[EHNUR WP 5]

BOTTLENECKS

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EXECUTIVE SUMMARY

In the growth of commercial NPPs bottlenecks are factors, which are possibly limiting or slowing the development of nuclear power technology and the rate at which new NPPs could possibly be added to power grids worldwide. The list of bottlenecks possibly includes:

- **High construction costs and financial risks**: In 2000-2006 vendors estimated the overnight cost for a new nuclear unit at $2000/kWe. That figure had risen and in 2009-2011 independent experts suggested that it will be at least $6250/kWe. Even US DoE and NEI suggest considering overnight costs of $5500/kWe. It has to be mentioned that the total cost are quite higher as is confirmed by experience. There are three major risks for construction of new NPPs: cost overruns due to construction overruns, power price insufficiency to provide a return on investment and operational losses due to breakdowns or regulatory delay. All of these risks result in lack of capital and a need for direct government support. The final cost of electricity from the new NPPs would be more than 12 US cents/kWh. **Major bottleneck**

- **Availability of possible sites** for construction of NPP: Safety of NPPs depends of many factors and one of the most important is the site. The future development of nuclear power technology depends on the proper selection of the sites for NPPs. The factors for proper considerations are: Use of land and water; Earthquakes; Meteorological events; Density of population; Aircraft crash related sitting requirements; Chemical explosions; and others. The situation is country specific. **Country specific bottleneck**

- **Limitations due to the designs of power reactors and their implementation in electrical grids**. The majority of power reactors are designed to operate as base - load electricity generating sources. Only a small number of existing and newer reactors have limited ability to significantly vary their power output. The present requirements for the stability of electrical grid put limits to the capacity of a single power unit, in some cases only 10 % of the total capacity on the grid. Most developing and middle size countries have electrical grids of 4-5 GWe. Thus, reactors with capacity of 1100 MWe and more would be too big for countries with small electricity grids. It would be difficult for countries which have ambitious plans to develop renewables to implement such reactors. A significant part of NPP sites are located on the sea/ocean coast, some of them on peninsulas, where construction of new transmission lines or upgrading of existing transmission capabilities would be problematic. **Country specific bottleneck**

- **Human resources**. This means availability of sufficient trained personnel to design, fabricate, construct, operate, support and regulate s large number of additional NPPs. The nuclear industry is facing difficulties to replace its personnel for existing reactors, due to lack of interest of young engineers in the field and aging of staff. According to a May 2008 assessment 35% of the people working at US nuclear utilities would be eligible to retire in the next 5-10 years, and that 90,000 new workers would be needed by 2011. The situation in Europe is similar - in 2009-2010 the number of nuclear engineering/nuclear energy-related subject students in the EU-27 was between 1800 and

2800. This could cover some 45% - 70% of the demand for nuclear experts by the nuclear energy sector in the EU-27 (on average 4000 per year by 2020). This is true if one assumes that all the relevant graduates mentioned are looking for an employment in the nuclear energy sector. **Major bottleneck**

- Availability of nuclear fuel over the 10-year time horizon. The fleet of nuclear power reactors uses as a fuel mainly uranium. Less than 10 % of LWRs reactors currently use MOX fuel and in a short term the picture will remain the same. Currently mining is providing about two-thirds of the existing demand for uranium. Thus in 2008 the total world production of Uranium was about 43, 850 t, whereas total consumption was about 78,000 t, from which 66,500 t were consumed by nuclear fleet. The difference between production and consumption is still covered by secondary supply sources, which however are declining. These factors possibly lead to the conclusion that an actual shortfall could occur as a result of the confluence of these factors, combined with new units going online in the 2020 time frame. **Bottleneck in case of the fast growth of nuclear power in the near future.**

- Impact of severe accidents & disposal of radioactive waste on public acceptance & political decisions. Political decisions regarding the use of nuclear power as well as public acceptance of nuclear technology depend on many factors, including concerns about occurrence and consequences of severe accidents in NPPs and the unresolved problems of final storage of spent fuel and high level radioactive waste. The Chernobyl catastrophe in 1986 has had a severe and long lasting effect on European public opinion and resulted in a dramatic slowdown of nuclear expansion. The Fukushima nuclear accidents influenced nuclear programs not only in Japan, but also in a number of states – Germany, Italy, Switzerland, Belgium, Lithuania and even in France. According to an October 2012 EU investigation the balance of public opinion remains negative in 16 out of the 24 countries surveyed. Most of the Europeans believed that the risks related to nuclear energy are underestimated, with a lack of security against terrorist attacks and the disposal and management of radioactive waste identified as the major dangers. **Major bottleneck.**

- **Capabilities to manufacture sets of heavy component**. These are components such as reactor pressure vessel & internals, reactor closure head, steam generators, primary coolant pumps and piping, etc. with a weight of several hundred tons. Industry capabilities for manufacturing reactor heavy components are a key issue for an expansion of the current size of the nuclear power. In order to fulfill ambitious plans of nuclear industry (to have 450 – 800 GWe in 2030) a new 1000 MW nuclear reactor has to be put in operation every 5-7 days. With a capability to support a rate of one unit every 11 days, the capacity to build heavy equipment sets would have to about double in the next ten years. **Bottleneck in case of the fast growth of nuclear power in the near future.**

- **Economic conditions & competition of other energy generation sources.** The world economic environment or in a particular state and the development of other generating sources could be an important bottleneck for the nuclear renaissance. Economic and financial crisis in the whole world during recent 5 years resulted in stagnation of demand in many countries. NPPs face challenges of regulatory mandated investments to fulfill post-Fukushima upgrades. In the US low cost natural gas become the big threat for some NPPs and already resulted in a final shutdown of the Kewaunee NPP in Wisconsin. Other US NPPs are also under threat. In December 2012 Santa María de Garoña NPP was shut down due to additional tax. **Country specific bottleneck.**

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OVERVIEW

The aim of this Work Package of the EHNUR report is to identify the problems which are possibly limiting the development of NPPs across the world and their relevance for impeding nuclear growth scenarios. The following questions are dealt with:

- What are the bottlenecks in the development of nuclear power reactors;
- What are financial risks (initial costs, availability of capital, construction delays and cost overruns) in construction of NPPs – section 4.1;
- Are there enough sites for construction of NPPs - section 4.2;
- What limitations exist due to the designs of power reactors and their implementation into electrical grids - section 4.3;
- Could we expect problems with human resources (availability of sufficient trained personnel to design, fabricate, construct, operate, support and regulate large number of additional NPPs) if many NPPs will be constructed - section 4.4;
- What is the influence of public opinion & political decisions on the development of nuclear power technology - section 4.5;
- Is there enough nuclear fuel over the 10-year time horizon - section 4.6;
- What are the capabilities to manufacture enough sets of heavy component (components such as steam generators, reactor pressure vessels & internals, primary coolant pumps, etc.) - section 4.7;
- What is the influence of economic conditions & competition of other energy generation sources for the growth of NPPs - section 4.8.

The importance of bottlenecks for the development of a possible Austrian nuclear power program is also discussed.

1 INTRODUCTION

The EHNUR project gives an answer to the hypothetical question of which problems would arise if the world would try to realize substantial growth of nuclear power with special attention to Austria if the country would decide to deploy a nuclear power program for electricity production. It has been assumed that Austria intends to operate up four Generation III power reactors, 1100-1150 MWe class PWRs, at several sites with total capacity of up to 4600 MWe.

Special focus is given to the bottlenecks, among which financial risks, availability of sites for NPPs, availability of nuclear fuel for a long term period, human resources, limitations due to the designs of power reactors, public opinion & political decisions, capabilities to manufacture sets of heavy components, economic conditions & competition of other energy generation sources.

2 METHODOLOGY

This part of EHNUR is based on literature research on the general situation in Europe (and single countries in Europe) and outside, which has then been extrapolated to draw conclusions for Austria. The main documents that have been used are reports from nuclear utilities and regulators, materials from international nuclear organizations (IAEA, IEA, WNA), reports to scientific conferences, articles in specialized magazines (Nucleonics Week, Nuclear Engineering International, Nuclear Fuel), reports of the European Commission, European Nuclear Energy Forum, nuclear operators, regulators, TSOs, independent experts, NGOs, as well as the author’s studies. One important aspect is that the quality of data from different sources was quite diverse. Another fact is the change of numbers of operating reactors, projections for future reactors, economic data for such reactors, etc.

3 BOTTLENECKS

What are bottlenecks, how are they defined.

A bottleneck is a stage in a process that causes the entire process to slow down or stop. Another understanding for a bottleneck in technical field is: a phenomenon where the performance of the system is limited by a single or limited number of components or resources.

In the growth of commercial NPPs bottlenecks are factors, which are possibly limiting or slowing the development of nuclear power technology and the rate at which new NPPs could possibly be added to power grids worldwide.

The list of bottlenecks includes possibly includes:

- Financial risks (initial costs, availability of capital to finance the projects & additional risks);
- Availability of possible sites for construction of NPPs;
- Limitations due to the designs of power reactors and their implementation in electrical grids;
- Human resources (availability of sufficient trained personnel to design, fabricate, construct, operate, support and regulate large number of additional NPPs);
- The availability of nuclear fuel over the 10-year time horizon;
- Impact of severe accidents & disposal of radioactive waste on public opinion & political decisions;
- Capabilities to manufacture sets of heavy component (components such as steam generators, reactor pressure vessels & internals, primary coolant pumps, etc.);
- Economic conditions & competition of other energy generation sources.

3.1 FINANCIAL RISKS (INITIAL COSTS, AVAILABILITY OF CAPITAL, COST OVERRUNS)

3.1.1 INITIAL COSTS TO CONSTRUCT AN NPP

Nuclear power reactors typically have high initial capital costs for building the plant and they are the highest among the base load electricity generating sources. In addition for certain projects there is significant uncertainty about the capital costs, and the cost of financing and costs overruns during construction, which are the main components of the cost of electricity from new NPPs. Cost estimates also need to take into account decommissioning of plants and long term storage of SF and RW.

In 60-ies nuclear enthusiasts claimed that nuclear power would be “too cheap to meter”. However construction delays, cost overruns and regulatory changes increased the costs of NPPs drastically and already in late 80-ies they became too expensive to build. As a result from 240 reactors ordered in the US until the end of the 70-ies more than half were cancelled, others were frozen and after 1977 no reactor was ordered in US (until 2012). The statistics on "cancelled orders" through 2002 indicate 253 cancelled orders in 31 countries, many of them at an advanced construction stage. The US alone accounts for 138 of these cancellations and many utilities suffered grave financial harm because of reactor construction projects (CEA, 2002).

In 2000-2004, when the nuclear community started to talk about an expected nuclear renaissance, vendors estimated the overnight cost[2] for a new nuclear unit at \$1600 - \$2000/kWe. That figure had risen to at least to \$4000/kWe two-three years later (NW, 2008).

In 2009 the US Moody's Investors Service suggested that the overnight cost for a new unit would be at \$6250/kWe (Cooper, 2009). US DoE's Energy Information Administration and NEI suggest that the overnight capital costs for new nuclear units would be \$5500/kWe.

It has to be pointed out that total costs to construct an NPP and to connect it to the electrical grid could be twice (or even more) the overnight cost. (NW, 2013c)

Analyses of independent experts demonstrate even higher numbers.

The estimates for the overnight cost of new NPPs in US given by nuclear enthusiasts, utilities, independent analysts (Wall Street) and actual are shown on **Fehler! Verweisquelle konnte nicht gefunden werden.** (Cooper, 2012). The utility estimates are three times higher than the initial enthusiastic renaissance projections, while independent analyses are five times higher.

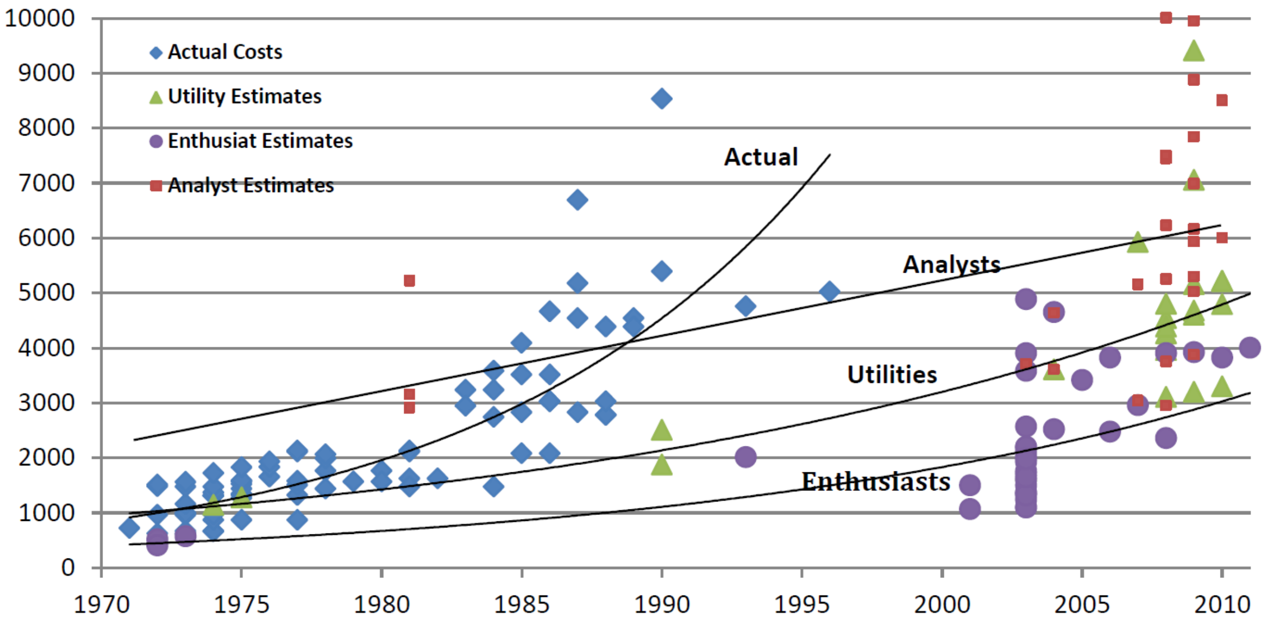


FIGURE 1: OVERNIGHT COSTS OF NEW NPPS, 2009\$/KWE (COOPER, 2012)

[2] **Overnight cost** is a hypothetical cost of a construction project if no interest was incurred during construction, as if the project was completed overnight. The unit of measure for power plants is \$/kWe.

Such capital costs (and associated high risks) are impossible for the majority of power companies. That's why without governmental subsidies construction of new plants would be a difficult or almost impossible task. For example – According to the 2005 Energy Policy Act the US government has a multibillion program in federal loan guarantees to cover as much as 80 percent of the cost of building a new plant, and the loan program may soon offer tens of billions more. In UK the Government decided that the nuclear power is "clean energy" and should have the same bonuses as renewables.

