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AN OVERVIEW OF NUCLEAR POWER ECONOMICS AND SAFETY ISSUES IN THE WORLD AND IN PAKISTAN

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Nuclear Power generation has been and is a serious option in the energy basket for economic competitiveness as well as energy autarky and security. However, two most important factors, i.e. economics and safety, need to be discussed from the developing markets point of view while watching global trends. The type, size and vendor information is presented in a manner that economic and safety paradigm is more clearly visible. Most of the 12,000 reactor-years operation experience in the world is obtained from generation I & II Nuclear Power Plants, and it is considered that they are still relevant in most energy markets. Currently, like countries such as the USA, UK and others, Pakistan has Generation II NPP technology, so both economics and safety conditions may not change in the near future. However, alternative data is presented to provide a better understanding; and its relevance to Pakistan is stressed.

Keywords: Nuclear power plants, Nuclear power hazards, Design, Operational experience, Lifetime output

1. Introduction

Nuclear energy is the energy stored in the bonds of the subatomic particles in the nucleus of an atom. During the period 1895-1932, the discovery of X-rays was followed by that of α, β, γ radiations and neutrons. In the late 1930s, fission was discovered. Since then there have been persistent efforts to use nuclear energy for strategic as well as economic reasons [1]. Today 274 research and isotope production reactors [2] and 443 Nuclear Power Plants (NPPs) [3] are in operation. The first Generation civilian-use NPPs were Obninsk, a Light Water Reactor (LWR), in the former Soviet Union, and Calder Hall, a Magnox type reactor in the UK. Among the strategic projects, the famous Manhattan Project, initiated in 1942, was officially terminated in 1946. The first nuclear powered submarine, Nautilus of USA, was also a landmark in the history of NPPs, since it has popularized LWR technology; it had served as a model for the civilian use of nuclear power. Since then, nuclear power generation has grown steadily and reached nearly 800 billion kWh in 2004.

Due to the nature of nuclear power generation hazards, a special kind of safety regime, which uses high technology and is expensive, has to be imposed on the NPPs. For this and other reasons development and installation of NPPs has been subsidized by governments. Two most important issues of nuclear power generation, i.e. economics and safety, are discussed here. Sometimes these are perceived as conflicting requirements. Both these issues are presented for Pakistan also.

2. Nuclear Power Generation

There are three modes of nuclear power generation: (1) Fission, (2) Fusion, and (3) Beta-emitters. Beta-emitters are popular for limited power use, i.e. remote research stations and space applications, and do not pose serious hazards due to the different principles involved and their relatively low radioactive material content. Fusion is still in the experimental stage. Fission-based NPPs, using both thermal and fast, neutrons, are used for bulk energy production. Between them, thermal-fission based NPPs are currently more popular, 3 out of 443 are fast reactors [4]. Over 400 of the operational NPPs of thermal type are supplied by Nuclear Steam Supply System (NSSS) vendors of ≥ 4 NPPs [5]. Table 1 presents data by reactor type, size and vendor.

Table 2 reveals that nearly 7.5% and 1.7% is the contribution of small Pressurized Water Reactors (PWRs) and small Pressurized Heavy Water Reactors (PHWRs), respectively. This contribution is accompanied by vast experience of nearly 12,000 reactor-years from all NPPs operated to date.

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Table 1. World NPP Market* *Adapted from* [5]

PWR				**BWR**				**PHWR**			
Atomenergoexport				**ASEA**				**AECL**			
8		2	10	1	5	4	10	12	19		31
B&W(Babcock & Wilcox)				**GE (General Electric)**				**Indian DAE**			
	7		7	7	20	22	49	8			8
CE (Combustion Engg.)				**Hitachi**							
1	6	6	13	2	2	4	8				
Framatome				**KWU(Kraft Work Union)**							
	40	25	65		3	2	5				
Hanjung				**Toshiba**							
		6	6	2	5	9	16				
KWU											
2	2	13	17								
Mitsubishi											
7	7	5	19								
Mintyashmash											
6		8	14								
Skoda											
10	2		12								
Westinghouse											
11	27	40	78								
Total 241				**Total 88**				**Total 39**			
AGR				**RBMK****				**Magnox**			
Natl. Nucl. Co.				**Mintyashmash**				**Natl. Nucl. Co.**			
	14		14			11	11	6	2		8
Total 14				**Total 11**				**Total 8**			

