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The Prospect of Nuclear Power after Fukushima Daiichi Accident in an Emerging Global Energy Crises

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Author's contribution

The sole author designed, analyzed and interpreted and prepared the manuscript.

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ABSTRACT

The purpose of this paper is to review the effect of Fukushima Daiichi accident on world nuclear power and the progressive growth the industrial had enjoyed from April, 2011 till January, 2015. The paper specifically considers the new reactors connected to the grid within the period, the ongoing constructions of new power plants worldwide licenced after the accident and stringent safety measures taken by the International Atomic Energy Agency (IAEA) to routinely check the existing reactors and incorporate during the design of new one in a bit to forestall future occurrences. The study remarkably showed that nuclear power industry has risen above the Fukushima Daiichi accident with an addition capacity of 18, 053 MW(e) generated from 21 nuclear reactors connected to the grid between April, 2011 and January, 2015. Moreover, 24 new reactors of combined capacity 22, 581 MW(e) licenced within the period are under construction. These new reactors are mostly advanced pressurized water reactors (PWR) of improved safety system. This marginal shift from generation II to generations III and III+ reactors with passive safety systems shows a confirmation of positive step towards achieving safe and reliable nuclear energy. From the study, it could be reliably assert that the contribution of nuclear energy to world energy mix is not debatable and more importantly, nuclear energy still remains safe even in the Fukushima challenges, cost-effective and very reliable source of base load power that will play a pivotal role in both global economic prosperity and a clean environment.

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1. INTRODUCTION

Nuclear power had come under great criticisms after the Fukushima Daiichi disaster in March 2011 which involved four of the six boiling water reactors. The incident altered long term plan for nuclear power as a means of clean energy. Many opponents of nuclear power believed that the incidence had permanently diminished the global role of nuclear technology as a viable means of environmental friendly power source. They saw the event as an instinctive reminder of the uncertainties and risks of nuclear energy, and they argued that its sustainability in the mixed of this hazard is in doubt questioning the concept of "defense in depth" as a means of defending against the operating risks [1]. While the nuclear advocate viewed the meltdown as an acutely localised phenomenon that was triggered by a single highly improbable event, with few implications for the entire industry. In their view, the safety features already built into more recent generation of nuclear plant designs and the industry decades-long history of safe operation proved the ongoing viability of nuclear power [1]. However, it is ostensibly clear that Fukushima Daiichi accident continues to raise doubt on the operations of the existing reactors and licensing for the construction of new ones. But the significance of these adverse effects might not be as those opponents are projecting them to be. On the other hand, the accident could be seen as a turning point toward the realization of a stronger nuclear industry based on efficient reactor design that can withstand any natural disaster like earthquakes or tsunamis. In a swift reaction to contain the effect of the accident, the International Atomic Energy Agency (IAEA) had issued directives captioned in the action plan that the safety system for all existing reactors should be reviewed. Similarly, the European Union had also issued some safety instructions to all the Member States to key into the action plan of IAEA. With the hope of stronger research and development for the design of the Generation IV reactors, the nuclear power still have some major role to play in the world energy outlook. This paper therefore intends to review the effect of the accident and the progressive growth witnessed in the industry from 2011 till 2014. Its specifically considers the new reactors connected to the grid within the period, the ongoing constructions of new power plants worldwide and necessary stringent safety measures taken by IAEA to routinely check the existing reactors in a bit to forestall future occurrences.

2. FUKUSHIMA ACCIDENT

Japanese north-eastern coast was struck by a massive earthquake of 9.0 magnitude on 11 March, 2011 setting a powerful tsunami in motion [2]. These two fold natural disasters triggered a chain of events that culminated in the fuel melting, a significant release of radiation and the leakage of contaminated water of four unit reactors in operation during the accident. As rated by the International Nuclear Events Scale, the Fukushima Daiichi disaster was categorized as a Level 7 being the highest level for any nuclear accident, while the tsunami was designated as Mw. 9.1 in an index for indicating the scale of tsunami [3,4] and was rated the fourth largest ever in the world and the largest ever in Japan [5]. The large quantities of radioactivity released into the environment necessitated the cordoned off and evacuation of over three hundred thousand residents. Two facts surround the effect of the accident on the plants; (i) the earthquake which occurred at a very extremely rate was not presumed in the national earthquake research projects engaged in by the majority of the Japanese experts [6]. (ii) From the official licencing documents, Fukushima Daiichi's plant design-basis for tsunamis was estimated to have a maximum height of 3.1 meters above mean sea level [7], so it was not actually designed to withstand a tsunami even half the size of the one that struck the Japanese Coast [8]. Therefore, the event of Fukushima could be seen as pure natural disaster with resulting effect on the nuclear plants.

