Country experience in relation to PLEX costs in view of the updating of the PINC document

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The mission of the JRC-IE is to provide support to Community policies related to both nuclear and non-nuclear energy in order to ensure sustainable, secure and efficient energy production, distribution and use.

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DG JRC – Institute for Energy
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1 Introduction

In the framework of the Memorandum of Understanding n. JRC.BXL n.30897 between DG TREN and the JRC on the "Supply of Scientific and Technical Support to DG TREN on Nuclear Safety, Waste Management, Radiation Protection, and Sustainability of Nuclear Energy", signed on 25/11/2008 in Luxembourg, this report addresses the request under the task n.13 on "EU Country experience in relation to PLEX costs in view of the updating of the PINC document" of the associated Work Plan [1], endorsed by Messrs. D.Ristori and G.De Santi in Petten on April 24, 2009.

This report also represents an official deliverable of the Work Plan of the JRC Action POS (Plant Operation Safety), n.52103, in Task 1: "Support to DG TREN in the framework of the MoU between DG TREN and the IE".

According to the Euratom Treaty, art.40, the EC should periodically publish the so called PINC document (Nuclear Illustrative Program):

*In order to stimulate action by persons and undertakings and to facilitate coordinated development of their investment in the nuclear field, the Commission shall periodically publish illustrative programmes indicating in particular nuclear energy production targets and all the types of investment required for their attainment.*

The first issue of the program was completed in 2007 under the coordination of TREN.H.1 [2]. That document is foreseen for review in the coming years, especially in the sections dealing with economics in relation to Nuclear Plant Life Extension (PLEX), which is becoming a very important item in the investment plans of EU Utilities.

Therefore, in preparation to that revision, DG TREN officers in H2 requested the JRC.F.05, in the framework of the above mentioned Work Plan, to develop a technical report with detailed analysis and data in order to extend the existing H2-report on PLEX/LTO issued in 2007 by H2 to H1, with new PLEX costs and projects information, with a view to use the result as one of the inputs to the future PINC document.

To this concern, JRC.F.05 experts carried out a thorough analysis of available literature, plant experience, data from EU Utilities mainly from the following sources:

- IAEA Technical documents
- OECD/NEA reports
- Technical Archive at JRC.F.05
- Other Internationally recognized sources

The result is provided in the following Chapters, which are organized according to the following scheme:

- Section 2 and 3 describes and discuss the PLEX approaches in the EU
- Section 4 and 5 present the current status of Nuclear power in the EU member states under the aspect of lifetime extension, safety improvements, power upgrading and their costs, as well as the situation for new nuclear power generation
- Section 6 describes in short the regulatory process
- Section 7 discusses the harmonization of ageing management
- Section 8 discusses effects of lifetime extension to electric power production in the EU
2 Background on PLEX approaches in the EU

The current social, economic and engineering framework for the energy production is characterized by the following trends:

1) The open electricity market, which is going to be a reality in most of the European Countries in few years. Such economical and financial framework demands for significant reduction of the generation costs, very strict investment planning, outsourcing, controlled reliability of the equipment and components (incl. obsolescence) and therefore for reliable indicators of the effectiveness of the maintenance programmes.

2) The generic trend towards the extension of the operating life of the existing plants. Such life extension requires a detailed review of the original design assumptions, also reflected into current maintenance practice, and the continuous monitoring of the component reliability (performance goals) in order to support a suitable trend of the safety evaluation beyond the design life.

3) The detection of significant ageing phenomena which have been challenging the original design assumptions, triggering some safety related events and questioning the long term safety of the nuclear installations and the engineering capability to prevent serious consequences from them.

4) The need for preservation of the human knowledge in time, particularly in Countries with growing opposition to nuclear expansion.

As a consequence, in last years many electric utilities and nuclear power plants adopted policies for improved coordination of both safety and non-safety programs, called plant life management (PLIM); mainly triggered by the urgent need of extension of plant operating life (PLEX) beyond the design age; usually at 30 years or 40 years.

Its implementation has followed many different approaches, being intrinsically dependent on the national regulatory framework and technical traditions. The PLEX process poses further challenges, particularly in view of the nuclear safety implications as well as the economic strategic and political ones. Therefore in recent years the need for tailoring available safety assessment tools to such needs has become very urgent, especially because the long time perspective of PLIM (typically 30-40 years) is much longer than the typical time framework where the available methods are currently employed (~10 years of the standard periodicity of the Periodic Safety Review process).

In Countries with some experience, the PLIM program proved very convenient, not only in PLEX perspective, but even in a framework of improved management of operating plants. Highest benefits were recorded when PLIM/PLEX programs were coupled with Maintenance, Surveillance and Inspection (MS&I) optimization: average savings are reported in the range of 20-30% of total (maintenance) costs.

Moreover, in terms of safety, the control of equipment reliability, significantly improved with PLIM/PLEX models for example through Ageing Management Program (AMP) and Reliability Centred Maintenance (RCM), made a long term asset management of the overall plant possible and the overall safety indicators significantly improved in many cases.

The Regulatory frameworks for PLEX differ from country to country in accordance with the licensing system. In countries where the operational license is granted for a well-defined operational lifetime, a
formal license renewal is practiced. In some countries the utilities have a license renewal for 20 years. Some other Countries have just started the development of regulations for license renewal and project planning. In the countries where the operational lifetime is not limited by license, the Periodic Safety Review (PSR) is sometimes chosen as the regulatory tool for PLEX assessment, but in a ten-year framework only, which therefore is an approach unsuitable to drive a PLEX process.

However, despite of the differences that affect the regulatory strategy in the countries and the consequent differences in the application/approval process for PLEX, the main technical components of the PLEX programmes and their basic technical tasks are shared among most of the countries.

Moreover, a generic misunderstanding still survives in the engineering community among objectives and content of the different programs put in place in the different Countries which developed experience in the PLIM/PLEX field. Programs such as License Renewal (LR), Long Term Operation (LTO), Plant Life Extension (PLEX), Periodic Safety Review (PSR), Ageing Management Program (AMP), etc. proved to share many technical tasks, but also to meet different objectives and to follow different regulatory frameworks.

Attempts to identify those objectives and tasks were made by many Organizations: in particular the IAEA, and the JRC-IE spent some research efforts in last years in the clarification of the many issues addressed by the European Countries’ programs and developed some unified models, which received very high consensus in many engineering communities and particularly in the research network of European Countries interested to this discipline, SENUF [3].

1) As outcome of this effort, a list of generic considerations was developed as support to the development of a more unified and consistent approach to the common issue of managing the plant assets in time, meeting the highest safety standards:

2) The PLIM program appears the type of program most suitable to address long-lasting safety and economical issues and to present the most comprehensive approach to the plant asset management

3) The PLIM program is neither necessarily related to plant life extension (PLEX), nor to license extension of any plant. It is a logical framework on which strategic thinking may find the appropriate answers in relation to safety, economy and human asset management.

4) Related programs such as LR, AMP, PSR, each with its own objective, may find in the PLIM framework the answers and the background information that they need to meet their specific objectives; however, they definitely represent separate programs, different from PLIM itself.

5) The PLIM/PLEX program is crucially based upon a strong integration of many existing programs at the plants, such as asset management, life extension, ageing management, configuration control, predictive maintenance, etc. that share common assumptions and contribute to the same overall objectives.

