that studies the production of very low temperatures (below –150 °C, –238 °F or 123 K) and the behavior of materials at those temperatures.

Decommissioning

The decommissioning of nuclear facilities is sometimes referred to as nuclear decommissioning, to mark the difference between "conventional" decommissioning and dismantling projects. In fact, the main difference to the dismantling of a "conventional" facility is the possible presence of radioactive or fissile material in a nuclear facility, which requires special precautions. Decommissioning involves many administrative and technical actions, whose purpose, after a facility has been taken out of service, is to allow its release from regulatory control and relieve the licensee of his responsibility for its nuclear safety.

Desertification

Desertification is the degradation of land in arid, semi-arid and dry sub-humid areas resulting from various factors including climatic variations and human activities. Modern desertification often arises from the demands of increased populations that settle on the land in order to grow crops and graze animals.

Dichotomy

A dichotomy is any splitting of a whole into exactly two non-overlapping parts. In other words, it is a mutually exclusive bipartition of elements, i.e. nothing can belong simultaneously to both parts, and everything must belong to one part or the other. They are often contrasting and spoken of as “opposites.” The term comes from dichotomos (divided): dich- ([in] two) temnein (to cut).

TEAC

Treaty establishing a European Atomic Energy Community, or EURATOM. It was established on March 25, 1957, signed the same day as the more famous Treaty of Rome, instituting the European Economic Community (EEC). The European Atomic Energy Community is a separate legal entity, but membership and organization is fully integrated with the European Union.

Economies of Scale

Economies of scale and diseconomies of scale refer to an economic property of production that affects cost if quantity of all input factors are increased by some amount. If costs increase proportionately, there are no economies of scale; if costs increase by a greater amount, there are diseconomies of scale; if costs increase by a lesser amount, there are positive economies of scale. When combined, economies of scale and diseconomies of scale lead to ideal firm size theory, which states that per-unit costs decrease until they reach a certain minimum, then increase as the firm size increases further.

Epitome

An epitome (Greek epitemnein, to cut short) is a summary or miniature form; it is also used as a synonym for embodiment. Many lost documents from the Ancient Greek and Roman world survive only now “in epitome” referring to the practice of some later authors (epitomators) who would write distilled versions of now lost larger works. Some writers would attempt to convey the stance and spirit of the original, while others would add further details or anecdotes regarding the general subject. As with all secondary historical sources, a different bias may creep in that was not present in the original.

Fast Breeder Reactor

The fast breeder or fast breeder reactor (FBR) is a fast neutron reactor designed to breed fuel by producing more fissile material than it consumes. The FBR is one possible type of breeder reactor.

Fizzle Explosion

A fizzle occurs if the nuclear chain reaction is not sustained long enough to cause a full-yield explosion. This can happen if, for example, the yield of the fissile material used is too low, the compression explosives around fissile material misfire or the neutron initiator fails to funcion properly. (Yield below the designed full yield but any yield above the yield of the chemical explosives)

Fuel Cell

A fuel cell is an electrochemical energy conversion device. Fuel cells differ from batteries insofar as they are designed for continuous replenishment of the reactants consumed; they produce electricity from an external supply of fuel and oxygen as opposed to the limited internal energy storage capacity of a battery. Additionally, while the electrodes within a battery react and change as a battery is charged or discharged, a fuel cell's electrodes are catalytic and relatively stable. Typical reactants used in a fuel cell are hydrogen on the anode side and oxygen on the cathode side (a hydrogen cell). Usually, reactants flow in and reaction products flow out. Virtually continuous long-term operation is feasible as long as these flows are maintained.

GHG

Greenhouse gases (GHGs) are gaseous components of the atmosphere that contribute to the "greenhouse effect". Although uncertainty exists about exactly how earth's climate responds to these gases, global temperatures are rising. Some greenhouse gases occur naturally in the atmosphere, while others result from human activities. Naturally occuring greenhouse gases include water vapour, carbon dioxide, methane, nitrous oxide, and ozone. Certain human activities, however, add to the levels of most of these naturally occurring gases.

Gross Domestic Product (GDP)

A region's gross domestic product, or GDP, is one of the several measures of the size of its economy. The GDP of a country is defined as the market value of all final goods and services produced within a country in a given period of time. Until the 1980ies the term GNP or gross national product was used. The two terms GDP and GNP are almost identical. The most common approach to measuring and understanding GDP is the expenditure method:

GDP = consumption + investment + government spending + (exports – imports). "Gross" means depreciation of capital stock is not included. With depreciation, with net investment instead of gross investment, it is the net domestic product. Consumption and investment in this equation are the expenditure on final goods and services. The exports minus imports part of the equation (often called cumulative exports) then adjusts this by subtracting the part of this expenditure not produced domestically (the imports) and adding back in domestic production not consumed at home (the exports).