Concerning the costs of electricity from new NPPs due to the very high initial costs, even according to the US NEI the electricity from the new NPPs in US would be **12,1 US cents/kWh** (assumed bus bar). This would be the most expensive source in US. (NW, 2013c)

The situation elsewhere in the world is similar. The planned Akkuyu NPP (four Russian reactors WWER 1200, total 4800 MWe) in Turkey would cost $20 billion. According to a 15-year Power Purchase Agreement, the power from Akkuyu NPP is to be sold at a weighted average price of **12,35 US cents/kWh** (bus bar), with a ceiling of 15,3 cents/ kWh (NW, 2012a).

Another example in Europe is the planned Visaginas NPP (ABWR, 1350 MWe supposed to be built by Hitachi - GE) in Lithuania. It is expected to cost about Eur5 billion ($6,5 billion). According to the a report released April 25 2013, consultants from Lithuanian Energy Institute prove that Lithuania could buy electricity at market prices for less than electricity from the Visaginas NPP would cost. If the reactor is not built Lithuania would save about 400 million litas ($152,8 million) a year through 2080, under the favorable conditions scenario. If electricity import conditions are not favorable about 15 million litas a year would be saved. In both cases, they estimated that the reactor operates for 60 years. (NW, 2013f).

The availability of capital

The availability of capital to finance the projects is being affected by the current (as of early 2009) economic crisis. An IEA report at the end of May 2009 (according to NucNet), says that the global economic downturn could lead to delays or cancellations of new NPP projects. The IEA is quoted as saying, "*Only a few electricity utilities are big enough to finance nuclear plants from their balance sheets, and that number has diminished in the current crisis.*" (NucNet, 2009).

Several proposed NPP projects have been cancelled in the US (Callaway Unit 2) and Canada (two-unit stations at both Darlington B and Bruce C) due to a combination of financing problems and high estimated construction costs.

The situation in Europe is similar - due to the financial crisis and lack of finances in Eastern Europe, a number of long-established projects are struggling to find finance. The Belene NPP project in Bulgaria was finally cancelled in March 2012 (Novinite.com, 2013). The potential backers have pulled out from consortium to finish two additional reactors at Cernavoda NPP in Romania (Bucur and Chirica, 2013).

The shares of the world's largest nuclear operator EDF have lost 82 percent of their value since 2007, while the largest nuclear builder AREVA has lost 88 percent. Of eleven assessed nuclear companies and utilities, seven were downgraded by credit rating agency Standard and Poor's over the past five years; four companies remained stable, while none were upgraded over the same period. If [a utility] is already on the edge of a ratings band, "a nuclear project could be the thing that pushes [the utility] over the edge—it's just another negative factor", explains Moody's (Schneider and Froggatt, 2012).

3.1.2 CONSTRUCTION DELAYS AND COSTS OVERRUNS

Lead times for NPPs include not only construction times but also long-term planning and lengthy financing negotiations and licensing procedures, including the following stages: Feasibility studies; Environmental Impact Assessment; Preparation of bid specifications; Evaluation of bids; Licensing procedure; Site preparatory works; Construction; Start-up. All these activities could take 15 years or more. In most cases the grid system also has to be upgraded - often using new high-voltage transmission lines, substations and replacing sources, which bring their own planning and licensing difficulties. In some cases, public opposition is significantly higher for the long-distance power lines that move the electricity than for the nuclear generating station itself.

Past experience shows that simply having an order for a reactor, or even having a nuclear plant at an advanced stage of construction, is no guarantee for grid connection and power supply. There are three major risks for construction of new NPPs (not speaking about the risk of a severe accident during operation): cost overruns due to construction time overruns, power price insufficiency to provide a return on investment and operational losses due to breakdowns or regulatory delay. These risks are potential corporate killers for most power companies and are the main reason that in many countries the new NPPs cannot be built without governmental support.

Projected NPP completion times should be viewed skeptically, and past nuclear planning estimates have rarely turned out to be accurate. During last 20 years 89 reactors were finished in 17 countries and the average construction time was almost 9 years (from 3,2 to 36,3). Only several Asian countries – Japan, China and South Korea – demonstrated low construction times for a significant number of reactors (IAEA, 2013).

A six-month breakdown can cost hundreds of millions of Euro in direct costs and lost output, particularly if the output has been pre-sold. This risk is too great for a single project to bear, in our view, and at the very least needs to be spread across a portfolio of assets.

Example 1: NPP construction in Europe

Evaluation of NPP construction delays and costs overruns in Europe

Two EPR are being constructed in Europe. The 1600 MWe reactor, the first unit of its kind, is being built as a third unit of Olkiluoto NPP in Finland by Areva and Siemens under a fixed-price turnkey contract. The second EPR is being built as a third unit of Flamanville NPP in France. In addition EDF Energy plans to build two 1600-MWe EPRs at Hinkley Point in UK (this is the only company in talks with the UK government to build reactors in the UK). Development of their initial costs and construction times is shown in Table 1. In addition data for Belene NPP in Bulgaria (2000 MWe, two WWER – 1000 reactors, cancelled in 2012) is shown.

TABLE 1: INITIAL AND ACTUAL COSTS AND CONSTRUCTION TIMES OF OLKILUOTO 3 AND FLAMANVILLE 3 (IN MARCH 2013) (NW, 2013b; WNA, 2012d,f; HSBC, 2012)

Reactor	Start of construction	Online date, initially / March 2013	Cost (billion Euro), initially / March 2013
Olkiluoto 3 (one EPR)	2005	2009 / 2016	3,2 / 8,5
Flamanville 3 (one EPR)	2007	2013 / 2016	3,3 / 8
Hinkley Point (two EPR)	?	?	16,2 (estimate)
Belene NPP	?	?	3,96 / 10,353 (2012)

Example 2: NPP construction in US

Watts Bar-2: The construction of Watts Bar 2 started in 1973, but was stopped in 1985 when it was about 55% completed. In 2007 it was decided to resume the job, expecting it to cost $2,5 billion. This reactivation project increased by 60 percent over the past five years – from initial $2,5 billion (2008) to $4,2 billion in 2012. Work resumed in 2008 and was scheduled to be completed in late 2012. In 2012 it was scheduled to be complete in December 2015 and the work still is targeted to cost about $4,2 billion (WNA, 2012b).

Levy NPP: Florida Power & Light (within consortium) has an EPC contract for two reactors (AP1000) with Progress Energy Florida for a greenfield site in Levy County. The estimated cost of the Levy NPP and online date have followed this track (NW, 2009; Penn, 2012; WNA, 2012c): **2006**: $4-6 billion, online date in 2016; **2007**: $10 billion, online date in 2016; **2008**: $17 billion; **2011**: $22,4 billion, online date 2021; **2013**: $24 billion, online date in 2024; About 1,6 million Florida customers have already paid $1,1 billion toward the Levy project, though the utility has not made a final decision whether to build the plant.

3.1.3 ESCALATION DUE TO THE STRENGTHENED REGULATORY REQUIREMENTS

Strengthening safety requirements

After the TMI and Chernobyl accidents the nuclear community accomplished a lot of investigations, focusing to the causes of the accidents, human behavior, weaknesses of designs, etc. Based on the lessons learned and operational experience the safety requirements of the national nuclear regulators and international organizations have been strengthened. The major outcome was improvement of the safety of the plants. However more sophisticated reactor designs significantly increased the construction costs of the new NPP. Modernization and upgrading programs of existing plants were also expensive.

Fukushima accident demonstrated need for additional safety measures for the new and existing NPPs. According to the EC post-Fukushima safety improvements to the EU's 134 nuclear power reactors could cost between Eur10 billion and Eur25 billion in the coming years. (NW, 2012c).

Strengthening environmental requirements

Regulatory requirements were and are strengthened also due to the environmental considerations, for example use of cooling water for thermal plants and NPPs. In US the federal Clean Water Act requires utilities to implement so-called "best technology possible" in the interest of protecting marine life. Some states already introduced environmental policies requiring certain industrial facilities, including NPPs, which use water for cooling purposes to recycle and reuse that water through a process known as "closed cycle cooling" technology. This means that NPPs will have to construct closed-cycle cooling towers, a modification that would cost hundreds of millions of dollars to implement for each unit.

Currently, there are total of 103 nuclear power reactors, 59 use once-through cooling from rivers, lakes or the sea, while 35 use wet cooling towers. Nine units use dual systems, switching according to environmental conditions.

Implementation of Clean Water Act requirements in the State of New Jersey has already affected the future of Oyster Creek NPP. The plant began operating in December 1969 as the first large-scale commercial NPP in the USA. It has a single BWR generating 636 MWe net. In April 2009, the US NRC extended the plant's operating license for a further 20 years, until April 2029. According to the original design the plant discharges heated water into a canal that is connected to Barnegat Bay. The plant is operated by Exelon (the largest nuclear operator in US).

In 2010 New Jersey regulators proposed a new draft permit requiring plant owner Exelon to build a closed-loop cooling system to protect aquatic life in the Barnegat Bay ecosystem. After negotiations in December 2010 it was announced that Exelon would permanently shut Oyster Creek NPP in New Jersey by the end of 2019. The agreement allows Exelon to operate the plant until then without installing cooling towers. (WNA, 2010a; NW, May 2013h)

The State of New York state has followed neighboring New Jersey in introducing a draft policy requiring certain industrial facilities, including NPPs, to construct cooling towers. In 2010 the State set draft compliance dates of 2018 for non-nuclear facilities and 2021 for nuclear facilities. The move could cost nuclear operators (6 reactors with 5500 MWe) in the State over $2 billion to comply. (WNA, 2010d)

In May 2010 State of California adopted a policy to establish wet closed-cycle cooling as the performance benchmark in meeting requirements of the Clean Water Act. The new policy requires 19 existing coastal power plants - including the state's two NPPs - to phase out the use of once-through cooling systems. The estimates show that the upgrades will cost on average some 1 cent per kilowatt-hour, excluding lost revenue while the plants are offline for the modifications. Californian regulators have given San Onofre NPP until 2022 to ensure the cooling system complies with the new regulations, while Diablo Canyon NPP will have time until 2024 to comply. (WNA, 2010e)

3.2 AVAILABILITY OF POSSIBLE SITES FOR CONSTRUCTION OF NPP: PROBLEMS, LIMITATIONS, CHALLENGES

3.2.1 GENERAL REMARKS

Safety of NPPs depends of many factors and one of the most important is the site characteristics. The future development of NPPs depends of the proper selection of the sites for them. Most countries with NPPs in operation plan to build new reactors on the existing sites. This option however is limited and selection of new sites is needed.

General criteria to characterize the NPPs site specific conditions and phenomena, as well as safety requirements are developed at international level, for example in IAEA Safety Series. The IAEA safety standards are arranged in three levels.

At the top is the Safety Fundamentals document (IAEA, 2006) which presents the fundamental safety objective and the principles of protection and safety that provide the basis for safety requirements.

Next are the Safety Requirements documents that establish the requirements that must be met to ensure the protection of people and the environment, both now and in the future. The Safety Requirements documents use mandatory "shall" statements together with statements of associated conditions that must be met.

Finally come Safety Guides that provide recommendations and guidance on how to comply with the Safety Requirements. Recommendations in Safety Guides are expressed as "should" statements. The Safety Guides represent an international consensus that it is necessary to take the measures recommended or equivalent alternative measures. According to IAEA, Safety Guides "***present***

international good practices, and increasingly reflect best practices, to help users striving to achieve high levels of safety".

The IAEA Safety Requirements document for siting is (IAEA, 2003).

The siting process generally consists of an investigation of a large region to select one or more candidate sites, followed by a detailed evaluation of those candidate sites.

3.2.2 SITE SELECTION LIMITING FACTORS

3.2.2.1 USE OF LAND AND WATER

The operation of an NPP may affect the local and regional environment, with the simplest example changes in water temperature. As part of the environmental impact assessment for the site, the proposed region shall be studied to evaluate the present and future uses of land and water in the region and account shall be taken of any special characteristics that may affect the potential consequences of radioactive releases. Environmental standards that regulate use of land and water are quite strict in some countries, which could create problems for selection and endorsement of new sites. The investigations should cover land devoted to agricultural uses, to dairy farming, to industrial, institutional and recreational purposes. Bodies of water used for fishing, navigation, community water supply, irrigation, and recreational purposes should be investigated. The study should cover direct and indirect pathways for potential radioactive contamination of the food-chain, products imported to or exported from the region which may form part of the food-chain, etc.

Special consideration should be given to any population centers for which drinking water is obtained from water bodies that may be affected by operation of an NPP. To the extent possible, future water flow and water uses should be projected over the lifetime.

Older NPPs have only 32-33% thermal efficiency, currently being built have about 34-36% efficiency, depending on cooling water temperature. Coal-fired plants as a rule have efficiencies of 36 - 40% (WNA, 2013a). Due to the low efficiency of NPPs only about one third of thermal energy generated in the reactor core can be converted into electrical energy. The rest of thermal energy has to be dispersed into environment. Thus the normal operation requires ability of huge amount of water, which could be assured by big rivers, lakes or seas. In addition NPPs also need big amount of water for the cooling functions of their safety systems. Due to these requirements NPPs need higher amounts of water compared with other thermal power plants as shown on the Figure 2.

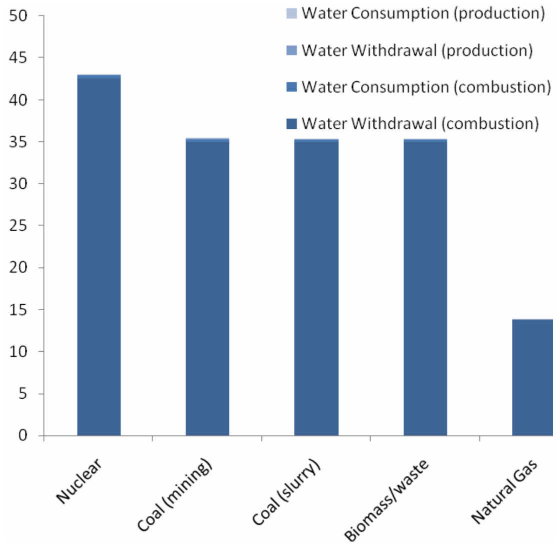


FIGURE 2: TOTAL WATER USE FOR THERMOELECTRIC GENERATORS (GALLONS/KWH) (US DOE, 2006A)

Due to high water consumption NPPs have to be situated near big rivers, lakes or at the sea (ocean) coast. It is important to mention that NPPs also contaminate the water at multiple points of the cooling cycle. The total thermal capacity of the plant to be installed on the site should be determined at the early stages of the siting process in order to assure the adequacy of the ultimate heat sink. If site is located nearby river or lake season variations of the water flow and elevation should be considered. The thermal effectiveness of the plant depends of the temperature of the cooling water and it is bigger for coastal sites. If it is proposed that the installed capacity be significantly increased to a level greater than that previously determined to be acceptable, the suitability of the site shall be re-evaluated, as appropriate.

