Nikola POPOV[*], Gligor KANEVCE[*], Ljubica KANEVCE[**]

NUCLEAR ENERGY IN THE WORLD AND EUROPE – DEVELOPMENT AND TRENDS

Abstract: This paper provides a summary of the current trends of nuclear energy utilization around the world. Various reactor types are in operation producing a significant portion of the electrical power around the world. The paper describes distribution of various reactor types in operation, and contribution of nuclear power in various countries. Also the paper discusses the planning for new nuclear builds in different countries, including the most important expectations from the advanced reactor designs. The impact of recent events from the accident at the Fukushima NPP in Japan is also discussed.

INTRODUCTION

Nuclear energy has been in use for power generation in the past 50 years in many countries in the world, particularly in US, Russia, France, and other western developed countries. Currently there are

443 power reactors operating in the world producing about 14% of the electrical power generated in the world [1].

As seen in Fig. 1, the US, France, Japan and Russia lead by the number of operating reactor units. However, power reactors are currently in operation in 30 countries, and many more countries plan to enter in new nuclear programs. Figure 2 illustrates the number of operating NPPs shown as a percentage of total number of reactors in the world. As seen from this figure, in addition to the above 4 countries, Germany is also part of the top 5 countries by the number of NPP units in operation. Similarly, Figure 3 shows the percentage of power production in the NPPs in the top 5 countries as a percentage of total NPP power production in the world. It is interesting to see that South Korea is also among the top 5 countries.

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[*] Macedonian Academy of Sciences and Arts
[**] Faculty of Technical Sciences Bitola

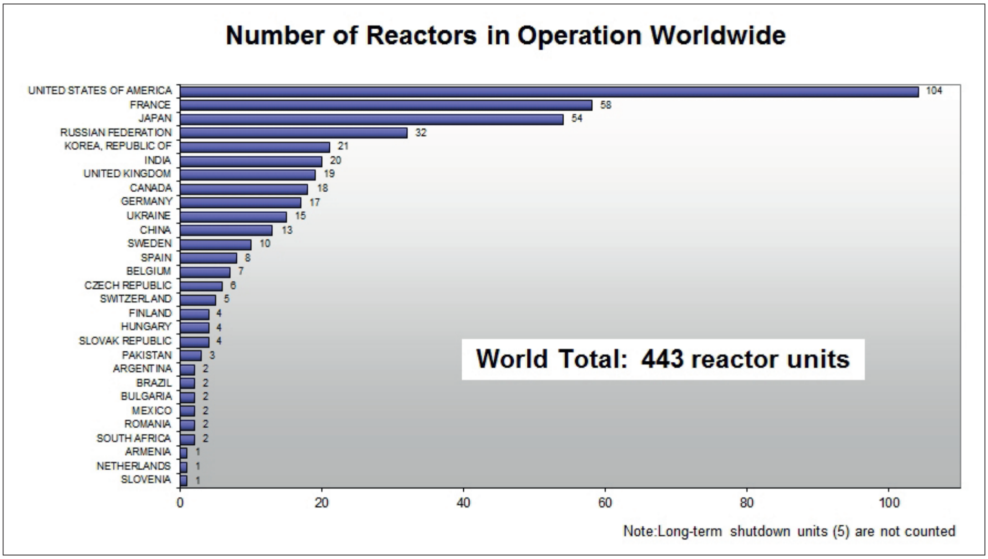

Fig. 1. Currently Operating Nuclear Reactors by Country in the World

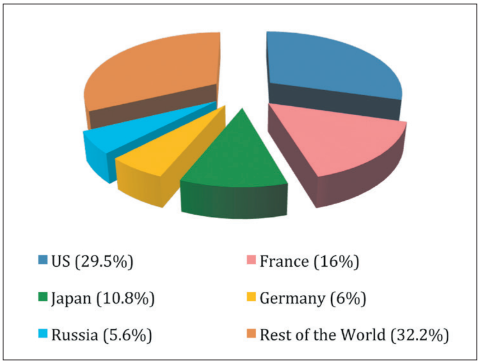

Fig. 2. World Nuclear Reactors in Operation

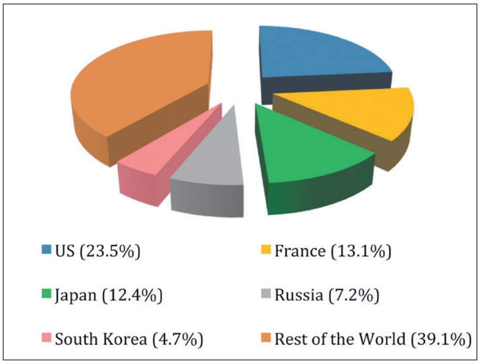

Fig. 3. World Nuclear Power Production

Figure 4 shows the reactor types currently in operation in the world. It is obvious that Light Water Reactors (LWRs) comprised of Pressurized Water Reactors (PWRs) and Boiling Water Reactors (BWRs) constitute about 80% of all operating reactors. The CANDU-type reactors, which shown as Heavy Water Moderated reactors take about 8%. The gas-cooled reactors are being replaced with LWRs in the UK, and the Russian graphite-moderated reactors (RBMK) are not planned to be build any longer.