Homozygote

A homozygote's cells are diploid or polyploid and have the same alleles at a locus (position) on homologous chromosomes. When an organism is referred to as being homozygous for a specific gene, it means that it carries two identical copies of that gene for a given trait on the two corresponding chromosomes (e.g., the genotype is AA or aa). Such a cell or such an organism is called a homozygote.

Howitzer

A howitzer or hauwitzer is a type of field artillery. The name is of Germanized origin and derives from the Czech word houfnice, denoting a 15th century cannon used by Hussites during the

Hussite Wars. Howitzers are distinguished from other types of cannon artillery by their trajectory in that they tend to fire at high angles and deliver plunging fire.

Howitzers are used either as unprotected versions moved around by trucks, or as armored Self propelled units. Recoilless howitzers of smaller caliber are also directly mounted on trucks as well as aircrafts.

Hydrocracking

In petroleum geology and chemistry, cracking is the process whereby complex organic molecules (e.g. kerogens or heavy hydrocarbons) are converted to simpler molecules (e.g. light hydrocarbons) by the breaking of carbon-carbon bonds in the precursors. The rate of cracking and the end products are strongly dependent on the temperature and presence of any catalysts. Cracking is also known as pyrolysis.

Hydrocracking is a catalytic cracking process assisted by the presence of an elevated partial pressure of hydrogen. The products of this process are saturated hydrocarbons; depending on the reaction conditions (temperature, pressure, catalyst activity) these products range from ethane, LPG to heavier hydrocarbons comprising mostly of isoparaffins. Hydrocracking is normally facilitated by a bifunctional catalyst that is capable of rearranging and breaking hydrocarbon chains as well as adding hydrogen to aromatics and olefins to produce naphthenes and alkanes.

Major products from hydrocracking are jet fuel, diesel, relatively high octane rating gasoline fractions and LPG. All these products have a very low content of sulfur and contaminants. It is very common in India because of the high demand for diesel and kerosene.

Hydrocarbons

In chemistry, a hydrocarbon is any chemical compound that consists only of the elements carbon (C) and hydrogen (H). They all contain a carbon backbone, called a carbon skeleton, and have hydrogen atoms attached to that backbone. (Often the term is used as a shortened form of the term aliphatic hydrocarbon.) Most hydrocarbons are combustible. Although the term carbohydrate sounds similar, carbohydrates contain oxygen.

Intestine Epithelium

In zootomy, epithelium is a tissue composed of a layer of cells. In humans, it is one of four primary body tissues. Epithelium lines both the outside (skin) and the inside cavities and lumen of bodies. The outermost layer of our skin is composed of dead stratified squamous epithelial cells, as are the mucous membranes lining the inside of mouths and body cavities. Other epithelial cells line the insides of the lungs, the gastrointestinal tract, the reproductive and urinary tracts, and make up the exocrine and endocrine glands.

Least Developed Countries

Least Developed Countries (LDCs or Fourth World countries) are countries which according to the United Nations exhibit the lowest indicators of socio-economic development, with the lowest

Human Development Index ratings of all countries in the world. A country is classified as a Least Developed Country if it meets three criteria based on:

low-income (GNI per capita of less than US $750)

human resource weakness (based on indicators of nutrition, health, education and adult literacy) and

economic vulnerability (based on instability of agricultural production, instability of exports of goods and services, economic importance of non-traditional activities, merchandise export concentration, and handicap of economic smallness, and the percentage of population displaced by natural disasters)

Leukaemia

Leukemia (or leukaemia; see spelling differences) is a cancer of the blood or bone marrow characterized by an abnormal proliferation of blood cells, usually white blood cells (leukocytes). It is part of the broad group of diseases called hematological neoplasms.

Light Water Reactor

A light water reactor or LWR is a thermal nuclear reactor that uses ordinary water, also called light water, as its neutron moderator. This differentiates it from a heavy water reactor, which uses heavy water as a neutron moderator. In practice all LWRs are also water cooled.

Load

The power consumed at a given point

MOX

Mixed oxide, or MOX fuel, is a blend of plutonium and natural uranium, reprocessed uranium, or depleted uranium which behaves similarly (though not identically) to the low enriched uranium feed for which most nuclear reactors were designed. MOX fuel is an alternative to low enriched uranium (LEU) fuel used in the light water reactors that predominate nuclear power generation.