In most countries there are strong environmental standards for thermal pollution of rivers (lakes) that prohibit the direct use of river’s water during summer period. In order to cope with this requirement NPPs have to build cooling towers and associated piping and pumping apparatus, which makes their construction more costly. For example at the end of 2012 there were 104 nuclear power reactors in the USA; 60 used once-through cooling from rivers, lakes or the sea, while 35 used wet cooling towers. Nine units used dual systems, switching according to environmental conditions (WNA, 2011a). Many states are discussing introduction of new legislation that will force NPPs to construct cooling towers.

In most European nuclear countries big rivers are already used for existing NPPs and the number of potential new sites is limited. In France, all but four of NPPs are inland (15 sites), and require fresh water for cooling. Eleven of the inland plants with 32 reactors have cooling towers, and the other four with 12 reactors use simply river or lake water directly. With regulatory constraints on the temperature increase in receiving waters, this means that in very hot summers generation output has to be limited.

3.2.2.2 DENSITY OF POPULATION

The main objective in site evaluation is to protect the public and the environment from the radiological consequences of radioactive releases due to severe accidents, as well as releases due to normal operation. The operation of a nuclear power reactor may affect the population in the surrounding area and the local and regional environment. One of the main factors in the evaluation process that shall be considered is population growth and population distribution over the lifetime of NPP. Emergency planning, including evacuation in case of severe accident must be also considered. Before final approval of the site, the feasibility of an emergency plan should be demonstrated on the basis of site specific natural and infrastructure conditions in the region.

Problems associated with population put additional difficulties and limitations for selection of new sites for future NPPs in the highly populated Western and Central Europe and North America east of the Mississippi River, and especially in countries where the majority of citizens are concerned of the multiple risks of nuclear power plants operation and decommissioning.

3.2.2.3 EARTHQUAKES

The seismological and geological conditions in the region and the engineering geological aspects as well as geotechnical aspects of the proposed site area shall be evaluated. For some sites it seems difficult to collect and document the information on prehistoric, historical and instrumentally recorded earthquakes.

In order to determine the hazards associated with earthquakes, seismotectonic evaluation of the region with the use to the greatest possible extent of the information collected should be applied. A thorough uncertainty analysis shall be performed as part of the evaluation of seismic hazards.

On the basis of geological, geophysical, geodetic or seismological data the potential for surface faulting shall be assessed for the site.

During the last three decades an important development concerning the determination of seismic hazard and risk took place. Apart from the traditional seismological approach, which concentrated on the refinement of actual seismic monitoring and the improvement and international coordination of historical earthquake catalogues, new scientific methods were initiated and developed quickly.

The broad spectrum of earth sciences had already developed rapidly, providing many useful tools in geomorphology, sedimentology, geochronology, and tectonics and of course geophysics and geodesy. Thus the investigation of recent crustal movements, displacements along faults and historical & archeological sites of destructive earthquakes lead to important new results. The scientific community in earth sciences refers to neotectonics, paleoseismology or actuo-geology. A big leap forward is mainly indebted to inter- and multidisciplinary research and the combination of different methods. But it is a fact that the new methods were mainly used in scientific projects. The application of these powerful tools in determining the seismic hazard originating from a certain fault during the process of siting or during re-assessments has been widely avoided. The reasons for this unsatisfactory situation can only partly be explained by the high costs for investigations and the uncertainty of obtaining new results. Despite the fact that IAEA recommends the application of paleoseismology in various documents the observation of the relevant recommendations and guidelines remained unsatisfactorily low.

3.2.2.4 METEOROLOGICAL EVENTS

Tornados: This meteorological phenomenon is a limiting factor for some regions in North America, but not only there. The potential for the occurrence of tornadoes shall be assessed on the basis of detailed historical and instrumentally recorded data for the region. The hazards associated with tornadoes shall be derived and expressed in terms of parameters such as rotational wind speed, translational wind speed, radius of maximum rotational wind speed, pressure differentials and rate of change of pressure. Missiles that could be associated with tornadoes shall be considered.

Cyclones and extreme winds: This meteorological phenomenon is a limiting factor for tropical regions. The hazards associated with tropical cyclones include factors such as extreme wind speed, pressure and precipitation. Missiles that could be associated with cyclones shall be also considered. Operating experience has shown that extreme winds mainly affect the power supply and availability of the electricity grid. The accidents typically evolved into turbine trip and loss of off-site power. Cyclones and extreme winds have been known to cause collapse of cooling towers and chimneys as a consequence of a 'group effect', while they were individually designed to withstand an even higher wind speed (WNA, 2011a).

Tsunamis: The region shall be evaluated to determine the potential for tsunamis that could affect the site. The historical data relating to tsunamis affecting the shore region around the site shall be collected and critically evaluated for their relevance to the evaluation of the site and their reliability. On the basis of the available prehistoric and historical data for the region and comparison with similar regions, the frequency of occurrence, magnitude and height of regional tsunamis shall be estimated with account taken of any amplification due to the coastal configuration at the site. The potential for tsunamis to be generated by regional offshore seismic events shall be evaluated on the basis of known seismic records and seismotectonic characteristics.

The hazards associated with tsunamis shall be derived from known seismic records and seismotectonic characteristics as well as from physical and/or analytical modeling.

Droughts: Droughts and extended periods of high temperatures can subsequently cripple nuclear power generation and it is often during these times when electricity demand is highest because of air-conditioning and refrigeration loads and diminished hydroelectric capacity.

Examples include:

- In July 2006, the D.C. Cook reactors in the US were shut down because temperatures in the containment exceeded 120 degrees F (Colover, 2003);
- In 2003 France had to cut back 6 GW of capacity and several German reactors operated at 40% capacity (Reuters, 2003);
- In July and August 2006, nuclear power plants at Prairie Island, Quad Cities, Dresden, and Monticello in US had to reduce power due to water discharge temperatures;
- In August 2008, all three units at Browns Ferry in US were shut down to prevent overheating Tennessee River water;
- In July 2009, almost a third of the nuclear generating capacity in France was lost due to power production cuts needed to avoid exceeding thermal discharge limits;
- In July and August 2011, all three units at Browns Ferry in US had to reduce power to 50% to avoid exceeding thermal discharge limits;
- In July 2012, the Vermont Yankee plant had to limit power generation four times because of low river flow;
- One of two reactors at Millstone in the US had to shut down in August 2012 because of high seawater temperature.

(Inside climate news, 2012**)**

3.2.2.5 AIRCRAFT CRASH RELATED SITTING REQUIREMENTS

Aircraft crashes are potentially affected by weather-related conditions such as lightning strikes, precipitation, icing, high winds, and fog. Historically, there have been 587 aircraft crashes due to weather conditions according to the statistics from the Aviation Safety Network database (updated as of 21 January 2013) of 13,558 aircraft accidents since 1919. Aircraft crash frequency statistics indicate that crash frequencies are dominated by takeoff and landing operations within 20 km of the airport (Aviation, 2013).

Some existing NPP sites with airports handle large enough aircraft to be a potential problem (commercial flights vs. general aviation). These sites are:

- Three Mile Island in the US (about 5 km from Harrisburg International Airport);
- Bugey in France (about 16 km from Lyon Airport);
- Calvert Cliffs in the US (15 km from Naval Air Station Patuxent River);
- Bushehr in Iran (11 km from the joint civil/military Bushehr International Airport, and 9 km from Bushehr Navy Airport);
- Doel in Belgium (20 km from Antwerp International Airport);
- Hamaoka in Japan (19 km from Suizuoka Airport);
- Chashma (CHASNUPP) in Pakistan (3.75 km from Chashma Airport, served only by government helicopters at present, but has a 1000 meter long asphalt runway);

- Millstone in the US (10 km from Groton-New London Airport); and
- Beaver Valley in the US (19 km from Pittsburgh International Airport).

There is no experience of damage induced by aircraft falling on nuclear islands, although some crashes have been recorded in their vicinity, sometimes with long skidding (300 m) of the engines far from the impact areas, with damage to residential and industrial facilities. Some malevolent and wartime attacks with non-explosive missiles have been recorded. The only massive terrorist attack with heavy airplanes was accomplished on September 11, 2001.

The main hazards are the mass and kinetic energy of the primary missile (airplane) and secondary missiles (engines) and the fire due to the amount of fuel in the plane.

In the IAEA Safety Requirements document NS-R-3 (IAEA, 2003) aircraft crash is addressed under external human induced events (however deliberate aircraft crash is excluded from consideration). The requirement is stated as (§3.44 to §3.47): The potential for aircraft crashes on the site shall be assessed with account taken, to the extent practicable, of characteristics of future air traffic and aircraft. If the assessment shows that there is a potential for an aircraft crash on the site that could affect the safety of the installation, then an assessment of the hazards shall be made. The hazards associated with an aircraft crash to be considered shall include impact, fire and explosions. If the assessment indicates that the hazards are unacceptable and if no practicable solutions are available, then the site shall be deemed unsuitable.

The corresponding IAEA Safety documents consider three types of aircraft crash events:

Type 1 Event: "A crash occurs at the site deriving from the general air traffic in the region. To evaluate the probability of occurrence of such crashes, the site is considered as a tract or circular area of 0.1-1 km^2 and the region as a circular area of 100-200 km in radius";

Type 2 Event: "A crash occurs at the site as a result of a takeoff or a landing operation at a nearby airport";

Type 3 Event: "A crash occurs at the site owing to air traffic in the main civil traffic corridors and the military flight zones".

The potential for aircraft crashes that may affect the plant site should be considered in the early stages of the site evaluation process and should also be assessed over the entire lifetime of the plant. NS-G-3.1 recommends a screening value approach where statistics and geographic information relating the proposed site to aircraft related hazards (airport locations, flight corridor locations, etc.) are used to calculate the frequency with which aircraft crashes are expected at the proposed site.

If the calculated value approaches or exceeds the screening value (the US NRC uses a screening value is 10^{-7} per year, a value enshrined in its Standard Review Plan) (NRC, 2007), it is recommended that the severity of the effects of the crash should be determined with consideration given to local structural effects, direct damage by primary and secondary missiles, induced vibrations, and effects caused by fuel (including burning of fuel, explosion of the fuel outside buildings, entry of combustion products into ventilation or air supply systems, and entry of fuel into buildings through normal openings and through holes caused by the crash).

In the two cases where the NRC methodology was used and the screening value was exceeded, the containments of the NPPs involved (Three Mile Island Unit 2 and Seabrook) were required to be designed to withstand the crash. In the case of TMI Unit 2, the design basis aircraft was a Boeing 707-320 (owing to the proximity of Harrisburg International Airport). In the case of Seabrook, the design basis aircraft was an FB-111 military aircraft (owing to the proximity of Pease Air Force Base). The NRC Standard Review Plan states that the screening value is considered to be below 10^{-7}/a by inspection if the all of the following criteria are met: (a) the plant-to-airport distances is between 5 and 10 miles (8-16 km) and the projected annual number of operations is less than 500 times the square of the distance; (b) the plant is at least 5 miles (8 km) from the nearest edge of military training routes, including low-level training routes, except for those associated with usage greater than 1000 flights per year, or where activities (such as practice bombing) may create an unusual stress situation; and (c) the plant is at least 3,2 km beyond the nearest edge of a Federal airway, holding pattern, or approach pattern (NRC, 2007).

IAEA NS-G-3.1 states that aircraft crashes in connection with takeoff and landing operations at nearby airports "*tend to occur within approximately semicircular areas of 7.5 km in radius centered at the ends of the runways*". This guidance, however, is contradicted by statistics from the ACRO which indicates that 53.89% of commercial and military aircraft crashes since 1963 (excluding fighter aircraft, helicopters, and balloons) occurred within 10 kilometers of airports (ACRO, 2010). A recent evaluation of the effects of large aircraft crashes at nuclear power plants prepared by GRS in Germany raises another possibility – that a BLEVE can occur due to the crash (Luther and Müller, 2009).

The US DoE guidance on aircraft crash evaluation states that for landing crashes, commercial aviation crashes end 1,6 km from the center of the runway but that military landing crashes extend up to 16 km from the end of the runway (US DoE, 2006b, p. 6).

ACRO statistics also include the following statistics which are potentially relevant to consideration of aircraft crashes at nuclear power plants (ACRO 2010): 3.25% of all aircraft crashes were the result of sabotage as the principal cause (about one out of 31 crashes); Human error was the principal cause in 67.6% of all crashes; 12% of all aircraft crashes involved cargo flights (about one out of eight crashes); Only 35.4% of all aircraft crashes involved regularly scheduled flights (said differently, nearly two-thirds of all aircraft crashes involve other than regularly scheduled flights); Military flights accounted for 12.8% of all aircraft crashes (about one out of eight crashes). Nearly 1% of all aircraft crashes involved inflight refueling accidents (military) (one out of 100 crashes). 50.4% of all crashes occurred during landing, 21% occurred during takeoff, and 27.7% during flight (the remainder involved crashes during taxiing and parking at the airport).

For non-airport crashes, the US DoE guidance gives average values for the continental United States for aircraft crash rates per square mile (one square mile = 2,59 square kilometers), centered at a site, as follows (US DoE, 2006b, p.25):

- Air Carrier – 4.7E10^{-7}/a (for air carriers, air taxis larger than 30 passengers, air travel clubs);

- Air Taxi – 1.0E10^{-6}/a (for air taxis smaller than 30 passengers or a payload of 3.4 t);

- Large Military – 2.0E10^{-7}/a (including bombers, cargo aircraft, and tankers); and

- Small Military – 4.0E10^{-6}/a (including fighters, attack aircraft, and trainers).

An important factor for the discussion above is that the IAEA standards exclude deliberate aircraft crash as part of a terrorist attack. There are important differences between accidental aircraft crash and deliberate aircraft crash, as shown in Table 2:

TABLE 2: DIFFERENCES BETWEEN ACCIDENTAL AIRCRAFT CRASH AND DELIBERATE AIRCRAFT CRASH (US DOE, 2006B, P. 25)

Factor	Accidental Crash	Deliberate Crash
Aircraft Type	Distribution of aircraft types based on crash statistics (with corresponding weights and fuel contents according to aircraft type)	Aircraft type deliberately selected by terrorists, likely to be large commercial aircraft (larger than the Boeing 767 aircraft used by terrorists on 11 September 2001) or large military aircraft, or could be smaller aircraft operating from unregulated airport and loaded with explosives;
Aircraft Control	Aircraft assumed to be under control with the possibility of pilots attempting to avoid hazardous facilities; crashes occur at random in any case	Pilots assumed to be able to deliberately target hazardous facilities
Impact Speed	Typically assumed to be 100 m per second for large aircraft and 200 m per second for small military aircraft (fighters)	Can be larger than assumed for accidental crash; crash speeds for 11 September 2001 were estimated to be in the range of 197-242 m per second

A comparison of maximum takeoff weights and fuel capacities of the aircraft used by terrorists in the 11 September 2001 attacks and other large aircraft is provided in Table 3. Clearly there are far more damaging possibilities (3-4 times heavier and 4-8 times more fuel) available to future terrorists compared with the aircraft selected by the 11 September 2001 attackers. Also to be noted that the aircraft below (except for the Boeing 777) are four-engine aircraft, whereas the 2001 attack aircraft were two-engine (this is important with respect to possible missile penetration by jet engine turbine axes).

