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Top down workforce demand from energy scenarios: Influence of Long Term Operation

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Abstract

EHRO-N provides the European Commission (EC) with essential data related to supply and demand for nuclear experts in the EU28 and the enlargement and integration countries based on bottom-up information from the nuclear industry. The objective is to assess how the supply of experts for the nuclear industry in the EU28 and the enlargement and integration countries responds to the needs for the same experts for the present and future nuclear projects in the region. Complementary to the bottom-up approach taken by the EHRO-N team at JRC-IET, a top-down modelling approach has been taken by Roelofs and Von Estorff (2013). In the current work, a similar top-down approach was taken with respect to a selected nuclear energy demand scenario to determine the influence of long term operation (LTO) on the HR requirements in the EU28 and enlargement and integration countries.

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Summary

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The selected '20% nuclear electricity' scenario from the EC Energy Roadmap 2050 shows a moderate growth of nuclear energy production in the EU28 countries including the integration and enlargement countries. The influence of LTO is assessed by comparing scenarios in which no LTO is assumed to scenarios in which LTO is assumed. The following conclusions are drawn from the work presented in this report:

- In the year 2014, about 135 nuclear reactors were operational within these countries with an average capacity of about 900 MWe. The analyses show the influence of LTO on the number of reactors to be constructed between 2010 and 2050. Under the influence of LTO the number decreases from ~115 in case no LTO is assumed down to ~95 when LTO is applied.
- Obviously, LTO leads to a delayed need for new build. This means that the considerable workforce for construction will be required at a later point in time. Practically, the large demand for construction workforce will shift approximately 20 years from 2020-2030 to 2040-2050. At the same time, LTO leads to a larger spread of new reactor construction. This is related to the fact that not all reactors in Europe will employ LTO. So, the date at which end-of-life is reached for the existing reactors will spread.
- The workforce for LTO is negligible compared to the total workforce required for operation and construction, even if it is assumed that no permanent staff for operations is used by the plants to perform such activities.
- LTO delays the peak demand for new people from the near future to around 2040. However, the absolute peak demand is significantly higher because of the large replacement of the retired workforce which is a result of this delay.

LTO relaxes the number of new reactors being installed at the same time compared to historical values and to the reference case in which no LTO is assumed.

1 Introduction

EHRO-N or the European Human Resource Observatory for the Nuclear Energy Sector is the initiative of the European Nuclear Energy Forum (ENEF), with the task to build a system for monitoring the supply of and demand for experts needed for the nuclear energy sector in the 28 European member states (EU28) and the enlargement and integration countries for the years to come until 2020. EHRO-N provides the European Commission (EC) with essential data related to supply and demand for nuclear experts in the EU28 and the enlargement and integration countries based on bottom-up information from the nuclear industry. The objective is to assess how the supply of experts for the nuclear industry in the EU28 and the enlargement and integration countries responds to the needs for the same experts for the present and future nuclear projects in the region.

The data is based on an analysis of responses of surveys that are sent to higher education institutions in EU28 and the enlargement and integration countries that offer nuclear-related degrees, and to nuclear stakeholders, who are active on the EU-28 and the enlargement and integration countries nuclear energy labor market. The quantitative data received is quality checked against a quality assurance procedure set within the Senior Advisory Group (SAG) of EHRO-N. Additionally, the EHRO-N data is assessed against data available from other sources (e.g. IAEA data, national nuclear human resource reports, if available). In addition to the bottom-up approach taken by the EHRO-N team, an alternative top-down modeling approach was undertaken by Roelofs and Von Estorff (2013).

The objective of the current analysis is to extend the previous study with an extrapolation of the workforce in the case that most European reactors will extend their lifetime. It was concluded from the previous study (Roelofs and Von Estorff, 2013) that the two energy demand scenarios which were considered did not reveal significantly different results. Therefore, the current analysis only takes into account the '20% nuclear electricity' (officially called 'Delayed CCS') scenario from the EC Energy Roadmap 2050.

First in chapter 2 the computational tool which serves as a base for the current analysis is introduced. After that, chapters 3 through 6 describe the input for the analysis. Chapter 3 describes the nuclear energy demand scenarios. Chapter 4 shows the current reactor park and the assumptions taken for new reactors to be constructed. Chapter 5 explains the workforce models used to calculate the workforce for construction and operation of a nuclear power plant. Chapter 6 describes the age profiles as derived from the bottom-up EHRO-N survey and shows how these are used to construct retirement profiles. Importantly, the results of the analysis for the bounding cases are described and explained in chapter 7. Finally, chapter 8 presents the conclusions.

2 DANESS Analysis Tool

2.1 DANESS Description

To assess the impacts of nuclear new build scenarios, the DANESS code ("Dynamic Analysis of Nuclear Energy System Strategies") version 4.0 (Van den Durpel et al., 2008) developed by Argonne National Laboratory has been used. DANESS simulates a reactor park and the corresponding flows of fuel, spent fuel, high and intermediate level waste as well as all intermediate stocks and fuel cycle facility throughput.

DANESS is a system dynamics model, and uses iThink-software (Isee Systems, 2009). DANESS simulates fuel cycles from uranium mining, reprocessing, to geological disposal. For any modeled combination of reactor types and fuel cycles DANESS projects electricity production cost, fuel mass flows, and waste quantities as a function of time, spanning periods from decades up to centuries.

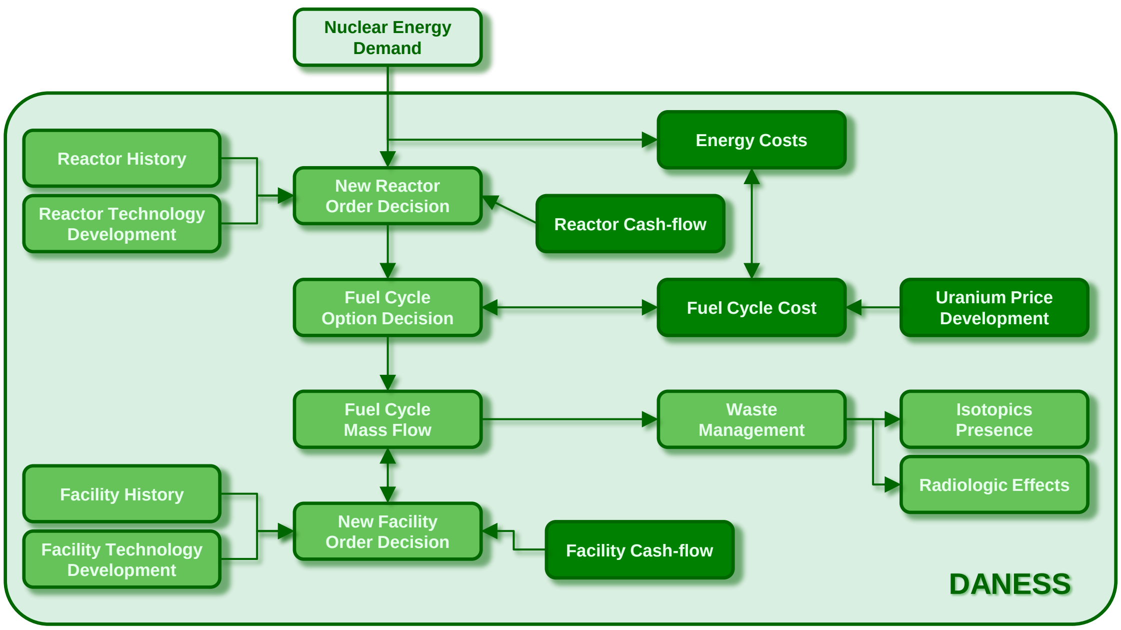

Figure 1: DANESS Fuel Cycle Functionality

New reactor types, characterized by techno-economic parameters representing their fuel consumption and overall effectiveness, are introduced based on the requirement to fulfill a certain scenario dependent nuclear energy demand. The technological readiness of reactors or fuel cycle facilities can be represented by means of delays in the availability of the technologies. Fuel cycle costs are calculated for each nuclear fuel input, and are combined with capital and O&M cost models to project electricity production cost per reactor type.

Figure 1 shows the full fuel cycle functionality implemented in the code.

2.2 Benchmarks and Verifications

A variety of benchmark and verification activities have been and are undertaken with DANESS within various international projects, e.g. IAEA-INPRO (2008), PUMA (2008), and Guérin et al. (2009). More benchmarking activities are reported in Van Den Durpel (2008). Within the MIT benchmark reported by Guérin et al. (2009), the focus was put on validation of material flows, uranium consumption, reprocessing, and storage. The results of the DANESS code were consistent with the results determined with the CAFCA code by MIT, the COSI code by CEA, and the VISION code by INL. Extensive benchmarking of the code was further performed within the framework of the European FP6 PUMA project (PUMA, 2008). Two benchmarks were performed within this framework in which also the ORION code by NNL and the OSIRIS code by AMEC were used. The focus in these benchmarks was put on the material flows, nuclide inventories, radiotoxities, and decay heat. Where the results for material flows and nuclide inventories showed a good agreement, the results for radiotoxities and decay heat showed deviations between the results of the different codes.

3 Nuclear Energy Demand Scenario

In 2011, the European Commission (2011) issued the EC Energy Roadmap 2050. Within this roadmap, different scenarios are analyzed for the energy production in the EU27 countries. Their reference business as usual scenario leads amongst those scenarios to a high contribution from nuclear. However, the EU policy goal in emission reduction will not be realized. Amongst the other scenarios described in this report, the so-called '20% nuclear electricity' (officially called 'Delayed CCS') scenario leads to the highest penetration of nuclear energy and will therefore be most demanding for the current assessment. Therefore, the '20% nuclear electricity' scenario is selected for the current workforce demand extrapolation.

As this nuclear energy demand scenario was derived for the EU27 countries at that time, extrapolation to the current EU28 countries including the enlargement and integration countries is required (see figure 2). This has been achieved based on energy consumption figures around 2010 taken from CIA (2013). When this extrapolation is taken into account, the nuclear energy demand for the EU28 with enlargement and integration countries is about 16% higher than the demand for EU27 countries without enlargement and integration countries.

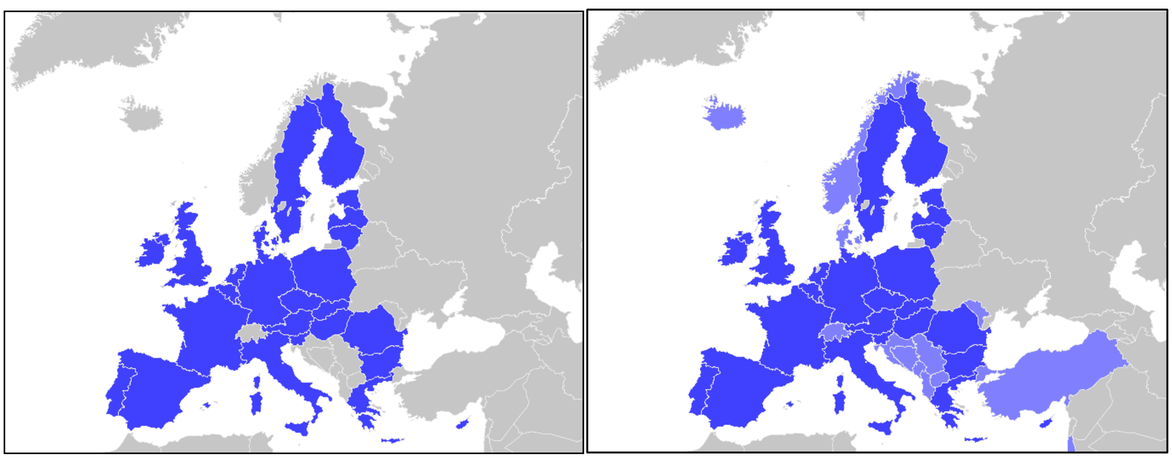

Figure 2: EU27 (left) and EU27 with enlargement and integration countries (right).