6) Some special features are required to standard programs and also some specific programs are needed to be in place at NPPs in order to feed a PLIM program adequately. These features/programs creates the pre-conditions for a PLIM program to be successfully applied, such as: the maintenance program should be mostly reliability based, the ISI program should be possibly risk informed, a fuel management program should be in place, an outage optimization program should make available all data in relation to the economic implications of the outage duration, a knowledge management program should be in place, public acceptance analysis should be available, etc.

7) In order to manage the very complex structure of a PLIM program, specialized software tools
and databases are highly recommendable, also for the management of the daily work, due to the huge amount of data to be processed and stored.

In the best European practices, the PLIM/PLEX programs aim at demonstrating that during the design and possibly the extended plant operational life [4] the following is valid:

1) The effects of ageing on the intended safety function(s) are adequately managed all along the envisaged lifetime;

2) There is a mechanism to deal with unexpected ageing mechanisms that can surface.

3) There is a pro-active process for decision making, also involving non-safety equipments significant to plant availability

4) There is a program to manage human resources and knowledge

5) Plant economic assets are properly managed in an integrated way with safety issues

A good formulation for PLIM/PLEX objective may refer to the development of a consistent framework program at the plant which enables the plant

- to produce electricity in a safe and responsible way by continuously improving the power plant operation and safety
- to secure an efficient generation portfolio

This objective is typically achieved with coordination of some key programs at the plant, such as: operation, asset management, maintenance surveillance and inspection (MS&I), ageing management, knowledge management, and nuclear safety.

In order to achieve the goals set up in the previous chapter, the PLIM program has to consider the following main components:

1) Nuclear safety and licensing

2) Production and economy (including fuel and waste management)

3) Human resources

The long term investment plan is the basic tool for managing the investment portfolio where all the technical programs provide input.

The generic PLIM structure is the result of the integration of selected existing programs at the plant and the development of suitable links and feedback loops. In particular the following programs are directly coordinated by PLIM:

- Maintenance, surveillance and inspection (MS&I), including control of human factors
- Ageing management, component obsolescence and plant configuration control
- Knowledge management
- Asset management and investment planning
- Major plant upgrading programs (if in place, such as power uprating, modernisation, etc.)
It has to be noted that plant modernization, power uprating, fuel management may also be part of PLIM, but they are not necessarily implemented at all plants.

It is clear that the MS&I program is a crucial part of PLIM/PLEX, being by far the main contributor to both operating costs (after operation) and operation planning. However, in order to support a PLIM/PLEX framework, MS&I should have a specific list of attributes, making both safety assessment and cost optimization possible.

In conclusion, the implementation of an AMP and a predictive MS&I (maintenance, surveillance and inspection) program is definitely a condition for the operation within the limits of design or licensed lifetime and is a condition for a PLIM as well.

KM and asset management are traditionally isolated programs from MS&I and AMP. PLIM recognizes the need for their integration and sets an overall optimization framework.

2.1 Countries' generic experience with PLIM

Thanks to the large survey on Countries' practice carried out at the JRC [4], also through the organization of many international events, it was possible to summarize the most relevant aspects of some Countries' practice in the field of PLIM, with special emphasis to the relationship with other programs running at the EU Countries.

- The USA, Canada, Spain and some other Countries accumulated a valuable experience in recent years in PLIM issues and related programs. The interest of the international community of plant operators on reliability based approaches to PLIM and maintenance optimisation in particular is definitely growing. The US approach is codified in the INPO AP-913 [5], closely followed by some European utilities.

- Other European Countries are more in favour of integrated approaches to Plant Life, such as Finland, with a more explicit control of the component degradation and a clear day-to-day basis for the decision makers on replacement, maintenance and operation.

- In many European Countries, PLIM is accompanied with a PSR program. The combination is not surprising, as PLIM is typically a utility driven program, while PSR is driven by the Safety Authority. Many technical tasks (that are safety related) are similar, but objectives, time frame and regulatory implications are definitely different.

- Some pre-conditions for PLIM in many countries include maintenance optimisation, RI-ISI, fuel management, outage optimisation, knowledge management, public acceptance, seismic upgrading, etc. making sometimes the program very complex. In all cases they are assisted by complex software tools and databases, also for the management of the daily work.

- The relationship among PLIM and the other programs running at the NPPs is now quite clear in the EU Countries: well known programs such as component integrity, ageing management (PLEX), periodic Safety Review (PSR) and Plant Life Management (PLIM) are in fact well connected, but definitely not interchangeable. Despite of the different names, mostly derived from the national regulatory and engineering frameworks, there is a clear hierarchy among them. In particular, component integrity is a basic science dealing with the failure modes of the different components, their detection and their control. The AMP is an operational program in place at any NPP, which integrates maintenance, ISI and organisational issues aiming at controlling the component degradation. PLIM addresses safety as well as economics, knowledge management as well as decision making, and provides an overall framework to keep the whole plant in a safe and economically sustainable condition.
2.2 PLIM at the design stage for the new reactors in the EU

The comparison of the approach to PLIM among other technology areas suggests some interesting considerations. For example, in the aerospace industry the maintenance program (considered one of the most crucial component in PLIM/PLEX) is optimized at the design phase, due to the large number of identical aircrafts; in the nuclear practice, time is needed to accumulate statistics and to develop confidence in the optimization procedures.

However, it is common judgment that PLIM should be applied since the design phase of the NPPs, possibly based on the lesson learnt from the operating fleets. In this sense, practice could be assimilated to that in other industrial technologies, as mentioned above.

Up to today, the development of standards and design rules for the new generation reactors is lagging behind. This delay also makes the certification of the new reactors quite difficult. At the same time, also the safety assessment methods and the QA rules for construction and operation need to be revised. The role of both licensee and regulators is still to be defined in many countries.

This generic statement is applicable also to the PLIM relevant aspects which do deserve an early understanding at the design phase. In particular, ageing considerations should be addressed since the design stage, for example providing inspectability, replaceability, and access to the most sensitive components and a solid basis for the control of their degradation.

Ageing should also be addressed since the beginning of operation in order to make available a broad range of data for trending and optimisation.

In particular, the following PLIM/ageing relevant issues should be addressed in the pre-design or pre-licensing phase of new reactors:

- Choice of materials
- Major drawings
- Operating conditions
- Collection of relevant data
- Monitoring, surveillance
- In-service inspection (ISI): inspectability / access
- Radiation protection of workers

For example, in the Areva/EPR, the following design actions are taken in order to improve the PLIM performance [7]:

- Accessibility of the reactor building during normal operation to perform maintenance tasks and inspections, but also to start refuelling seven days before reactor shutdown and to continue demobilisation three days after reactor restart
- Improved main coolant loop cool down, depressurisation and vessel head opening after shutdown bringing the standard outage time to 16 days.
- Very low radiation level to workers
• Some modifications in Steam Generator and Pressurizer
• Improvements of nozzles and tees for thermal fatigue reduction
• In general Fatigue usage factors (FU) have to be less than 0.5 for limited (ISI) in Operation

In the Westinghouse AP1000 [8] the following design actions intend to address the PLIM issues:
• Large use of passive features, also to reduce MS&I tasks
• Variable speed in the reactor coolant pump, to shorten start up and shutdown
• Special design of the digital I&C which reduces the I&C surveillance testing
• Large use of component standardization to reduce parts inventory and training
• Built-in testing capabilities is provided for many critical components
• Easy access for MS&I tasks and lifting devices
• Few nuclear grade equipment
• Very low radiation level to workers

A comprehensive analysis of PLIM/PLEX program features may be found for example in [3, 4].