*Third row (in red) has 4 columns and gives no of small NPPs (< 600 MWe), medium NPPs (≤1000 MWe), large NPPs (>1000 MWe) and total.
**Reactor Bolshoy Moshchnosty Kanalny

Table 2: Lifetime output (TWh) (in blue) and Reactor-years (in red) by type, vendor and size up to 2003* *Adapted from* [5]

PWR			**BWR**			**PHWR**	
Atomenergoexport			**ASEA**			**AECL**	
544.4		124.5	78.2	648.2	639.2	648	1599
169.0		29.0	32.4	134.6	84.3	266	307
B&W			**GE**			**Indian DAE**	
	1088.		506.1	2407.4	3098.2	107	
	202.5		233.4	533.6	474.4	94	
CE			**Hitachi**				
96.6	891.3	941.4	127.6	219.	467.6		
30.4	157.6	112.9	41.1	41.4	64.0		
Framatome			**KWU**				
	4957.7	2905.5		407.8	361.3		
	842.6	364.6		78.3	39.0		
Hanjung			**Toshiba**				
		245.	146.9	453.4	938.7		
		32.0	49.6	93.0	126.7		
KWU							
191.5	317.2	2322.3					
65.8	59.5	251.1					
Mitsubishi							
590	837.8	497.2					
162.1	144.5	59.2					
Mintyashmash							
398.2		587.7					
165.8		123.3					
Skoda							
498.3	17.2						
166.9	4.2						
Westinghouse							
1004.3	3543.3	5703.2					
343.1	639.3	782.3					
Total 28302.4 **Total 4907.5**			**Total 10499.5** **Total 2025.8**			**Total2353.5** **Total 666.9**	

Table 2. Continued…

AGR			**RBMK**			**Magnox**		
Natl. Nucl. Co			**Mintyashmash**			**Natl. Nucl. Co**		
	1038.4			1322.		354.8	217.	
	289.3			248.3		223.7	65.4	
Total 1038.4 **Total 289.3**			**Total 1322.** **Total 248.3**			**Total 571.8** **Total 289.1**		

*Third and fourth row has 3 columns and gives the generation of small NPPs (< 600 MWe), medium NPPs (≤ 1000 MWe) and large NPPs (> 1000 MWe) respectively.

Table 2 also shows that PWRs have nearly 58% of experience while PHWRs have 7.9% of the operating experience. Small PWRs and PHWRs have 1103.1 and 359.5 reactor-years of experience, respectively. Such experience is achieved at the cost of aging of NPPs, which is a significant issue both for economics and safety. The age distribution of NPPs [3] is shown in Fig. 1, with a maximum of 40 years. It is to be noted that 79 NPPs have aged beyond 30 years.

3. Nuclear Energy Economics

The world energy markets can be divided into: developed, rapidly developing and developing markets. These markets are exploiting all possible resources, usually with a portfolio mix of resources. Countrywide nuclear share is presented in Fig. 2 [3] and energy mix of Pakistan [6] and Spain [7] are presented in Fig. 3.

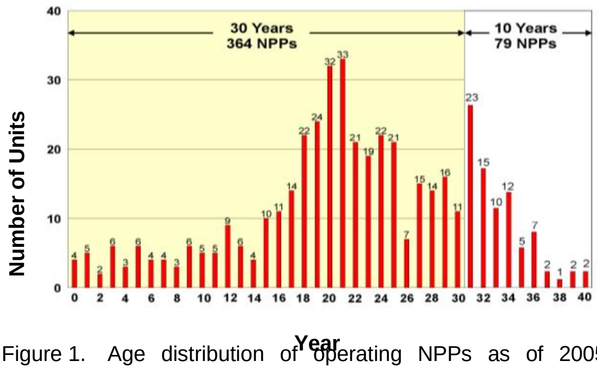

Figure 1. Age distribution of operating NPPs as of 2005 *Adapted from* [3]