Figure 3 shows the resulting nuclear energy demand for the period 2000-2050. As the current analyses start in 2010, the period 2000-2010 is omitted for the actual calculations.

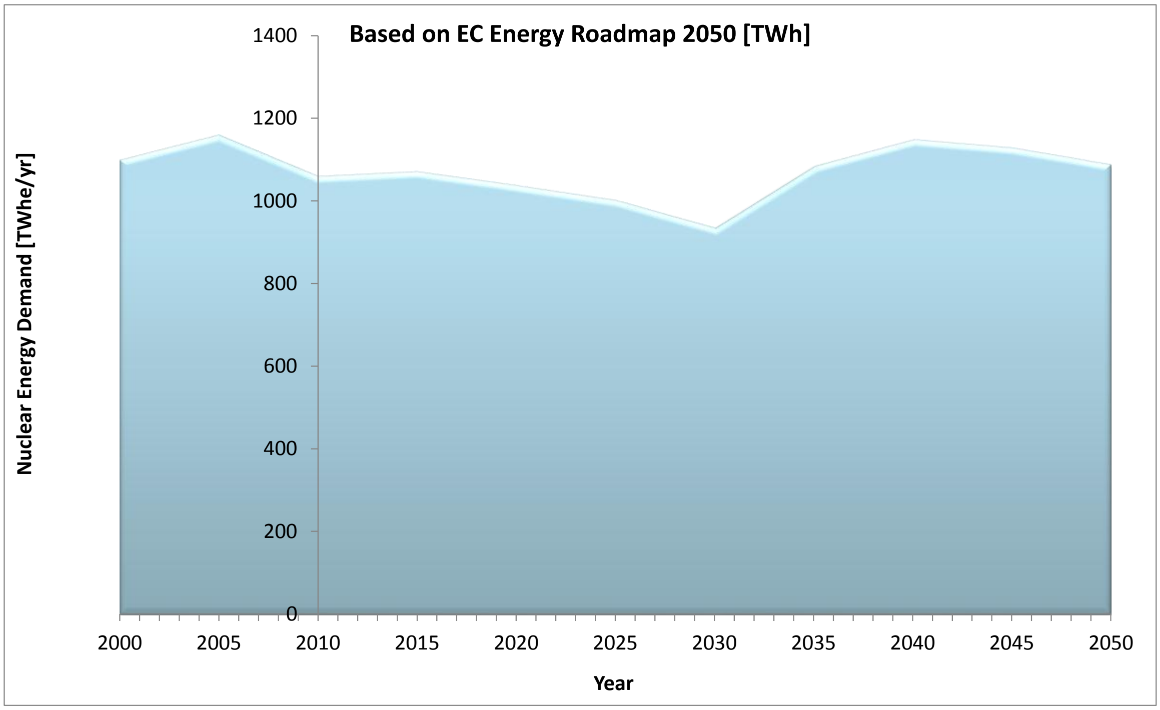

Figure 3: Nuclear Energy Demand based on the EC Energy Roadmap 2050 for EU27 countries including enlargement and integration countries

4 Reactor Park

4.1 Current Reactor Park

The current reactor park is modelled based on data retrieved from WNA (2014). This data was firstly used to model the existing reactor park. In addition, four reactors for which construction is ongoing were added to the current reactor park. These reactors are:

- Olkiluoto 3 in Finland,
- Flamanville 3 in France,
- Mochovce 3 & 4 in Slovakia.

Although it is known that there are plans to construct more nuclear reactors, these have not explicitly been taken in account. However, the DANESS model will implicitly take these into account when it determines new reactors to be constructed to balance the installed capacity with the nuclear energy demand.

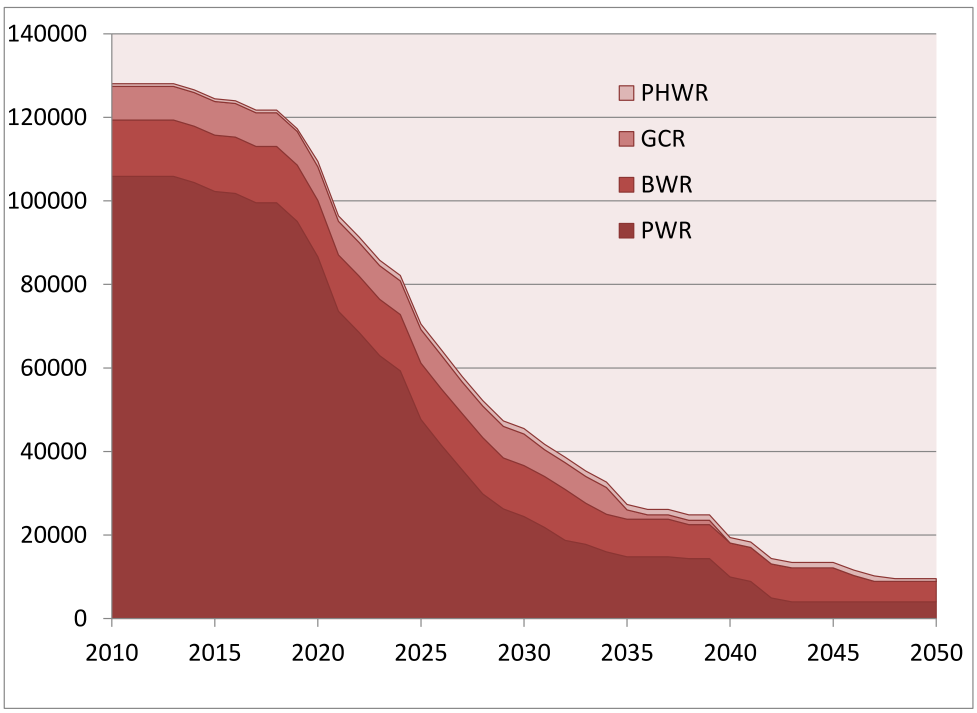

Figure 4: Shutdown profile (installed power) of the current reactor park.

The lifetime of the existing reactor park is determined again from data provided by WNA (2014). Thus, this takes into account e.g. the post-Fukushima decisions in Germany, but also life-time extensions for nuclear reactors like in the Netherlands. Using this data, and in addition assuming that the EPR's under construction in Finland and France will have a 60 year lifetime and the two Slovakian reactors will have a 40 year lifetime, the shutdown profile of the current reactor park was determined and shown in figure 4. Note that this shutdown profile will differ slightly from the shutdown profile assumed in the previous study from Roelofs and Von Estorff (2013) due to updates in the information at the WNA website.

4.2 Long Term Operation

After the lifetime of the existing reactor park was determined, also the lifetime extension resulting from possible long term operation is determined. In order to do so, the following assumptions were made:

- Lifetime extension is applied to individual reactors based on information provided by WNA (2014).
- Time horizon of lifetime extension
  - When not indicated differently, the lifetime of a reactor is extended to 60 years.
  - A lifetime of 50 years is assumed for
    - Advanced Gas-cooled Reactors in the UK
    - The Loviisa plant in Finland
    - The Paks plant in Hungary
    - The Kozloduy plant in Bulgaria
- No lifetime extension is assumed for:
  - reactors in Belgium
  - reactors in Germany
  - reactors in Switzerland
  - the Fessenheim plant in France
  - the magnox reactor in Wyllfa (UK)

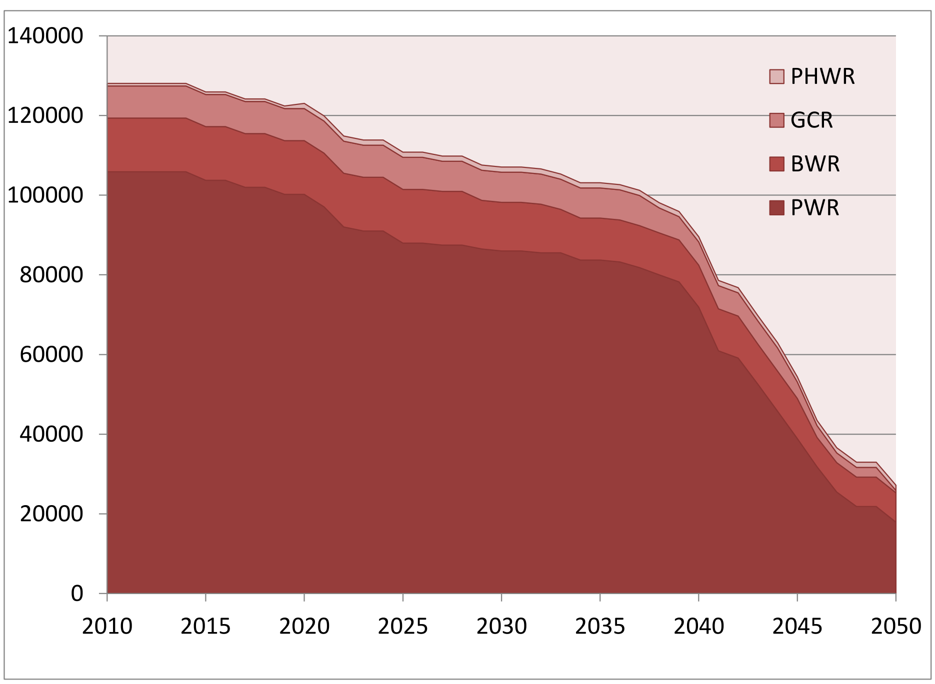

Figure 5: Shutdown profile (installed power) of the current reactor park under long term operation.

Comparing figure 4 with figure 5 clearly shows the influence of the long term operation of the current reactor park with respect to the planned shutdown. Reactors will be taken out of operation much more gradually and the major decrease will de delayed from 2020-2030 to 2040-2050.

4.3 New Reactors

As specified by EHRO-N (2013) two different generic third generation nuclear reactors are assumed to be constructed in order to fulfil the energy demand. These reactors only differ in net electric output. The first generic reactor to be assumed produces 1400 MWe, whereas alternatively, the second generic reactor assumed produces 1000 MWe. The nuclear energy demand scenario described in chapter 3 is simulated assuming construction of only one of these types of generic reactors. In both cases, an efficiency of 36%, a load factor of 80%, and a lifetime of 60 years are assumed. Table 1 summarizes the main characteristics of these two generic nuclear reactors.

Table 1: Main characteristics of two assumed generic third generation reactors

Reactor	Power [MWe]	Efficiency [%]	Load Factor [%]	Lifetime [yr]
Gen III LWR: A	1400	36	80	60
Gen III LWR: B	1000	36	80	60

5 Workforce Models

5.1 Operations

One of the purposes of the current analysis is to determine an estimate for the workforce required for operation of the nuclear plants. Most data in literature are based on a typical nuclear plant of about 1000 MWe, e.g. Johnson (1982), NIA (2006), IAEA (2007), Tuohy (2009), Mazour et al. (2010). For such plants, the estimates vary from 300 to 500 workers. This is significantly lower than the results for the current Gen-II reactor park of a yearly US survey by Goodnight (2009) which shows an average staff of 600 to 800 workers for a 1000 MWe plant. However, it is expected that future reactors can be operated more efficiently. The reactors under consideration in this article (for existing reactors an average size is assumed for reactor type) have a capacity varying from about 500 MWe to 1600 MWe.