2.3 PLIM model

This concept is described in Fig.1, where the four main components of PLIM are highlighted in the central program, the input and the output are in the vertical lines and other programs are listed in the lateral boxes.
Figure 1— Approach to PLIM and interfaces with related programs

The long term investment plan generated out of PLIM is the basic tool for managing the investment portfolio where all the technical programs provide input.

These programs should also meet specific pre-conditions on their main features, as discussed in previous chapter and summarized in Fig.2.

Figure 2 – Preconditions for the key programs to be part of PLIM

Other programs represent a generic background for PLIM, and exchange data with PLIM, but they are not explicitly part of it, such as: operation, nuclear safety, fuel management, waste management, licensing (including the continuous updating of the Safety Analysis Report), engineering, etc.
At last, important programs may be based upon PLIM, but they are not part of it, such as: plant life extension, license renewal, periodic safety review, plant upgrading (including power uprating), public acceptance, etc. From the technical standpoint, the approach to plant life management consists of:

- Identification of critical systems, structures and components (SSCs) from the standpoint of the plant operation and safety
- Classification of the identified SSCs
- Identification of loadings and ageing mechanisms
- Development of method for the lifetime prediction
- Identification and implementation of applicable ageing countermeasures
- Feedback to MS&I programs and other relevant programs
- Development of the investment planning

2.4 Economics of PLIM / PLEX – Business plan for PLEX - the economic model

The investment plan divided in short and long term investments can be developed with interfaces from all the above mentioned programs in order to represent a realistic tool for simulation and planning of a balanced investment plan for the remaining lifetime of the plant. The IAEA technical report on “Cost Drivers for the Assessment of NPP Life Extension” [8] develops a methodology to determine the cost inputs required to perform cost-benefit analysis for plant life extension schemes and is a good basis, but significant adaptations should be applied to meet the plant optimised practice.

Its content may be organized as in the following [9]:

- Content of the projects which are planned for 1 - 4 years onwards in the short term
- and in the long term, with less detail, even until the end of the plant lifetime
- The database should include component identification data, classification and component status information
- The economic data base should include the annual costs of each project
- Summary reports should give the big picture of the investment portfolio, including all planned projects

Examples of output from economic models are illustrated in the figures 3, 4, 5 & 6 below. The model covers two lifetime extension options, 50 years and 60 years. In this model three scenarios –optimistic (yellow), realistic (green) and pessimistic (blue) - have been evaluated for the both options [10].
Figure 3 – Investment for three scenarios – 50 years operation

Figure 4 - Investment for three scenarios – 60 years operation
Indeed, extending the operating lives of existing plants provides clear advantages. High capacity factors and low operating costs make EU nuclear plants some of the most economical power generators in the EU countries. And even when major plant components must be upgraded to extend operating life, these plants represent a cost effective, carbon-free asset that is critical to the Member States’ energy future.

Extending the life of a major generating asset avoids the need for immediate investment in new generating capacity. The capital costs of plant life management for long term operation will be much smaller than investment in any type of replacement capacity, although there might be a need for additional investment in plant upgrading and safety improvements. Combining the plant upgrading and
safety improvements with power uprating made lifetime extension even more cost effective. In addition, the kWh costs for waste management and decommissioning can be reduced.

Nevertheless, quantification of the PLEX costs is not an easy task. It is recognized that PLEX costs are highly dependent on specific conditions related to each NPP, such as: design of the plant; NPP operating history including ageing conditions; condition of the critical SSCs; regulatory requirements; full or partial replacement of components; refurbishment for PLIM versus refurbishment for PLEX; accounting methodologies; etc.

4 Analysis of Country experience

4.1 Current situation in EU

At the territory of 15 European Union member states 145 nuclear power reactors were in operation during 2009 with an installed net capacity of 131 620 MWe. The plants are built to 6 different basic design, 88 were of type PWR, 17 of type BWR, 18 of type VVER, 18 of type GCR, 2 of type PHWR, 1 of type FBR and 1 of type RBMK.

The operation age of the plants is in the range from 2 to 42 years, figure 7 shows the age distribution of the power plants in operation. Two reactors, one in France (Phenix) and one in Lithuania (Ignalina) were shutdown permanently in December 2009.  

Since the early 1980 the plants were continuously upgraded. Today, in 2009 the increase of the net power is counting for 3495MWe and plants in approved lifetime extension are counting for 922MWe.

The power plant data used in this report where collected from the IAEA PRIS data base (public part) from the basic data and operation history.

\[\text{Figure 7 - Age distribution of nuclear power reactors as per 30.12.2009}\]

\[1\] Based on public data from IAEA PRIS www.iaea.or.at/programmes/a2/
Figure 8 shows the installed net power over the operation years by showing the design power, uprating power, lifetime extension power, planned lifetime extension power, under construction power and planned construction power. The “planned lifetime extension power” illustrate scenario V1 assuming the situation: German NPPs as agreed in phase out; France NPPs operate to 40 years, other countries like Sweden, Czech, Belgium, etc extent lifetime as planned by utilities. More scenarios are illustrated in annex 1.

The definitions of the legends used in the chart are as follow:

- **Design power** - net power output of the plant as designed
- **Uprating power** - additional net power gained through uprating during operation
- **Lifetime extension power** - approved installed power (design and possible uprating) in operating period beyond design lifetime
- **Planned lifetime extension power** - as before, planned by the utilities but not yet approved by the authorities
- **Under construction power** - net power output from plants under construction, power production starts at actual informed startup date
- **Planned under construction power** - net power output from planned plants where decision process is undergoing but no final government decision

![Figure 8 - Nuclear power generation (installed and planned 1961 - 2040) in the European Union (Net output in MWe)](image)

In this report three scenarios are used and shown in different figures.

- **Scenario V1**: Germans’ NPPs as agreed in phase out; France NPPs operate to 40 years, other countries like Sweden, Czech, Belgium, etc extent lifetime as approved or planned by utilities.

- **Scenario V2**: Germans’ NPPs as agreed in phase out; France extent lifetime of 40 years by 10 years except the 6 oldest one, other countries like Sweden, Czech, Belgium, etc extent lifetime as
approved or planned by utilities.

- Scenario V3: Germans’ NPPs operate 40 years; France extent lifetime of 40 years by 10 years except the 6 oldest one, other countries like Sweden, Czech, Belgium, etc extent lifetime as approved or planned by utilities.

In 2008 the total electric power production of the fifteen countries with nuclear power plants was 2 418 324 GWh(e) thereof 888 312 GWh(e) about 36.7% produced by Nuclear power. For the EU27 the total net electric power production was 3 095 790 GWh(e) thereof 28.7% were produced by nuclear power.² The shares of the different power production in the EU27 for the last years are shown in figure 9 & 10.

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² Based on Eurostat DS-073191 nrg_105m –Supply – electricity – monthly data, index 107100, 107103 extracted on 7.10.2009 and 26.01.2010
installed net capacity and the produced net power as indicated in Eurostat has decreased in the last years from around 80% in the mid of the decade to 76.8% in 2008, see also figure 11.