Summarizing, hazards for NPP sites deriving from airplane crash should be re-evaluated, having in mind the present and future airplanes (both civilian and military) with heaver mass and fuel amount and potential terrorist attack.

TABLE 3: TAKEOFF WEIGHTS AND FUEL CAPACITIES OF DIFFERENT AIRCRAFTS (US DOE, 2006B, P. 25)

Aircraft	Maximum Takeoff Weight	Fuel Weight
11 September 2001 Aircraft – High	159 t	77752 l
11 September 2001 Aircraft – Low	116 t	42680 l
Boeing 747-400	285 t	215991 l
Boeing 747-400ER	413 t	240196 l
Boeing 747 Freighter	397 t	215991 l
Boeing 777	347 t	181283 l
Airbus A340-600	380 t	204500 l
Airbus A350-1000	298 t	156000 l
Airbus A380	560 t	320000 l

3.2.2.6 4.2.2.6 CHEMICAL EXPLOSIONS

Activities in the region that involve the handling, processing, transportation and storage of chemicals having a potential for explosions or for the production of gas clouds capable of deflagration or detonation shall be identified. All types of potential explosions – with or without fire, with or without secondary missiles, originating from off-site (hydrogen or methane storages) and on-site sources (but external to safety related buildings), such as hazardous or pressurized materials in storage, transformers, pressure vessels or high speed rotating equipment (for example several units with parallel orientation of turbines).

Transportation of methane, hydrogen or LPG in large amounts creates significant threat due to their high explosive potential. Explosion of a big truck or ship-carrier of such gas could damage the entire plant. The site selection process shall evaluate the possible transportation of such substances near to the proposed site and its increase in the future. If such potential exist, hazards from possible explosions due to the collision of ships (tracks) or terrorist actions shall be considered.

Explosions of gas or vapour clouds could also affect the entire plant area. Therefore the postulated gas or vapour cloud should be the most severe credible hazard relevant to the site. An analysis of the ability of plant structures to resist the effects of a gas cloud explosion can normally be limited to an examination of their capacity to withstand the overpressure loading. Other effects should be considered: fire, smoke and heated gases, ground and other vibratory motions, and missiles resulting from the explosion.

Hazards associated with chemical explosions shall be expressed in terms of overpressure and toxicity (if applicable), with account taken of the effect of distance. A site shall be considered unsuitable if such activities take place in its vicinity and there are no practicable solutions available.

The region shall be investigated for installations in which flammable, explosive, asphyxiant, toxic, corrosive or radioactive materials are stored, processed, transported and otherwise dealt with that, if released under normal or accident conditions, could jeopardize the safety of the installation. This investigation shall also include installations that may give rise to missiles of any type that could affect the site.

Any combination of the above as a result of a common initiating event (such as an explosion with fire and release of hazardous gases and smoke) shall be considered.

3.2.2.7 OTHERS

Transportation of heavy components

In the analysis to determine the suitability of the site, consideration shall be given to additional matters such as the transportation of heavy components of primary circuit, transformers, generators, turbine components and transport of spent fuel casks and radioactive wastes packages. These components could have weight of several hundred tons, diameter more than 4 m and length – up to 12 m, so there transportation is complicated. This factor limits the potential construction of NPPs in maintains and other regions without adequate transport infrastructure. Recently two accidents were reported during transportation of heavy components. First took place in December 2012 during transportation of reactor vessel for Vogtle NPP in US (AtomInfo.Ru, 2013). The second – on January 31 2013 during movement of the Unit 1 of Arkansas NPP (in US) main turbine generator stator (~500 tons). The turbine temporary lift device failed, the stator dropped and caused a loss of all off-site power on Unit 1 (NRC, 2013)

Volcanos

No operating NPP plant has yet suffered from strong volcano induced effects (only ash rains and earthquakes have been recorded). However several plants were built in vicinity of volcanos:

- Genkai in Japan is about 91 km from Mount Unzen;
- Fukushima Daiichi in Japan is 73 km from Mount Adatara and about 90 km from Mount Bandai;
- Metzamor in Armena is located in a volcanic province, about 55 km from Mount Aratat to the southeast, about 72 km from the Gegham Ridge volcanoes to the east, and about 40 km from Mount Ararats to the north.

In addition in some states it is planned to build new plants in rather volcanic areas, where such issues should be an essential part of the considerations for the design basis.

The manifestation of volcanic activity that may affect the site can be listed as follows: Launching of ballistic projectiles; Fallout of pyroclastic material such as ash or pumice; Lava flows, including debris avalanches, landslides and slope failures; Lahars, maars and floods induced by snow melt; Air shocks and lightning; Release of gases; Earthquakes; Ground deformation; Tsunamis; Geothermal and groundwater anomalies.

In any case the design against such phenomena should take into account the extremely short warning time available, which excludes any defense based on operating procedures alone and therefore necessitates specific passive design protection measures.

Floods due to the precipitation and other causes

The region shall be assessed to determine the potential for flooding due to one or more natural causes such as runoff resulting from precipitation or snow melt, high tide, storm surge, seiche and wind waves that may affect the site. If there is a potential for flooding, then all pertinent data, including historical data, both meteorological and hydrological, shall be collected and critically examined. A suitable meteorological and hydrological model shall be developed with account taken of the limits on the accuracy and quantity of the data, the length of the historical period over which the data were accumulated, and all known past changes in relevant characteristics of the region. The possible combinations of the effects of several causes shall be examined – for example, for coastal sites the potential for flooding by a combination of high tide, wind effects on bodies of water and wave actions, such as those due to cyclones, shall be assessed and taken into account in the hazard model.

The parameters used to characterize the hazards due to flooding shall include the height of the water, the height and period of the waves (if relevant), the warning time for the flood, the duration of the flood and the flow conditions.

3.3 LIMITATIONS DUE TO THE DESIGNS OF POWER REACTORS AND THEIR IMPLEMENTATION IN ELECTRICAL GRIDS

3.3.1 BASE LOAD OPERATION

Majority of existing power reactors are designed to operate as base - load electricity generating sources. This means that they work at full power 24 hours per day, 7 days per week and are shut down for refuelling and repair. Most are design to operate 12 months, some 18 or even 24 months. Only a limited number of existing reactors have limited ability to significantly vary their power output to match changing demand during a day, or in the weekend, called load – follow. With these features power reactors have limited possibilities to regulate the balance between the production and the demand, as well as the frequency in the grid.

Some new reactors offer limited form of enhanced load-following capability. For example, the Areva EPR can slew its electrical output power between 990 and 1650 MW at 82, MW per minute (AREVA, 2013).

Thus, the issue is important for new units of the following designs: **ABWR** (GE-Hitachi & Toshiba), 1350-1700 MWe net; **ACR-1000** (CANDU Energy Inc./SNC-Lavalin), 1080-1200 MWe net; **AP1000** (Toshiba-Westinghouse), 1117 MWe net; **APR-1400** (KOPEC), 1350-1400 MWe net; **APWR** (Mitsubishi), 1350-1620 MWe net; **ATMEA1** (ATMEA is joint venture of Areva and Mitsubishi), 1150 MWe net; **CAP-1400** (SNPTC, larger Chinese derivative of AP1100), 1400 MWe net; **ESBWR** (GE-Hitachi), 1535 MWe net; **KERENA** (Areva NP), 1250 MWe net; **WWER-1200/MIR-1200**/AES 2006 (Atomstroyexport), 1170 MWe net.

The restrictive load-following capability of new reactors is a limiting factor, when discussing their implementation in the countries electrical grids. Furthermore, nuclear legislation of several WENRA countries does not allow nuclear plants to participate in frequency control or load following (WNA, 2013j).

The problem is even bigger if significant part of electricity generating sources on the grid is generated by renewables (wind turbines and photovoltaic), which output is dependent of weather conditions. The situation in Bulgaria in April – May 2013 clearly demonstrated these risks. Due to the decreased electricity consumption in the country (2200 - 2500 MWe) and reduced export (150 - 300 MWe), the NPP (2000 MWe) and renewables (wind power and photovoltaic total about 1600 MWe) were ordered to decrease generation by more than 40 %. (Bulgarian News Agency, 2013)

3.3.2 HUGE ELECTRICAL CAPACITY

Another limiting factor of new abovementioned reactor designs is their huge electrical capacity. It is believed that the big capacity of new designs leads to improved economic competiveness. However the present requirements for the stability of electrical grid put limits to the capacity of a single power unit, in some cases only 10 % of the total demand. Thus, reactors with capacity of 1100 MWe and more would be too high for small electricity grids and would create risks for their stability. Most of developing countries and for middle size states have electrical grids under about 4 GWe (depending on the seasons).

In order to cope with this shortcoming during recent decade a number of reactors with small power output are designed. IAEA and US DoE define a SMR as a reactor with an output of 300 MWe or less that. It is supposed that SMR designs could be manufactured in factories and shipped to utilities as demand arises. It is expected that SMRs would be innovative and effective solutions for enhanced safety, operations and performance.

However SMRs face significant economic disadvantages compared to larger reactors due to economies of scale. Those economies mean SMRs would be about 70 % more expensive per MWe of capacity. But SMR also offer other potential benefits, including reducing the need to build large transmission lines. SMRs can also be built at sites with limited access to cooling water and at non-traditional sites such as oil fields or where grid systems cannot cope with the load from a 1000+ MWe NPP, or in remote locations. These may be built independently or as modules in a larger complex, with capacity added incrementally as. Factors such as reduced construction time, greater use of modular fabrication and standardization and productivity gains from building a series of units could significantly reduce the cost disadvantage (NW, 2012f).

A 2009 assessment by the IAEA under its INPRO program concluded that there could be 96 SMRs in operation around the world by 2030 in its 'high' case, and 43 units in the 'low' case.

A number of small reactor designs from 25 MWe up to around 300 MWe are in various stages of development in US, China, Russia, South Korea and Argentina. While the US has focused its attention on light-water reactors, other countries are also looking at high-temperature gas-cooled reactors and other technologies for SMRs (WNA, 2013d).

US DoE laid out the rules for applications for government funding of a program that will pay up to half the cost of developing and licensing up to two SMR designs. A total of $452 million will be allocated over five years to the project. In November 2012 DoE selected Babcock & Wilcox to receive a funding on a 50:50 cost-share basis, to support the development of its mPower design and its licensing by the NRC. DOE announced March 11, 2013 that it was accepting applications through July 1 for proposals with the potential to deploy a SMR design around 2025 (NW, 2013d).

For a fleet of SMRs to be deployed, a substantial number of units — about 100 MW in new capacity per month for several years — must be on order to encourage investment in manufacturing facilities. Also, licensing issues must be resolved early and government support in some form provided to the lead units.

3.3.3 ELECTRICAL GRIDS LIMITATIONS

A significant portion of NPP sites are located on the sea/ocean coast, some of them on peninsulas, where construction of new transmission lines or upgrading of existing would be problematic. One example that speaks for itself is Sweden.

Sweden's parliament decided in 2010 not to phase out the country's nuclear power and abolished a legal ban on building new reactors. The law allows for the country's 10 operating reactors to be replaced when they are shut down. Reactors may only be built on the sites of the three plants where units are still operating — Oskarshamn, Ringhals and Forsmark — and only to replace existing units. There is no limit on the size of the replacement units.

Existing grid connections for each of Sweden's nuclear plants were reviewed by national grid operator Svenska Kraftnaet in the investment plan, which goes through 2025. The Ringhals NPP is the only one where the grid could be upgraded to take capacity from a replacement reactor (NW, 2012g).

Another example: The proposed new NPP in Levy County, Florida US will be constructed at greenfield site and needs to be connected with the state electrical grid. A cost estimate in 2008 had put a $17 billion price tag on the project - $14 billion for the reactors and $3 billion for the required 320 km transmission lines. The latest (2013) cost assessment of this project reached already $24 billion, the cost for transmission lines is not mentioned (WNA, 2012c).

3.4 HUMAN RESOURCES

3.4.1 SHORT TECHNOLOGICAL OVERVIEW AND CHARACTERISATION

Human resources means the availability of sufficient trained personnel to design, fabricate, construct, operate, support and regulate a number of NPPs. The main requirements for NPP personnel are defined in IAEA safety documents (IAEA, 2002).

The nuclear industry would have to produce enough nuclear power reactors and spare components, nuclear fuel, and other nuclear power infrastructure to not only replace the existing NPPs but to expand their use and to play even more of a role. Nuclear enthusiasts project a rapid growth in nuclear power that will require a growing workforce with the necessary educational background, skills and experience.

In this regard the availability of sufficient trained personnel to design, fabricate, construct, and operate large number of additional nuclear power plants and to decommission the existing NPPs is crucial. This consideration derives from the current number of graduates in appropriate technical disciplines and training in appropriate trades, as well as the ageing of the current workforce which will see large numbers of the most experienced and most qualified personnel retiring within the next decade. The need for workforce development is not just limited to nuclear engineers, but also includes other engineering and scientific disciplines as well, not to mention the skilled craft workers such as I & C technicians, electricians, welders, pipe-fitters, mechanics, and others needed to construct and operate the plants.

Construction of an infrastructural multibillion project as a NPP is a huge challenge and could be accomplished by a limited number of companies worldwide. Hundreds of managers, operating and vendors engineers, boilermakers, iron workers, welders, electricians, I&C workers, pipe fitters, insulators, carpenters, painters, craft supervisors, QC inspectors, licensing inspectors engineers are needed for many years. The number of personnel needed for construction of two reactors (at one site) in Republic of Korea is shown on Figure 3.