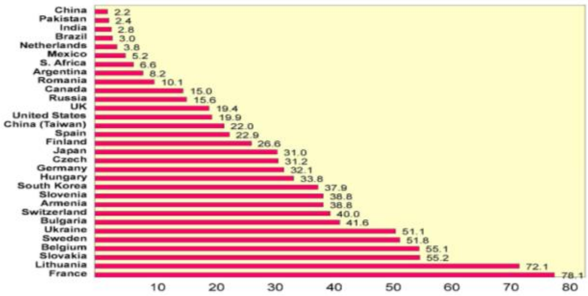

Figure 2. Countrywide share (%) of nuclear electricity generation [3]

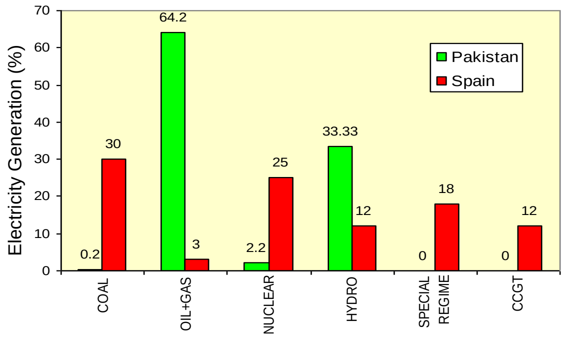

Figure 3. Electricity generation by source in Pakistan and Spain during 2003-2004 [6,7]

Though gradually nuclear energy has attained nearly 16.5% of the global market share [8], however this has been done only by 31 of the 191 UN Member States. Despite the fact that energy markets are deregulating at an ever faster pace, the energy issue still has an important strategic dimension. For example, the USA (104 NPPs) has no market share for non-USA vendors supplying NPPs listed in Table 1. The same is the case for France (59), Russia (31) and Canada (18). It is worth noting that the USA, China, Russia, Japan and France are the greater energy markets [7]. Information presented in Table 1 and Fig.2 shows that 11 out of 31 countries have indigenous vendors of ≥ 4 NPPs and are reluctant about giving market access to others. This demonstrates that usual economic data may reveal only partly.

Table 1 also shows that large NPPs (> 1000 MWe) were of PWR (105), BWR (41) and RBMK (11) type only. The largest is the Framatome N4 with an output of 1450 MWe [7], a generation III NPP benefiting from the concept of economy of scale. Westinghouse has successfully applied this concept to its generation III NPP, namely AP-600 by reintroducing it as AP-1000. Top vendors and operating organizations have identified economic drivers to make nuclear even more economical, see Table 3 [9].

Among these nuclear energy is already enjoying higher industry Capacity Factor (the amount of power actually produced in a year / the amount that could have been produced if the plant operates all year round at maximum power) compared to other sources, see Table 4.

Economic competitiveness of operating NPPs is also gauged in terms of operating income ratio and the average rate of return. These are shown in Fig.4 for South Korean case (KHNP representing nuclear power) [11]. It seems that the rate of return, in case of nuclear, is lower. However, customarily the rate of return is multiplied with volumes (kWh) when it is done, it is again higher for KHNP (Korea Hydro Nuclear Power).

Electricity is a commodity in an energy market, and most markets are provided by more than one source. There are at least 4 mainstream alternatives to oil (coal, nuclear, gas, hydro), within cost brackets of around ±25% from the cheapest to the most expensive. Korean experience shows that a simple comparison of generating costs, a tradition currently common, needs to be replaced with a comparison based on base-load marginal price and system marginal price [11]. This approach secured price stability and reasonable returns also.

NPP construction is capital intensive; so in a deregulated market it is highly likely that low capital generation companies opt for oil and gas, thus giving the impression that nuclear power is uneconomical. Whereas its economic justification is evident in Fig. 5. Another factor ready to be introduced in energy market is the “carbon tax”, for plans are there to see the reduction in CO_2 emissions. The projected contributory factors in CO_2 reduction [12] are shown in Fig. 6. The share of nuclear is reasonable showing its economic competitiveness in different markets. In addition, it is to be noted that nuclear is also a part of end efficiency gains. Particularly in USA these gains are already demonstrated.

Now if we refer to a more traditional economic factor, i.e. levelized generation cost, see Fig. 7 [8], nuclear power is seen comparable to clean coal and natural gas.