3. EFFECT OF THE ACCIDENT

The accident triggered social, political and economic debate around the world [9]. Many saw the accident as an antidote to much politicised phasing out of nuclear power plant, while other believed that the end is very near for nuclear energy. The quickest response to the Fukushima accident came from Japanese government who immediately ordered the shutting down of all the country's plants. Even after the first reactor was reopened in July, 2012, a policy aimed at phasing out nuclear power plant by 2040 was released in September, 2012. In the policy captioned Enecan's "Innovative Energy and

Environment Strategy", the Japanese government directed that reactors currently operable but shut down would be allowed to restart in the short term [10], once they gained permission from the newly established Nuclear Regulation Authority (NRA), but a 40-year operating limit would be imposed. This policy, however, could not be sustained as the new government backed out on Enecan maintaining that flexibility should be central in energy policy.

Similarly, Germany Chancellor immediately announced that the country will phase out all its nuclear power plants by 2022 [11-14]. Before the accident, Germany had 17 nuclear power plants. According to the Chancellor, eight plants will be shut down permanently, while the remaining nine will be phased out gradually by shutting down one each in 2015, 2017 and 2019, and also shutting down three each in 2021 and 2022 [15]. Also, Italian government in July, 2011 responded to the accident by scrapping her plans to reintroduce nuclear power in the country energy mix. In Switzerland, the government planned decommissioning of its five reactors between 2019 and 2034. The very hard decision taken by the government of Switzerland was to suspend the licencing of three new nuclear plants that were under consideration before the accident [1].

Obviously, others countries responded to the accident and in all, the resultant effect of the shutdowns and cancellations of new power plants worldwide became very significant. By the end of 2011, fifteen percent of the total capacity was taken off the grid [1], thus generating panic in the nuclear industry, and opening up global debate on the sustainability of nuclear power.

4. PROGRESS AFTER THE ACCIDENT

In the face of all these challenges, the future of nuclear power is far from gloomy because nuclear power plant is not only a source of base load electricity, but it also provides energy security [16]. Remarkably, the industry started picking and confidence gradually returned. IAEA stepped up and became very responsive to ensure better operating environment. This strong will to move nuclear energy high above the accident took less time before yielding results such that between April, 2011 and January, 2015, a total of 21 power plants of installed capacity 18,053 MW(e) were connected to the grid. This represents 4.79 percent of the world energy from nuclear power reactors presently in operation (Table 2). Conversely, 17 nuclear power plants of installed capacity 12167 MW(e) (3.23 percent) were taken off the grid (permanently shut down) after the accident (Table 4) for one reason or the other ranging from operational age and safety issues. Promisingly, as at 31st January, 2015, there are 439 reactors operating in 31 countries of the world, generating a total capacity of 376.931 GW(e) of electricity into the grid (Table 1) which account for over 16 percent of world's electricity output. Among the countries, China's quest for nuclear energy renaissance were evidently shown. Out of the 21 new reactors connected to the grid within the period under review, 11 reactors of combined capacity 9767 MW(e) representing 54 percent of the total energy connected in that period were by China. Similarly, 8 reactors of combined capacity 7, 523 MW(e) out of 24 reactors (total capacity 22, 581 MW(e)) under construction in China were licenced after Fukushima accident (Table 3). Altogether, a total of 69 reactors are under construction worldwide. Obviously, the progress recorded indicates that nuclear power remains a significant contributor to a global power supply even in the mist of legislations against it by some countries. This is an evidence that the end to nuclear power as an environmentally means of energy mix is not in sight [17].