The load factor of an energy technology is the ratio (expressed as a percentage) of the net amount of electricity generated by a power plant to the net amount which it could have generated if it were operating at its net output capacity.

![Graph](image)

Figure 11 - Development of load factor of EU nuclear power reactors

### 4.2 Situation in EU Countries

#### 4.2.1 Belgium

In Belgium are seven (7) NPPs (PWRs) in operation with an installed net capacity of 5824 MWe. In 2008 the total power production was 80 679 GWh(e) thereof 43 359 GWh(e) about 53.7% produced by Nuclear power.

Recently the government made a change in the phase out of the nuclear energy. The design lifetime for three reactors (Doel 1&2, Tihange 1) ends after 40 years operation in 2015. The government decided in 2009 a principal extent of the lifetime to 2025 considering a positive decision to the 4th Periodic Safety Review by the nuclear regulator.

#### 4.2.2 Bulgaria

In Bulgaria are two (2) NPPs (VVERs) in operation with an installed net capacity of 1908 MWe. In 2008 the total power production was 40 028 GWh(e) thereof 14 742 GWh(e) about 36.8% produced by Nuclear power.

An extensive modernisation program for unit 5 &6 was implemented from 2002 to 2008. The objectives of the program were: provide level of safety of the units in compliance with the current international norms and standards, enhance operation reliability, enhance units’ efficiency, extend units’ operational lifetime with 15-20 years beyond their design life. The estimated cost for the implementation of the modernization program amounts to a total

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3 15/10/2009 HET FANC en BEL V publiceren technische nota betreffende verlenging levensduur Belgische kerncentrales
of 491M €.  

The financing of the completion of two VVER 1000 units at the Belene site is still open. The construction originally started in 1987 but was suspended in 1991 is planned to be finish in 2014/2015.

4.2.3 Czech Republic

In Czech Republic in 2009 six (6) NPPs (VVERs) are in operation with an installed net capacity of 3677 MWe. In 2008 the total power production was 77 091 GWh(e) thereof 25 016 GWh(e) about 32,4% produced by Nuclear power.

The total net power upgrading for 2009 is 145 MWe and is planned to increase to 274 MWe in 2012.

The design life time (Technical design USSR) for the Czech VVER 440 power plants are for equipments 30 years and for the reactor pressure vessel 40 years. Currently the utility CEZ plans a life time extension to 40 years but in long terms an extension from 50 to 60 years is considered. The life time management is supported by diagnostic software DIALIFE where the equipment residual lifetime is calculated using verified calculation programs.

The regulatory requirement based on the Atomic Act requires proofs that the high level of nuclear safety will be ensured for the time of the license duration. Basically the Long Term Operation Concept was accepted and applied for all Czech NPP’s. The operation license is given for 10 years after a periodic safety review together with an assessment of main components Lifetime Monitoring Program.

Power upgrading and safety improvements

A large power upgrading was performed in 2009 at Dukovany unit 3 from 462 to 500 MW gross (~470 MW net); the upgrading program for the other three units will be completed by 2012. Extensive safety improvements were implemented at Dukovany NPPs.

The results of the safety improvements for the Dukovany NPPs are shown in figure 12. For the time being the level of CDF is around 1.0E-05 (PSA-1) which is the level recommended by the IAEA for new reactors. Through two more sets of modifications it is planned to reach a level of CDF as 7.75E-06 during operation.

With Temelin unit 1 & 2, each nominally 981 MWe gross but performing at 994 MWe, Skoda modified the high pressure turbines over 2004-07 in a EUR 26 million project to achieve 1013 MWe gross, 963 MWe net. A further upgrade since that is expected to result in 1050 MWe gross.

Plans for construction of Temelin NPP unit 3 and 4 are in discussions with an expected connection to the grid after 2020. 

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4 Kozloduy NPP Units 5&6 Moderization program, R Zlateva, KNPP Vienna, 3-6.10.2006,
5 Presentation “Approach to the Long Term Operation of PWRs“ SUJB NERS Meeting 2006 Bled, Slovenia (lto.cz.pdf);
Notes of M Novakova e-mail 9.10.2009; IAEA-CN-82/36 “A way of Dukovany NPP to privatization and liberalized market, Kouklik I. Dukovany NPP
4.2.4 Finland

In Finland four (4) NPPs (2 VVERs & 2 BWRs) are in operation in 2009 with an installed net capacity of 2696 MWe. In 2008 the total power production was 74 055 GWh(e) thereof 22 035 GWh(e) about 29.8% produced by Nuclear power.

Since 1983 the power of the plants were continuously upgraded. Today the increase of the net power is 496 MWe, 96MWe at Loviisa NPP and 400 MWe at Olkiluoto NPP.

Loviisa NPP

The design life time (Technical design USSR) for the Loviisa VVER 440 power plants are for equipments and reactor pressure vessel 30 years. Loviisa NPP introduce an extensive life time extension program (basic for the model describe in chapter 2.3) at the beginning of 2002. The life time extension is approved by the regulator for 20 years with the request for a periodic safety review after 10 years.

An upgrading program was implemented from 1994 to 1998 for the reactor plant and until 2002 for the turbine plant which increased the thermal power output of the reactors by 9% and the total power by 48 MWe per unit. The total cost of upgrades was 33 Mill. Euros.

Besides the power upratings large safety improvements were implemented. The Loviisa 1 unit risk distribution is illustrated in figure 13.  

Olkiluoto NPP

The design life time of the BWR units is 40 years and a lifetime extension is planned by the utility beyond 60 years operation.

Since 1985 the power was continuous uprated by increasing the thermal efficiency of the turbine plant and reactor thermal power. By today the net power per unit was increased by 200 MWe.

Besides the power upratings large safety improvements have been implemented. The core damage frequency due to internal initiating was in 1989 around 4.0E-04 per reactor year and is now by around

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6 E-mail K Mäkelä Loviisa NPP; Fortum and Climate Change 2009
1.0E-05 per reactor year. Continuous improvements and modifications of procedures have reduced the core damage frequency during an outage significantly. In 1992 the CDF during an outage was assessed to be approximately 3.6E-06 per refuelling outage and was decreased to 2.0E-07 per reactor year in the year 2006.\(^7\)

The average capacity factor for the last ten years is well above 90%

In Finland the fifth unit, an EPR 1600 MWe PWR, is under construction since 2005 and the grid connection is now expected in 2012.

There are three (3) principle applications for the construction of new nuclear power plant units (1000 – 1600 MWe) submitted to the Government for approval. A decision of the government is expected in Spring/Summer 2010. Earliest connection to the grid is 2018.

\[\text{Figure 13 – Development of CDF at Loviisa NPP}\]

### 4.2.5 France

In France in 2009 59 NPPs (58 PWRs & 1 FBRs) are in operation with an installed net capacity of 63 280 MWe. In 2008 the total power production was 54 8977 GWh(e) thereof 418 298 GWh(e) about 76,2% produced by Nuclear power. One reactor (Phenix, a FBR) was shutdown permanently in December 2009.

The NPPs are licensed for a period of 40 years and are subject to a periodical safety review every 10 years. EDF is in favour of lifetime extension from 40 to 60 years. Improving of safety is a main objective of EDF lifetime policy. Examples of the development of two safety indicators are shown in figure 14 & 15. The costs for lifetime extension are estimated with €400 million per unit.