Different assumptions may lead to different scenarios, sometimes misleading, as shown in Fig. 7. Since the current installed capacity of nuclear power globally is nearly 370,000 MWe [3], it shows that most forecasts are just ‘guestimates’. Moreover, it is almost a standard practice to present data from USA in such studies, being the largest producer of nuclear energy, while we recommend to use data from other markets as well, such as France, where production costs (1.4 ¢/kWh, 2002) are lower than in USA (1.6 ¢/kWh, 2002). Similarly French operating expenses were 75% of those in the USA in 2002.

Moreover, nuclear power markets are tightly regulated by safety regulators, especially after the accidents of Three Mile Island (TMI) and Chernobyl. This has definitely resulted in increased costs. To control costs, US NRC (Nuclear Regulatory Commission) has shifted emphasis towards risk-informed decision making and cost justification in some areas. It has proved its worth in applying this to hydrogen mitigation in severe accident scenarios [13].

Table 3: Economic drivers identified for NPPs [9]

	Total Capital	Plant Efficiency	Capacity Factor	Construction Time	Generation Costs	Other Applications & Byproducts
Objective:	$750/KW	> 50%	> 90%	2 years	3¢/kWh	
Overall Value	1	1	2	2	3	3
Research priorities						
Advanced Simulation	A	B	B	A	C	C
Construction Processes	A	C	C	A	C	C
Coolant Technology	B	A	B	C	C	C
Digital Technology	A	B	B	A	A	C
Human Factors	B	C	A	C	B	C
Information Technology	B	B	B	A	A	C
Low-Level Radiation Health Effects	C	C	B	C	B	C
Materials	B	A	B	C	C	B
Manufacturing/Const Technology	A	C	C	A	B	C
Non-proliferation Technology	B	C	C	C	C	C
Nuclear Fuels	B	A	B	C	C	C
Operator Training	C	C	B	C	B	C
Reactor Analysis	C	B	B	C	C	C
Regulatory Reform	B	C	B	A	B	C
Robotic Technology	C	C	B	B	B	C
Safety Technology	B	C	C	C	B	C
Sensor Technology	B	A	A	C	B	C

Overall value 1,2, 3 stands for high, medium and low, while A,B,C stands for urgency, high, moderate and low.

Table 4: 2004 USA industry capacity factors by fuel type [10]

Fuel Type	**Average Capacity Factor (%)**
Nuclear	90.5
Coal	70.8
Gas (Combined Cycle)	38.2
Gas (Steam Turbine)	16.6
Oil (Steam Turbine)	26.2
Solar	22.4
Hydro	29.6
Wind	32.1

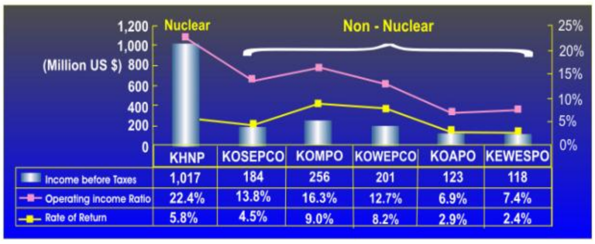

Figure 4. Economic data for Korean power generation companies [11]

The nuclear power market at least in some aspects behaves like traditional market and is currently undergoing mergers; see Fig. 8 [14]. A similar trend is going on in the US operating companies: the number of NPP operating companies has fallen from 54 in 1989 to 24 in 2001 and is further expected to reduce.

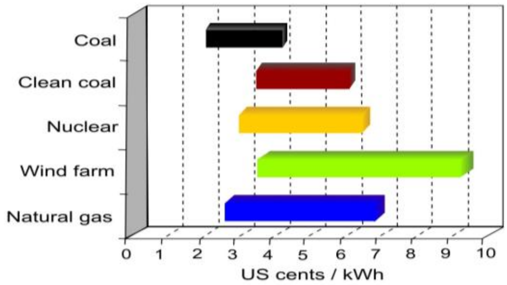

Figure 5. Levelized generating costs [8]

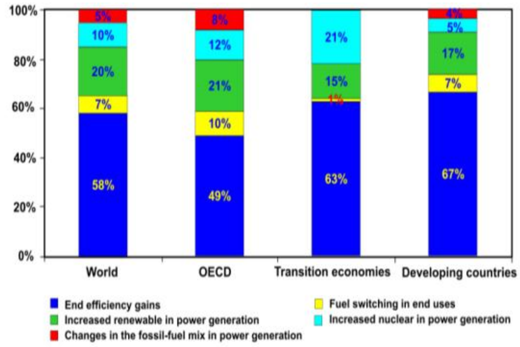

Figure 6 Contributory factors in CO_2 reduction 2004-2030 [12]