An attraction of MOX fuel is that it is a way of disposing of surplus weapons-grade plutonium, which otherwise would have to be handled as a difficult-to-store nuclear waste product, and a nuclear proliferation risk

Mutagen

In biology, a mutagen (Latin, literally origin of change) is an agent that changes the genetic information (usually DNA) of an organism and thus increases the number of mutations above the natural background level. Mutagens are usually chemical compounds or ionizing radiation.

Negajoules

Negajoules represent energy not consumed because of enhanced energy efficiency.

Nuclear Reprocessing

Nuclear reprocessing separates any usable elements (e.g., uranium and plutonium) from fission products and other materials in spent nuclear reactor fuels. Usually the goal is to recycle the reprocessed uranium or place these elements in new mixed oxide fuel (MOX), but some reprocessing is done to obtain plutonium for weapons. It is the process that partially closes the loop in the nuclear fuel cycle.

Opportunity Costs

Opportunity cost is a term used in economics to describe the cost of something in terms of an opportunity forgone (and the benefits that could be received from that opportunity), or the most valuable forgone alternative. For example, if a city decides to build a hospital on vacant land that it owns, the opportunity cost is some other thing that might have been done with the land and construction funds instead. In building the hospital, the city has forgone the opportunity to build a sporting center on that land, or a parking lot, or the ability to sell the land to reduce the city's debt, and so on.

The consideration of opportunity costs is one of the key differences between the concepts of economic cost and accounting cost. Assessing opportunity costs is fundamental to assessing the true cost of any course of action. In the case where there is no explicit accounting or monetary cost (price) attached to a course of action, ignoring opportunity costs may produce the illusion that its benefits cost nothing at all. The unseen opportunity costs then become the hidden costs of that course of action.

OSPAR Commission

The 1992 OSPAR Convention is the current instrument guiding international cooperation on the protection of the marine environment of the North-East Atlantic. It combined and up-dated the 1972 Oslo Convention on dumping waste at sea and the 1974 Paris Convention on land-based sources of marine pollution. The work under the convention is managed by the OSPAR Commission, made up of representatives of the Governments of 15 Contracting Parties and the European Commission, representing the European Community .

Paradigm

Since the late 1960s, the word paradigm has referred to a thought pattern in any scientific discipline or other epistemological context. Initially the word was specific to grammar: the 1900 Merriam-Webster dictionary defines its technical use only in the context of grammar or, in rhetoric, as a term for an illustrative parable or fable. Also, in linguistics, Ferdinand de Saussure used paradigm to refer to a class of elements with similarities.

Scientific paradigm: Philosopher of science Thomas Kuhn gave this word its contemporary meaning when he adopted it to refer to the set of practices that define a scientific discipline during a particular period of time. Kuhn himself came to prefer the terms exemplar and normal science, which have more exact philosophical meanings.

Paradigm Shift

A change of paradigm

Phenological Phases, Phenology

Phenology is the study of the times of recurring natural phenomena. The word is derived from the Greek Phainomai - to appear, come into view, and indicates that phenology has been principally concerned with the dates of first occurrence of natural events in their annual cycle. Examples include the date of emergence of leaves and flowers, the first flight of butterflies and the first appearance of migratory birds, the date of leaf colouring and fall in deciduous trees, the dates of egg-laying of birds and amphibia, the timing of the developmental cycles of honeybee colonies. Because many such phenomena are very sensitive to small variations in climate, especially to temperature, phenological records can be a useful proxy for temperature in the study of climate change.

Proliferation

Nuclear proliferation is the spread of nuclear weapons production technology and knowledge to nations that do not already have such capabilities.

PUREX Process

PUREX is a nuclear reprocessing method which is the de facto standard aqueous method based on liquid-liquid extraction for the recovery of uranium and plutonium from used nuclear fuel. This process can be used to recover weapon-grade materials as well as reprocessed uranium from spent nuclear reactor fuel, and as such, its component chemicals are monitored. PUREX is an acronym standing for Plutonium and Uranium Recovery by EXtraction. The PUREX process is a liquid-liquid extraction method used to reprocess spent nuclear fuel, in order to extract uranium and plutonium, independent of each other, from the fission products.

Radiolysis

Radiolysis is the dissociation of molecules by radiation. It is the cleavage of one or several chemical bonds resulting from exposure to high-energy flux. For example water dissociates under alpha radiation into hydrogen and oxygen. The chemistry of concentrated solutions under ionizing radiation is extremely complex. Radiolysis can locally modify redox conditions, and therefore the speciation and the solubility of the compounds.