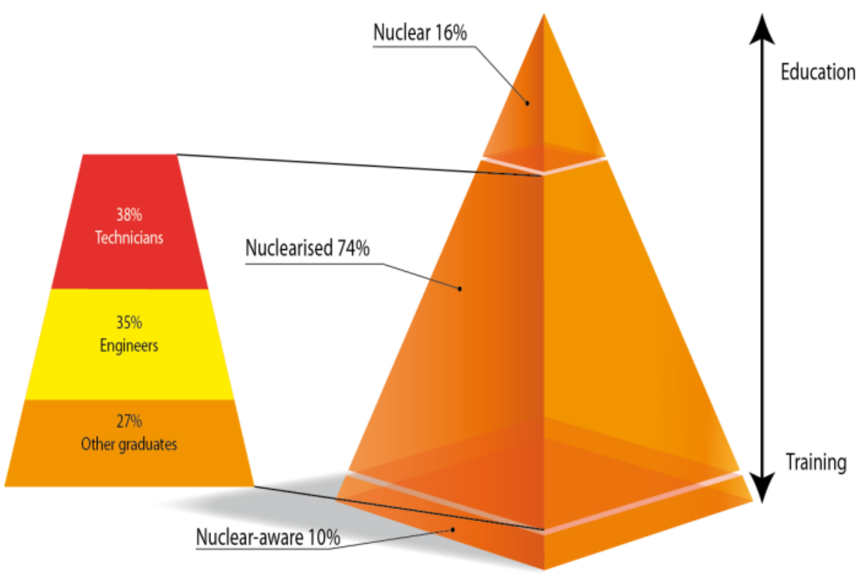

Figure 6: Nuclear Skills Pyramid (Simonovska & Von Estorff, 2012)

Kenley et al. (2004) propose an approximately linear relationship between capacity and direct employment, assuming that no scale effects would occur. For the current assessment however, scale effects are taken into account, assuming that with increasing power, the growth in workforce would gradually decrease. In such cases, this would lead to large differences between small sized reactors (200 MWe) and medium sized reactors (600-1000 MWe). Whereas, the differences between medium sized reactors and large sized reactors (up to 2000 MWe) are not that large (assuming indeed that the workforce becomes more or less independent from the reactor capacity). To this purpose, an equation has been developed which reads $w = max[a \cdot ln(P+b)+c; 100]$, in which w represents the workforce in fte (full time equivalent), P represents the electric power in MWe and a, b, and c are model constants equal to 400, 400, and -2450 respectively. This equation is applied for nuclear power plants smaller than 2000 MWe. The workforce derived from this model is subdivided with respect to the data from the nuclear skills pyramid as presented by Simonovska & Von Estorff (2012) in figure 6. Figure 7 shows the outcome of the above described equation. Indeed for a plant of 1000 MWe, this graph shows that the above mentioned model predicts a workforce in the range of 300 to 500 fte.

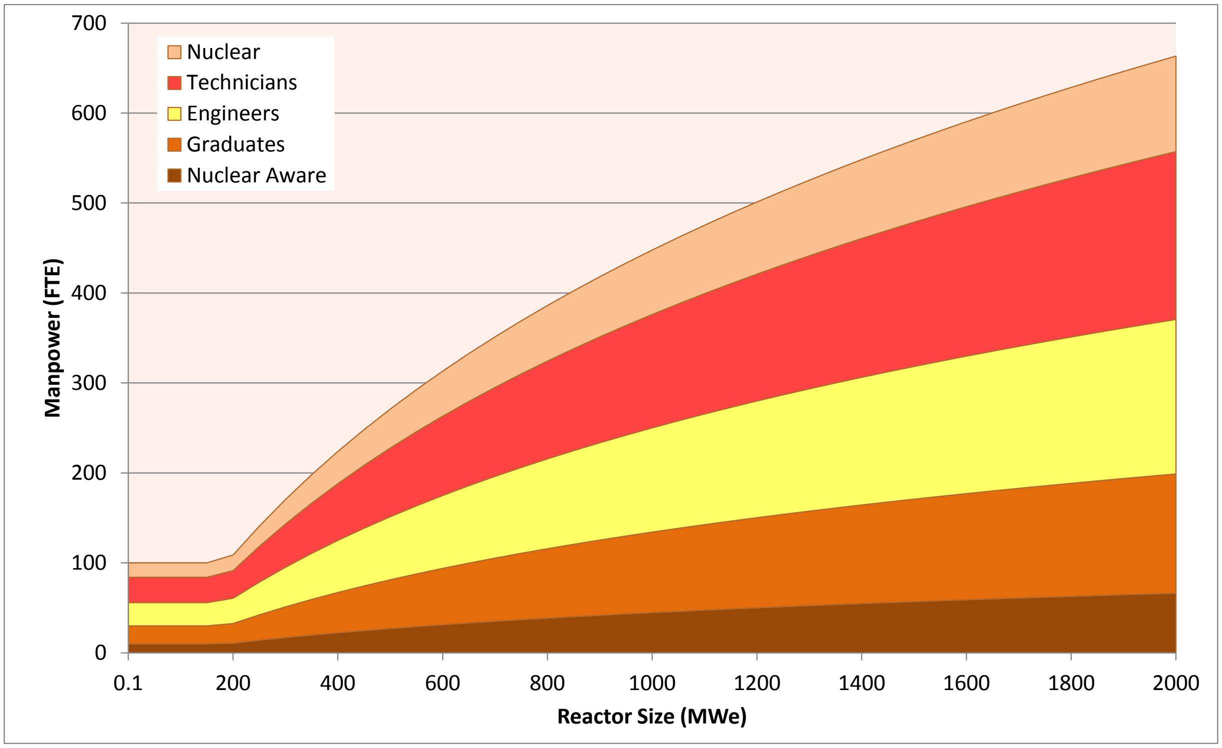

Figure 7: Graphical representation of the manpower required for different sizes of nuclear reactors based on the model described by Roelofs et al. (2011).

This model can be compared to data reported in EPRI (2005) and IAEA (2001). EPRI (2005) provides data obtained from the database of Goodnight Consulting Inc. concerning staffing for existing US reactors. EPRI explains that staffing levels have decreased over the years and that it may be expected that the staffing levels reported may be optimized to about 30-50%. In the current comparison, conservatively an optimization to about 50% of the current staffing levels is assumed. Apart from that, IAEA (2001) provides staffing data on small to medium sized existing and planned reactors. Figure 8 shows how these data from EPRI (2005) and IAEA (2001) compare to the developed model.

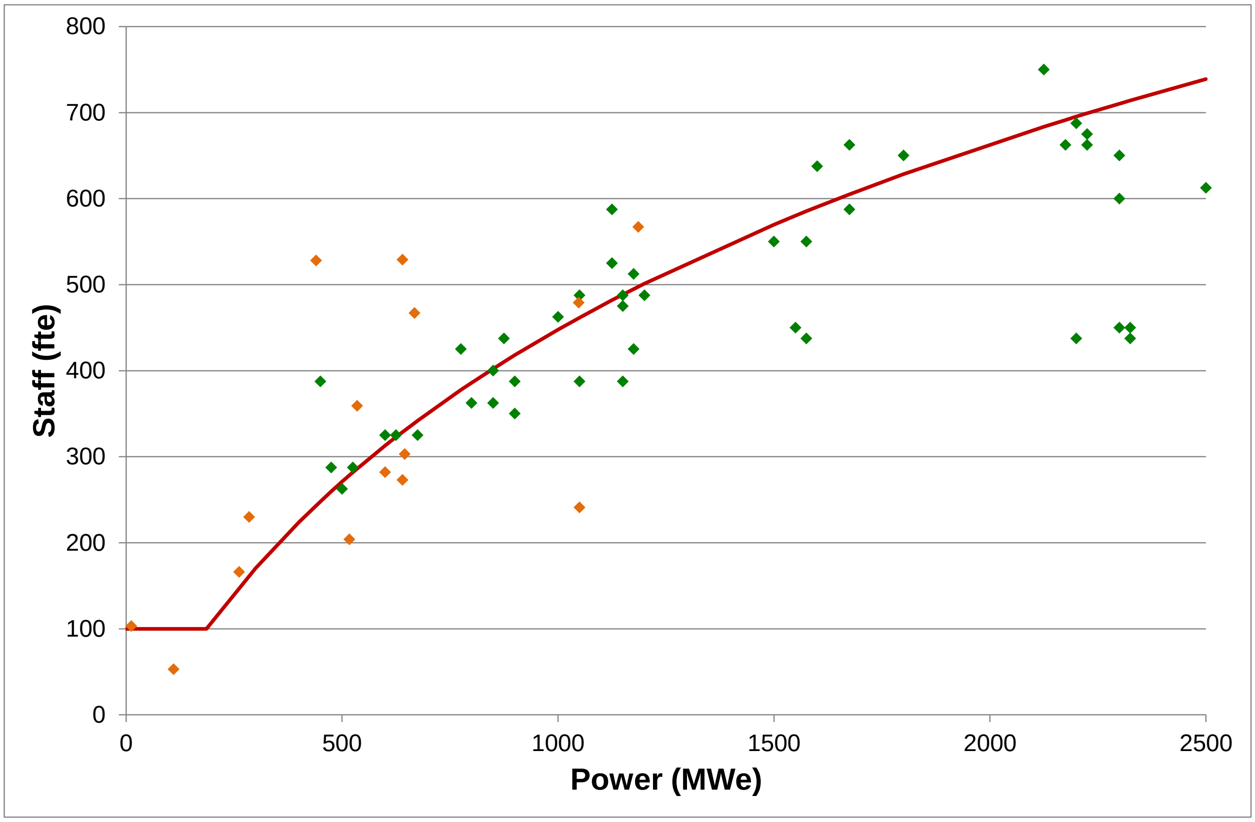

Figure 8: Comparison of existing data from EPRI (2005): ◆(green) and IAEA (2001): ◆ (orange) with the model of Roelofs et al. (2011): - (red).

Furthermore, the equation of Roelofs et al. (2011) which is applied for the current assessment, can be put in perspective when compared to data of Goodnight (2014) shown in figure 9 (top). The graph shown by Goodnight (2014) is based on information which is presented such that individual database entries can't be derived. Therefore, no values are shown on the y-axis. Nevertheless some indication on the values can be derived from the average US plant staffing for 1- and 2-unit plants. Rough estimates for these values can be found elsewhere in Goodnight (2014). Based on this information, the model of Roelofs et al. (2011) can be put into perspective with the data from Goodnight (2014). The comparison in figure 9 (bottom) shows that both, the data for the US plant staffing, and the staffing model of Roelofs et al. (2011) are in a similar range.