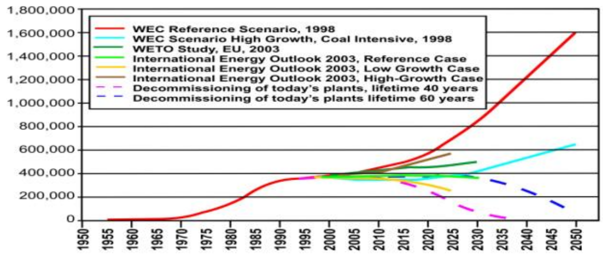

Figure 7. Forecasts for worldwide installed capacity of NPPs.

4. Nuclear Energy Safety

Major issues of NPP safety are enlistment of hazards, design, operation and establishment of national safety framework (including regulator, technical safety organizations and owner/operating organization fora).

4.1. Energy hazards

Popular energy sources include hydro, fossil fuels (coal, oil, gas), nuclear, solar and wind [15]. All these sources have hazards associated with them, although, the kind, severity and psychological perception of these hazards is different for different sources, see Fig.9.

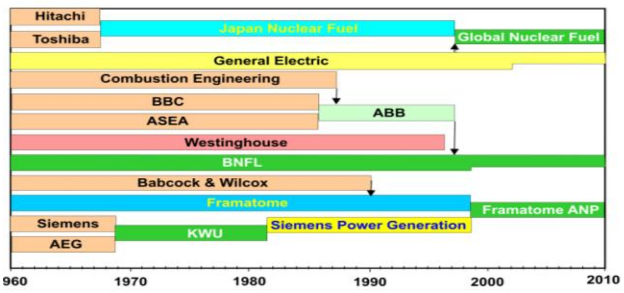

Figure 8 Consolidation of nuclear vendors, 1960-2001

Enlistment of these hazards is the first step in considering the safety implications. NPPs have hazards associated with radioactivity in addition to other power plant hazards. Nuclear accidents are classified in the IAEA's International Nuclear Event Scale (INES) [16] on the basis of their severity, including both on-site and off-site effects. In NPP safety no general approach can be taken, since methods for dealing with the issues of safety, including reliability and aging, depend on the specific reactor design i.e. type & vendor, materials used and national approach, etc.

We recommend in the following to analyze the events categorized in INES to learn and incorporate the information in the design and operation to enhance safety. It is recommended that the following be considered to minimize the hazards and consequently enhance safety:

i) Technology ii) Organization

iii) Man, and iv) Environment

The Chernobyl accident involved all the four mentioned above, while TMI accident did not involve the environment. Traditionally, as the hazards and risks associated with a facility increase, the formality of the analysis, its documentation, and the level of effort to produce them all increase. The safety regime has to be expanded to accommodate the demands of the others, such as environmental stakeholders, etc. The operation of Jose Cabrera NPP, 300 MWe Single Loop Westinghouse type PWR, in Spain until recently demonstrate safety of NPP despite having more options in energy basket, see Fig. 3.

Currently due to increased security concerns, national regulators in collaboration with IAEA are trying to expand the present safety regime to include the physical protection and security, which are essentially not core safety issues.

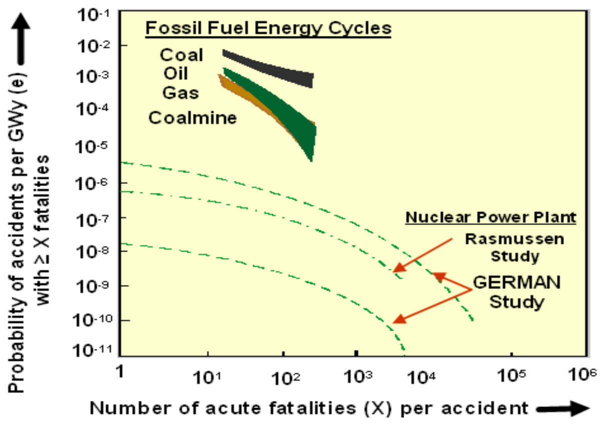

Figure 9. Number of fatalities for coal, oil and nuclear power.