Radiotoxicity

Measure of how nocuous a radio nuclide is to health. The type and energy of rays, absorption in the organism, residence time in the body, etc. influence the degree of radiotoxicity of a radio nuclide.

RODOS (Software)

In case of a nuclear accident in Europe, the Real-time On-line DecisiOn Support system for off-site emergency management in Europe (RODOS) provides consistent and comprehensive information on the present and future radiological situation, the extent and the benefits and drawbacks of emergency actions and countermeasures, and methodological support for taking decisions on emergency response strategies. Main users of the system are those responsible at local, regional, national and supra-national levels for off-site emergency management. The application of the system for training and exercises was a further important consideration in its development.

RPG (Rocket-Propelled Grenades)

A rocket propelled grenade (RPG) is a loose term describing hand-held, shoulder-launched anti-tank weapon capable of firing an unguided rocket equipped with an explosive warhead. RPG is the Russian acronym of "Ruchnoy Protivotankovy Granatomyot" and is translated into English as "handheld antitank grenade-launcher". The commonly used term "rocket-propelled grenade" is a mistranslation, backformed from the acronym RPG and does not follow correct naming conventions used by English speaking militaries to describe these weapons.

Sustainability

Sustainability is a systemic concept, relating to the continuity of economic, social, institutional and environmental aspects of human society, as well as the non-human environment. It is intended to be a means of configuring civilization and human activity so that society, its members and its economies are able to meet their needs and express their greatest potential in the present, while preserving biodiversity and natural ecosystems, and planning and acting for the ability to maintain these ideals in a very long term. Sustainability affects every level of organization, from the local neighbourhood to the entire planet.

"Sellers Market"

Jargon for a climate that generally favors sellers. Such a market exists when the number of qualified buyers seeking products generally exceeds the available inventory. In other words, it is a case of Supply and Demand, with the demand of buyers out-pacing the supply of the required goods.

Steam Reformer Production

Steam reforming, hydrogen reforming or catalytic oxidation, is a method of producing hydrogen from hydrocarbons. On an industrial scale, it is the dominant method for producing hydrogen. Small-scale steam reforming units are currently subject to scientific research, as a way to provide hydrogen to fuel cells.

Tamper

In nuclear weapon design, a shell surrounding the fission core and keeping the nuclear material assembled during the explosion for longer time, raising yield.

Tar-sand

Oil sands, also referred to as tar sands or bituminous sands, are a combination of clay, sand, water, and bitumen. Technically speaking, the bitumen is neither oil nor tar, but a semisolid, degraded form of oil which will not flow toward producing wells under normal conditions, making it difficult and expensive to produce. Oil sands are mined to extract the oil-like bitumen which is upgraded into synthetic crude oil or refined directly into petroleum products by specialized refineries. Conventional oil is extracted by drilling traditional wells into the ground whereas oil sand deposits are mined using strip mining techniques, or persuaded to flow into producing wells by in situ techniques which reduce the bitumen's viscosity with steam and/or solvents. On average bitumen contains 83.2 % carbon, 10.4 % hydrogen, 0.94 % oxygen, 0.36 % nitrogen and 4.8 % sulphur.

Transaction Costs

In economics and related disciplines, a transaction cost is a cost incurred in making an economic exchange. For example, most people, when buying or selling a stock, must pay a commission to their broker; that commission is a transaction cost of doing the stock deal. Or consider buying a banana from a store; to purchase the banana, your costs will be not only the price of the banana itself, but also the energy and effort it requires to find out which of the various banana products you prefer, where to get them and at what price, the cost of travelling from your house to the store and back, the time waiting in line, and the effort of the paying itself; the costs above and beyond the cost of the banana are the transaction costs. When rationally evaluating a potential transaction, it is important to consider transaction costs that might prove significant.

Transmutation

Transmutation is the conversion of one object into another. Transmutation of chemical elements occurs through nuclear reactions. This is called nuclear transmutation. Natural transmutation is when radioactive elements spontaneously decay over a long period of time and transform into other more stable elements. Artificial transmutation occurs in machinery that has enough energy to cause changes in nuclear structure of the elements. The machines that can cause artificial transmutation include the particle accelerator and tokamak reactor.

Ton of Oil Equivalent

The ton of oil equivalent (toe) is a unit for measuring energy. It corresponds to 10 $Gcal_{th}$ or 41,868 GJ, or 11.63 MWh. It is the rounded-off amount of energy that would be produced by burning one metric ton of crude oil. Since crude oil of different provenance will have a different chemical make-up and therefore give off varying amounts of heat when burnt, the value is conventional to a certain extent.