In France one unit an EPR 1600 MWe PWR is under construction since 2006 at the Flamanville site.

\(^7\) STUK-B 80/Sept. 2007 4\textsuperscript{th} Finnish report on nuclear safety
EdF said that the cost of constructing its new Evolutionary Power Reactor (EPR) at Flamanville, France, has increased by 20%. In 2005, it was estimated that the plant would cost €3.3 billion ($4.2 billion) to build, but the company now says it will cost some €4.0 billion ($5.1 billion). EdF said the revised cost "takes into account increase in prices and the effects of some contractual indexes due to higher raw material costs and the impact of technical and regulatory evolutions."

With the increased construction cost of the Flamanville EPR, generating costs at the plant have also been revised. Total production costs are now put at €54 per megawatt-hour (MWh) ($68/MWh), up from the 2005 estimate of €46/MWh ($58/MWh).  

Figure 14 & Figure 15 - Development of safety indicators

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The French Government announced in January 2009 that a second EPR reactor could be constructed at the Penly site. The construction is expected to begin in 2011. Earliest connection to the grid is 2017/2018. EDF's view of development of Nuclear Power in France considering lifetime extension and new construction is shown in figure 16.

4.2.6 Germany

In Germany in 2009 17 NPPs (11 PWRs & 6 BWRs) are in operation with an installed net capacity of 20 491 MWe. In 2008 the total power production was 540 779 GWh(e) thereof 140 708 GWh(e) about 26% produced by Nuclear power.

Since the beginning of nuclear power operation the plants were continuously upgraded. Today the increase of the net power is 999 MWe, so much as a medium/large size plant.

Besides the power upratings large safety improvements were implemented. In figure 17 is shown the development of the CDF at Biblis NPP.

After the parliament election in 2009, the Phasing-Out Agreement (2001) between the nuclear power producers and the Federal Government is suspended. Further acts regarding the agreement will be discussed and agreed on at the end of the year 2010.
After 3 safety improvement phases the CDF has decreased by a factor 20. The two IAEA levels are for present installations ($10^{-4}$) and for new reactors (generation III, $10^{-5}$).

### 4.2.7 Hungary

In Hungary in 2009 four (4) NPPs (VVERs) are in operation with an installed net capacity of 1859 MWe (1889 MWe at End 2009). In 2008 the total power production was 37 264 GWh(e) thereof 13 898 GWh(e) about 37.3% produced by Nuclear power.

Since 1990 the power of the plants were continuously upgraded. Today the total increase of the net power is 234 MWe.

The power uprating was achieved by increasing the thermal efficiency of the turbine plant and in the last years by increasing the reactor thermal power by 8%. The costs for the power uprating are estimated to be 5.537 billion HUF (~ € 20.416 Mill.).

Besides the power upratings large safety improvements were implemented. The core damage frequency (nominal power & shutdown) decreased from around 6,0E-04 per reactor year to around 1,0E-05 per reactor year.

The basic concept of lifetime extension by 20 years from 30 to 50 years was accepted by the Hungarian Parliament on 21.11.2006. The legal licensing process is ongoing.

### 4.2.8 Lithuania

In Lithuania in 2009 one (1) NPPs (RBMK) was operation with an installed net capacity of 1185 MWe. The plant was permanent shutdown in December 2009. In 2008 the total power production was 12 260 GWh(e) thereof 9225 GWh(e) about 75,2% produced by Nuclear power.

Discussions regarding the construction of a new NPP are ongoing but no concrete decisions on

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9 RWE – brochure VORWEG GEHEN "Ergebnisse der periodischen Sicherheitsüberprüfung des Kernkraftwerkes Biblis, Block A und B"

10 [http://paksnuclearpowerplant.com/capacity-upgrade](http://paksnuclearpowerplant.com/capacity-upgrade)
implementation and time schedule are done.

### 4.2.9 The Netherlands

In The Netherlands in 2009 one (1) NPP (PWR) is in operation with an installed net capacity of 482 MWe. In 2008 the total power production was 102 281 GWh(e) thereof 3933 GWh(e) about 3.8% produced by Nuclear power.

The net power is uprated by 32 MWe.

The design lifetime ends after 40 years operation in 2013. The government decided in 2006 to give permission for an extent of the lifetime to 2033, considering that the plant belongs to the 25% safest NPPs of EU, USA and Canada which will be proved by verification every five years. Periodic safety reviews performed in 1985, 1997 and 2007 shows the effect of back fitting and modernization programs in improving of plant safety recently, as shown in figure 18. The costs for the modernization program implemented in 1997 were around 250 million Euros.

A power upgrade to a gross capacity of 510 MWe was carried out in 2006. The last significant safety improvements were implemented from 2005 to 2007.\(^{11}\)

![Figure 18 - Changes in total core damage frequency as a result of safety improvements](image)

Discussions regarding the construction of a new NPP are ongoing but no concrete decisions on implementation and time schedule are done.

### 4.2.10 Romania

In Romania in 2009 two (2) NPPs (PHWRs) are in operation with an installed net capacity of 1300 MWe. In 2008 the total power production was 58 456 GWh(e) thereof 10 315 GWh(e) about 17.6% produced by Nuclear power.

At 30.6.2009 Romania’s EnergoNuclear notifies EU of plan to add to Reactors to Cernavoda NPP. The two reactors of Candu design are scheduled to be completed in 2015/2016 and the estimated costs are 4000 Million Euros.

\(^{11}\) Regering.nl Nieuwsbericht 10-01-2006 “ Kerncentrale Borssele uiterlijk in 2033 dicht”, ENS news Issue No. 17 July 2007 “Periodic Safety Review NPP Borssele reduced TCDF by a factor of 4”
4.2.11 Slovakia

In Slovakia in 2009 four (4) NPPs (VVERs) are in operation with an installed net capacity of 1711 MWe. In 2008 the total power production was 27 489 GWh(e) thereof 15 465 GWh(e) about 56.3% produced by Nuclear power.

The total net power of the four units is uprated by 85 MWe.

Extension of the Bohunice unit 3&4 lifetime to a minimum of 40 years is planned. During the last decade large safety improvements and upgrading were implemented for more than 10000 million SKK.

At Mochovce unit 1&2 safety improvements were implemented prior commissioning in 1998 respectively 2004. Two more VVER 440 units at the Mochovce site are under construction (reactivated 11.6.2009) and scheduled for operation in 2012/2013.

4.2.12 Slovenia

In Slovenia in 2009 one (1) NPP (PWR) is in operation with an installed net capacity of 666 MWe. In 2008 the total power production was 15346 GWh(e) thereof 5973 GWh(e) about 38.9% produced by Nuclear power. The net power is uprated by 34 MWe.

Westinghouse designed NPP Krško is originally designed to operate 40 years, until 2023 but plant life extension is considered. Based on nuclear industry practices, good plant conditions and energy consumption demands, several plants around the World decided to extend their lifetime for 20 or even 40 years. The most developed processes for lifetime extension or license renewal applications are at present in the US regulated NPP’s through applying the 10CFR54 rule.