4.2 Design

The experience obtained from design and operation of an NPP is incorporated in design of successive NPPs, both on individual and on collective basis. Technology, organization and man are all addressed during design.

4.2.1 Technology

A large amount of operational data related to component and systems performance already exists, and is being incorporated into reactor design directly and by equipment & system qualification. Technology has been appropriately addressed in evolving generations of NPPs, by incorporating natural processes (passive features), power down-rates (e.g. AP-600), advanced materials and I&C. It has been addressed in evolutionary manner in relevant international [17,18] and national design codes [19]. Operational experience feedback to operating organizations and relevant vendor-specific fora has contributed to the development of design codes & guides. Core Damage Frequency (CDF) and Large Early Release Frequency (LERF) are revised for improved targets with the aim of practically eliminating Chernobyl and TMI type accidents.

Due to uncertainties in our knowledge and the conservative nature of safety standards, it is believed that significant amounts of energy in the NPPs are not being utilized. The potential for cost savings in current reactors or reduced costs for future NPPs is quite large. This has been demonstrated recently in case of AP design by Westinghouse. The power has been increased from 600 to 1000 MWe with little changes.

4.2.2 Organization

Until the early 1980s, NPP industry safety activities focused mostly on design and construction. Since then focus has shifted to operational safety. In 1982, IAEA added the Operational Safety Review Team (OSART) in its services to its Member States. Among others, OSART focuses on operating organizational structure, management, etc. It is now becoming an integral part of the operation codes & standards. Even the issue of competency of regulatory bodies has also come to the forefront. By utilizing the extensive operational experience (see Table 2), particularly that related to transients, there has been a shift of emphasis from event-based emergency operating procedures to Symptom-based Emergency Operating Procedures (SEOPs).

4.2.3 Man

The issue of man was not part of safety studies in Generation I NPPs; however, it has been addressed to some extent during the design of Generation II NPPs. In fact, now a days this has become a high priority area. Human factors and operator training are identified in economic as well as in safety studies. It is now the main area of focus for risk-informed decision making for regulators as well as owners. With the introduction of the latest technology, man-machine interface is now an integral part of design in Generation III NPPs. Use of human factors and ergonomics in control room design is common; and this is increasingly getting better and sophisticated. It has become more common to use Causal Loop Diagrams and Stock & Flow Diagrams.

4.3 Operation

There are several dimensions of safety in operation. It is in much sharper focus in some power markets, e.g. USA, since the rate of new NPP addition is minimal. This has resulted in power uprates without any safety degradation. Another dimension is strengthening and augmenting of the existing operating procedures.

4.4 Establishing nuclear safety framework

In developed markets, as a principle, regulation is needed upon achieving a critical market capitalization and number of operators. Thus, despite the fact that first civil NPP was introduced elsewhere, USA took the lead in establishing a regulatory framework by introducing Atomic Energy Act of 1954. Since then it is recognized that NPPs need stringent regulations, owing to perceived hazards. The resultant increase in resources may be compensated for by government subsidies. These days, more and more energy markets are deregulating - making this framework more relevant. This has been one of the reasons that the IAEA has stressed on governmental organizations (see Section 4.4.2). Both market developments, and efforts of the IAEA, have made many countries realize the need to charter a course of autonomous governmental organizations, i.e. regulators.

4.4.1 Convention on nuclear safety

The IAEA convened a diplomatic conference which adopted the Convention on Nuclear Safety (CNS) on 17th June 1994. This convention allows participants to question other participants on any matter relating to nuclear safety, thus facilitating even the international stakeholders to access, analyze and comment on nuclear safety-related issues of NPPs operated by parties to the CNS. This is a confidence-building measure. As a consequence, safety issues that could be overlooked in national reviews and assessments can be highlighted. The CNS encompasses all civilian land-based NPPs and requires that 'all reasonably practical improvements are made as a matter of urgency to upgrade the safety'.

4.4.2 Role of the IAEA

The IAEA is playing a vital role in cooperation in nuclear safety among its Member States. The IAEA started the Nuclear Safety Standards (NUSS) programme in 1974 to guide Member States on various aspects of the safety. It broadly covered: (1) Siting, (2) Design, (3) Quality Assurance, (4) Operation, and (5) Governmental Organization. Revision 1 of NUSS was issued in 1988. In view of the more encompassing safety needs of the CNS, IAEA reorganized its NUSS structure in 2000.