On the Regional scale, 26.88% of the reactors operating worldwide are in north America, 26.65% are in western Europe, 23.01% are in the far East Asia, 15.72% are in Central Europe, 5.69% are the Middle East (Asia), 1.59% are in the Latin America and the least percentage of 0.46 are in Africa (Fig. 1). Out of the 69 nuclear power plants under construction (UC), 7.25% are being constructed in the Northern America, 49.27% of them are going on in the Far East Asia, 21.74% are in the Central Europe, 15.94% are in the Middle East (Asia), while Western Europe and Latin America have 2.9% each. Presently, there is no reactor under construction in Africa (Fig. 1), a situation attributed to lack of strong and functional continental nuclear regulatory body.

As evident from the above analysis, nuclear power is still making meaningful contributions to the world's energy mix promoting low-carbon energies. The sustenance of these contributions has received great boost by the effort being put into the nuclear industry by Asian power hungry countries like China, Korea Republic, India, United Arab Emirate (UAE).Therefore, instead of thinking how to kill off nuclear power as an important form of energy mix, it is expedient that the action plan on safety issued by IAEA in 2012 be holistically implemented, and each operating countries be forced with a dead line to review their operating procedures to ensure that they comply with IAEA standard. According to Charles Ferguson in Nature Magazine, "phasing out nuclear power worldwide would be an overreaction. It provides about 15 percent of global electricity and even larger percentages in certain countries, such as France (almost 80 percent) and the United States (about 20 percent) eliminating nuclear power would lead to much greater use of fossil fuels and raise greenhouse-gas emissions" [18]. Similarly, according to Mitch Singer of the USA Nuclear Energy Institute, "there are plenty of studies showing that nuclear is key in providing base load power. Wind and Solar are so variable that they really present a problem when you put that much on the grid" [19]. One would certainly suggest that efforts should be made in ensuring safety of both operators and environments. This could be achieve by constantly and consistently reviewing the IAEA 2012 action plan.

Table 1. All commercial reactors in operation worldwide as at 31st January, 2015

Country	Type of reactor	Number of reactors	Capacity (MWe)
Argentina	3 PHWR	3	1627
Armenia	1 PWR	1	375
Belgium	7 PWR	7	5927
Brazil	2 PWR	2	1884
Bulgaria	2 PWR	2	1906
Canada	19 PWR	19	13500
China	2 PHWR, 20 PWR& 1 FBR	24	20056
Czech Republic	6 PWR	6	3884
Finland	2 PWR& 2 BWR	4	2752
France	58 PWR	58	63130
Germany	7 PWR& 2 BWR	9	12068
Hungary	4 PWR	4	1889
India	18 PHWR, 2 BWR& 1 PWR	21	5308
Iran Islamic REP	1 PWR	1	915
Japan	24 PWR& 24 BWR	48	42388
Korea Republic	19 PWR& 4 PHWR	23	20721
Mexico	2 BWR	2	1330
Netherlands	1 PWR	1	482
Pakistan	2 PWR& 1 PHWR	3	690
Romania	2 PHWR	2	1300
Russia	18 PWR, 15 LWGR& 1 FBR	34	24654
Slovakia	4 PWR	4	1815
Slovenia	1 PWR	1	688
South Africa	2 PWR	2	1860
Spain	6 PWR& 1 BWR	7	7121
Sweden	7 BWR& 3 PWR	10	9470
Switzerland	3 PWR& 2 BWR	5	3333
Taiwan, China	4 BWR& 2 PWR	6	5032
Ukraine	15 PWR	15	13107
United Kingdom	16 GCR	16	9243
USA	64 PWR& 35 BWR	99	98476
Total		**439**	**376931**

(Source: International Atomic Energy Agency (IAEA);www.iaea.org/pris/) [27]