Toxicity

Toxicity is a measure to the degree to which something is toxic or poisonous. The study of poisons is known as toxicology. Toxicity can refer to the effect on a whole organism, such as a human or a bacterium or a plant, or to a substructure, such as the liver. By extension, the word may be metaphorically used to describe toxic effects on larger and more complex groups, such as the family unit or "society at large".

UNFCCC

The United Nations Framework Convention on Climate Change (UNFCCC or FCCC) is an international environmental treaty produced at the United Nations Conference on Environment and Development (UNCED), informally known as the Earth Summit, held in Rio de Janeiro in 1992. The treaty aimed at reducing emissions of greenhouse gas in order to combat global warming.

Uranium Hexa Fluoride

Uranium hexa fluoride, or UF6, is a compound used in the uranium enrichment process that produces fuel for nuclear reactors and nuclear weapons. It forms solid grey crystals at standard temperature and pressure (STP), is highly toxic, reacts violently with water and is corrosive to most metals. It reacts mildly with aluminum, forming a thin surface layer of AlF3 that resists further reaction.

Yellowcake

Yellowcakes (also known as urania) are uranium concentrates obtained from leach solutions. They represent an intermediate step in the processing of uranium ores. Yellowcake concentrates are prepared by various extraction and refining methods, depending on the types of ores. Typically yellowcakes are obtained through the milling and chemical processing of uranium ore forming a coarse powder which is insoluble in water and contains about 80 % uranium oxide, and which melts at approximately 2878 °C.

World Bank

The World Bank Group is a group of five international organizations responsible for providing finance and advice to countries for the purposes of economic development and poverty reduction, and for encouraging and safeguarding international investment. The group and its affiliates have their headquarters in Washington, D.C., with local offices in 124 member countries.

World Energy Council

World Energy Council (WEC) has Member Committees in over 90 countries, including most of the largest energy-producing and energy-consuming countries. Established in 1923, the organisation covers all types of energy, including coal, oil, natural gas, nuclear, hydro, and renewables, and is UN-accredited, non-governmental, non-commercial and non-aligned. WEC is a UK-registered charity headquartered in London.

The Authors

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Oda Becker

Professor at the University of Applied Science and Arts, Hannover; as well as freelance scientific consultant for energy and the environment; Hannover, Germany

Oda Becker studied physics and education science at the University of Hanover. She has been working as an independent scientific consultant in the field of nuclear safety and security for many years. Her clients include the Austrian Federal Government as well as German municipalities and NGOs.

Recent work includes: Studies of the hazards of spent fuel cask storage facilities; contribution to a study of the vulnerability of the German nuclear power plants Biblis and Brunsbüttel to terror attacks; contribution to a study of the ongoing dangers of operating nuclear technology in the 21st century; study of the situation at the NPP Chernobyl site; work concerning the planned lifetime extension of Paks NPP, Hungary; study of severe accidents at the NPP Unterweser in Northern Germany (focus: terror attacks).

Antony Froggatt

Independent European energy consultant

Since 1997 Antony has worked as a freelance consultant on energy and nuclear issues in the EU and neighbouring states. He has worked extensively on EU energy policy issues for European Governments, the European Commission and Parliament, environmental NGOs and commercial bodies. He has given evidence to inquiries and hearings in the Parliaments of Austria, Germany and the EU. He has also worked extensively with environmental groups in Eastern Europe, particularly, in the run up to enlargement, helping to establish a network on energy efficiency. Furthermore, he is a regular speaker at conferences, universities and training programmes across the region and the EU.

Prior to working freelance Antony worked for nine years as a nuclear campaigner and co-ordinator for Greenpeace International.

Helmut Hirsch, Dr.

Scientific consultant for nuclear safety and security issues. Austrian citizen, living in Hannover, Germany.
Member of the Austrian Nuclear Advisory Board (Forum für Atomfragen, FAF)

Training in radiation protection at the Austrian research center Seibersdorf, study of physics at Vienna University. In the 30 years of his career as nuclear expert, Helmut Hirsch has been working for the Austrian Federal Government as well as for German state governments and municipal administrations and international NGOs. He was scientific coordinator of the Austrian Government's nuclear energy information campaign 1976/77 and founded Gruppe Ökologie Hannover, an ecological research institute, in 1981, where he remained until 1995. Subsequently, he was employed as nuclear expert in the German Greenpeace office and is working freelance since 1997.