NPP Krško (NEK) decided to use similar approach during development of Aging Management Program (AMP), which represents the major part of license renewal application within NRC licensing process. NEK AMP was finalized in 2008, Time Limited Aging Analyses (TLAA) were verified and some will be repeated for the extended lifetime. Changes in plant processes and programs were identified and will be implemented. Licensing documents changes were proposed as a basis for design lifetime extension for 20 years. Based on AMP program findings, actions to be implemented and good plant condition, NEK considers being ready for plant lifetime extension. ¹²

4.2.13 Spain

In Spain in 2009 eight (8) NPPs (6 PWRs & 2 BWRs) are in operation with an installed net capacity of 7450 MWe. In 2008 the total power production was 281 879 GWh(e) thereof 56 403 GWh(e) about 20.0% produced by Nuclear power.

Since the beginning of nuclear power operation the plants were continues upgraded. Today the increase of the net power is 514 MWe, so much us a medium size plant.

The Santa Maria de Garoña nuclear power plant, a BWR reactor, went through a PLEX process to extend its life beyond the 40 years of design life. In June 2009 the Spain's Nuclear Security Council (Consejo de Seguridad Nuclear, CSN) recommended to the government that the 446-megawatt boiling water reactor unit Santa Maria de Garoña should operate 10 years beyond its original 40-year design life until 2021. Nevertheless, the present Spanish government with a policy of closing down Spanish nuclear plants as early as possible, decided on July 2⁰⁰⁹ that Santa Maria de Garoña remains open

¹² Presentation “NPP Krško Lifetime Extension” B Glaser, Nuclear Energy for New Europe 2009 §
until 2013, only two years after the end of its planned lifespan.

4.2.14 Sweden

In Sweden in 2009 ten (10) NPPs (3 PWRs and 7 BWRs) are in operation with an installed net capacity of 8996 MWe. In 2008 the total power production was 145 913 GWh(e) thereof 61 268 GWh(e) about 42% produced by Nuclear power.

Since the beginning of nuclear power operation the plants were continues upgraded. Today the increase of the net power is 688 MWe, so much as a medium size plant.

Life time extension is planned after change of the phase-out for 10 to 20 years.

A Nuclear Phase-Out Act with the plan to shut all Sweden’s reactors by 2010 led to the shutdown of 2 units at Barsebäck site in 1999, respectively 2005. In 2009 the Swedish government changed the police and agreed among others: 13

- Applications for increasing power capacity will be assessed as previously.
- The transitional period during which nuclear power will be in use will be extended by allowing new construction at existing sites within the framework of a maximum of ten reactors. It will be possible to grant permits for successively replacing current reactors as they reach the end of their technological and economic life.
- The Nuclear Phase-Out Act will be annulled. The prohibition against new construction in the Nuclear Activities Act will be lifted. An inquiry will be appointed to design nuclear power legislation that enables a controlled generational shift in Swedish nuclear power.

Oskarsham NPP 14

At the end of 2011 the total investments since beginning of 1990 in safety improvement and power uprating as well as lifetime extension, have been more than €1500 million.

Unit 1: Large modification program in 1993 to 1995, 1998 and 2002, uprating thermal efficiency of turbine by around 22MW.

Unit 2: Lifetime extension planned for 20 years. Modifications of the unit will be carried out during outages until 2011. Modifications include improvement of thermal efficiency of the turbine by around 50 MW in 2009 and thermal efficiency of the reactor from 1800 MW to 2300 MW (28%) which corresponds to an uprating from 613 MWe to 840 MWe 36% in 2011, if finally approved.

Unit 3: A large modification program with a power uprate of some 20% from 1200 MWe to 1450 MWe net, achieved by improvement of thermal efficiency of turbine by around 50 MW in 2009 and thermal efficiency of the reactor to 3900 MWth. Since the initial approval for the uprate given in 2005, OKG has spent €313 million on improvements to the reactor and turbines, a project expected to extend the reactor's operating life to 60 years and to improve reactor safety according to new regulations. Approval for test operation of the reactor has been given in September 2009.

Forsmark NPP 15

13 Regeringskansliet-2009 02 05 - A sustainable energy and climate policy for the environment, competitiveness and long-term stability
14 http://www.okg.se/
Lifetime extension is planned for more than 10 years and €1300 million including €225 million for power uprating are being invested in the three units to meet increased safety and environmental requirements, to prolong the service life of the reactor and to increase the output. In total the output will be increase by 410 MW in 2014.

**Ringhals NPP**

More than 300 modification projects are planned to be implemented at the four units. In the period until 2012, €1300 million is being invested in regeneration, improved safety, reduced environmental impact and increased output. A further €1200 million will be invested after 2012. Around €1800 million will be spent for safety improvements, lifetime extension to more than 50 years and environment. Around €400 million will be spent for power uprating by 10% in 2012.

Unit 1: Large safety improvement and upgrading projects from 2004 to 2009 and power uprating by 15 MWe in 2009.

Unit 2: Large safety improvement and upgrading projects.

Unit 3: Large safety improvement and upgrading projects in the last decade and power uprating by around 130 MWe in 2009.

Unit 4: Large safety improvement and upgrading projects in the last decade and power uprating by increasing the thermal efficiency of turbine and reactor by 18.6% in 2011.

**4.2.15 United Kingdom**

In the United Kingdom in 2009 19 NPPs (1 PWRs & 18 GCRs) are in operation with an installed net capacity of 10097 MWe. In 2008 the total power production was 375827 GWh(e) thereof 47674 GWh(e) about 12.7% produced by Nuclear power.

There is no large lifetime extension program for the GCRs. Four reactors (2 at Hartlepool and 2 at Heysham) have been cleared to operate for another 5 years beyond their scheduled closure in 2014. The British Government made reservation for new plant construction sites. The French EDF planned that the first EDF-EPR should be connected to the grid in 2017/2018. Also other utilities announced the intention to start construction of new nuclear power plants.

**5 Economics of lifetime extension and safety improvements**

In a deregulated electricity market power plant lifetime extension and upgrading are driven by cost and revenue consideration. Decision to continue operating an existing plant is based on its marginal generation cost, i.e., operation & maintenance, fuel cycle cost, taxes and capital cost compared to generation costs of other options. The marginal cost is lower for existing nuclear power plants than for most alternatives, therefore lifetime extension is a lucrative option.

In Europe lifetime extension and uprating of NPPs are going hand in hand together with safety improvements. Based on the information provided in chapter 4.2 the cost for lifetime extension and consequently necessary safety upgrading are in the average €400 million per unit despite of the size. These large costs increase the generation cost during the amortisation period by 0.2 – 0.6%

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15 www.vattenfall.se
16 www.vattenfall.se
17 WNA Nuclear Power in the United Kingdom, 6.11.2009
eurocent/kWh. Figure 19 & 20 shows a calculation the influence of a large costly investment on the production costs of a nuclear power plant. In the given example the generating costs increases from 0.013 USD/Kwh to 0.019 USD/Kwh and remains less than the generating costs for coal or gas.

Operators in Sweden announced at their web site production costs of 1.9 to 2.3 eurocent/kWh, (around 22 öre / kWh for Oskarsham NPPs, 23.9 öre/kWh for Forsmark NPPs and 20 öre/kWh for Ringhals NPPs). In relation thereto the production costs estimated by EDF for the Flamanville EPR plant are 5.4 eurocent/kWh. The more than 3 eurocent difference is considered by the operators of existing plants as a large margin for investments in upgrading and safety improvements required for a lifetime extension.