Table 2. List of NPPs connected to the grid after Fukushima Daiichi Incident

S/N	Nuclear power plants	Net capacity(MW(e)	Reactor type	Country	Date connected
1	CHASUNPP-2	300	PWR	Pakistan	14/03/2011
2	LINGAO-4	1000	PWR	China	03/05/2011
3	CEFR	20	FBR	China	21/07/2011
4	BUSHEHR-1	915	PWR	Iran	03/09/2011
5	KALININ-4	950	PWR	Russia	24/11/2011
6	QINSHAN 2-4	610	PWR	China	25/11/2011
7	SHIN-WOLSONG-1	997	PWR	Korea	27/01/2012
8	SHIN-KORI-2	960	PWR	Rep.	29/11/2012
9	NINGDE-1	1000	PWR	Korea	28/12/2012
10	BRUCE-1	772	PHWR	Rep.	19/09/2012
11	BRUCE-2	772	PHWR	China	16/10/2012
12	HONGYANHE-1	1119	PWR	Canada	17/02/2013
13	KUDANKULAM-1	917	PWR	Canada	22/10/2013
14	HONGYANHE-2	1000	PWR	China	23/11/2013
15	YANGJIANG-1	1000	PWR	India	31/12/2013
16	NINGDE-2	1018	PWR	China	04/01/2014
17	ATUCHA-2	692	PHWR	China	27/06/2014
18	FUQING-1	1000	PWR	China	20/08/2014
19	FANGJIASHAN-1	1000	PWR	Argentina	04/11/2014
20	ROSTOV-3	1011	PWR	China	27/12/2014
21	FANGJIASHAN-2	1000	PWR	China	12/01/2015
				Russia	
				China	

(Source: International Atomic Energy Agency (IAEA);www.iaea.org/pris/)[27]

Table 3. List of NPPs under construction Licenced after Fukushima Daiichi incident

S/N	Nuclear power plants	Net capacity (MW(e)	Reactor type	Country	Construction start date
1	CHASUNPP-3	315	PWR	Pakistan	28/05/2011
2	RAJASTHAN-7	630	PHWR	India	18/07/2011
3	RAJASTHAN-8	630	PHWR	India	30/09/2011
4	CHASUNPP-4	315	PWR	Pakistan	18/12/2011
5	BALTIC-1	1082	PWR	Russia	22/02/2012
6	SHIN-HANUL-1	1340	PWR	Korea Rep.	10/07/2012
7	BARAKAH-1	1345	PWR	UAE	18/07/2012
8	FUQING-4	1000	PWR	China	17/11/2012
9	YANGJIANG-4	1000	PWR	China	17/11/2012
10	SHIDAO BAY-1	200	HTGR	China	09/12/2012
11	TIANWAN-3	933	PWR	China	27/12/2012
12	SUMMER-2	1117	PWR	USA	09/03/2013
13	VOGTLE-3	1117	PWR	USA	12/03/2013
14	BARAKAH-2	1345	PWR	UAE	28/05/2013
15	SHIN-HANUL-2	1340	PWR	Korea Rep.	19/06/2013
16	YANGJIANG-5	1000	PWR	China	18/09/2013
17	TIANWAN-4	1050	PWR	China	27/09/2013
18	SUMMER-3	1117	PWR	USA	02/11/2013
19	BELARUSIAN-1	1109	PWR	Belarus	06/11/2013
20	VOGTLE-4	1117	PWR	USA	19/11/2013
21	YANGJIANG-6	1000	PWR	China	23/12/2013
22	CAREM25	25	PWR	Argentina	08/02/2014
23	BELARUSIAN-2	1109	PWR	Belarus	26/04/2014
24	BARAKAH-3	1345	PWR	UAE	24/09/2014

(Source: International Atomic Energy Agency (IAEA); www.iaea.org/pris/)[27]

Table 4. List of NPPs permanently shut down after Fukushima Daiichi incident

S/N	Nuclear power plants	Net capacity (MW(e)	Reactor type	Country	Date shut down
1	FUKUSHIMA DAIICHI -1	439	BWR	Japan	19/05/2011
2	FUKUSHIMA DAIICHI -2	760	BWR	Japan	19/05/2011
3	FUKUSHIMA DAIICHI -3	760	BWR	Japan	19/05/2011
4	FUKUSHIMA DAIICHI -4	760	BWR	Japan	19/05/2011
5	BIBLIS-A	1167	PWR	Germany	06/08/2011
6	BIBLIS-B	1240	PWR	Germany	06/08/2011
7	BRUNSBUETTEL	771	BWR	Germany	06/08/2011
8	OLDBURY A-1	217	GCR	UK	29/02/2012
9	WYLFA-2	490	GCR	UK	25/04/2012
10	GENTILLY-2	635	PHWR	Canada	28/12/2012
11	CRYSTAL RIVER-3	860	PWR	USA	05/02/2013
12	KEWAUNEE	566	PWR	USA	07/06/2013
13	SAN ONOFRE-2	1070	PWR	USA	07/06/2013
14	SAN ONOFRE-3	1080	PWR	USA	07/06/2013
15	FUKUSHIMA DAIICHI -5	760	BWR	Japan	17/12/2013
16	FUKUSHIMA DAIICHI -6	1067	BWR	Japan	17/12/2013
17	VERMONT YANKEE	605	BWR	USA	29/12/2014