Recent work includes: Participation in the technical support for the monitoring process for the Czech NPP Temelín; participation in a study of potential hazards due to the spent fuel storage facility at Skull Valley, Utah (USA); evaluating possible countermeasures against terror attacks against NPPs; evaluation of the Swiss plans for a nuclear repository, concerning potential effects on Austrian territory, and of the Swiss procedure of repository site selection; membership of the Expert Group on Impacts of Longer Term Operation of Nuclear Capacities of the OECD/NEA; work concerning the planned lifetime extension of Paks NPP, Hungary.

Georgui Kastchiev, Dr.

Senior Scientist at the University of Vienna, Institute of Risk Research

G. Kastchiev graduated from University of Sofia in Bulgaria in 1972 as a diploma physicist. In 1972 he started his career as reactor physicist in NPP Kozloduy. He received a Ph.D. in reactor physics and safety from the University of Sofia in 1987. Dr. Kastchiev worked as a lecturer at the Institute of Nuclear Engineering, Kozloduy/Sofia from 1989 to 1993 and as a guest engineer in the AP 600 Project, Westinghouse, USA in 1994. During 1995-1997 Dr. Kastchiev acted as a consultant to the Institute of Risk Research, University of Vienna, Austria, until he was appointed head of the Bulgarian Nuclear Safety Authority in 2002. He worked there for four years and he spent one year as a guest professor in the Tokyo Institute of Technology. Since 2002 he is back in the Institute of Risk Research, University of Vienna, Austria.

Wolfgang Kromp, a.o. Univ.-Prof. Dr.

University Professor at the University of Vienna, Institute of Risk Research,
Member of the Austrian Nuclear Advisory Board (Forum für Atomfragen, FAF)

Professor, Ph.D. in Physics, University of Vienna, Head of the Institute of Risk Research of the University of Vienna, Faculty of Earth Sciences, Geography and Astronomy, forty years of experience in research and teaching at university level, extended research fellowships and visiting professorships at the Max-Planck Institute in Stuttgart, Germany and the Carnegie-Mellon University in Pittsburgh, USA. Research in the area of material related problems, using ultrasonic techniques for material testing and composition; focus on material related questions concerning nuclear safety. W. Kromp is member of the Scientific Commission of the Austrian Federal Ministry of Defence and the Technical Committee for Standardization ON-K 246 Risk, Safety and Crisis Management of the Austrian Standards Institute. Konrad Lorenz Environmental Award 1991 of the Austrian Ministry of the Environment. Participation in safety assessments of several nuclear power plants and spent fuel interim storages; research on radioactive contamination and risk perception; socio-economic research on fusion (SERF). Feasibility and risk studies on sustainable energy production from biomass. Study on security of food production in oil reduced agriculture.

Helga Kromp-Kolb, Univ.-Prof. Dr.

University Professor at the BOKU - University of Renewable Resources and Applied Life Sciences, Vienna, Institute of Meteorology,
Chairperson of the Austrian Nuclear Advisory Board (Forum für Atomfragen, FAF)

Helga Kromp-Kolb had her schooling in France, Luxemburg, India and Austria and studied meteorology at the University of Vienna. As a university teacher and researcher she has focused on environmental meteorology, engaging in problems of air pollution dispersion, UV-radiation and stratospheric ozone depletion as well as climate change. Her publications include assessments of radioactive dispersion from Chernobyl as well as for potential accidents at near border NPPs and methodological and practical work on downscaling of GCM climate scenarios to the Alpine region. She is member of a number of scientific boards as well as advisory committees to the Austrian Government. With one short interruption she has headed the Austrian Nuclear Advisory Board since its founding in 1990.

Roman Lahodynsky, Dr.

Scientist at the University of Vienna, Institute of Risk Research

Studies in geology, paleontology and geophysics at the Universities of Vienna and Innsbruck, staff-member of the Institute of Geophysics, Technical University of Vienna. Research in sedimentology of deep sea deposits, catastrophes in earth history, faults and joints in rock, rock stresses, rock slides. Scientific projects with the Austrian Geological Survey: asteroid impact at the cretaceous/tertiary boundary, geological mapping. Technical projects with private engineering companies: hazard assessments of old municipal waste disposals and finding new suitable sites, exploration for drinking water and establishing safety zones, tunneling. Certificate as radiation protection engineer from Austrian Research Centre Seibersdorf during military service. Projects at the Institute of Risk Research: seismic hazard and risk in connection with nuclear installations (siting & external hazards), problems of final radioactive waste disposals, environmental problems (water & waste) in an EU-China project on sustainable development of rural China (2002-2005).