![Graph showing the influence of a large refurbishment on nuclear generation costs](image)

**Figure 19** - Example from a NEA report of the influence of a large refurbishment on nuclear generation costs – Generating costs of nuclear and coal power built in 1976 and gas power in 2006

<table>
<thead>
<tr>
<th></th>
<th>Nuclear</th>
<th>Coal</th>
<th>Gas</th>
</tr>
</thead>
<tbody>
<tr>
<td>Investment at 1976 (a)</td>
<td>1 540 USD/kWe</td>
<td>880 USD/kWe</td>
<td>880 USD/kWe</td>
</tr>
<tr>
<td>Investment at 2006 (b)</td>
<td></td>
<td>20 years</td>
<td>15 years</td>
</tr>
<tr>
<td>Amortisation period</td>
<td>20 years</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Refurbishment at 2006 (c)</td>
<td>300 USD/kWe</td>
<td>5%</td>
<td>5%</td>
</tr>
<tr>
<td>Interest rate</td>
<td>75%</td>
<td>75%</td>
<td>75%</td>
</tr>
<tr>
<td>Load Factor</td>
<td>95%</td>
<td>34%</td>
<td>52%</td>
</tr>
<tr>
<td>Thermal Efficiency</td>
<td></td>
<td>34%</td>
<td>52%</td>
</tr>
<tr>
<td>O &amp; M cost (b, d)</td>
<td>58.6 USD/kWe/year</td>
<td>52.5 USD/kWe/year</td>
<td>27.0 USD/kWe/year</td>
</tr>
<tr>
<td>Coal &amp; Gas cost (b)</td>
<td>0.2 USD/kg</td>
<td>2.09 USD/Gjoule</td>
<td>3.58 USD/Gjoule</td>
</tr>
<tr>
<td>Uranium cost (b)</td>
<td>103.8 USD/SWU</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Enrichment cost (b)</td>
<td>310.5 USD/kg</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

(a) Average in OECD countries in 1981 (OECD 1983); it is assumed that the investment was the same in 1976.
(b) Average in OECD countries (OECD 1998b).
(c) Assumed large refurbishment costs 300 USD/kWe (NDC 1999) and amortisation period is 15 years.
(d) The data of power plants expected to be commercially available by 2005-2010 (OECD 1998b).

**Figure 20** – Example from a NEA report of the influence of a large refurbishment on nuclear generation costs – Assumptions adopted in the generating cost calculations (fig. 19)

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6 Regulatory Process

6.1.1 Periodic Safety Review (PSR)

In the major part of the EU Member States the safety performance of the nuclear plants is periodically controlled via the PSR system. The regulatory review and acceptance of the PSR give the right for the licensee to operate the plant for the next PSR cycle (usually 10 years). The regulatory system is not limiting the number of PSR cycles even if the new cycle is going beyond the original design life of the plant. The only condition is to demonstrate the safety of the plant operation for the next PSR cycle with some margins. The PSR is therefore a regulatory tool for the identification and resolution of safety issues. In this framework the plant long term operation is achieved by applying the PSR, by identification and resolution of the safety issues as a condition of operation for the new PSR cycle. It is clear that the PSR is not a proper tool to control changes and tendencies with an evolution time shorter than 10 years.

According to recent practice, the PSR has to focus on the cumulative effects of plant ageing, assessment of plant status and modifications, operating experience, modifications of national safety standards, science and technology developments, and site hazard modifications [ref. 9]. If the PSR process is to be used for the justification of long term operation of the plant, then special emphasis should be given to the assessment of aged status and ageing management of those structures, systems and components (SSC) related to safety that limit the operational time of the plant.

In conclusion, a full scope PSR applied for life extension or long term operation is not different in principle from a PSR applied during the design life, but the emphasis has to be oriented to the ageing of SSCs limiting the plant operational time and on the related safety issues.

6.1.2 License (LR)

The concept of Licence Renewal is usually followed by the countries where the operational license is granted for a fixed time span limited either by the design life or by other considerations. This concept is based on the correlation between the continuous control of the current licensing basis and the control of those aspects of the plant safety, which are depending on the unavoidable ageing of safety related SSCs.

In these regulatory systems current licensing bases are maintained and they are documented in the (annually updated, living) Final Safety Analysis Report (FSAR). In addition to this, the efficiency of the maintenance system is controlled with some performance criteria for the active safety related SSCs. The LR process itself is focused on the ageing management of long-lived passive SSCs, on the review of the validity of the time limited ageing analyses and environmental qualification. The licensee should be able to demonstrate that actions have been identified and have been or will be taken to manage the effects of ageing on SSCs within the scope of the LR such that there is reasonable assurance that system, structure, and component intended functions will be maintained in accordance with the current licensing basis during the long term operation.

In this regulatory system both type of processes and tendencies are controlled: the processes and tendencies with a short time constant are controlled via regular updating of FSAR and control of efficiency of the maintenance, the long term tendencies are controlled by the LR procedure.

6.1.3 Methodologies for long term operation in the EU

Most of the EU Member States use the PSRs to evaluate arguments for life extension or long term operation. From the regulatory point of view it is important to control the operating organization’s ageing management practices and to check the validity of ageing forecasts for systems, structures and
components important to safety. In addition, the environmental impact of long term operation has to be assessed, although the detail of the study depends on the regulatory requirements.

A combination of PSR and LR applications is used in Hungary and Spain. The periodic safety review will validate the forecast made for the licence renewal application and the efficiency of the ageing management programme.

7 Ageing Management program review and improvement

As indicated in Figure 18, ageing management is the most important aspect of a life extension programme and, in particular, the activities aim to the structural integrity evaluation of structures, system and components that are relevant to safety. In this context, the medium term challenge for the EU, as established in the Strategy Research Agenda of the SNETP, is to harmonize the European methodologies to assess integrity and performance in the case of internal and external hazards, and the selection of indicators and agreement upon end of life criteria.

So far, plant life extension is not considered by the European Commission as an issue in its own right. It is treated as part of the activities aimed at enhancing the safety of operating nuclear power plants. These activities consist mainly of projects that are part of the successive R&D framework programmes implemented by the EU.

In addition to the basic research on materials science conducted by the European Commission’s JRC research establishment at Petten, a number of other projects are funded, mostly based upon attempts to establish and improve networks of excellence that enable the various industrial actors and national research bodies to collaborate in an efficient way, and afterwards to share the results of their work between the participants. Within this framework there are two valuable European efforts. Namely, NULIFE, Network of Excellence on Plant Life Management, and VERLIFE, a project aims at harmonize the management of ageing issues of VVER power plants.

![Figure 21 – Important components of any Life Extension Programme](image)

One of the visions of NULIFE is to create sustainable forum for realizing harmonized technical procedures giving impact for nuclear energy industry, national regulators and European regulatory working groups. NULIFE is seen as a key instrument in implementing long term operation related topics of the SNETP strategy.

The main goal of the VERLIFE project is the preparation, evaluation and mutual agreement of a unified procedure for life assessment of components and piping in VVER type NPPs. This procedure is based on former Soviet rules and codes, as VVER components were designed and manufactured in accordance with requirements of these codes and from prescribed materials. Critical analysis of the possible application of some approaches used in PWR type components is being performed, and such
approaches are incorporated into the prepared procedure as much as possible with the aim of a harmonization of VVER and PWR codes and procedures.