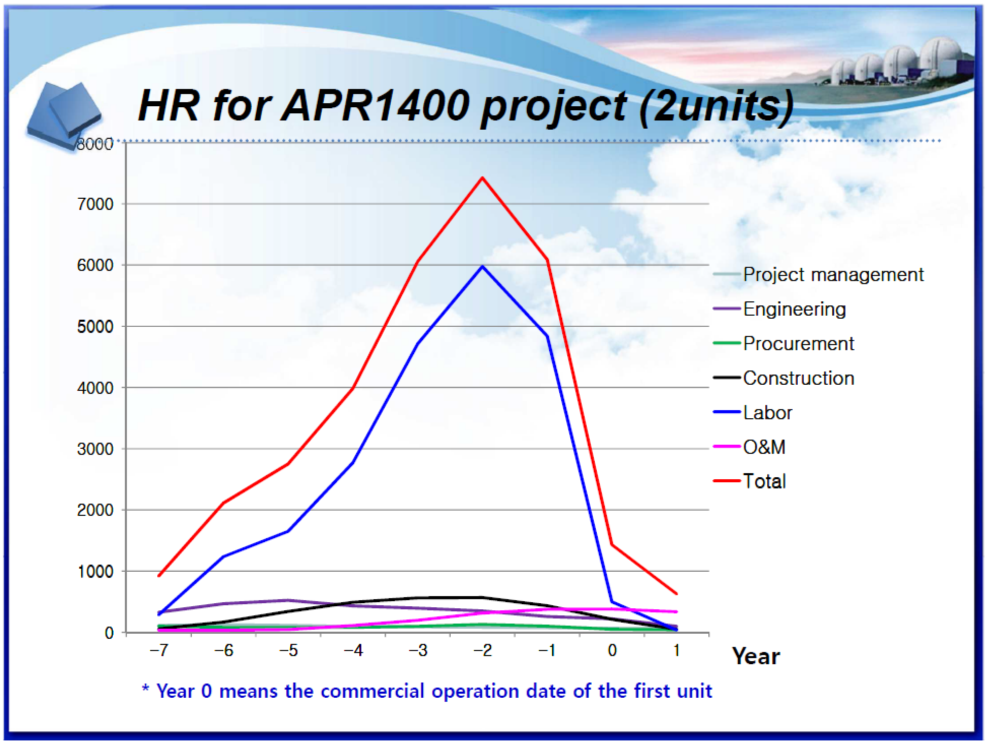


FIGURE 3: NUMBER OF PERSONNEL TO CONSTRUCT TWO APR 1400 AT ONE SITE (KHNP, 2012)

From Figure 3 one can see that for construction of an NPP a significant number of skilled worker is needed. In Korean case the maximum construction personnel at the site is about 6000 people and average 5500 people are needed 1 - 3 years before the start-up of the first unit (the second is supposed to start a year later).

For construction of the single unit at the site the number of construction personnel is less, but also significant. For example the expected peak of workers during construction of Olkiluoto 3 unit in Finland is about 4500. (NW, 2009)

For operation of existing NPPs a significant number of qualified and skilled personnel is also needed. The number of NPP operational staff (worldwide) versus plant size (in MWe) is shown on Figure 4.

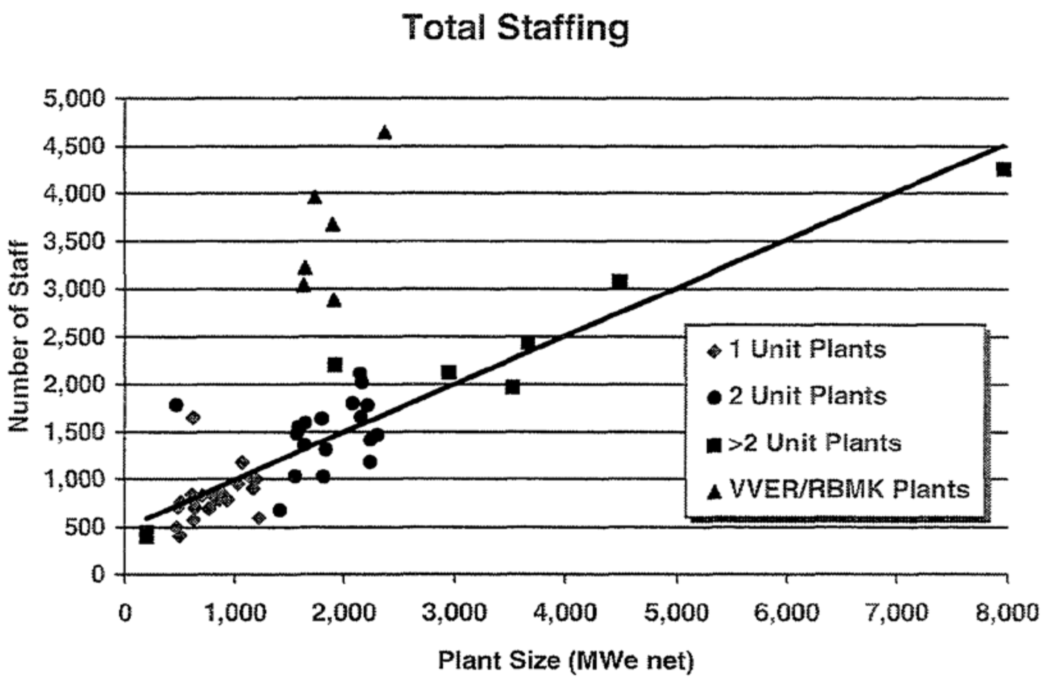


FIGURE 4: NUMBER OF EMPLOYED STAFF VERSUS PLANT SIZE (WNA, 2007).

Data for US plants for 2007 show that the average two-unit staff was 1154 **(**0,60 staff per MWe), while the single unit staff averaged 752 (0,97 staff per MWe). (NW, 2007) It has to be mentioned that during recent years and especially after Fukushima accidents the nuclear utilities started to increase the number of licensed personnel at NPPs. For example in May 2013 before its final shutdown, there were about 630 workers at 583 MWe single unit Kewanee NPP in US (1,08 staff per MWe). (NW, 2013g)

There is a spectrum of working positions in an NPP, among them one of most important is the group of reactor operators. These are experts who work in shifts and are responsible for the safe operation 24 h per day and as a role are licensed by the state authority. The shift includes a reactor operator, balance of plant operator and senior reactor operator or shift supervisor, supported by advisers and other people. Several years are needed for their initial general and specialized training, including training on simulators. One example from US, where two new reactors (AP1000) are in initial phase of construction at Vogtle site. The new units are expected to start commercial operation in late 2017 and late 2018. Under the technical specifications, a sufficient number of licensed operators must be in place before first fuel load. The plan is to have about 110 senior reactor operators and reactor operators trained around 2017. Operators have to complete NRC-mandated exams starting 2014. To train future operators in the beginning of 2013 there already were two simulators on the site. One of them is so called full-scope simulator that reflects in exacting detail the behavior of the plant and the appearance of the control room. This simulator is to be upgraded to reference level till mid-2014. Meanwhile the training of initial group of operators is accomplished on the full scope simulator of the Westinghouse Electric Company - designer of AP1000. (NW, May 2013i)

Experienced and qualified personnel are needed not only for the staff of NPPs, but also for the Regulatory Authorities for nuclear safety and radiation protection, for technical consulting companies, for research and development activities, emergency preparedness, etc.

The human resources of two countries with different nuclear power programs are discussed.

South Korea. South Korea is a country with a comprehensive nuclear power program, including design and engineering of nuclear reactors, R&D activities, manufacturing of reactor components, construction and operation of NPPs, etc. On the following Figure 5 the number of the staff in Korean nuclear power industry is shown.

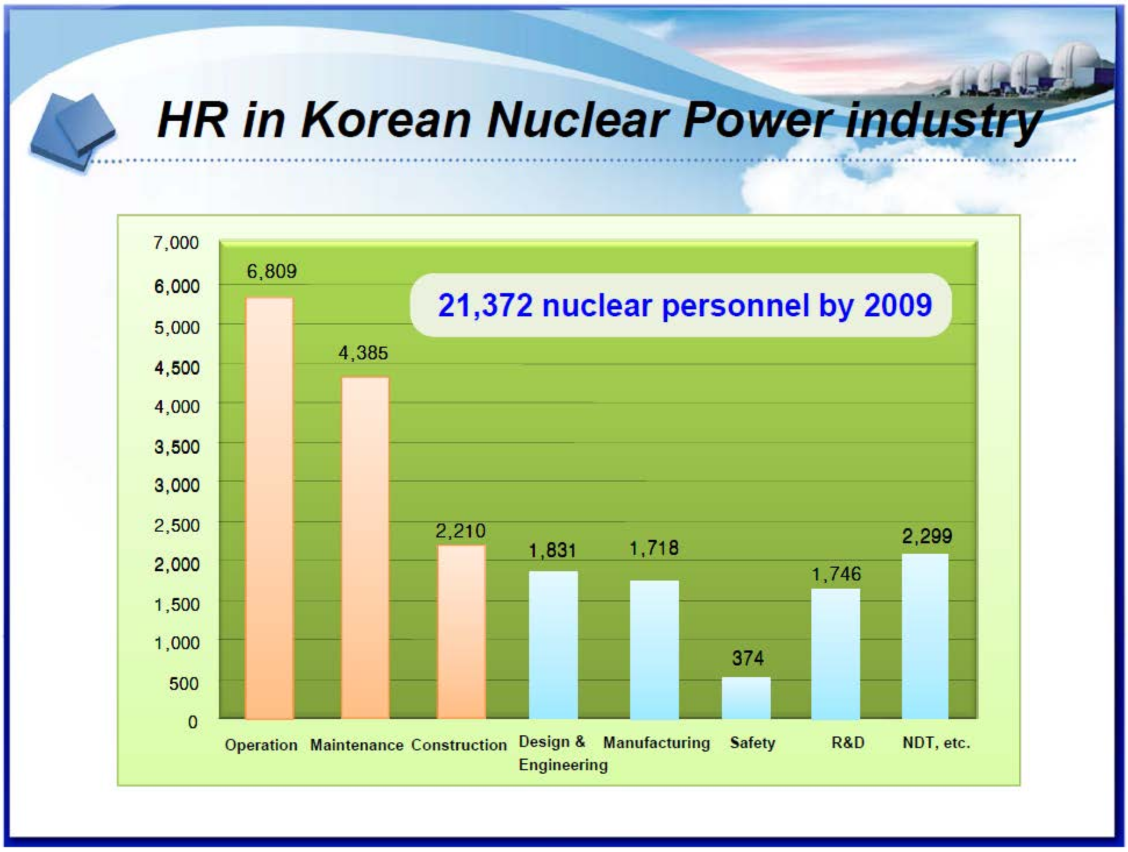


FIGURE 5: NUMBER OF THE STAFF IN KOREAN NUCLEAR POWER INDUSTRY (KHNP, 2012)

In 2009 in South Korea there were 20 power reactors in operation with total installed net capacity about 17,600 MWe. About 11,200 persons (52,3 % of all) were involved in operation and maintenance of operational reactors.

Bulgaria is a country similar to Austria without nuclear manufacturing facilities and without facilities of the front end of nuclear fuel cycle. There is one operational NPP (Kozloduy) with two

Russian designed reactors WWER-1000 with total installed capacity of 2000 MWe. Four reactors WWER-440 are in early phase of decommissioning. At Kozloduy site there are also wet and dry SF storage facilities and a RW treatment facility and temporary storage for packaged waste. A national storage facility for low and intermediate RW is in initial phase of preparation.

According to Bulgarian Ministry of Economy and Energy 7370 people were engaged in Bulgarian nuclear sector in 2008. About 4800 people (65 %) work in operation and maintenance of Kozloduy NPP (including units 1-4) and spent fuel storage facilities; the rest in repair (contracting companies), technical support organizations, research and development organizations and regulatory authorities. More than 1/3 (38 %) of them have university diploma (Magister) and the average age of people in nuclear sector is quite high - about 50 years. Evaluations show that for the period 2008 – 2013 about 970 new qualified workers and engineers are needed to the sector. According to the prognosis in 2013 the nuclear sector will need about 180 nuclear engineers but Bulgarian universities could produce maximum 60; from needed 60 nuclear physicists and radiation protection experts universities could assure only 15; from needed 67 experts in radiochemistry and radioecology universities could assure only 15. The main problems include: lack of interest of young people to technical sciences and especially to nuclear sector, declining number of young people due to the demographic problems, etc. (**MEE Bulatom, 2008**)

European Community

In EU 27 the situation in the nuclear power industry is similar. The distribution of nuclear experts and workers into different stakeholders of the nuclear energy sector in EU-27 in 2009 is shown on Figure 6. About 51 % of nuclear workers are directly involved in operation of NPP.

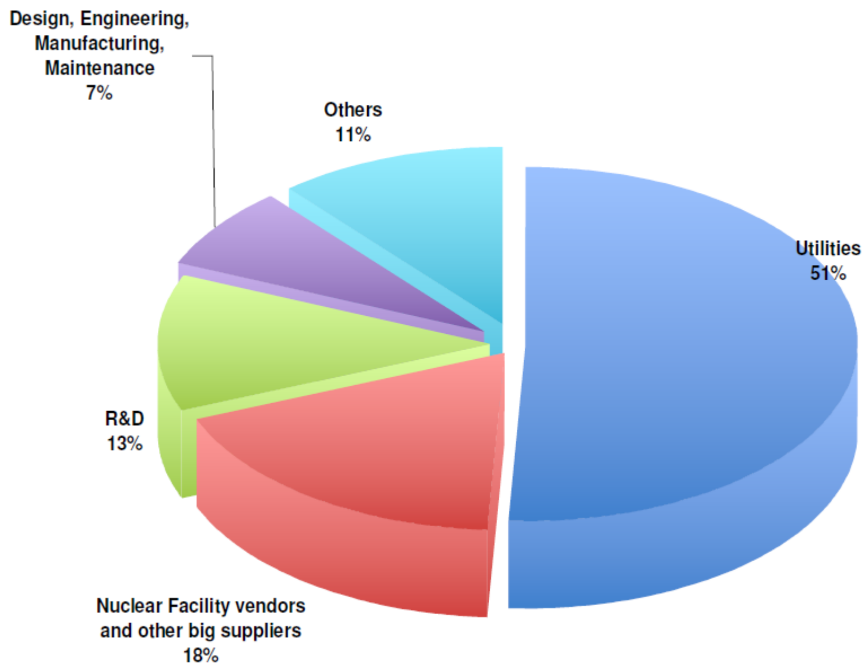


FIGURE 6: NUCLEAR EXPERTS DIVIDED INTO THE VARIOUS STAKEHOLDERS OF THE NUCLEAR ENERGY SECTOR IN EU-27 IN 2009 (SIMONOVSKA AND VON ESTORFF, 2012).

Aging of nuclear workforce

Worldwide, the nuclear power industry employs around 250,000 people. Many of the first-generation nuclear staff have just retired or will do so in the next few years, taking with them skills and knowledge of complex, costly projects. The departure of the first generation of nuclear workers is a big concern all over the world. IAEA stated that even in a number of countries with operating NPPs, nuclear education and training have experienced declines, and even for their currently operating reactors, many countries face significant challenges to deal with expected attrition from the existing workforce (IAEA, 2012).

Former NRC Chairman Dale Klein, in a speech delivered on 28 November 2007, noted that the industry's "NEI had stated that 35% of the current utility personnel in the United States will be eligible for retirement within five years.