(Source: International Atomic Energy Agency (IAEA);www.iaea.org/pris/) [27]

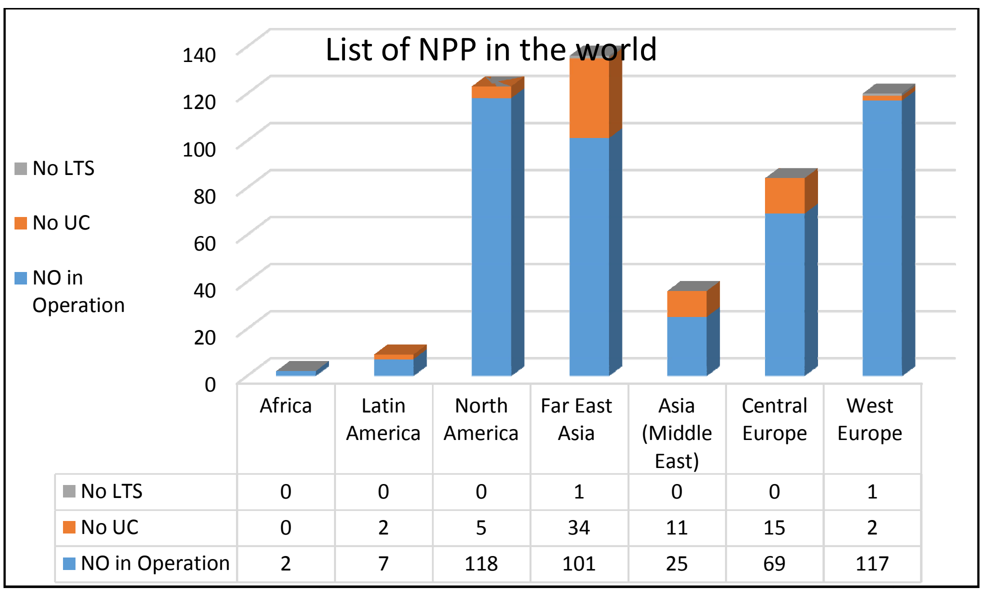

Fig. 1. Regional distribution of nuclear power plants in the world (LTS = Long-term shutdown, UC = under construction)

5. NUCLEAR SAFETY AND IMPLEMENTATION

Immediately after the accident, many countries responded by amending their legal framework in a bit to ensure the independence of the regulatory bodies and to prevent future occurrence. Regionally, European Union in 2014 adopted a legislative framework on Nuclear Safety Directive which intended to strengthens the power and independence of each member national authorities and introduces a high-level EU-wide safety objective to prevent accidents and avoid radioactive releases, sets up a European system of peer reviews on specific safety issues every six years, increases transparency on nuclear safety matters by informing and involving the public, enhances accident management and on-site emergency preparedness and response, and promotes an effective nuclear safety culture [20]. Also, the Nuclear Regulatory Commission of the United State adopted a recommendations that included more stringent requirements for the design and construction of nuclear plants to be able to withstand a more extreme accident scenarios than Fukushima. The high point of the safety calls came from IAEA in an action plan aimed at strengthening the global nuclear safety framework. 12 main actions contained in the action plan deal with the assessment of the accident and the future of the industry [21,22]. The main statement of the action plan include:

- To undertake assessment of the safety vulnerabilities of the nuclear power plants in the light of lessons learned to date from the accident.
- To strengthen IAEA peer reviews in order to maximize the benefits to member States.
- To strengthen emergency preparedness and response.
- To strengthen the effectiveness of national regulatory bodies
- To strengthen the effectiveness of operating organization with respect to nuclear safety.
- To review and strengthen IAEA Safety Standards and improve their implementation.
- To improve the effectiveness of the international legal framework.
- To facilitate the development of the infrastructure necessary for Member States embarking on a nuclear power programme.
- To strengthen and maintain capacity building.
- To ensure the on-going protection of people and the environment from ionizing radiation following a nuclear emergency.
- To enhance transparency and effectiveness of communication and improve dissemination of information.
- To effectively utilize research and development.