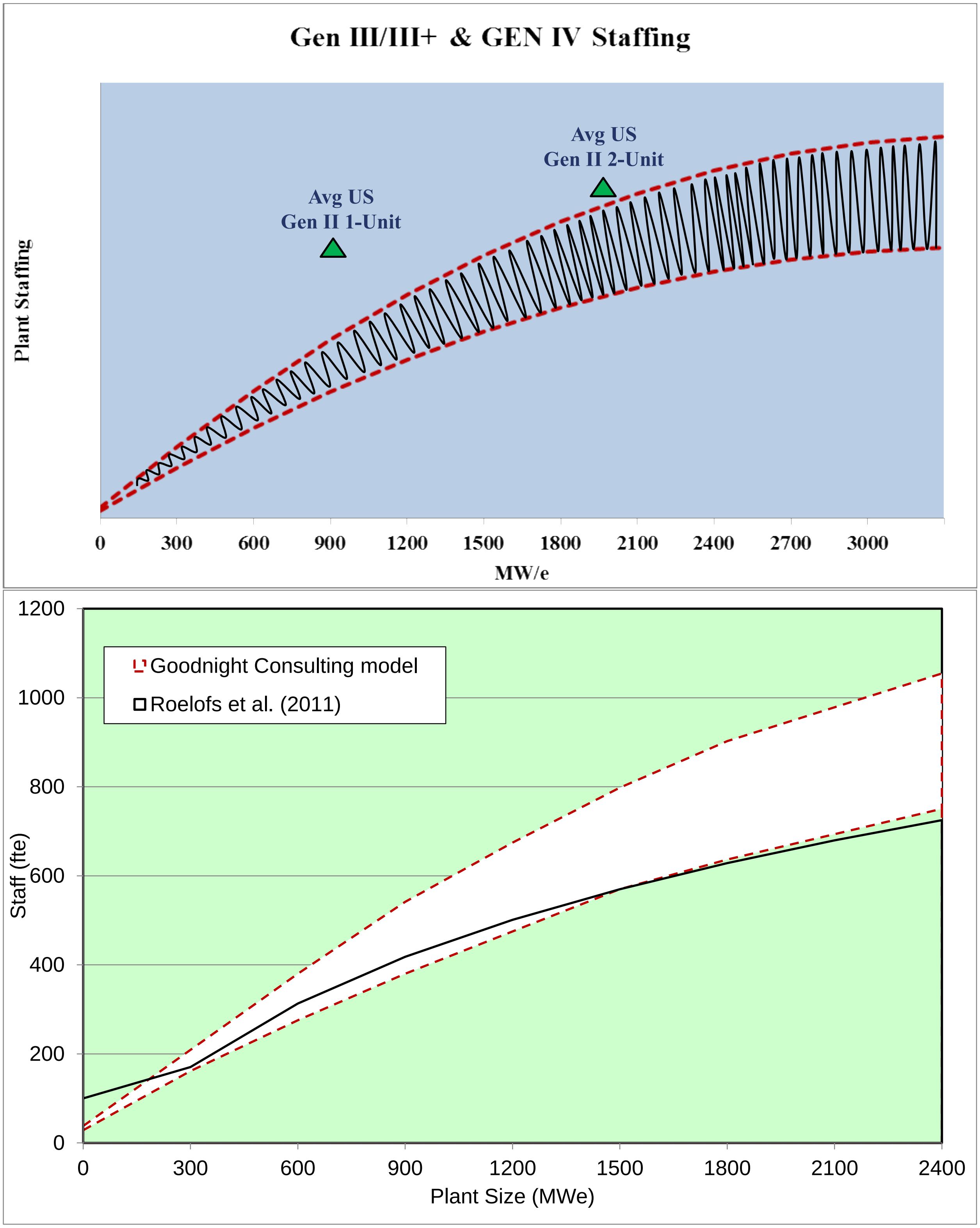

Figure 9: Graph (top) for staffing of advanced reactors from Goodnight (2014) and the model of Roelofs et al. (2011) in comparison to this data (bottom).

5.2 Construction

In order to evaluate the manpower requirements for the construction of a future fleet of nuclear reactors in Europe, manpower requirements are largely based on Mazour (2007), which is basically in line with the estimates provided by NIA (2006) and Orkilow et al. (2008). The literature data is interpreted and from this data, profiles have been derived for the construction of nuclear reactors, taking into account a foreseen construction time of the reactors of about 6 years. It should be noted that the largest part of this construction workforce will require no specific nuclear skills, see e.g. DOE (2005). Although it is recognized generally, that workers with experience in nuclear projects provide better quality services. For the scenarios, the time evolution of the determined construction manpower requirements will be presented as a 5 year walking average.

Figure 10 shows the manpower requirements for the construction of one nuclear power plant based on data provided by Mazour (2007). Within his data, Mazour (2007) distinguishes between high grade professionals, professionals, technicians, and craftsmen. These categories have been translated to the nomenclature used in the nuclear skills pyramid, i.e. it is assumed that high grade professionals correspond with nuclear educated employees, professionals correspond with nuclearized engineers, technicians correspond to nuclearized technicians, and craftsmen correspond to the nuclear aware workforce.

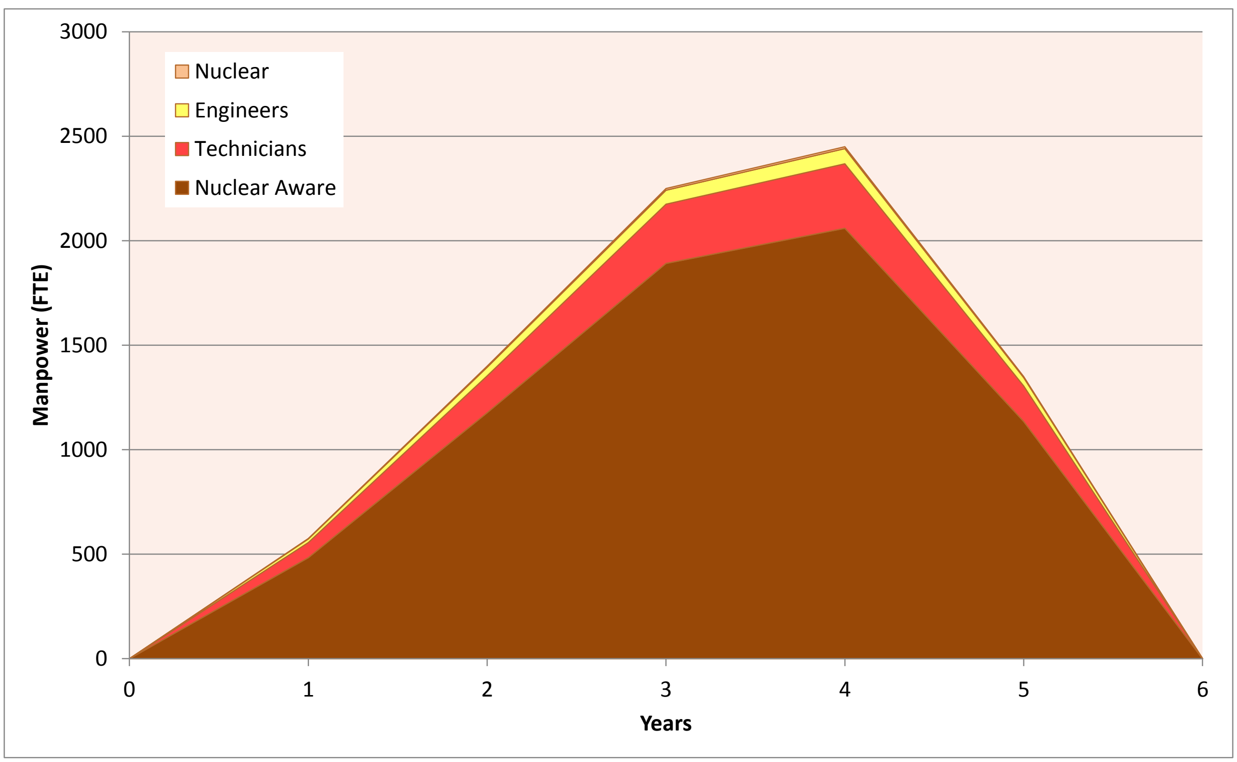

Figure 10: Graphical representation of the manpower required for construction of a nuclear power plant based on data from Mazour (2007)

Deffrennes & Gress (2012) in their study for DG-Energy assume 2700 people working for construction of a nuclear power plant during 7 years. Assuming a part-time rate of 5% (Brinkman et al., 2013) this leads to about 2500 fte during 7 years. In comparison with the data shown in figure 9 based on IAEA data from Mazour (2007), it can be noted that this 2500 fte corresponds well to the peak value.

5.3 Long Term Operation

Generic data on manpower needed for the assessment of long term operation is hard to obtain. Even most power plants involved with long term operation, do not have such data at hand. Therefore, model development was done via comparison of investment costs for long term operation and new build.

The data from D'Haeseleer (2013) which are largely based on OECD (2012) show that the costs for LTO including the upgrades as outcomes from the stress tests range from 400 to 850 €/kWe. Such data is confirmed by the nuclear industry by Foratom (2014) which states that the costs for LTO are 'well below 1000 €/kWe'. This means that the average costs of LTO for an average size (~900 MWe) existing nuclear reactor are in the order of 0.5 B€.

EC (2012) provides a relationship between the investment costs for new build and the number of jobs. This relationship shows that the investment costs for 100 new build plants are estimated at 500 B€, creating in total 150000 direct and indirect jobs. This paper further mentions that 'LTO activities are closer to new build than standard maintenance and operation'. Therefore, these numbers provide a direct estimate for the number of jobs created for LTO which equals about 166 jobs/GWe.

ENEF (2013) refers to PWC (2011) which concentrates the LTO efforts over a two year span. In reality however, the span of time over which the LTO efforts have to be provided will be much longer. Krajnc (2014) presents the significant safety upgrade plan at the Krsko plant in preparation for LTO. This plan comprises at least the 8 years before the original end-of-life of the plant is reached. IAEA (2002) indicates that the preparations for LTO have to start well (5-10 years) before the end-of-lifetime of the reactor. On the other hand, NRG involvement in LTO projects at existing nuclear power plants shows that also after the original end-of-life, a significant effort is needed to ensure actual implementation of all the necessary additional studies and measures for LTO.

Therefore, in the current assessment, it is assumed that the total effort for LTO is spread over a time span of about 15 years, starting 8 years before the original end-of-life is reached. Taking into account again the nuclear skills pyramid and referring to the assumed similarity of the works with new build rather than with operations, figure 11 shows a graphical representation of the manpower required for LTO.