8 Effects of lifetime extension to the electric power production in the EU

The current situation in the EU27 regarding the total net electric power produced and the nuclear produced power is describe in figure 19 & 20. The first part of the graph shows the actual situation from the previous years (2003-2008) and is based on the figures obtained from Eurostat. The second part of the diagram shows the expected production with an increase by 1.0% per year. The nuclear part is calculated from the data used for figure 6 in chapter 4.1, whereby the nuclear production was calculated by a load factor of 77% and the three scenarios V1, V2 and V3 for life time extension power as describe in chapter 4.1.

Figure 22 - Net electric energy production in European Union 2003 – 2008 and estimations from 2009 to 2040 for total net production and nuclear production for 3 scenarios V1, V2, V3

The difference between estimated total net power production and estimated nuclear power production is the needed electric power production by other production than nuclear and is also illustrated in figures 24, 25 and 26 by using different growth rates.
Figure 23 - Estimated net electric nuclear power production for LF 77% for scenarios V1, V2, V3, plants under construction are included

Figure 24 – estimated needs of "non nuclear power production" for nuclear power scenarios V1, V2, V3 (incl. plants under construction)
In an analysis of the above charts we can say:

- By 0% growth of total electric production in the EU, there is a need for 27 TWh additional production in the next 10 years (from 2216TWh in 2010 to 2243TWh in 2020) with the planned new constructions until 2010 (France 1, Finland 3, United Kingdom 1, Romania 2).

- To generate 27 TWh by modern 2MW (net) wind power plants (load factor 35%) 4400 plants are needed in the next 10 years or 2.5 NPPs (1600MW net, LF 80%)

- By 0% growth of total electric production in the EU, there is a need for 90 TWh additional productions in the next 10 years (from 2216TWh in 2010 to 2306TWh in 2010) without the planned new constructions.

- To generate 90 TWh by modern 2MW (net) wind power plants (load factor 35%) around 14700 plants are needed in the next 10 years or 8 NPPs (1600MW net, LF 80%)

- By 1% growth of total electric production in the EU, there is a need for 358 TWh additional production in the next 10 years (from 2278 TWh in 2010 to 2636 TWh in 2020) with the planned new constructions until 2010 (France 1, Finland 3, United Kingdom 1, Romania 2).

- To generate 358 TWh by modern 2MW wind power plants (load factor 35%) around 58600 plants are needed in the next 10 years or 32 NPPs (1600MW net, LF 80%).

- By 1% growth of total electric production in the EU, there is a need for 420 TWh additional productions in the next 10 years (from 2278 TWh in 2010 to 2698 TWh in 2010) without the planned new constructions.

- To generate 420 TWh by modern 2MW wind power plants (load factor 35%) around 68900 plants are needed in the next 10 years or 37 NPPs (1600MW net, LF 80%).
9 Conclusions

The report provides an overview of methodology and developments in PLEX/PLIM approaches, followed by a detailed presentation of the current situation of European power plants life time extension and operation status.

Permanent safety improvements are belongings to the daily life of European power plant operators and utilities to ensure safe and economic operation of the plants. Lifetime extension and uprating of NPPs are going hand in hand together with safety improvements.

Plant power upratings are standing today in the European Union for more than 3400 MW capacity and represent together with lifetime extension a cost effective, carbon-free benefit to the Member States' energy strategy.

In an outlook of a further role of nuclear power it is to point out that after decreasing of nuclear power production by 6.5% in the EU27 countries from a total 945 TWh in 2003 to 885 TWh in 2007, due to shut down of plants in the new member states and some long extensive modification and repair periods of several power plants, the power production increased slightly in 2008 and will stay quit stabilized by around 900 TWh until 2018/19 and after that will decrease rapidly. To avoid the rapid decrease of nuclear power production at a time where the missing production cannot be covered by other low carbon generation means plant lifetime extensions has to continue as planned by the utilities and more new plants need to be constructed. For keeping nuclear power at that current level and assuming a construction time of 5 to 6 years, utilities' financial decisions and government' approval need to be made frequently from the year 2011 on forward.

10 References

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/5/ INPO AP-913, Institute of Nuclear Power Operations, Equipment Reliability Process Description, Atlanta, 2004


/7/ Westinghouse, AP1000, www.AP1000.westinghousenuclear.com

/9/ Mäkelä K, Technical documentation developed for the JRC-IE, Loviisa NPP, 11.5.2007
ANNEX 1: Installed nuclear power for three lifetime extension scenario's

Figure 1: V1 scenario: German NPPs as agreed in phase out; France NPPs operate to 40 years, other countries like Sweden, Czech, Belgium, etc extend lifetime as planned by utilities.

Figure 2: V2 scenario: German NPPs as agreed in phase out; France extend lifetime of 40 years by 10 years except the 6 oldest one, other countries like Sweden, Czech, Belgium, etc extend lifetime as planned by utilities.

Figure 3: V3 scenario: German NPPs operate 40 years; France extend lifetime of 40 years by 10 years except the 6 oldest one, other countries like Sweden, Czech, Belgium, etc extend lifetime as planned by utilities.
ANNEX 2: Net electric energy production in European Union 2003 – 2008 and estimations from 2009 to 2040 for different growth rates

- **EU27 net total 2003-2008**
- **EU27 net nuc 2003-2008**
- **EU27 net total est growth “0,5%”**
- **EU27 net nuc est V1 LF 77%**
- **EU27 net nuc est V2 LF 77%**
- **EU27 net nuc est V3 LF 77%**

![Graph showing net electric energy production](chart1.png)

![Graph showing net electric energy production](chart2.png)

![Graph showing net electric energy production](chart3.png)
ANNEX 3: Estimated nuclear power production for lifetime extension scenario's – Influence of load factor (LF)
ANNEX 4: Estimated need of "non nuclear power" production for lifetime extension scenario's – Influence of electrical production growth by LF 77%
ANNEX 5: Estimated need of "non nuclear power" production for lifetime extension scenario's – plants under construction included – Influence of electrical production growth by load factor LF 87% -
ANNEX 6: Estimated need of non "nuclear power production" for lifetime extension scenario’s – plants under construction and planned included – Influence of electrical production growth by load factor LF 77% -
Abstract
The report provides an overview of methodology and developments in PLEX/PLIM approaches, followed by a detailed presentation of the current situation of European power plants life time extension and operation status. Permanent safety improvements are belongings to the daily life of European power plant operators and utilities to ensure safe and economic operation of the plants. Lifetime extension and uprating of NPPs are going hand in hand together with safety improvements. Plant power upratings are standing today in the European Union for more than 3400 MW capacity and represent together with lifetime extension a cost effective, carbon-free benefit to the Member States’ energy strategy. In an outlook of a further role of nuclear power it is to point out that after decreasing of nuclear power production by 6.5% in the EU27 countries from a total 945 TWh in 2003 to 885 TWh in 2007, due to shut down of plants in the new member states and some long extensive modification and repair periods of several power plants, the power production increased slightly in 2008 and will stay quit stabilized by around 900 TWh until 2018/19 and after that will decrease rapidly. To avoid the rapid decrease of nuclear power production at a time where the missing production cannot be covered by other low carbon generation means plant lifetime extensions has to continue as planned by the utilities and more new plants need to be constructed. For keeping nuclear power at that current level and assuming a construction time of 5 to 6 years, utilities' financial decisions and government' approval need to be made frequently from the year 2011 on forward.

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