James Davis, President of Hoskins Davis (a management consulting firm), reported in September 2008 that 40% of the current nuclear industry workforce would exit the industry by 2011 (Davis, 2008). By 2010, he reported, half of the overall utility workforce will be eligible to retire.

Capgemini, a nuclear industry consulting firm, cited a US NRC report in May 2008 that 35% of the people working at U.S. nuclear utilities would be eligible to retire in the next 5-10 years, and that 90,000 new workers would be needed by 2011. (Lewiner and Qian, 2008).

Several reports recently, from utilities, vendors, and regulatory authorities have cited insufficient trained personnel for nuclear industry, as well as projecting ahead and considering the retirements expected in the next decade which make the problem even more serious.

The survey for US showed that in 2011 total 59,700 people (1500 more comparing with 2009) were employed by the nuclear industry. Concerning the age of employers - about 39 % of them (equivalent to approximately 22,300 people) would retire over the next five years (NEI, 2011).

There's also a gap in the nuclear workforce across the Western European countries. French utility EdF says around 50 percent of employees in its nuclear branch will retire by 2015 and that its workers are on average 43-44 years old. Britain estimates that up to two-thirds of its top-tier nuclear managers will retire by 2025. For the moment, the operator of the Olkiluoto NPP TVO is getting by with its most experienced staff. As those workers retire, though, the skills shortage could become a crisis (Westall, 2009).

Similar problems are reported for Asia countries in which nuclear power is growing -about two thirds of reactors under construction are in China, South Korea and India. In China for example there are enough young students and engineers, but there is lack of old, experienced engineers. In India media report about lack of mechanical engineers who can go into the nuclear field. The universities cannot produce the needed number of engineers and physicists (WNA, 2010c).

Fukushima accidents in Japan demonstrated the need for more qualified personnel on the site in order to cope with severe accidents and mitigation of their consequences. As a result some nuclear operators already in 2012 started to increase the number of experienced personnel.

3.4.2 FUTURE DEVELOPMENT EUROPE

The problems with human resource in nuclear sector have deteriorated in the EU in the past decades and there is a risk of the loss of important nuclear knowledge if no action is taken. It was recognized that it is essential to maintain in the EU a high level of training in the nuclear field and, at the same time, preserve the skills that we already have.

The recent main documents that have been used are is a report of the EHRO-N and ENEF (Simonovska and von Estorff, 2012). The idea of EHRO-N emerged within the European energy Nuclear Forum was launched by the EC and it started in October 2009.

ENEF is a platform for a broad discussion on transparency issues as well as the opportunities and risks of nuclear energy. ENEF is divided into three working groups – Opportunities, Risks, and Transparency.

The main document is based upon is a recent report published by the working group Risk – Education and Training. The report estimated the supply and demand for nuclear experts in the EU-27. Its objective is to assess how the supply of experts for the nuclear industry in the EU-27 responds to the needs for the same experts for the present and future nuclear projects in the region. The report is based on an analysis of responses to two surveys that were sent throughout 2010 and in the first half of 2011 to:

- Higher education institutions in EU-27 that offer nuclear-related degrees, and
- Nuclear stakeholders, who are active on the EU-27 nuclear energy labour market.

The quantitative data received was checked against data available from other sources (e.g. IAEA data, national nuclear human resource reports, if available). The relevant statistical information from OECD, IAEA, WNA, and Eurostat (especially on the numbers of science, engineering and technology (SET) graduates and HRST (Human Resource in Science and Technology) employees supplied and/or demanded in EU-27) was used, so that the quantitative data gathered via the questionnaire was put into the wider context of supply of and demand for highly skilled personnel.

The methodology was gathered and analyzed followed these steps:

1. Desk research of the higher education institutions in EU-27 offering nuclear related degrees (for the supply side of the report);

2. Desk research of the nuclear organizations active in the EU-27 nuclear energy industry (for the demand side of the report) complemented with the information available from the existing EURATOM national contact points (source: DG Research and Innovation);

3. Design of the questions and sending out the questionnaires to the institutions from the points 1 and 2 above;

4. Analysis of the responses received;

5. Estimation of the missing data (where the nuclear employers in EU-27 did not provide us directly with it) as well as benchmarking of the supply data received;

6. Putting the data into wider context using statistical data available from OECD/NEA, IAEA, WNA and Eurostat.

The main results regarding the **supply side** are, after evaluation of roughly 190 higher education institutions questionnaires asking them about the: Number of nuclear engineering students that graduated in year 2009; Number of students following nuclear subjects that graduated in 2009; Number of nuclear engineering students that started with their studies in the school year of 2009/2010; and number of students following nuclear subjects that started with their studies in the school year of 2009/2010.

These are some examples of nuclear – related studies covered with the above data: Nuclear engineering, Nuclear physics, Nuclear chemistry, Nuclear energy.

The initial results showed that:

1. Slightly less than 1800 nuclear engineering students and students following nuclear energy – related subjects graduated in the year 2009 on BSc, MSc, or PhD levels in the higher education institutions in EU-27, and

2. Around 2300 students started their nuclear engineering and nuclear energy – related studies in the year 2009/2010.

The response rate of the higher education institutions contacted was above 90 %.

The total number of nuclear engineering students/students following nuclear energy – related subjects that graduated in the year 2009 on BSc, MSc, or PhD levels was somewhat above 2800.

On the other hand, regarding the **demand side**, 358 nuclear stakeholders contacted have been contacted, 242 or nearly 70% responded. The information requested covered these data:

1. The total number of nuclear experts employed in 2010;

2. The division of the total number of nuclear experts employed in 2010 into 4 age groups - below 35; between 35 and 45; between 45 and 55, and above 55.

3. The need for new nuclear experts within 1, 5, and 10 years (without making distinction whether these were needed in order to fill a position because of retirement or because of a creation of a completely new post).

The 242 organizations that responded to the questionnaire had together 62 958 nuclear experts employed in 2010, the biggest share of which fell into the age group “between 45 and 55”. At the same time the sum of the age group “below 35” and the age group “between 35 and 45” was slightly smaller than the sum of the remaining two age groups, suggesting that there is indeed a need to replace the nuclear experts that will retire in the next 10 to 20 years. The need for nuclear experts by 2020 reported by these 242 organizations was 30,664.

For the remaining 32% of the nuclear stakeholders, that did not respond to the EHRO-N questionnaire, the estimated figure of nuclear experts employed in 2010 was 14 647 and their estimated need for nuclear experts by 2020 was 8 236. Thus, the total number of nuclear experts in the 358 nuclear organizations employed in the 358 nuclear utilities in the EU-27 in 2010 was 77,605:

Received data (RD) + Estimated data (ED) = 62,958 +14,647 = 77,605

The highest share of nuclear experts employed in EU-27 was located in France, followed by the United Kingdom. The distribution per age of these experts stayed similar as stated above (the biggest share of experts fell into the age group “between 45 and 55”).

The total need for nuclear experts by 2020 of the 358 nuclear utilities active in the EU-27 in 2020 was 38 900:

Received data (RD) + Estimated data (ED) = 30,664 + 8236 = 38,900

The highest share of nuclear experts needed by 2020 was again in France, followed by the United Kingdom.

Summarizing, The authors state that on the basis of the statistical data available from the Eurostat and on the basis of the results of the EHRO-N questionnaire coupled with the hypothetical breakdown by main profiles of employees in the nuclear energy sector for the EU-27 as a whole, the future demand of this sector up to 2020 is estimated to be as follows (these numbers are related in the most part to the needs of the employers to replace the retired personnel):

- Somewhat less than 40,000 nuclear experts (for new posts and in order to replace retired personnel)
- Around 35,000 technicians (due to retirements)
- Around 32,000 non-nuclear engineers (due to retirements), and
- Somewhat less than 25,000 other graduates (due to retirements).

The supply of nuclear engineering students and students having had a nuclear energy-related subject in their studies (between 1800 and 2800 in the EU-27 graduated in 2009) cover some 45%-70% of the demand for nuclear experts by the nuclear energy sector in the EU-27 (on average 4000 per year by 2020). This is true if one assumes that all the relevant graduates mentioned are looking for an employment in the nuclear energy sector. A worrying observation is that by 2020 nearly 50% of nuclear experts employed today will retire (the retirement rate for other engineers is much lower).

3.5 AVAILABILITY OF NUCLEAR FUEL IN SHORT TERM

The fleet of nuclear power reactors uses as a fuel mainly uranium. Less than 10 % of reactors currently use nuclear fuel composed by oxides of uranium and plutonium (MOX fuel). Only LWRs can use MOX fuel and in short term the picture will remain the same. In addition only 1/3 of fuel assemblies in current LWRs can use MOX fuel. Currently about 40 reactors in Europe are licensed to use MOX but about 30 are doing so. In Japan about ten reactors are licensed to use it and several do so. Thus, the MOH fuel provides only 2 % of the new nuclear fuel used today. Two plants currently produce commercial quantities of MOX fuel – in France and UK. So far about 2000 t of MOX fuel has been fabricated and loaded into power reactors. The first reactor in the world that will have full core of MOX assemblies is Ohma-1 in Japan – ABWR with net capacity of 1325 MWe, that is scheduled for operation in late 2015. (WNA, 2013g)

Uranium is a silver-white-grey heavy radioactive metal, density - 19 g/cm3 (1,6 times more than lead). It is more plentiful than silver, or cadmium, and is about as abundant as molybdenum. It occurs in numerous minerals and also is found in phosphate rock, lignite, monazite sands. Uranium as a coal and gas is limited and not renewable. Traditionally the total world uranium production was bellow or about 40000 t U. Due to the expectations for nuclear renaissance, starting from 2008 the production was increased - 2008 – 43,798 t U; 2009 – 51,450 t U ; 2010 54,660 t U and in 2011 – 54,610 t U. (WNA, 2012e).

In 2002 the current fleet of nuclear power reactors used roughly 68,000 t of uranium. Mining is providing the biggest part (about 85 % in 2012) of the existing demand for uranium. The difference between production and consumption is covered by secondary supply sources, which however are declining.

- The approaching end of uranium from down-blending HEU from Russian and American nuclear weapon programs. US-Russia weapon to fuel program expiring in 2013;
- The approaching end of down-blending weapons grade plutonium from Russian and US nuclear programs to MOX fuel;
- The approaching end of availability of previously stockpiled uranium;

- The approaching end of feasible re-enrichment of previously rejected uranium enrichment tails;
- Mining activity is growing rapidly, especially from smaller companies, but developing a uranium mine takes a long time, 10 years or more

These factors possibly lead to the conclusion that by 2020 an actual shortfall could occur as a result of the confluence of these factors, combined with new units going online.

Availability of nuclear fuel in the mid - term is not secured due to the existing shortfall of uranium supply from mining combined with the long lead time required to bring new uranium mines into production, combined with new units going online in the 2010-2030 time frame

All aspects and problems with supply of nuclear fuel are discussed in detail in WP6.

3.6 IMPACT OF SEVERE ACCIDENTS & DISPOSAL OF RADIOACTIVE WASTE ON PUBLIC ACCEPTANCE &POLITICAL DECISIONS

3.6.1 GENERAL REMARKS

Political decisions on a state level regarding use of nuclear power and public acceptance of this technology depend on many factors, including concerns about appearance and consequences of severe accidents in NPPs and unresolved problems of final storage of spent fuel and highly radioactive waste. New nuclear power plants are designed for a minimum of 50 years. This is a quite long period during which governmental instabilities and change in public acceptance could lead to the change of nuclear policy and effect of severe accidents.

In the end of April 2013, a total of 437 nuclear power reactors were operating worlwide, down 7 from the maximum of 444 in 2002. The current reactor fleet has a total capacity of about 373,2 GWe net (IAEA, 2013). However the numbers include 46 shutdown reactors in Japan and already shutdown reactor in Garona NPP in Spain. Also in February 2013 it was announced that the only reactor in Crystal River (damaged in 2009) in US will be retired (Duke-Energy, 2013).

A total of 30 countries are operating nuclear power reactors, with one newcomer - Islamic Republic of Iran that started up its Bushehr NPP in 2011.

In 2011 NPPs worldwide generated the same amount as in 2001 and about 5% less than the historic maximum in 2006. The maximum share of nuclear power in commercial electricity generation worldwide was reached in mid-1990-ies with 17%; it had dropped to about or less 12 % by 2011, a level last seen in the early 1980s. For comparison – in 1970-ies and beginning of 1980-ies, IAEA predicted that in 2000 nuclear electricity will be 50 – 55 % of total electricity generation. (Laue, 1982; Rurik, 1974)

The actual number of operating reactors and their installed capacity are also by order of magnitude (or more) less than the historical projections of nuclear community. For example in 1973-1974, the IAEA gave a forecast of installed nuclear capacity of 3600-5000 GW worldwide by 2000. Mr. Laue, Director of the IAEA's Division of Nuclear Power projected in 1980 that in year 2000 the installed nuclear power capacity will be 740-1075 GWe - a factor of two to three above the actual. (Laue, 1982)

The Chernobyl catastrophe in 1986 has had a severe and long lasting effect on European public opinion, which remains diffident in its attitudes to nuclear energy and fears the possibility of new breaches of nuclear safety. The impact on the global nuclear industry development resulted in dramatic slowdown of nuclear expansion. After the Chernobyl disaster, only four countries - Mexico, China, Romania and Iran - have started new nuclear power programs.

The Chernobyl reactors were a product of Soviet technology and society, but the Fukushima NPP was operated by private company (TEPCO). It was the largest utility in Asia and the fourth largest in the world and was viewed as a low risk regulated utility. Japan is a highly industrialized country with a reputation for high discipline, scientific knowledge and engineering prowess. Nevertheless the major nuclear accidents at this NPP confirmed that severe accidents are more probable compared to results of probabilistic safety analyses. They also demonstrated how severe economic and other consequences are.

3.6.2 ECONOMIC COSTS OF SEVERE ACCIDENTS IN NPPS

The severe accidents in NPPs have a huge potential for widespread health, economic and environmental impacts. In the evaluation of the total costs have to be included not only typical radiological costs, but also indirect economic impacts like the cost of replacing power, impact to other entities, loss of tourism revenue, loss of export, rejection of products and long-term closure of multiple nuclear power units.

Chernobyl 1986

Ukraine estimates the cost at Eur195 billion and neighboring Belarus at Eur235 billion to its budget (NW, 2013d). According to another source (Cooper, 2012) in 2007 the total costs for both states were about $620 billion.

Fukushima 2011

The president of TEPCO Naomi Hirose, stated at a press conference November 7, 2012 that the cost of recovering from the Fukushima accidents, including site management and compensation for victims, could reach about $113 billion. That figure does not, however, include economic costs to other entities in Japan. The cost for decontamination of Fukushima prefecture, would "possibly" exceed Yen 5 trillion (about $62.5 billion), the amount could even double to Yen 10 trillion eventually.

Other groups and individuals, including an Osaka University professor and a coalition of anti-nuclear groups, have put forward estimates of total Fukushima costs ranging from $600 billion to $775 billion (NW, 2012h).