4.4.3 Owner / Operating organization fora

Owner/Operating organizations such as CANDU Owners Group (COG) and World Association of Nuclear Operators (WANO) have played a very important role in furthering the cause of safety. WANO has included some safety indicators in its nine NPP Performance Indicators.

4.4.5 Role of technical safety organizations

The role of Technical Safety Organizations (TSOs) in facilitating regulators, and also the operating organizations, to perform and evaluate safety analyses is well established. In USA the

NRC heavily relies on TSOs such as INL (Idaho National Laboratories).

5. Pakistan's Case

Pakistan has a Chinese-supplied CHASNUPP-1 (C-1) (325 MWe): a PWR, and a Canadian-supplied KANUPP (137 MWe): a PHWR. C-1 is not part of the information presented in Section 2, which incorporates vendors of ≥ 4 NPPs; however KANUPP, designed by AECL, is included in the information presented in Section 2.

5.1 Nuclear energy economics

The energy electricity mix of Pakistan (Fig. 3) it is noted that in the order of merit gas, hydro, oil, nuclear and coal based power have their share. Combined Cycle Gas Turbine (CCGT) plants, based on gas are less capital intensive and are the favorite choice of independent power producer world wide. While hydro and nuclear power are capital intensive, among these hydro has been favored by the money-lenders, e.g. the World Bank. Additionally, for Pakistan, NPPs are on the embargoed list by some countries. It is estimated that gas reserves may deplete in coming decades; thus alternatives need to be developed. In this regard we consider that Pakistan should follow the example of the Republic of Korea (ROK) and France. Like Pakistan, ROK and France have negligible energy resources. Please see Fig.4 where KHNP, responsible for NPP operation, has demonstrated the economic feasibility in terms of operating income ratio and weighted rate of return. Such a scenario will emerge as Pakistan implements its newly announced plans to install 8,800 MWe nuclear power by 2030.

It can be inferred from global data of Fig. 5, that the generating cost of nuclear energy is competitive with hydro, gas and oil generated energy; and trends are promising. The World Nuclear Association (WNA) in its recent report "*The New Economics of Nuclear Power*" [20] has also shown that once the initial significant capital cost burden for the very first units of a series is overcome, nuclear power will be competitive even without attaching economic weight to the global environment virtues. The same has been stated by an IAEA-sponsored study [21] for Pakistan.

The average availability factor for KANUPP, after the 1st relicensing outage, for the years 2004 and 2005 are 78.1% and 79.3%, respectively. Similarly for CHASNUPP-1 they are 78.2%, 68.2% and 83.5% for the years 2003, 2004 and 2005, respectively. This shows that Pakistan's NPP availability is comparable to the world average as shown in Fig. 10. Since nuclear energy is capital intensive, to increase the impact it is suggested that US market trends be followed, i.e. up-rate the power of both existing NPPs after a careful safety assessment and any needed up-gradation. In this regard, aging should not hinder - as Fig. 1 shows that 79 NPPs have age > 30 years.

In the USA life extensions are now being granted up to 60 years from a nominal designed life of around 40 years. It is also to be noted that nearly 138 GWe in the European Union is generated by plants (including NPPs), older than 31 years at present. Since Pakistan does not have any indigenous vendors as yet, all economic drivers, identified in Table 3 have little importance except generation costs, by-products and regulatory reforms.

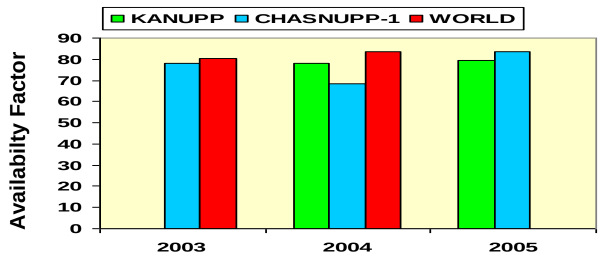

Figure 10. Plant availability factor for KANUPP, CHASNUPP-1 and the World.