Franz Meister

Expert at the Umweltbundesamtes Vienna

Meister studied history, political sciences and philosophy at the University of Vienna. Beginning 1986 he worked at the Österreichisches Ökologie-Institut in the energy department before moving to the Umweltbundesamt in 1991. His main topics of interest are: energy and environment, energy and emission modelling and risks of nuclear power plants near the Austrian border. He coordinated projects of the Umweltbundesamt on the NPPs Chmelnitzky-2/Rowno-4, NPP Temelín, NPP Mochovce, NPP Bohunice, NPP Packs, the German interim storage projects, the Swiss final repository project, as well as assessments of the energy concepts of the Czech and the Slovak Republics.

Nikolaus Müllner

Research Associate of the University of Vienna, Institute for Risk Research and of the University of Pisa, Dipartment of Mechanical, Nuclear and Production Engineering. Ph.D. student of the University of Vienna, IRR.

Müllner studied Physics at the University of Vienna and at the Technical University of Berlin. After graduating in 2001 he was working two years in the field IT in London, and decided 2003 to accept an offer to work as research associate and to start as Ph.D. student at the Institute for Risk Research. In this frame he is currently staying at the University of Pisa. His fields are Safety Analyses with the Thermal Hydraulic System Codes Relap5 and Cathare2, and Analyses of Severe Accidents with the Integral Code MELCOR, as well as project preparation and project management.

Manfred Rotter, Univ.-Prof. Dr.

University Professor emer. of the Johann Kepler University Linz, Institute for Public International Law and International Relations,
Member of the Austrian Nuclear Advisory Board (Forum für Atomfragen, FAF)

Professor for Public International Law, European Community Law and International Relations (1983 - 2004); Head of the Institute for European Community Law (1990 - 2004); Head of the Institute for Public International Law and International Relations (1996 - 2004); Director of the European Documentation Centre of the European Commission at Linz University (1990 - 2004); Member of the Scientific Board of the Conference of Rectors of the Alps-Adria Community (1982-97); Member of the Governing Board of the Joint Programme of the Czech Republic and Austria for Scientific Co-operation (since 1996).

Numerous Publications on various problems of Public International Law, European Community Law and International Relations. The latest are dedicated to the legal fallacies of Nuclear Security, the traces of Kelsen‘s Pure Theory of Law in Public International Law, the changes in the concept of Defence and the legal dimension of Israel‘s so called Security Fence on Palestinian Territory.

Steven Sholly

Senior Risk Analyst at the University of Vienna, Institute of Risk Research

Steven Sholly graduated from Shippensburg State College (now Shippensburg University) in Pennsylvania in the United States in 1975 with a Bachelor of Science degree in Science Education. Since 1979 he has been engaged in hazard analysis, safety analysis, risk assessment, and environmental impact assessment work primarily involving nuclear and hazardous chemical facilities. Mr. Sholly served as a contract seismic analysis reviewer for the US Nuclear Regulatory Commission‘s Individual Plant Examination of External Events (IPEEE), and also performed accident analyses of the US Department of Energy‘s nuclear weapon-related facilities at Los Alamos National Laboratory and the former Rocky Flats facility (now largely decommissioned). Mr. Sholly has lived in Austria and worked at the Institute of Risk Research since early 1998. Mr. Sholly is a member of the IAEA‘s Nuclear Safety Standards Committee (NUSSC) for 2004-2007.

Geert Weimann, DI

Senior Engineer, seibersdorf research G.m.b.H, Seibersdorf, Austria,
Member of the Austrian Nuclear Advisory Board (Forum für Atomfragen, FAF)

After obtaining a degree in mechanical engineering at the University of Technology in Vienna and working on plant projects, he acquired in graduate trainings for nuclear technology in the US and Germany basic knowledge on safety in nuclear installations. Practical experience in licensing and start-up, as well as emergency planning and accident consequences management followed. Design of pressurized water reactors, high temperature reactors, one fast breeder reactor and safety analyses for spallator and fusion installations were applications. He analysed questions of long term options for energy supply and of energy saving technologies at Austria's EU accession. As a nuclear technologist engaged in a number of safety analyses regarding design and operation, as well as in the long term operation of nuclear power plants, he has 35 years experience in energy technology. He is co-author of a number of detailed studies in the related areas.