Worthy of note is that the implementation of these measures depends on the sincerity and sense of purpose of Member countries [23,24]. While the action plan reaffirms that the Member state and nuclear plant operating organization are responsible for ensuring the application of the highest standards of nuclear safety [25], IAEA should prevail on the Member countries to have an independent sources of funding for the regulatory bodies to wholly make them free from government inordinate decisions that may undermine the application of those safety requirements contained in the action plan. Fundamentally, the Fukushima Daiichi nuclear power plant accident identified significant human, organisational and cultural challenges, which include ensuring the independence, technical capability and transparency of the regulatory authority [26].

6. FUTURE OF NUCLEAR POWER IN GLOBAL ENERGY

Evidently, the international nuclear agencies had risen up to the challenges of Fukushima Daiichi accident and in effect are poised to run an industry that will not only be one of the major energy contributors but a means of achieving environmentally free energy to cushion the effect of climate change in the world.

Notably, the new reactors licenced for construction within the period are either Generation II+ or Generation III reactors which possess stronger passive safety design than the generation II reactors in operation at present. 21 reactors out of 24 under construction licenced after Fukushima accident are pressurized water reactors of either generation II+ or generation III models (Fig. 2).

While two are pressurized heavy water reactors (PHWR) and one is high temperature gas-cooled reactor (HTGR). Among the model of the licenced reactors are CPR-1000 which is improved generation II in terms of safety systems and a designed life time of 60-years. Also, ACPR-1000 being an improved design of CPR-1000 is a generation III reactors with additional safety measure of core catcher and double containment to withstand seismic and other external hazards. The most recent model of the PWR under construction in the USA is the AP 1000 being a generation III+ reactors. The reactors employs passive safety system that rely on gravity, natural circulation and condensation to safely scram the reactor and maintain the cooling process for more than two day even with a complete loss of power supply. At present, AP 1000 is the safest reactors in operation with high passive safety design, economically manageable and with improve efficient operation. Also, there is VVER with high fuel efficiency, enhanced safety and up to 50 years designed plant life. With these model of PWR into the market and many under construction, it is hoped that the ageing BWR and PWR will soon be phased out leaving reliable and stable reactors in operation worldwide.

Thus, to sustain the effort being made in nuclear industry, greater attention needs to be paid on research and development. There are about 247 research reactors in operation worldwide, while 6 are under construction (Fig. 3). More collaborative and exchange research across continents need to be enshrined in the industry by IAEA. Younger scientists should be encouraged to pursue career in nuclear industry and IAEA needs to ensure that each Member country comply strictly with all existing safety regulations both in normal operation and during emergency situations.