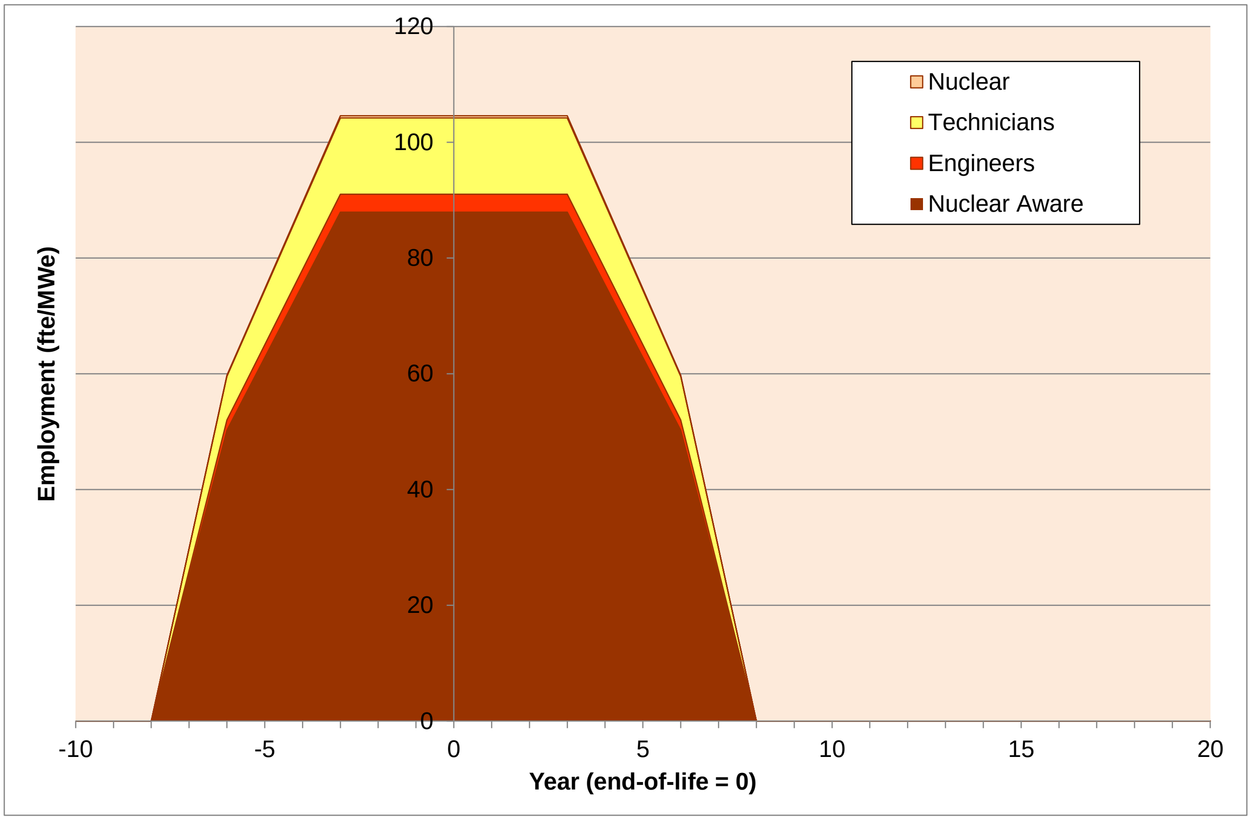

Figure 11: Graphical representation of the manpower required for LTO of a 900 MWe reactor.

Care has been taken that the total effort from the model represented in figure 10 is similar to the total effort following from the analysis of PWC (2011) which concentrates all LTO efforts in only two years.

Finally, a remark has to be made that in the current assessment, the manpower needed for LTO will be supplementary to the manpower for operations. However, it is common practise that part of the permanent staff of a nuclear power plant will participate in the LTO program of the plant. In such case, additional personnel will be hired on a case by case basis. This will make the current analysis of the total manpower involved in operations and LTO of a nuclear power plant conservative.

6 Retirement Profile

Simonovska & Von Estorff (2012) provide an age distribution of employed engineers in European countries. In a follow up of this study, Simonovska (2012) has derived the age distribution for nuclear experts. This distribution is represented in figure 12.

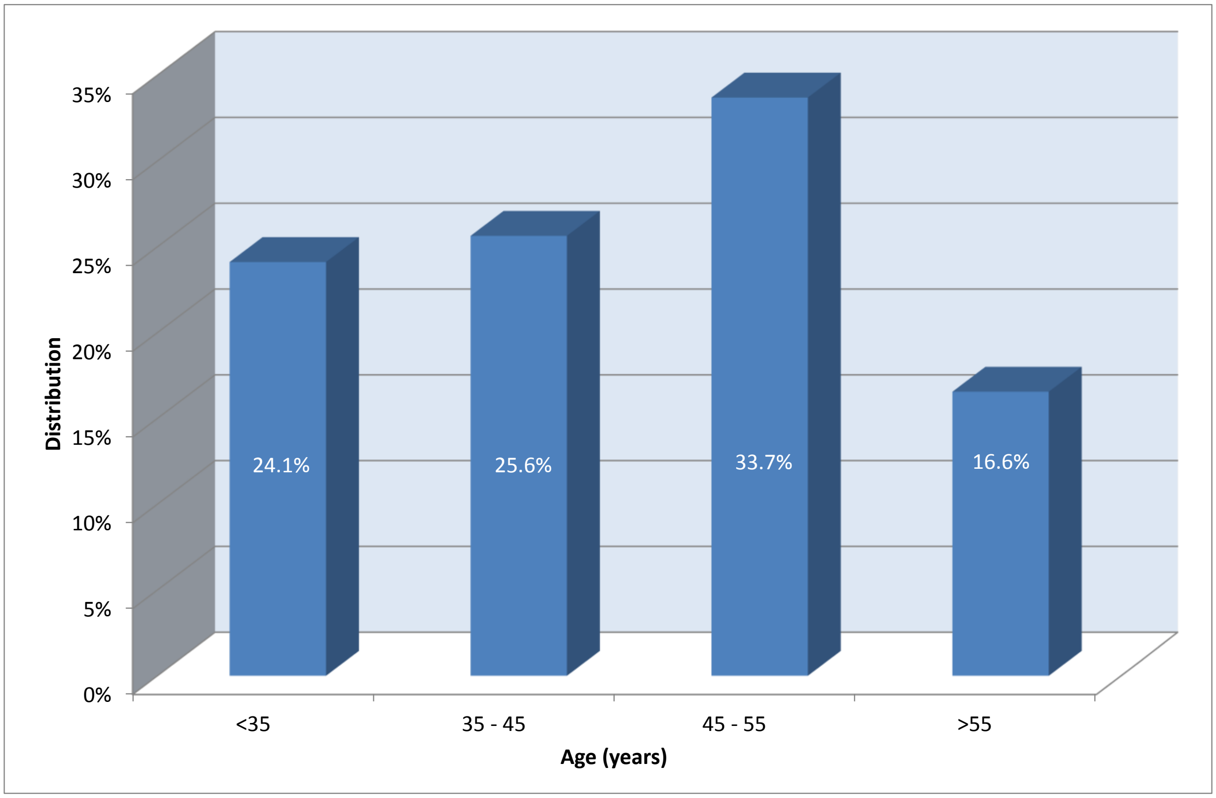

Figure 12: Age profile of nuclear experts according to Simonovska (2012)

For the current analysis, the following assumptions have been made in order to derive the retirement profile of the nuclear workforce which is shown in figure 13:

- The EHRO-N data represented in figure 12 on a five yearly basis has been interpolated to a yearly profile,
- The retirement profile based on EHRO-N data for the nuclear experts is also used for the nuclearized and nuclear aware workforce as no detailed data is available for these categories,
- An average retirement age of 65 is assumed,

A third order polynomial fit is constructed through the EHRO-N data for further use.

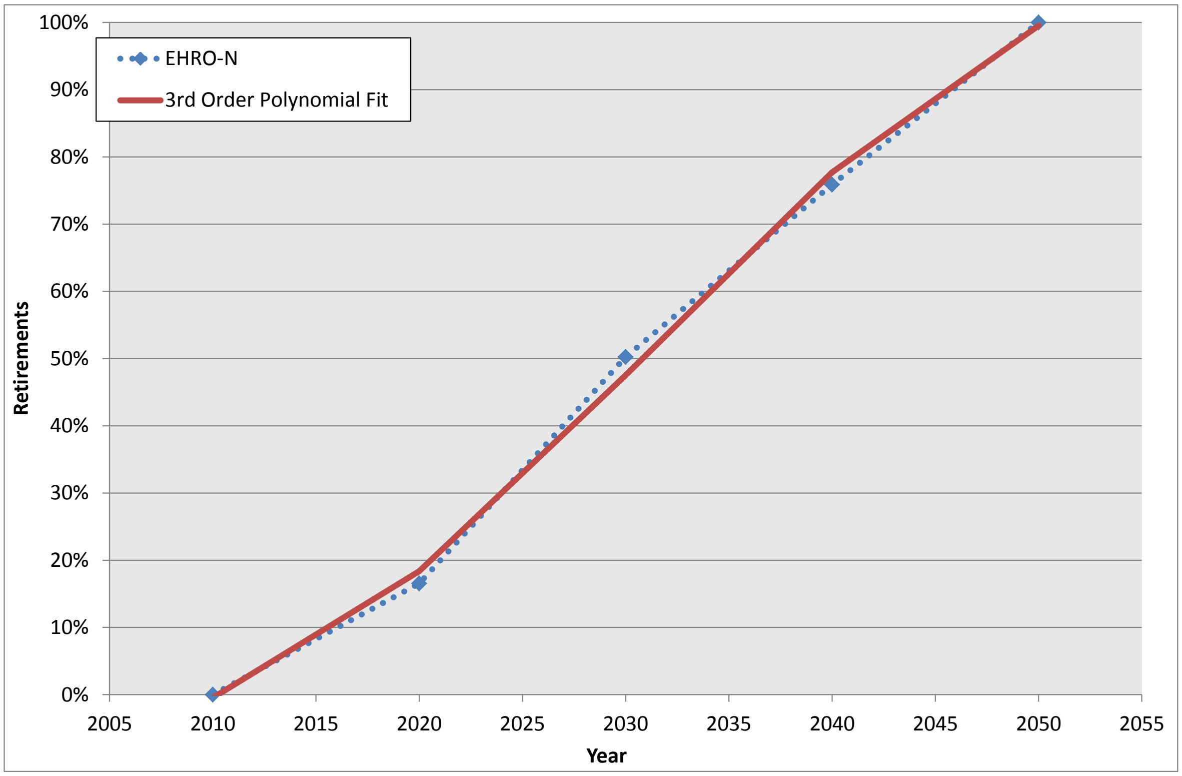

Figure 13: Retirement profile

7 Results

The analyses were performed for two sizes of Generation III reactors. However, the construction and operation of 1000 MWe reactors sets the higher boundary of the range of results. Therefore, mostly data for this size of reactors will be shown in this chapter.

7.1 Reactor Park Development

The reactor park development is determined by the DANESS code. For a short explanation of how this is established, the reader is referred to Roelofs and Von Estorff (2013). Figures 14 and 15 show the reactor park evolution during the period 2010-2050 for the situation in which no LTO is assumed and the situation in which LTO is assumed as explained in section 4.2. Both figures show a replacement of the current reactor park by third generation light water reactors. On top of that, the growing nuclear energy demand is fulfilled by construction of new reactors. Depending on the assumed size of the Generation III reactors (1000 MWe or 1400 MWe), typically about 95-130 reactors have to be constructed between 2010 and 2050 if no LTO is foreseen (see also Roelofs and Von Estorff, 2013). When LTO is taken into account, this number may go down to 80-115 reactors.

It is also evident from these figures that the period in which the largest effort of new build will have to be delivered is delayed from about 2020-2030 with about 20 years to about 2040-2050. Furthermore, the absolute number of new reactors to be constructed during this period will decrease under the influence of LTO. This is related to the fact that LTO is assumed only in countries supportive to nuclear and not in countries which employ a nuclear phase-out strategy. This leads to a larger spread in the efforts for new build.