Possible accident in Europe: A major nuclear accident in a typical 900 MWe PWR in France with uncontrolled releases would be an unmanageable European catastrophe, with even more devastating economic impacts than those of Fukushima, the French IRSN has found. The costs for France alone of a major accident with an uncontrolled release of radiation could exceed EUR430 billion, stifling growth for a decade and likely leading to profound political and social transitions. Non-health costs would represent the bulk of the economic impact because French nuclear NPPs are in areas of dense population and often surrounded by high-end symbolic agricultural production like wine and/or near tourist destinations. Widespread contamination would require permanent displacement of 100,000 people (average) from areas declared as exclusion zones. (NW, 2012h).

3.6.3 IMPACT OF FUKUSHIMA ACCIDENTS

3.6.3.1 IMPACT ON COUNTRY NUCLEAR PROGRAMS

Japan. Following the severe accidents at units 1-4 of Fukushima I, all reactors were shut down for scheduled maintenance and “stress tests” to review their safety. In May 2013 only two units have been granted permission to restart, with these coming back online in July 2012. In September 2012, the Japanese government released the Innovative Strategy for Energy and the Environment, which includes the goal of reducing reliance on nuclear energy (NW, 2013j).

Italy. In June 2011 in a national referendum Italians have voted overwhelmingly (94% of those who participated) against a return to nuclear power, repealing regulation that allowed for the construction of new reactors (WNA, 2012a).

Germany. After the Fukushima accidents the German government decreed that eight of the country's nuclear power reactors which began operation in 1980 or earlier should be immediately shut down (plus the Kruemmel NPP) and accepted an accelerated schedule for retiring all plants till 2022 (WNA, 2013e).

Belgium. Belgium also confirmed nuclear phase–out policy. The reversal came in November 2011 when the government decided to reverse a 2009 policy that would have seen reactors operate for about 50 years, and instead shut them down 10 years earlier. The country’s oldest reactors may now need to close by 2015, though this will depend on whether the country can obtain adequate amounts of energy from other sources. The country also decided to increase the tax on nuclear fuel so as to rake in some €550 million per year (WNA, 2013h).

Switzerland. The federal government has decided to phase out the five nuclear reactors which generate 40% of the country's electricity by not replacing them with new nuclear capacity and to shut down all five reactors by 2035. A new initiative by an alliance of environmental groups, political parties, anti-nuclear organizations and trade unions in November 2012 secured enough support for a national referendum to shutdown reactors in 2029. (WNA, 2013b)

China. China government introduced an 18 months moratorium in issuing approvals for new plants in because of Fukushima. The new plan envisages that only Generation-III reactor designs are to be approved and only on coastal sites (WNA, 2013i).

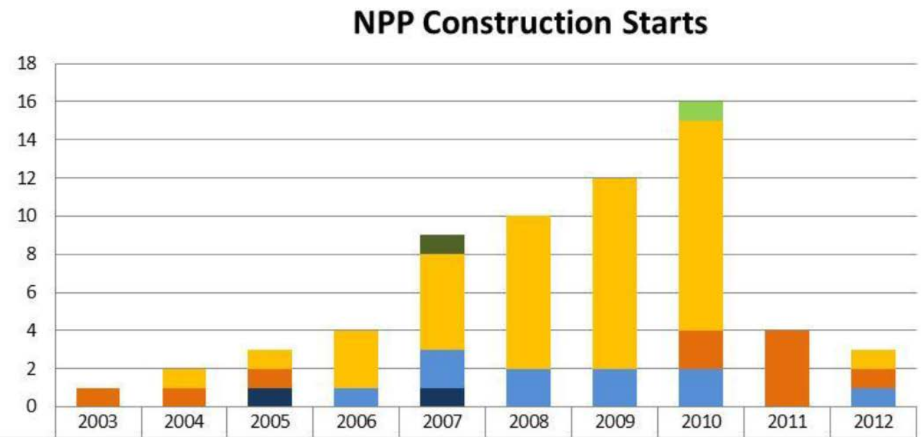
France. The new French government has decreed the closure of the Fessenheim NPP and announced a goal for 2025 of reduced reliance on nuclear in electricity supply (WNA, 2013c).

Lithuania. About 63% of those voting rejected nuclear power in a non-binding referendum October 14, 2012. The final decision is to be made by the new government and the new parliament in 2015 (NW, 2012e).

Many nuclear countries tend to have much stricter safety regulations, which increase the cost of nuclear new builds.

In addition nuclear power's competitors - most notably wind and solar generation - are rapidly gaining market share as long lead times, construction delays, cost overruns, and safety concerns have combined to make nuclear power a risky investment that the markets are increasingly unwilling to make.

On the following Figure 7 the impact of Fukushima accidents to the number of construction of new reactors is shown.



	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
America - Latin								1		
America - Northern					1					
Asia - Far East		1	1	3	5	8	10	11		1
Asia - Middle East and South	1	1	1					2	4	1
Europe - Central and Eastern				1	2	2	2	2		1
Europe - Western			1		1					

FIGURE 7: IMPACT OF FUKUSHIMA ACCIDENTS TO THE CONSTRUCTION OF NEW REACTORS (MOORE, 2013)

3.6.3.2 IMPACT ON PUBLIC OPINION

The opinion of the public worldwide regarding nuclear power also is strongly influenced by severe accidents at nuclear reactors. The poll, conducted in 2011 by Ipsos (global market research company), one month after the Fukushima accidents in Japan clarified that just 38% were in favor of nuclear power, with almost two thirds (62%) opposed. 18 months after the percentage of those surveyed support the use of nuclear energy increased to 45%, according to a global online poll of 18,000 conducted by Ipsos (NEI, 2012).

Similar were results from the poll conducted by GlobeScan. It surveyed 23,231 people in 23 countries from June 3 to September 16, 2011 (NW, 2011).

According to Ipsos in October 2012 the balance of opinion remains negative in 16 out of the 24 countries surveyed (Argentina, Australia, Belgium, Canada, Germany, Hungary, Indonesia, Italy, Japan, Mexico, Russia, South Africa, South Korea, Spain, Turkey). The lowest levels of support were recorded in Mexico (26%), Germany (26%), Italy (29%) and Argentina (29%).

Two-thirds (66%) of those polled in the United States supported the use of nuclear energy, making it the second most supportive country after India (75%). A majority also supported nuclear energy in China (59%), Great Britain (59%), Saudi Arabia (59%), Poland (53%) and Sweden (52%). In France, the population is split with 50% each supporting and opposing nuclear energy (NE, 2012)

3.6.3.3 IMPACT ON NUCLEAR PROJECTIONS

The IAEA's 2012 projections of future nuclear generating capacity have dropped again, with a low scenario seeing 456 GWe of nuclear capacity in 2030 compared with 546 GWe in projections just two years ago (IAEA, 2012). In 2010 the IAEA was predicting an additional 73 GWe in new net nuclear power plant capacity by 2020 and an additional 546-803 GWe in service by 2030. It has to be mentioned that in the mid-seventies IAEA forecasted an installed nuclear capacity of 3600-5000 GWe in the world by 2000 – ten times more that the present forecast for 2030.

In 2012 the OECD International Energy Agency has cut its forecast for global installed nuclear power capacity in 2035 by 10% (or 50 GWe) to 580 GWe. Nuclear power production is expected to grow by about 60% between 2010 and 2035, from 2756 TWh in 2010 to about 4370 TWh in 2035. But that is 10% less growth than the agency predicted last year and nuclear power's share of total electricity generation will decline over that period from 13% to 12%. The agency projects that of the new generation capacity that is built to 2035, around one-third is needed to replace plants that are retired (IEA, 2012).

Prior to the Fukushima accident, Russian nuclear company Rosatom forecasted that the global installed capacity of nuclear power would total 652 GWe in 2030. Following the accident, the company revised its forecast downwards by 11% to 588 GWe. (NW, September 2012b)

3.6.4 IMPACT OF RADIOACTIVE WASTE DISPOSAL ON PUBLIC OPINION

Citizens are also extremely sensitive to the unknown factors raised by the effects of high level radioactive waste, whose management and disposal remain a complicated issue. Among the European nuclear states only Finland and Sweden have real plans to start operation of final repository for such waste at about 2025.

These were confirmed by the results of the survey of 26470 European citizens across all 27 EU member states, carried out in September and October 2009, published by the EC (EC, 2010).

Most of the Europeans believed that the risks related to nuclear energy are underestimated, with a lack of security against terrorist attacks on power plants and the disposal and management of radioactive waste identified as the major dangers. Not surprisingly, then, the vast majority - 82% - agreed that it would be useful for nuclear waste management to be regulated at the European level.

The picture is similar in the USA – the poll by Angus Reid Public Opinion questioned 1010 randomly-selected adult Americans between 19 and 21 February 2010 in an online survey. When asked if they were concerned about the management of radioactive waste, 81% of Americans said they were, 51% being very concerned, while only 16% said they were less concerned. (WNN, 2010)

Severe accidents and lack of demonstration of technical capabilities for long term storage of spent fuel and high level RW are a major bottleneck to the growth of nuclear power. Severe accidents in NPPs appeared to be more probable compared with probabilistic safety analysis. They resulted of huge radioactive emissions to the environment, contamination of big territories and extremely high economic consequences. Severe accidents strongly influenced the opinion of public worldwide and political decisions regarding the development of nuclear power. Lack of plans for final storage of spent fuel and high level RW has a similar effect.

3.7 CAPABILITIES TO MANUFACTURE SETS OF HEAVY COMPONENTS

Industry capabilities for manufacturing reactor heavy components are a key issue for an expansion of the current size of the nuclear power. Heavy components include, for example, RPVs and their internals, reactor closure head, SGs, pressurizers with a mass of several hundreds of tons, diameters up to 5,5 m and length up to 13 m. Heavy components also include steam turbines and associated equipment, as well as generators and transformers.

In the early part of the 21st Century, the available heavy component manufacturing capacity was barely adequate to keep pace with the nuclear industry’s construction program, and it was by far inadequate to keep place with plans to replace fossil-fired generation with nuclear generation, and to otherwise expand nuclear generation in a so-called "Nuclear Renaissance" (Kidd, 2009).

This issue is particularly important for units with very large generation 3+ reactors (1100 MWe and higher). Production of the pressure vessel requires forging presses of about 15,000 t capacity which accept hot steel ingots of 500-600 t.

The very heavy forging capacity in operation today is in **Japan** (Japan Steel Works), **China** (China First Heavy Industries and China Erzhong) and **Russia** (OMZ Izhora) (WNA, 2012g).

Japan (Japan Steel Works) is the largest and best-known supplier of heavy forgings and claims 80% of the world market. Its capacity to 2007 had been only four reactor pressure vessels and associated sets per year, but this had been tripled to twelve by 2011.

China's heavy manufacturing plants can make about seven sets of pressure vessels and steam generators per year, a doubling from 2007.

Russian industry in 2007 was still is capable of building only one set of nuclear steam supply system components a year. According to the plans in the coming years, that capacity would rise to three reactor equipment “sets” a year and then to four equipment sets.

However, following the March 2011 Fukushima accident the nuclear power perspective changed the considerably, reducing and/or slowing nuclear construction plans. For example JSW expected orders to fill only 70% of the expanded capacity. Given current industry plans and planned heavy component manufacturing capacity additions, the situation is currently stable and capacity is adequate or nearly so.

Heavy component manufacturing capacity is being added in the Czech Republic (by Skoda Pilsen), France (by Areva’s Le Creusot plant), Japan (by JSW and JCFC), the People’s Republic of China (by Changhai Electric Group and subsidiaries), the Republic of Korea (by Doosan), and the Russian Federation (by OMZ Izhora and ZiO-Podolsk). New capacity is planned in India (Larsen & Toubro, Bharat Heavy Electricals or BHEL, and Bharat Forge Ltd.), in the People’s Republic of China (by Harbin Boiler Co. and SENPE), and in the United Kingdom (by Sheffield Forgemasters). With these additions the maximum capacity to manufacture heavy equipment sets for NPPs will be about 34 per year. At a rate of 34 per year, the world could add a GW of nuclear capacity every 10 - 11 days.

There are currently 67 reactors under construction with total electrical capacity of 64 GW. For perspective, the peak of units in progress was 234 in 1979. Nine reactors have been listed as under construction for more than 20 years. Approximately 160 units are ordered or planned (with a combined capacity of 179,7 GWe). The nuclear industry lists 329 units as "proposed" with a combined capacity of about 180 GWe) (WNA, 2012i).

In 2010 (prior to the Fukushima Daiichi nuclear accidents in March 2011), the IAEA was predicting an additional 73 GWe in new net nuclear power plant capacity by 2020 (a rate equivalent to new 1000 MWe nuclear unit every 50 days), and an additional 546-803 GWe in service by 2030 (a rate equivalent to a new 1000 MWe nuclear unit every 5-7 days). With a capability to support a rate of one unit every 11 days, the capacity to build heavy equipment sets would have to about double in the next ten years.

In August 2011, the World Nuclear Association (WNA) was projecting that 1100 GWe of nuclear capacity would be in operation by 2060, and possibly as high as 3500 GWe (WNA, 2011b). At the peak of nuclear capacity additions in the 1980-ies, a new power reactor (with an average capacity of 923,5 MWe) was added every 17 days. The WNA predicted as recently as February 2012 that nuclear capacity additions would reach double this level by 2015 (i.e., about one reactor every 8-9 days), and also projected that the industry could be adding new units every 5 days at an unspecified later date (WNA, 2012g).

It should be noted that some margin above current capacity (and those forecasted) would be required in order to provide high assurance of attaining the necessary heavy component production rates. Such margin would provide additional heavy component manufacturing capacity as a hedge against such contingencies as:

- Damage to heavy component manufacturing capacity resulting from natural hazards (such as earthquakes, tsunamis, river and coastal flooding);
- Heavy component manufacturing capacity losses resulting from man-made hazards (such as strikes, large aircraft impact, fires, etc.);
- Heavy component manufacturing capacity losses resulting from in-plant accidents, causing unavailability for extended periods of critical equipment (such as large forges).

If heavy component manufacturing capacity above the minimum required to attain WNA's projections does not exist, any loss of such capacity would have ripple effects through multiple nuclear power projects. With delays in constructing high level radioactive waste repositories (especially in the United States), it is also important to recognize that there will be competing requirements for heavy component manufacturing of storage vessels for dry storage of spent fuel. Finally, the planned Areva/Newport News heavy component manufacturing facility, which was to have begun operation earlier in 2012, was put on indefinite hold with a construction stop in May 2011. The reasons for this cited by Areva were "*unfavorable market conditions and uncertainty over U.S. energy policy*" (Frost, 2011; Dolley, 2011).