Figure 5 provides information about the contribution of nuclear power in the total electrical power production in selected countries. It is interesting to compare

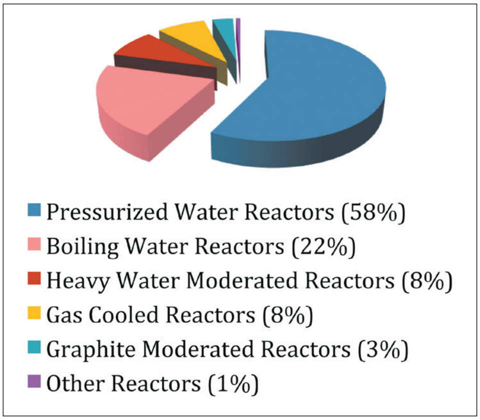

Fig. 4. Nuclear Reactor Types

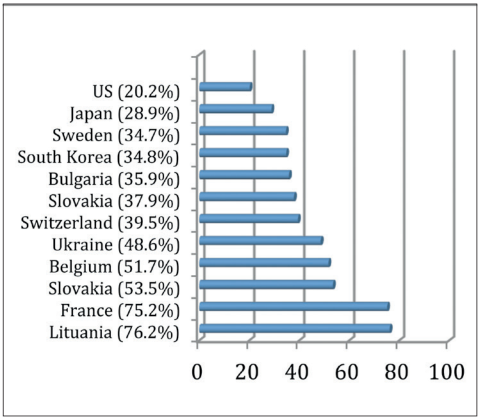

Fig. 5. Nuclear Reactor Power Contribution

two western industrial countries, namely France and US. Both have very developed nuclear energy programs, but in US power production totals only about 20% of the total electric power production, whereas in France it is around 75%.

Figures 6 and 7 show the average NPP unit contribution in the electric power system in selected countries. Figure 6 shows this for a number of developed western countries, where the average NPP unit contribution is low because these NPPs are connected to relatively large electric power systems. Figure

7 shows the other end of the spectrum, in which selected countries are shown with highest average NPP unit contribution in the electric power system. The situation in Slovenia is a unique, because it has only one nuclear power plant in a relatively small electrical power system. Good connections and transmission lines with its neighbors ensure stability of the Slovenian electric power system. Thus for countries with small electric power systems NPPs implementation should be at a regional level.

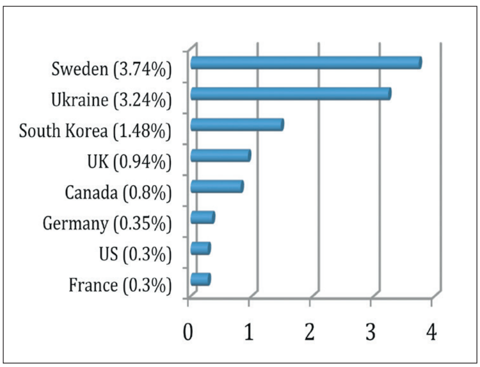

Fig. 6. NPP Unit Contribution – Low

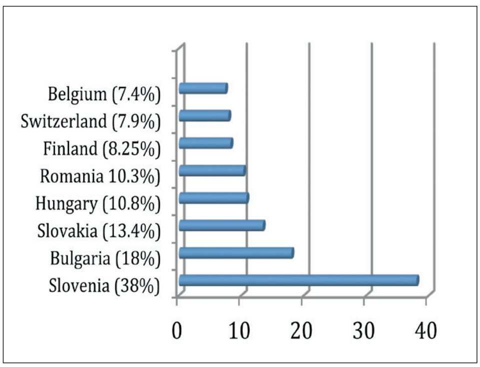

Fig. 7. NPP unit Contribution – High

EXPECTATIONS FROM ADVANCED REACTOR DESIGNS

In the past 10 years, in many western countries new reactor designs have been produced that are known as advanced reactor designs. To establish better understanding of the level of advancement, and to be able to compare and assess different designs, EPRI (Electric Power Research Institute) in US, and WNA (World Nuclear Association), have developed a set of expectations (attributes) to assess the level of advancement of different new reactor designs.