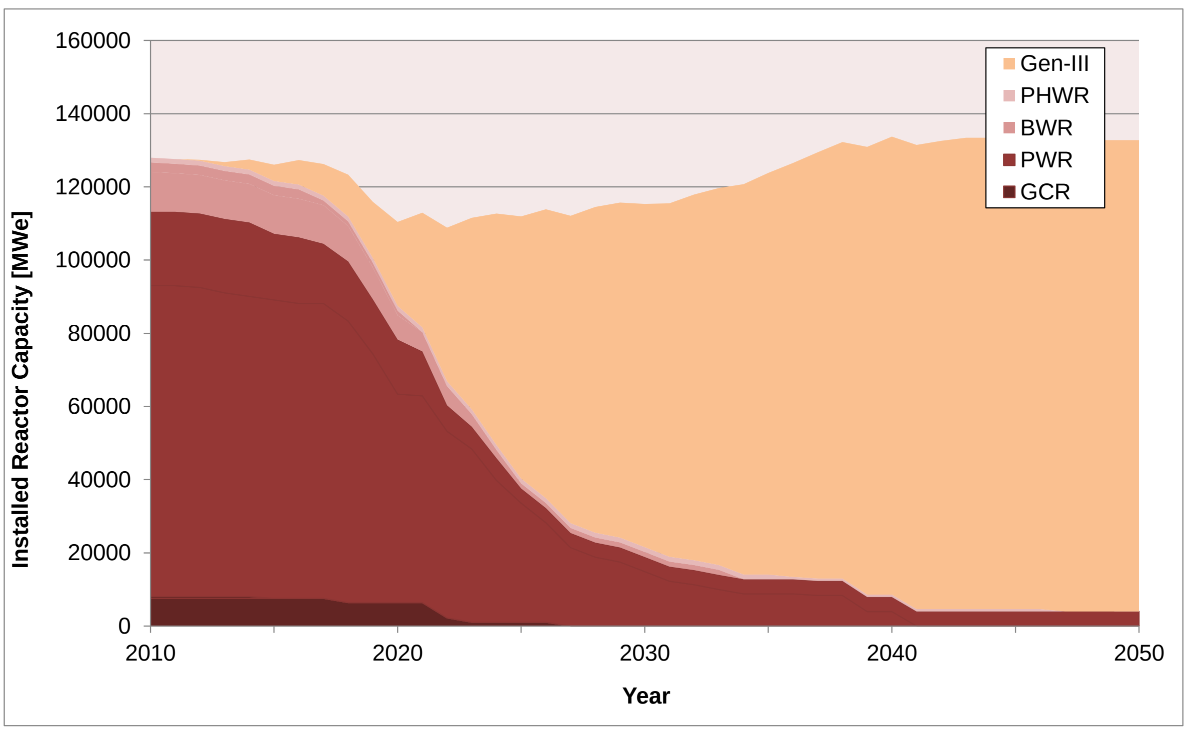

Figure 14: Reactor park development in case no LTO is assumed

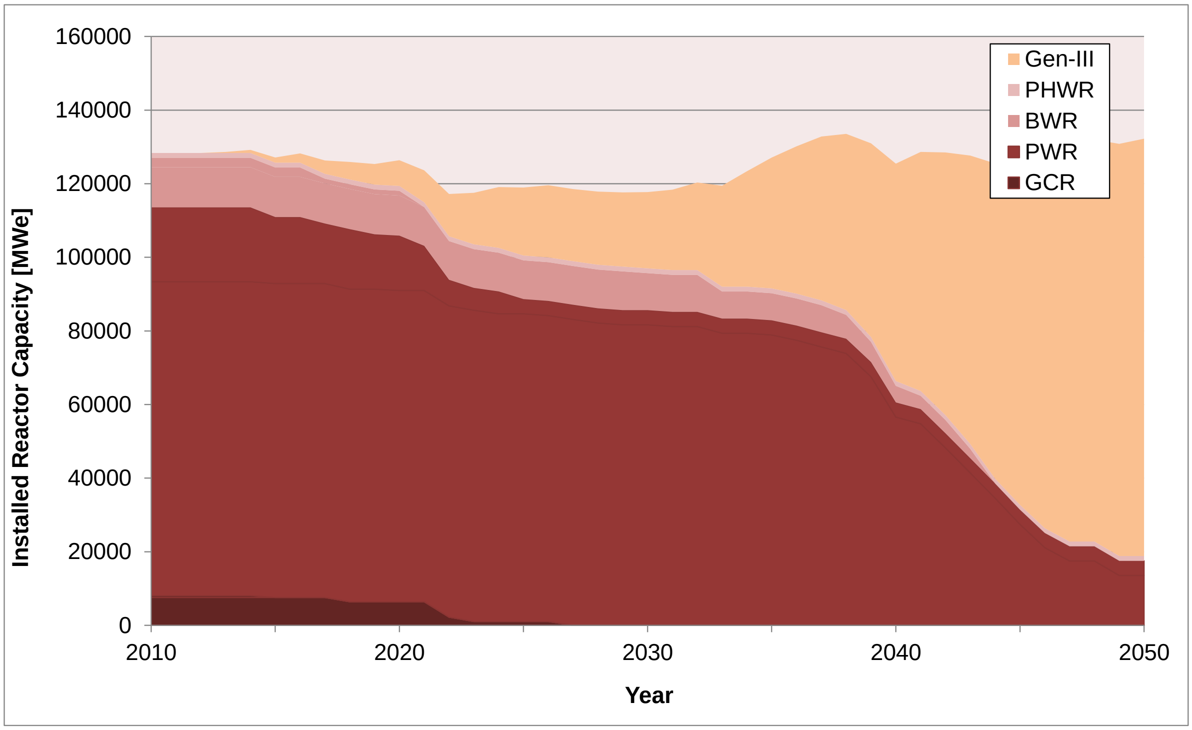

Figure 15: Reactor park development in case LTO is assumed

7.2 Manpower Operations & Construction

Applying the workforce models for operations and construction described in chapter 5, the workforce demand can now be determined top-down. Figures 16 and 17 show the workforce demand for manpower involved in operations and construction for the case of 1000 MWe reactors under the assumption of no LTO and LTO. Using the nomenclature from the nuclear skills pyramid (figure 6), the data in these figures is visualized for the nuclear, nuclearized (technicians, engineers, graduates), and nuclear aware workforce. These figures clearly show that the peak in workforce demand shifts from around 2020 to around 2040. Furthermore, it is also clear that the absolute peak demand is slowly decreased in case LTO is assumed. The reasons for this have already been explained in section 6.1.

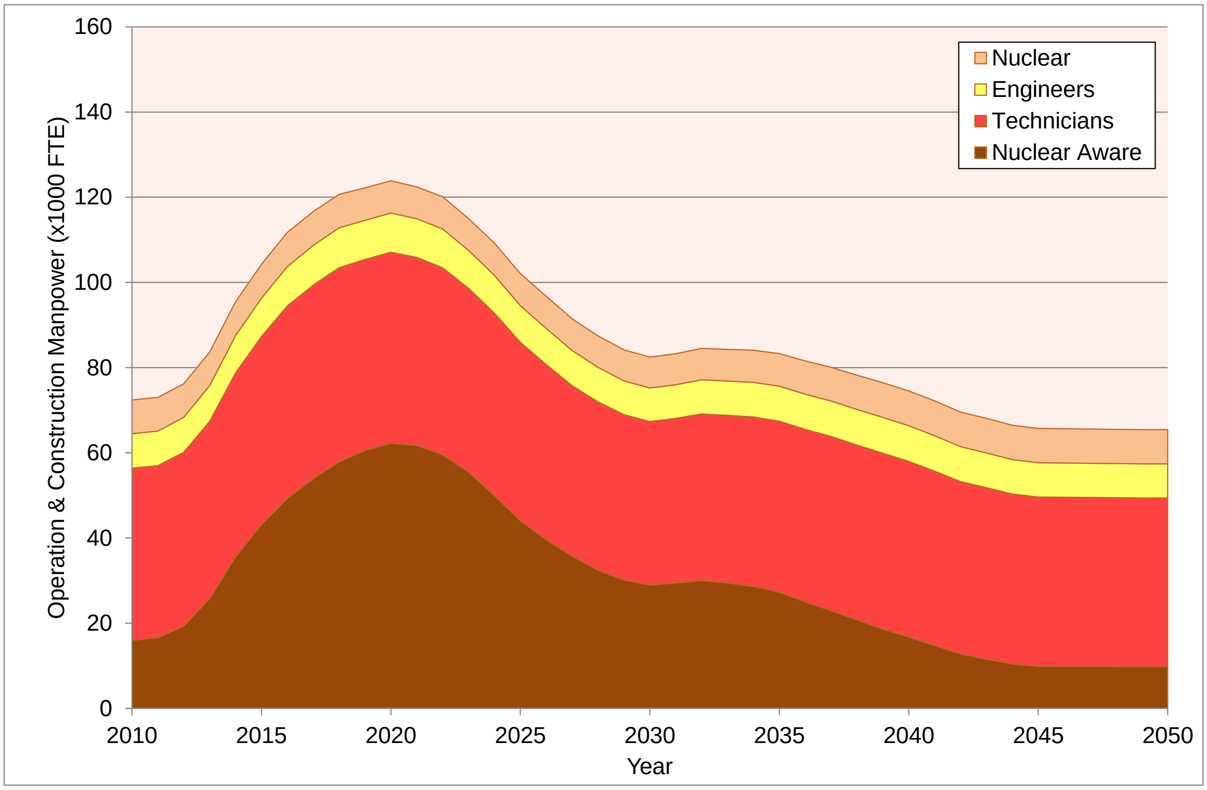

Figure 16: Manpower operations and construction in case no LTO is assumed

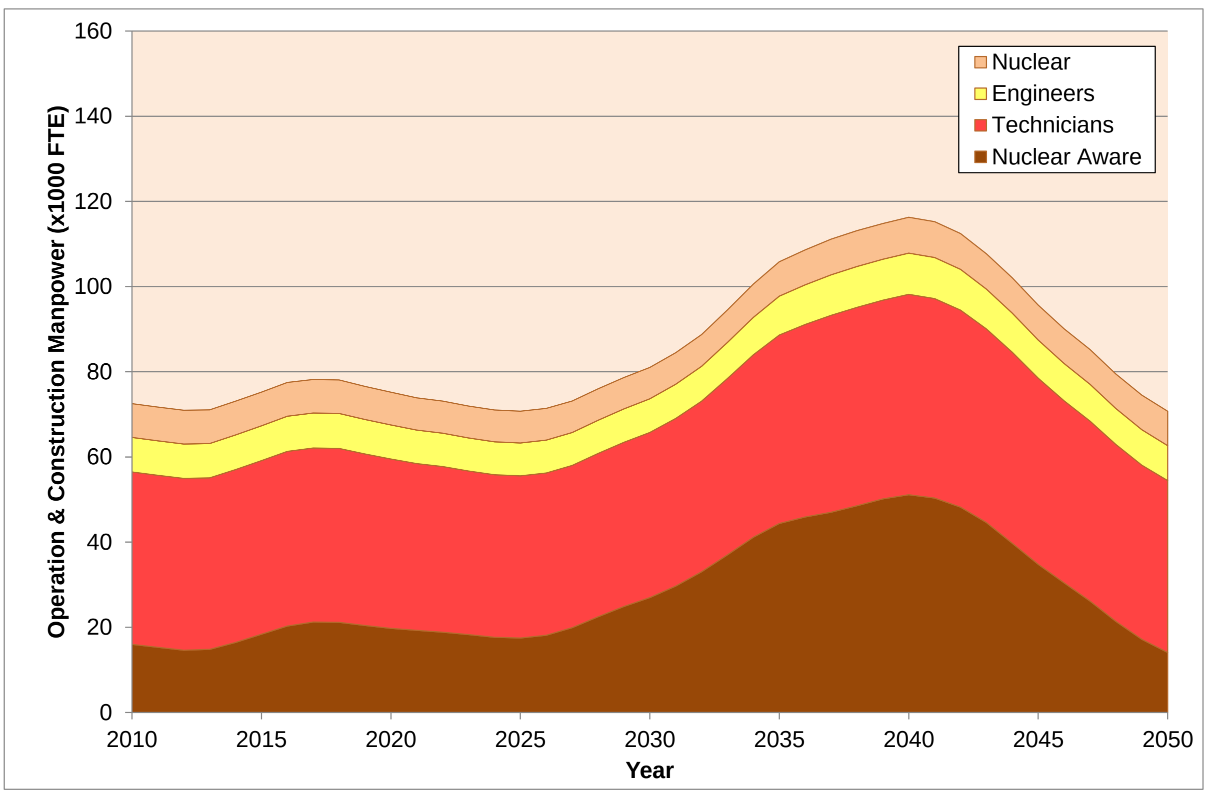

Figure 17: Manpower operations and construction in case LTO is assumed

7.3 Manpower Long Term Operation

Applying the workforce model for LTO described in chapter 5, the workforce for LTO demand can now be determined top-down. Figure 18 shows the workforce demand for manpower involved in LTO for the case of 1000 MWe reactors. Using the nomenclature from the nuclear skills pyramid (figure 6), the data in these figures is visualized for the nuclear, nuclearized (technicians, engineers, graduates), and nuclear aware workforce. When this figure is compared to figures 16 and 17, one can easily notice that the main efforts for LTO are to be performed close to the expected peak demand of construction manpower in the case no LTO is foreseen. This is obvious, because this coincides with the original end-of-life of most existing reactors.