3.8 ECONOMIC CONDITIONS & COMPETITION OF OTHER POWER GENERATION SOURCES

The economic environment in the world or in a particular state and the development of other power/electricity generating sources could be important bottleneck for the nuclear renaissance. The economic and financial crisis in the whole world during recent 5 years resulted in stagnation of demand in many countries. NPPs face challenges of regulatory mandated investments to fulfill post-Fukushima upgrades. European nuclear countries currently have diverse liability requirements and even more diverse insurance requirements, which distorts competition and means that some citizens are better protected than others. EC will bring a legislative proposal to set minimum liability insurance requirements for European nuclear operators to the EP by the end of September 2013 (NW, 2013e).

In US the cheap natural gas become the big threat for other power generation sources.

US

In 2007 and during the following years natural gas prices were at their highest level ever in real terms. The 2005 Energy Policy Act provided loan guarantees, production tax credits and other bonuses for construction of new NPPs. US NRC received 17 license applications for 26 reactors proposed for construction. It seemed that it was the right time for a nuclear power renaissance in the US.

Then everything changed. Natural gas prices fell sharply in 2009. The global recession slowed the growth of electricity demand. In 2012 many high level nuclear managers expressed pessimism about the prospects for building new nuclear units in the US. Factors working against an economic rationale for building new nuclear units include cheap natural gas, no price on carbon, and anemic growth in demand. (NW, 2012d)

In October 2012 US company Dominion announced that it decided to shut down permanently its single-unit **Kewaunee NPP** (PWR 583 MW, 1974) in Wisconsin, near Green Bay (Dominion, 2012). Decision was due to the unfavorable economic circumstances. When Dominion bought Kewaunee in 2005, Midwest power prices were in the range of $40-50/MWh, wellhead natural gas prices were $6-10 per million Btu, and US electricity demand was growing. In the end of 2012 Midwest power prices dropped to around $30/ MWh, gas - to $2-3/MMBtu, and the US has had 5 years of no growth in electricity demand, thanks to the worst recession in 80 years. The shutdown is expected in the second quarter of 2013. Finally the plant was shut down permanently at May 7, 2013. (NW, 2013g)

Operators of other NPPs in US are also at risk for retirement. A report from UBS Securities said this will be a challenging year for nuclear generation and as many as 3000 MWe of nuclear capacity, or nearly 3% of the US fleet, could be at risk of retirement. These concerns possibly include Entergy's FitzPatrick NPP and Vermont Yankee NPP and Constellation Nuclear Energy Group's Ginna NPP as the most likely to close prematurely. They face twin challenges of regulatory mandated investments and a low power price environment as a result of inexpensive natural gas in US. (NW, 2013a).

One of potentially affected companies would be Exelon. Exelon is US largest nuclear operator with 17-unit nuclear fleet that is operated very well and with almost a 0% forced outage rate. According to existing information some of Exelon NPPs (Byron-1&2 and Quad Cities-1&2) in the State of Illinois are not profitable in their market, where power is sold at "negative pricing at the bus" about 14% of the time. The single-unit Clinton is experiencing similar competition and is not making a profit and with negative free cash flow.

Exelon also announced in November 2012 that it would defer plans for power uprates at Limerick-1&2 in Pennsylvania and LaSalle-1&2 in Illinois, reducing capital expenditures by $1.025 billion through 2015 (NW, 8 Nov. '12, 4). The uprates, however, were deferred not only to save capital. The uprate plans remain on hold because the power the uprates would produce would not be competitive in current markets. (NW, 2013h)

Spain

On December 16, 2012, the operator of Santa María de Garoña NPP (Nuclenor) has begun shutting down the NPP, which consists of one BWR of 466 MWe. The decision was spurred by an impending law, which would impose a tax in the annual sum of approximately €150 million. The safety upgrades required for extension of the operation would cost some €120 million. Among other provisions, the law imposes a 7% flat tax on all electricity generation and an additional tax of Eur2,190/kilogram on spent fuel discharged from NPP (NW, 2013a). The text of the bill approved by the parliament was promulgated on December 28 without modification to the tax measures.

4 CONCLUSIONS

Major bottlenecks for the growth of nuclear power in the world are:

Financial risks

Financial risks include high initial costs, availability of capital to finance the projects & additional risks. In 60-ies nuclear enthusiasts claimed that nuclear power is "too cheap to meter". In 2000-2004, when nuclear community started to talk about expected nuclear renaissance, vendors estimated the overnight cost for a new nuclear unit at $1600 - $2000/kWe. That figure had risen to at least to $4000/kWe two-three years later. The 2009-20013 official assessments already demonstrate that the overnight capital costs would be about or more than $5500/kWe. Analysis of independent experts demonstrate even higher numbers. The total costs to construct an NPP and to connect it to the electrical grid could be twice (or even more) the overnight cost. In addition there is a huge potential for cost overruns and high financial risks due to construction delays, strengthening regulatory safety & environmental requirements. The availability of capital to finance the projects is being affected by the current (as of early 2009) economic crisis. Due to a combination of financing problems and high estimated construction costs a number of new nuclear projects were cancelled in US, Canada and Europe. There are three major risks for construction of new NPPs - cost overruns due to construction delays, power price insufficiency to provide a return on investment and operational losses due to breakdowns or regulatory delay. Construction of new units in US and Europe are clearly demonstrated the risks of costs overruns and delays.

Austria: Financial risks would be a major bottleneck for potential Austrian nuclear program

Human resources

Availability of sufficient and well trained personnel to design, fabricate, construct, operate, support and regulate large number of existing and additional NPPs is a key factor for their safe operation. Construction of a new NPP is a huge challenge and could be accomplished by a limited number of companies worldwide. Hundreds of managers, operating and vendors engineers, boilermakers, iron workers, welders, electricians, I&C workers, pipe fitters, insulators, carpenters, painters, craft supervisors, QC inspectors, licensing inspectors engineers are needed for many years. The need for operational personnel is not limited to nuclear engineers, but also includes other engineering and scientific disciplines and skilled craft workers such as I & C technicians, electricians, welders, pipe-fitters, mechanics, and others needed to construct and operate the plants. The nuclear industry is facing serious difficulties to replace its personnel even in the existing NPP. One of the main reasons is aging of the existing staff and retirement of big number of nuclear workers and experts in the following years. Another reason is the lack of interest of young engineers in the field. The supply of nuclear engineering students and students having had a nuclear energy-related subject in their studies could cover some 45%-70% of the demand for nuclear experts by the nuclear energy sector in the EU-27. There is a real danger of losing tacit knowledge, which is usually passed from one generation to another by practical training, due to the generation gap in the nuclear field.

Austria: It has been assumed that four power reactors with total installed capacity up to 4600 MWe would be constructed at four sites. The need of skilled personnel to construct the units has not been investigated, it has been assumed that four units are already in operation and an estimate has been made that roughly 4500 persons would be needed only for operation. Based on current employment figures one can assume that the total need of personnel in the nuclear sector, including nuclear infrastructure for Austria would amount roughly to 7000 persons. Austria is currently not training nuclear engineers, and probably would have to attract foreign experts, which poses additional difficulties. Austria also has to create from almost zero a Nuclear Regulatory Authority to regulate the safety of nuclear facilities, Safeguard of nuclear material, Management of spent fuel and radioactive waste, Decommissioning of nuclear facilities, Licensing of personnel, etc.

Impact of severe accidents & disposal of radioactive waste on public opinion & political decisions

Political decisions regarding use of nuclear power and public acceptance of this technology depend on many factors, including concerns about appearance and consequences of severe accidents in NPPs and unresolved problems of final storage of spent fuel and highly radioactive waste. The severe accidents in NPPs have a huge potential for widespread health, economic and environmental impacts. Total costs include not only radiological costs, but also indirect economic impacts like the cost of replacing power, impact to other entities, loss of tourism revenue, loss of export, rejection of products, etc., and are calculated in hundreds of billions of EUR. The recent severe accident in Fukushima NPP heavily affected nuclear programs of different (mainly European) countries, the number of new construction, public opinion, nuclear projections, etc. Citizens are also very sensitive to the unknown factors raised by the effects of high level radioactive waste, whose management and disposal remain a complicated issue. Among the European nuclear states only Finland and Sweden have real plans to start operation of final repository for such waste at about 2025. Most of the Europeans believed that the risks related to nuclear energy are underestimated, with a lack of security against terrorist attacks on power plants and the disposal and management of radioactive waste identified as the major dangers.

Country specific bottlenecks for the growth of nuclear power

Availability of possible sites for construction of NPP

Safety of new NPPs depends of many factors and one of the most important is the site where the plant will be constructed. Site selection limiting factors include: Use of land and water; Density of population; Seismological and geological conditions; Meteorological events and other external threats; Aircraft crashes and others. For some countries no problems were identified up to know - for example in US there is big number of sites with one or two reactors and many former nuclear sites. China reports about 100 potential sites for NPPs. In some of candidate Asian countries there is a spectrum of external threats – earthquakes, tsunamis, volcanos, extreme winds, flooding etc. For most highly populated European countries siting would be a bottleneck for substantial growth of nuclear power and for some countries the options are limited to existing sites only, e.g. Belgium.

Austria: In the beginning and mid 1970-ies three potential sites for construction of NPP were identified – two on the Danube river and one at the Drau river in Carinthia. These (and other possible sites) have to be re-evaluated using the up-to-date knowledge and requirements and licensed by the Nuclear Regulatory authority.

Limitations due to the designs of power reactors and their implementation in electrical grids

Majority of new power reactors are designed to operate as base - load electricity generating sources. Only some of them offer limited form of enhanced load-following capability. This is a limiting factor, when discussing their implementation in the countries electrical grids. Huge electrical capacity of new reactors (1100 – 1650 MWe) is another limiting factor for countries with medium and small size grids. **Huge capacity, limited load follow capabilities of new reactors and electrical grids limitations would be a significant bottleneck for countries with small and medium size electrical grids and for countries which have ambitious plans to develop renewables.**

Austria: The Austrian electrical grid has limited capacity and special structure. The biggest unit in operation is 730 MWe and a new one with 760 MWe is in phase in construction. The new nuclear units should be of the same capacity. For Austria the best reactor technology is light water technology and especially PWR. There are several designs of this type, all of them in the range of 1100 – 1200 MWe: **AP1000** -1117 MWe net, **ATMEA 1 -** 1150 MWe net and **WWER-1200/MIR-1200 -** 1170 MWe net. It is supposed that there will be four single unit NPPs in Austria. To accommodate them the national grid has to be significantly upgraded.

Economic conditions & competition of other energy generation sources

Economic environment in the particular state and the development of other electricity generating sources could be important bottleneck for the growth of nuclear power. Many NPPs have difficulties to fulfill regulatory mandated investments about after Fukushima upgrades. Economic and financial crisis in the world during recent 5 years resulted in stagnation of electricity demand in many countries that reflected in delay of planned constructions and uprates. NPPs face challenges of strengthen state and regulatory requirements. Thus, in December 2012, Santa María de Garoña NPP **(**Spain) was finally shut down and the decision was spurred by an impending law, which would impose additional annual tax. In US the cheap natural gas became the big threat for other power generation sources. In May 2013 US single-unit Kewaunee NPP in Wisconsin was finally shut down. Decision was due to the unfavorable economic circumstances, mainly cheap natural gas and lack of growth in electricity demand. Operators of other NPPs in US are also at risk for retirement due to the same reasons.

Other bottlenecks

The availability of nuclear fuel over the 10-year time horizon

The fleet of nuclear power reactors uses as a fuel mainly uranium. Less than 10 % of reactors currently use nuclear fuel composed by oxides of uranium and plutonium. Currently mining is providing about two-thirds of the existing demand for uranium. The difference between production and consumption is covered by secondary supply sources, which however are declining. These factors possibly lead to the conclusion that by 2015-2020 an actual shortfall could occur as a result of the confluence of these factors, combined with new units going online in the 2020 time frame.

Capabilities to manufacture sets of heavy component for NPP

Industry capabilities for manufacturing reactor heavy components are a key issue for an expansion of nuclear power. Heavy components include reactor pressure vessel and its internals, reactor closure head, steam generators, pressurizers, main coolant pumps and piping. Heavy components also include steam turbines and associated equipment, as well as generators and transformers. Production of the pressure vessel for new reactors requires forging presses of about 15000 t capacity which accept hot steel ingots of 500-600 t. The very heavy forging capacity today is in Japan, China and Russia. Heavy component manufacturing capacity is being added and planned in a number of countries. With these additions the maximum capacity to manufacture heavy equipment sets for NPPs will be about 34 per year, that means a GW of nuclear capacity every 10 - 11 days. This capacity is enough to support the slow increase of nuclear power, but would be a bottleneck in case if nuclear industry would will try to increase significantly the number of nuclear power reactors and the percentage of nuclear electricity.

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ABBREVIATIONS

ABWR	Advanced Boiling Water Reactor
ACRO	Aircraft Crash Records Office (in Geneva)
APR1400	Advanced Power Reactor 1400 (capacity about 1400 MWe, Korea)
APWR	Advanced Pressurized Water Reactor (capacity 1538 MWe, Mitsubishi)
AP1000	Advanced Project (capacity more than 1000 MWe, US)
CANDU	CANadian Deuterium Uranium (reactor type, developed in Canada)
DoE	Department of Energy (US)
EdF	Electricite de France
ENEF	European Nuclear Energy Forum
EdF	Electricite de France
HEU	Highly Enriched Uranium
EPC	Engineering, Procurement and Construction (contract)
HRO-N	European Human Resources Observatory for the Nuclear Energy Sector
I & C	Instrumentation and Control
IAEA	International Atomic Energy Agency
IEA	International Energy Agency
INPRO	Innovative Nuclear Power Reactors & Fuel Cycle (IAEA)
IRSN	Institute for Radioprotection and Nuclear Safety (France)
JSW	Japan Steel Works (Japan)
KOPEC	Korea Power Engineering Company
LPG	Liquid Pressurized Gas
LWR	Light Water Reactor
MOX	Mixed (uranium and plutonium) OXides (nuclear fuel)
NEA	Nuclear Energy Agency (OECD)

NEI	Nuclear Energy Institute (US)
NGO	Non-Governmental Organization
NPP	Nuclear Power Plants
NRC	Nuclear Regulatory Commission (US)
OMZ	Ozhorskie Mashinostroiteljnie Zavodi (Russia)
QC	Quality Control
PRIS	Power Reactor Information System (IAEA)
RW	Radioactive Waste
RPV	Reactor Pressure Vessel
SF	Spent (nuclear) Fuel
SG	Steam Generator
SMR	Small Modular Reactor
SNPTC	State Nuclear Power Technology Company (China)
TEPCO	Tokyo Electric Power Company
TMI	Three Mile Inland NPP
TSO	Technical Support Organization
TVO	Teollisuuden Voima Oyj (Power company, Finland)
WNA	World Nuclear Association
WWER	Water Water Energy Reactor (Russia)