EPRI has established reactor grouping along the following lines. Generation I reactors are those early designs that were built in the early stages of the world nuclear program from late 40s to mid 60s. Generation II are all currently operating reactors built from mid 60s to mid 90s. Generation III are the advanced reactors, some of them built from mid 90s to present time. The Generation III + reactors are being designed for implementation from about 2010 until 2030, and they have higher safety and economic margins compared to Generation III designs. Generation IV reactors are being designed for future use, and they still need a long R&D process to be market ready for commercial implementation.

EPRI expectations for Gen III and Gen III + reactor are shown in the following groups: design simplification; design margin improvement; implementation of human factors; improved safety; improved design basis and safety margins; regulatory certainty thru regulatory stabilization and harmonization; design standardization; use of proven technology; ensuring better maintainability and constructability; higher level of quality assurance; better economics; improved sabotage protection; and better environmental protection. Many of the above attributes are already achieved to a high level in many of the modern reactor designs, and further efforts are in progress to further improve them.

NUCLEAR ENERGY PLANNING FOR THE FUTURE

The IAEA has completed a recent study of the expectations for future development of the use of nuclear power in the world [2]. This study as based on three scenarios that assumed three different NPP power increases in the world, as shown in Figure 8. The scenario with low demand increase was assumed in this paper, with NPP total power increase to 2500 GWe. Figure 9 shows the distribution of the NPP total power between different reactor types planned for implementation in the next 100 years.

As seen in Figure 9, from 2020 to 2100 the level of NPP power generation will increase steadily based on implementation of LWRs with higher fuel burnup and higher thermodynamic cycle efficiency (denoted by green area in Figure 9). In the period from 2050 to 2100, a small part of the NPP power generation is planned to be generated by small PWR reactors having a somewhat higher specific consumption of natural U compared with LWR (amber area in Figure 9). The current LWRs in operation will decrease their contribution to the power production until 2050.

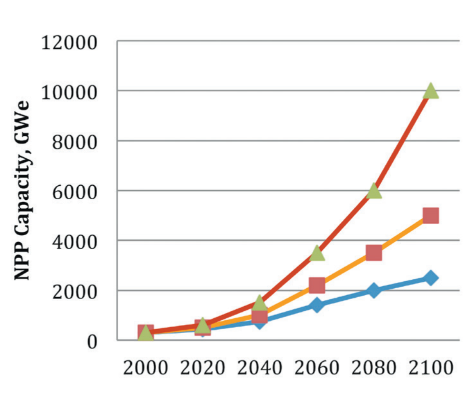

Fig. 8. NPP Development Scenarios

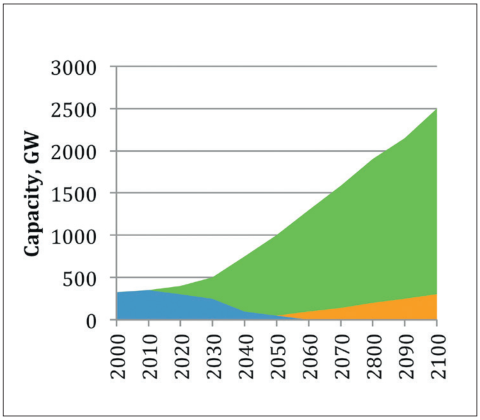

Fig. 9. Implementation of NPP Types

Figures 10 shows the new build NPPs planned by different countries. It is obvious that most of the new NPPs are planned to be build in China, India and Russia, which already have developed nuclear programs. However, significant NPP new build programs are planned in countries, which have not yet entered into nuclear power implementation programs, such as Vietnam and Italy.

Figure 11 shows the new build NPP programs by world regions for three representative years (2007, 2050, and 2100). It is interesting to see that in some world regions that currently have no nuclear programs these countries plan to engage in new NPP build programs, such as in Africa. However, the highest planned rate of NPP new builds is in the Far East region, comprised of China, Japan and South Korea.