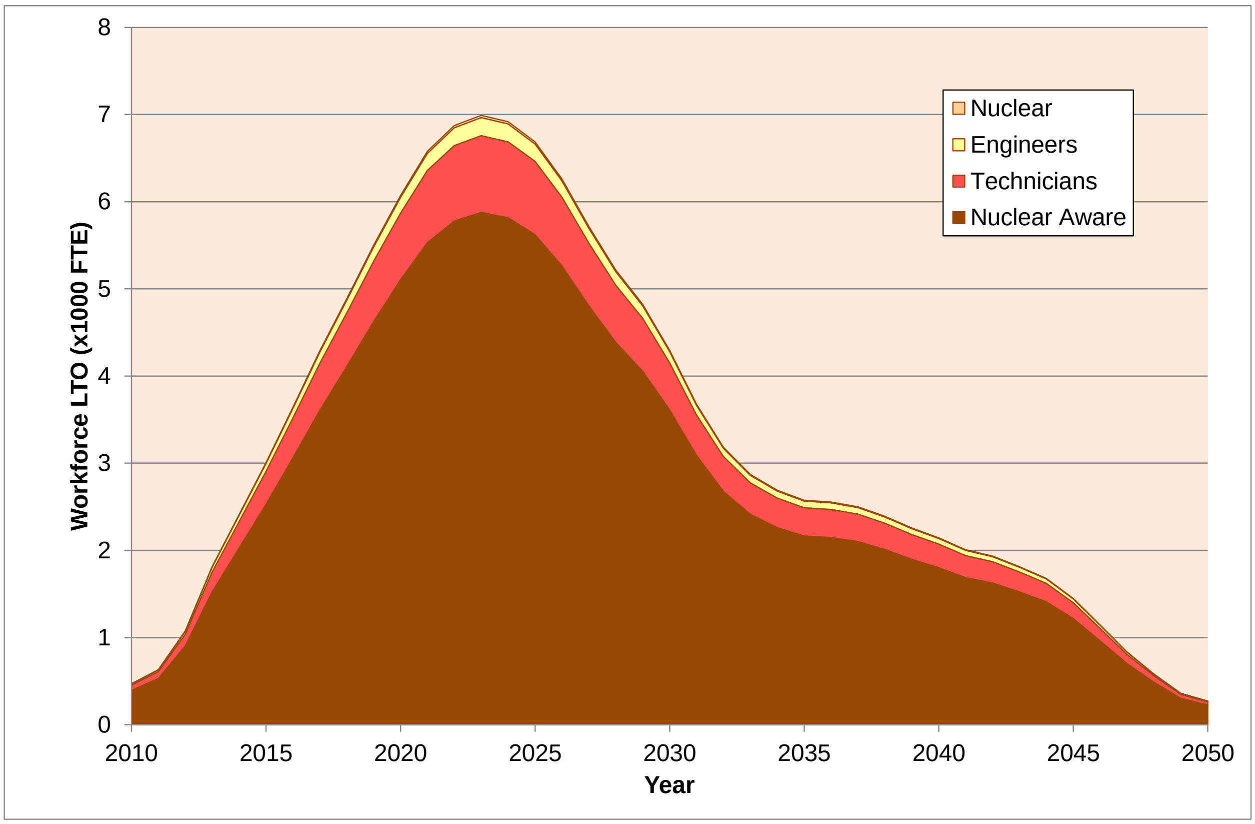

Figure 18: Manpower required for LTO

Figure 19 shows the required manpower for operations, constructions and LTO. When compared to figure 17 which only shows the required manpower for operation and construction, the differences are negligible. If in addition, we realize that most plants will use part of their permanent staff to form the LTO workforce, it is clear that the workforce for LTO has a negligible effect on the total workforce.

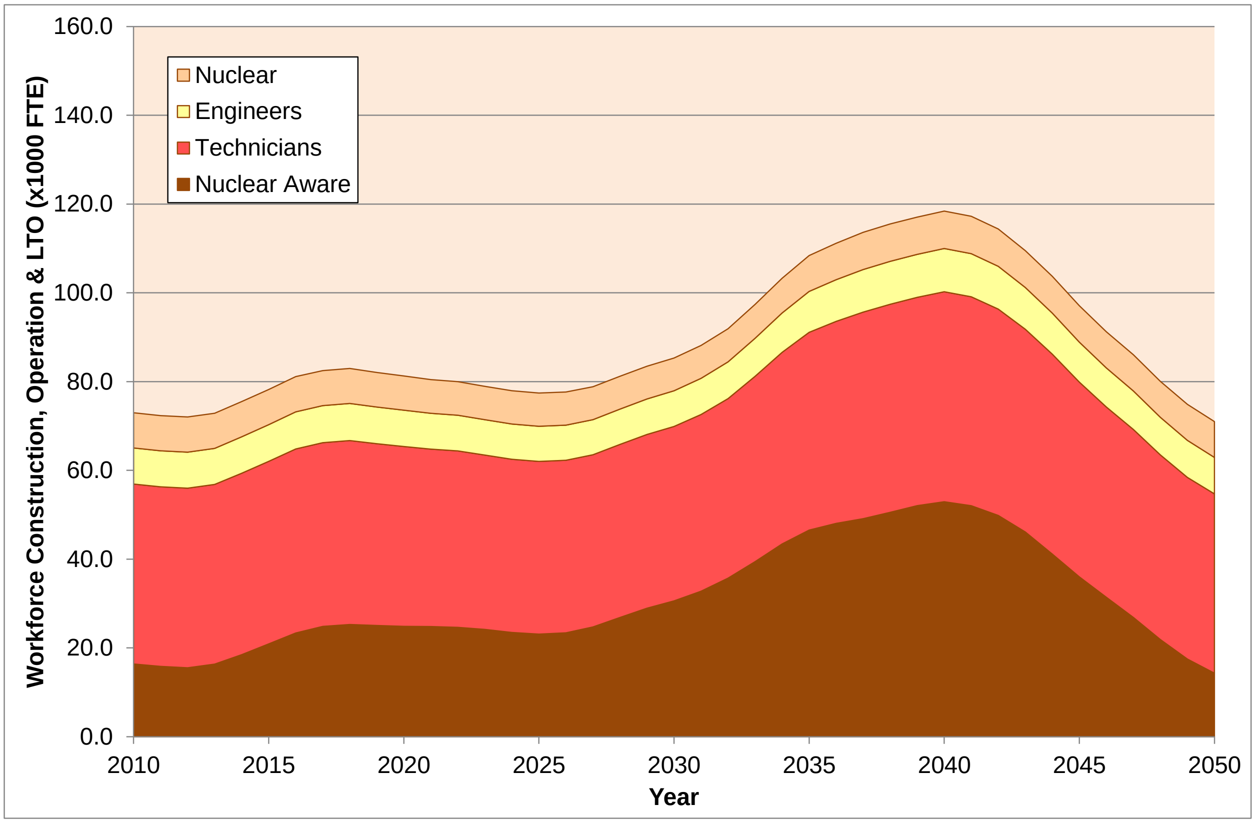

Figure 19: Manpower operations, construction, and LTO

7.4 Retirement and Replacement

The previous section has clearly demonstrated that the large majority of the workforce is involved in operation and construction, and the manpower required for LTO is negligible. Therefore, the impact of the retiring workforce on the manpower requirements is assessed solely for the manpower required for operation and construction.

Like in Roelofs and Von Estorff (2013), the retirement profiles which have been derived in chapter 6 are used to determine the 'new workforce' needed, i.e. the workforce which partly has to replace the retiring workforce and which additionally has to keep up with the total workforce demand. This 'new workforce' is shown in figure 20 in case no LTO is assumed. Obviously, this figure is similar to the figures shown by Roelofs and Von Estorff (2013). Like in the previous report, the peak demand for new people can be expected around 2020.

Figure 21 shows the effect of LTO on the requirements of such a 'new workforce'. The peak demand in the near future (around 2020) in case no LTO is assumed, will not be there. On the contrary, there is a relative low demand for new people. However, when time progresses, the peak demand for new people will around 2040, when even more people per year will have to be hired than in case no LTO is assumed. This is due to the fact that the largest part of the existing workforce will be retired by the time that new people will be needed for operation of existing and in the meantime construction of new plants.