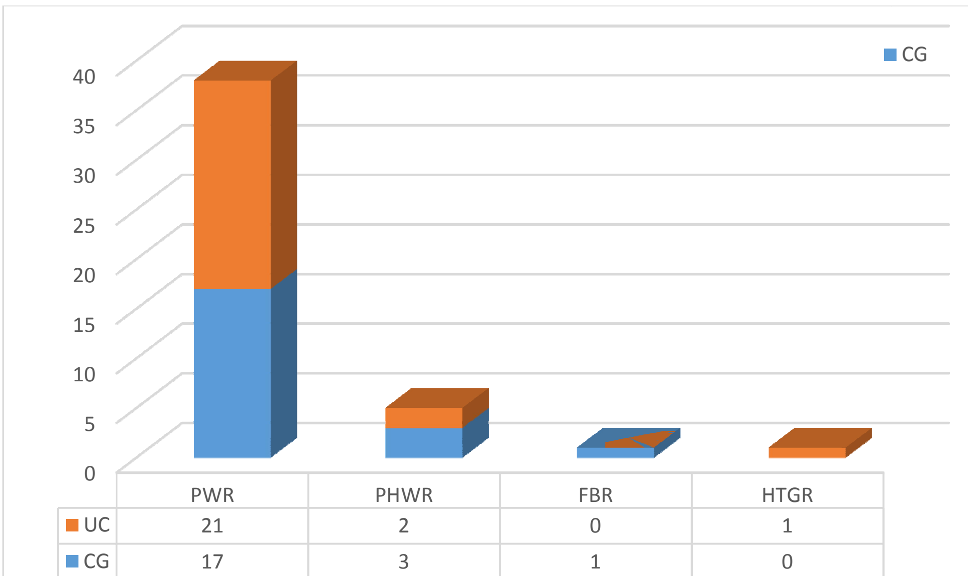

Fig. 2. NPPs types connected to the grid (CG) and Licenced for construction (UC) after Fukushima Daiichi accident

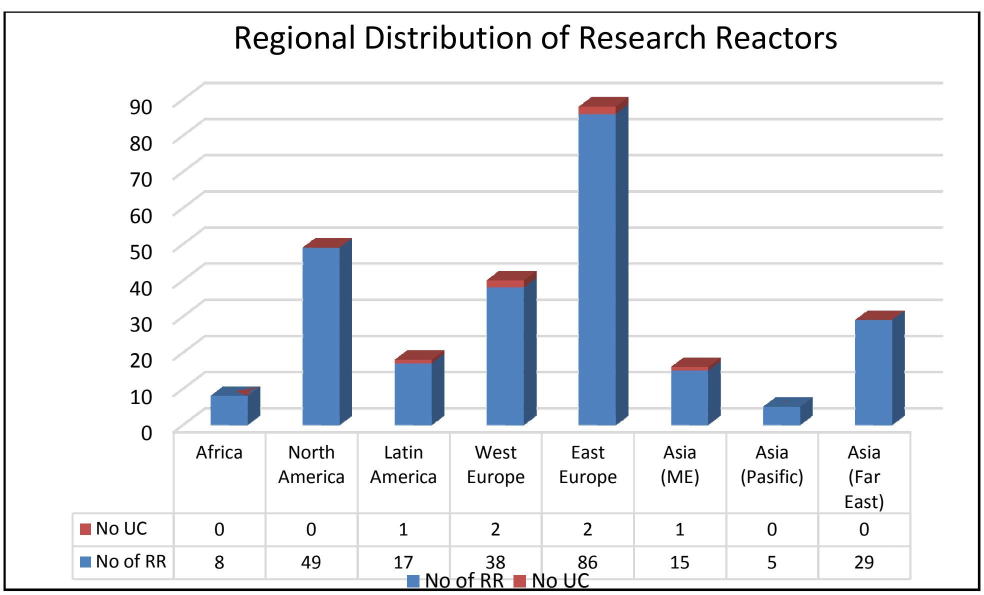

Fig. 3. Regional distribution of research reactors (RR) and research reactors under construction (UC)

7. CONCLUSION

The purpose of this paper is to review the progress recorded in the nuclear industry since the unfortunate but natural whip on the Japanese coast where six reactors were built. As unfortunate the accident might seem, the lesson learned is helping to shape the safety systems in reactor design and imbibe conscientious attitude towards the operation of the power plants worldwide.

This report showed that the contribution of nuclear energy to world energy mix is not debatable and that nuclear energy still remains safe even in the Fukushima challenges, cost-effective and very reliable source of baseload power that will play a pivotal role in both global economic prosperity and a clean environment. It therefore recommended that this vital contributions needs to be sustained and holistically improved upon. The shift margin from Generation II reactors to Generation III and III+ reactors are encouraged since the later designed system can withstand some emergency situation like Fukushima and even severe conditions.

As a follow up to the IAEA action plan on safety, public sensitization for nuclear technological acceptance should be vigorously pursued by Member States. Urgent attention should be giving to existing technical solutions while research and development takes important stage in the nuclear processes. With the current status, the nuclear power will earnestly take its proper stand in the world energy outlook.

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COMPETING INTERESTS

Author has declared that no competing interests exist.

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