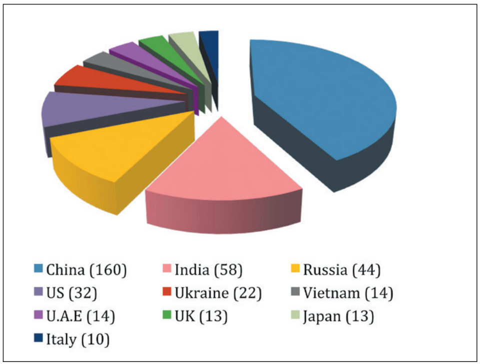

Fig. 10. New Build NPP Planning

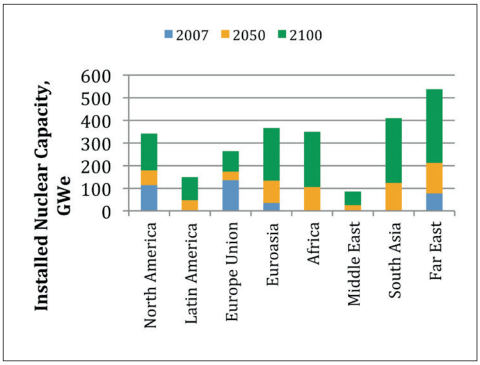

Fig. 11. New Build NPP by World Region

IMPACT OF RECENT EVENTS AT THE FUKUSHIMA STATION IN JAPAN

On 11 March 2011 Japan suffered its worst recorded earthquake, known as the Tohuku event. The epicentre was 110 miles East North East from the site of the Fukushima–1 site. Reactor Units 1, 2 and 3 on this site were operating at power before the event and on detection of the earthquake shutdown safely. Initially on-site power was used to provide essential post-trip cooling. About an hour after shutdown a massive tsunami from the earthquake swamped the site and took out the AC electrical power capability. Sometime later alternative back-up cooling was lost. With the loss of cooling systems, Reactor Units 1 to 3 overheated as did a spent fuel pond in building of Reactor Unit 4. This resulted in several disruptive explosions because overheated zirconium cladding reacted with water and steam generated hydrogen. Major releases of radioactivity occurred, initially by air but later by leakage to sea. The operators struggled to restore full control.

The nuclear industry in the world has reacted strongly on this event, and has already taken a number of activities to better understand the consequences of the event, and to assess vulnerability of other operating NPPs, or those being planned as new builds. Some of the possible outcomes of this event in Japan, and the resulting activities are summarized below.

In terms of the NPP design by different NPP vendors, it is expected that assessment of NPP safety robustness and design margins will be conducted. It is likely that a number of design improvements will be made particularly for safety systems and safety supporting systems. Also, it is likely that the list of Design Basis Accidents (DBAs) will be expanded to include some Beyond Design Basis Accidents (BDBAs), or combinations of DBAs. The above activities will be considered for new builds, and for operating NPPs.

The operating organizations have been requested to perform assessments and improvements of the operating procedures. Also, assessment and improvements of the Severe Accident Management Guidelines (SAMGs) will be performed, including implementation of more rigorous NPP staff training.

As a result of all above activities, an increase of the cost of NPPs design, construction, operation, is expected, probably also the cost of energy in general. It is expected that more stringent requirements for siting of NPPs will result. The schedule for obtaining construction license and Environmental Assessment approvals will probably take longer time.

It is already felt that the regulatory requirements and expectations have become more demanding. The World Organization of Nuclear Operators (WANO) sent a request to all operating NPPs in the world to perform assessment of the station safety robustness against severe accidents. WENRA (Association of European Regulators) issued a request to perform a "stress test" for all operating and new build NPPs in Europe, aimed at quantifying the level of NPP severe accident robustness. It is likely that rare severe accidents with serious consequences will be given more attention. Likely a number of regulatory changes will be made in the direction of

(a) more stringent regulatory requirements for new NPP designs, (b) more stringent operating requirements for operating NPPs and those that are planned for life extension, and (c) more stringent requirements for NPP operation and maintenance. Additional activities by the international regulatory agencies, particularly IAEA, WANO and WENRA, will be directed to more stringent monitoring and assessment of NPP design and operation, and periodic safety assessments.

CONCLUSIONS

Nuclear energy is extensively used in the world today as reliable base-load energy. Nuclear energy planning at the low-level demand increase in the next 100 years involves building of significant number of new NPPs around the world, with highest rate of new builds expected in Eastern Asia.

New advanced reactor designs known as Gen III and III + have emerged in recent years. These reactor designs offer improved safety features that maximize use of proven reactor design solutions with enhanced design safety features.

As a result of the Fukushima event in Japan, the advanced reactors will be subjected to additional level of scrutiny and design improvements and changes. Also, as obvious from current developments, the regulatory requirements are expected to become more stringent and demanding. This will likely result in an increase of the cost of nuclear energy, and along with it the cost of energy in general.

REFERENCES

[1] IAEA information available on the web site http://www.iea.org.
[2] Nuclear Energy Development in the 21st Century: Global Scenarios and Regional Trends, IAEA report NP–T–1.8, Vienna, 2010.