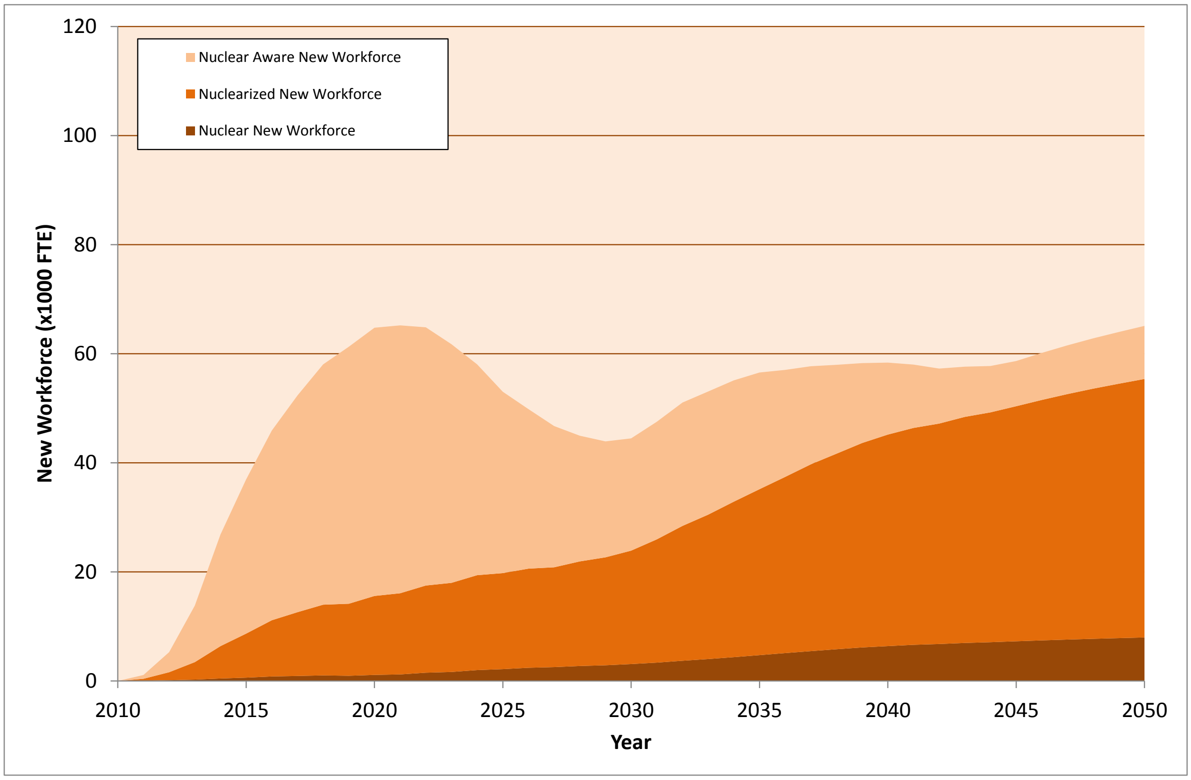

Figure 20: New workforce operations and construction in case no LTO is assumed

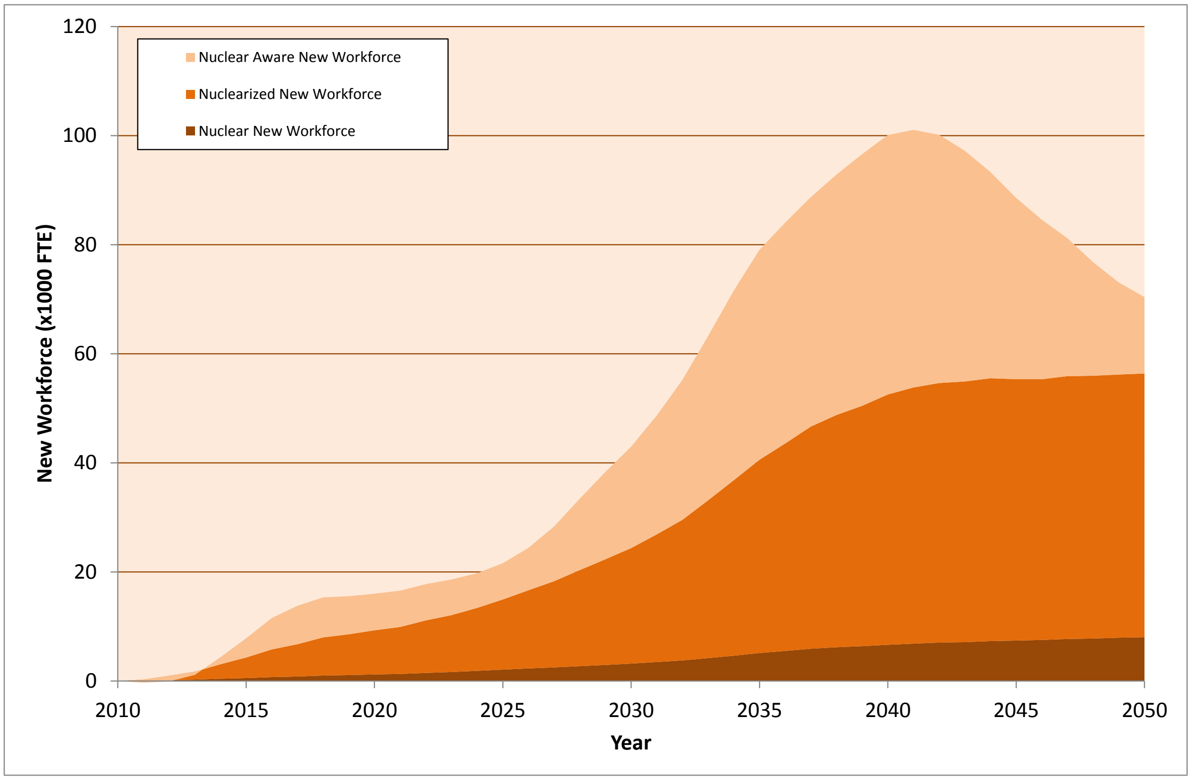

Figure 21: New workforce operations and construction in case LTO is assumed

7.5 Comparison with Historical Data

In order to put the numbers determined in the current study into perspective, a comparison is made with historical data from the IAEA for the nuclear capacity being installed at the same time like was done in Roelofs and Von Estorff (2013).

Figure 22 shows that when these data are compared, the historical peak values are much larger than the values computed for the coming 40 years. The figure reveals that the future peak value in case no LTO is assumed is to be expected within 10 to 20 years and moreover the gradient to reach the peak value appears to be steeper than the historical values. This means that during a relatively short time, more reactors have to be constructed per year than historically achieved. Furthermore, it is important to realize that given the assumed nuclear energy demand curves and nuclear reactor park shutdown profile, these peak values have to be realized in only 10 to 20 years from now, which was different in the past. The figure also shows that as could be expected, implementation of LTO will buy time. Implementation of LTO not only leads to a significant shift in the peak workforce demand, it also relaxes the number of new reactors being installed at the same time compared to historical values and to the reference case in which no LTO is assumed.

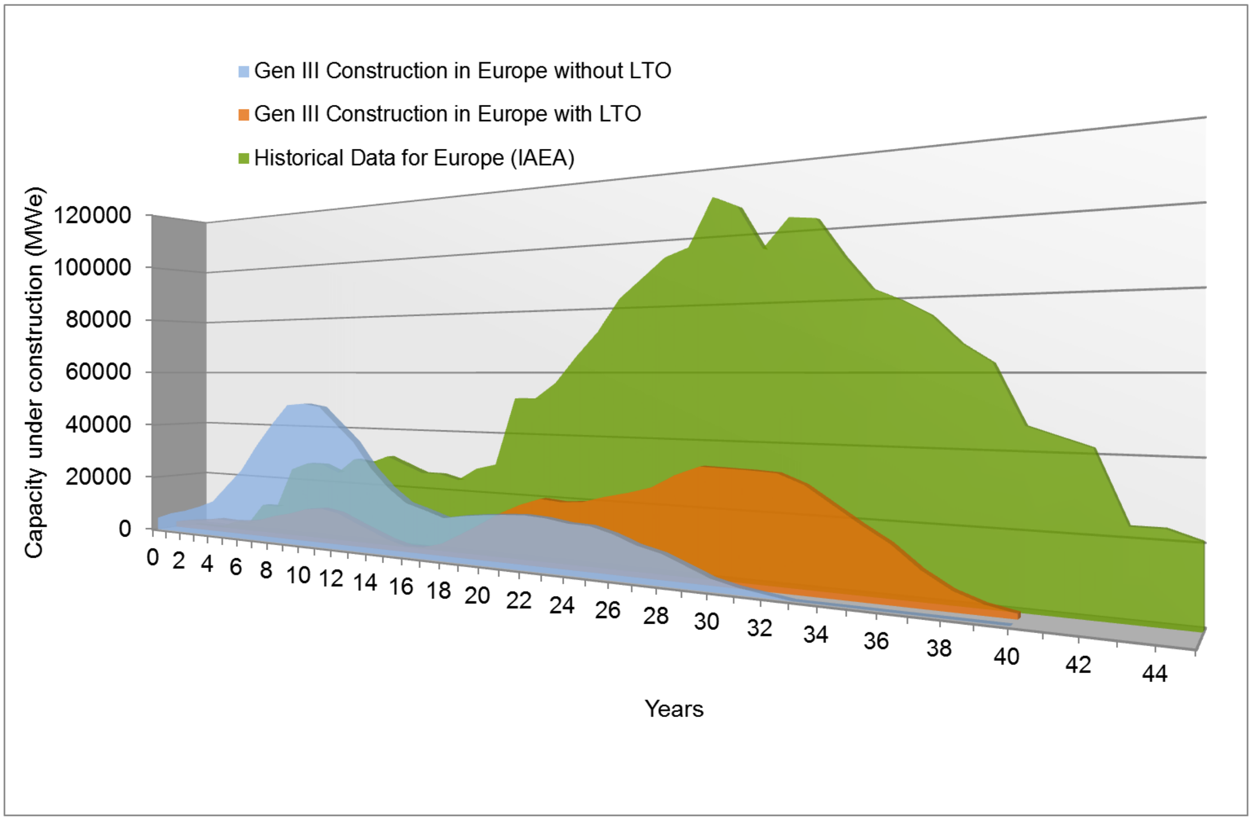

Figure 22: Capacities under construction assuming no LTO and LTO compared to historical data.

8 Conclusions, Discussion and Recommendations

8.1 Conclusions

A top-down analysis has been made to derive figures to assess the influence of long term operation on HR development for a selected nuclear energy demand scenario, i.e. the '20% nuclear electricity' scenario from the EC Energy Roadmap 2050. This nuclear energy demand scenario shows a moderate growth of nuclear energy production in the EU27 countries including the integration and enlargement countries. The following conclusions are drawn from the work presented in this report:

- In the year 2014, about 135 nuclear reactors were operational within these countries with an average capacity of about 900 MWe. The analyses show the influence of LTO on the number of reactors to be constructed between 2010 and 2050. Under the influence of LTO the number decreases from ~115 in case no LTO is assumed down to ~95 when LTO is applied.
- Obviously, LTO leads to a delayed need for new build. This means that the considerable workforce for construction will be required at a later point in time. Practically, the large demand for construction workforce will shift approximately 20 years from 2020-2030 to 2040-2050. At the same time, LTO leads to a larger spread of new reactor construction. This is related to the fact that not all reactors in Europe will employ LTO. So, the date at which end-of-life is reached for the existing reactors will spread.
- The workforce for LTO is negligible compared to the total workforce required for operation and construction, even if it is assumed that no permanent staff for operations is used by the plants to perform such activities.
- LTO delays the peak demand for new people from the near future to around 2040. However, the absolute peak demand is significantly higher because of the large replacement of the retired workforce which is a result of this delay.
- LTO relaxes the number of new reactors being installed at the same time compared to historical values and to the reference case in which no LTO is assumed.

8.2 Discussion

The assumptions taken into account for the current analysis are described in sections 3 through 6. However, the following aspects also need discussion and elaboration:

- Cross-sectoral mobility

  In particular for higher-educated people, the cross-sectoral mobility is often referred to. Where in the past, people stayed with one employer in one industrial sector for their complete career, currently people tend to switch employer and industrial sector more easily. This means that nuclear educated people tend to move to other industries, but also that non-nuclear educated people move to the nuclear industry and 'nuclearize'. In the current assessment, these aspects are neglected and only the HR demand is calculated. However, this aspect will influence the numbers for new people to be hired by the nuclear industry.

- Cross-national mobility
  The effect of European people going abroad and people from outside the EU coming to Europe to be employed within the nuclear industry is considered to be neutral although this may not reflect reality. Such cross-national mobility may mainly be expected for the temporary jobs, e.g. in the construction. Most plants will prefer permanent local staff for the operation of their plant. This may relax the HR requirements for construction from the European labor market.

8.3 Recommendations

- It should be mentioned that the data presented from the current assessment are deterministic best estimate data. Because of the generic and European scale nature of this assessment, the input data incorporates significant uncertainties and sensitivities. These uncertainties and sensitivities have not been examined in the current assessment.
- The previous and also the current assessment focus on HR requirements for the nuclear power plants. Although especially for the nuclear experts this is considered to be the main employment, it would be worthwhile to consider in addition the HR requirements for the fuel cycle focusing on the activities being performed in the EU28.
- Finally, other important aspects with respect to HR requirements for nuclear experts at a European scale are the experts employed by the regulatory bodies, their technical support organizations, and in nuclear research, education, and training.

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