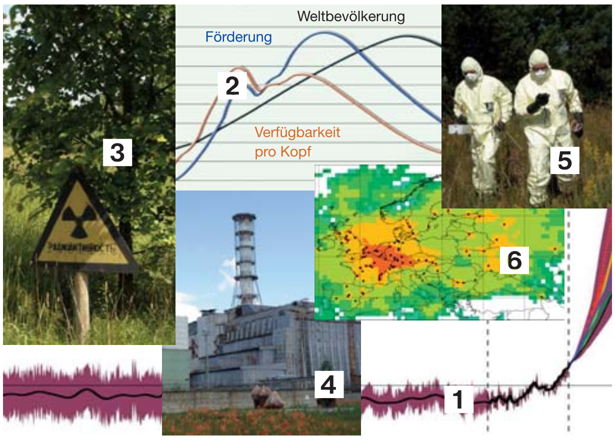
Peter Weish, Univ.-Doz. Dr.

University Docent at the University of Vienna, Faculty of Ecology,
Member of the Austrian Nuclear Advisory Board (Forum für Atomfragen, FAF)

Peter Weish is a graduate of the University of Vienna (Chemistry, Physics, Biology); he was professional active at the Institute for Radiation Protection of the Austrian Research Centre Seibersdorf, at the Institute of Zoology of the BOKU University of Renewable Resources and Applied Life Sciences and at the Institute for Environmental Sciences and Nature Protection of the Austrian Academy of Sciences.

Since the late 1960ies he has focussed on the problems of nuclear energy from the human ecology viewpoint, as well as on general questions of energy, nature- and environmental protection and development cooperation. Cooperation with various environmental organisations and advisory bodies. Lecturing at the BOKU and the University of Vienna in the fields of Human Ecology and Environmental Ethics.

Legend to the Title Page Pictures



1 Average temperature on the Northern Hemisphere during the last 1000 years [IPCC 2001]
2 Production rate of oil, world population and availability of oil per capita through the years 1950 to about 2100, with production peaking around 2010 [Kromp-Kolb und Formayer 2006]
3 Sign warning of contamination in the Chernobyl exclusion zone [Photo: Kromp-Kolb]
4 Sacophagus covering the exploded Unit 4 of the NPP Chernobyl [Photo: Kromp-Kolb]
5 Radiation protection exercise of the Institute of Risk Research of the University of Vienna in the 30-km-Exclusion Zone around the NPP Chernobyl 2005 [Photo: Kromp-Kolb]
6 Distribution of nuclear risk by commercial power plants in Europe as modelled in the “Riskmap” project 1999 [http://www.umweltbundesamt.at/umwelt/kernenergie/akw/riskmap/?wai=1]

Contact Address

Federal Ministry of Agriculture and Forestry,
Environment and Water Management
Division V/6 Nuclear Co-ordination
Stubenbastei 5
1010 Vienna, Austria
Phone: +43 1 515 22-4004
Email: nuklearkoordination@lebensministerium.at
www.lebensministerium.at

Univ. Prof. Helga Kromp-Kolb
Chairperson of the Austrian Nuclear Advisory Board
c/o University of Natural Resources and Applied Life Sciences
Institute of Meteorology
Department of Water, Atmosphere and Environment
Peter Jordanstraße 82
1180 Vienna, Austria
Phone: +43 1 47654-5601
Email: helga.kromp-kolb@boku.ac.at
www.boku.ac.at

Informationen zu Landwirtschaft, Lebensmittel, Wald, Umwelt und Wasser:

www.lebensministerium.at

Das Aktionsprogramm des Lebensministeriums für aktiven Klimaschutz:

www.klimaaktiv.at

Die Jugendplattform rund ums Wasser:

www.generationblue.at

Die bundesweite Initiative zur getrennten Sammlung von Altstoffen:

www.richtigsammeln.at

Die Internetseite zur Österreichischen Nachhaltigkeitsstrategie:

www.nachhaltigkeit.at

Das Internetportal der Österreichischen Nationalparks:

www.nationalparks.at

Der Walddialog ist die Suche nach Problemlösungen für Interessenkonflikte im Waldbereich:

www.walddialog.at

Das Österreichische Umweltzeichen ist Garant für umweltfreundliche Produkte und Dienstleistungen:

www.umweltzeichen.at

Umweltdaten u.a. zu den Bereichen Wasser, Luft, Lärm, Kernenergie, Klima, Gentechnik, Altlasten, erhebt laufend das UBA:

www.umweltbundesamt.at

Waldforschungszentrum BFW. Forschung, Monitoring und Wissenstransfer zu Wald und Naturgefahren:

http://bfw.ac.at

lebensministerium.at