5.2. Nuclear energy safety

Nuclear energy hazards are much the same as elsewhere and need not be discussed here, while the rest of Section 4 will be reviewed. However, it is to be noted that Pakistan has an excellent safety track record compared to many of the 31 nuclear power generating countries. However as nuclear power is nearly 50 years old, perceptions regarding its maturity also need to be re-focused. Pakistan operates PHWR and PWR types of NPPs; these technologies should not be considered esoteric. Nuclear power has an experience of 12,000 reactor-years, out of which PWR and PHWR have 4908 and 667 reactor-years, respectively, until 2003, and is growing further. See Fig. 11 for typical failure trends for new technology with time. The 12,000 reactor-years suggest that the gap between unidentified failure modes and identified failure modes is much narrower now and is diminishing. Moreover, it can also be stated that accidents are usually considered a learning experience of the kind depicted in Fig. 12.

5.2.1 Design

Pakistan is probably leading the world by adopting in its regulations [22] IAEA's latest design requirements [18]. This means that current "safety in design regime" in Pakistan is even more advanced than countries operating Generation III NPPs. The target CDF value in design regulations may be conceived as a problem for some vendors of less than 4 NPPs. This issue needs to be addressed. Design is a major concern for licensing and relevance of US NRC is accepted as an alternate by Pakistani regulatory body. US NRC as well as licensing authorities in France accord much weight to similarity in NPP design and this is one of the reasons that there are 104 NPPs in operation with 68 site licenses in the USA. If this approach is adopted then licensing of new NPPs may be facilitated. It is to be noted that regular safety reviews are conducted for both KANUPP and C-1.

5.2.2 Operation

Pakistan has also adopted the latest IAEA safety requirements in operation [23] as its operation regulation [24]. Currently, operation of KANUPP as well as of CHASNUPP-1 is proceeding unhindered, and "safety in operation regime" is not too demanding as in design, (see Section 5.2.1). Additionally, at CHASNUPP-1 efforts are being made to incorporate SEOPs.

5.2.3. Establishing nuclear safety framework

Currently, the Pakistan Nuclear Regulatory Authority (PNRA) has issued regulations dealing with NPPs, on: (1) Siting, (2) Design, (3) Quality Assurance, and (4) Operation. Since this is a recent phenomenon, there are provisions in the regulatory framework that the latest US NRC regulations / guides be deemed as alternative. However, the licensee may choose another country's approach provided it is able to fully satisfy PNRA, the regulator. In order to strengthen and harmonize the regulator and utility relations, the Pakistan Atomic Energy Commission has created a Directorate of Safety (DOS) at a corporate level. The DOS is acting as "internal safety auditor", the focal point for interaction with PNRA and also a TSO.

i. Convention on nuclear safety

Pakistan signed the CNS in 1994, and ratified it in 1997. Pakistan submitted to CNS, its 3rd National Report on NPPs safety issues, which was reviewed in early 2005. The report was reviewed thoroughly by the convention participants. Among the many questions raised (written and oral), no questions of safety significance were asked. This is an indication of the high priority accorded to nuclear safety in Pakistan.

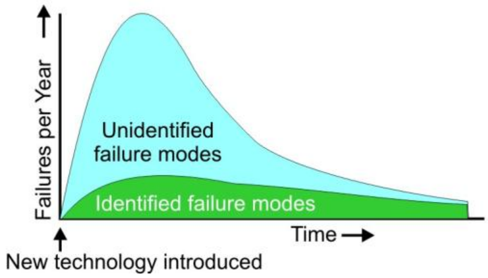

Figure 11. Typical failure trend for a new technology [14].

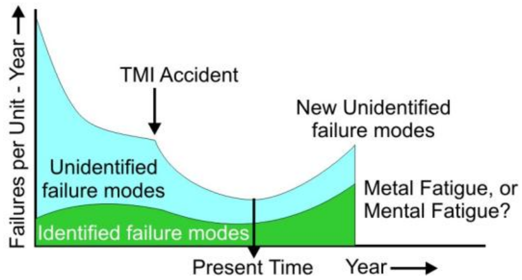

Figure 12. Typical learning from failures [14].

ii. Role of the IAEA

PNRA has followed the latest IAEA safety requirements for relevant regulations. The IAEA has conducted an International Regulatory Review Team mission to Pakistan with no findings of safety significance. The IAEA, under a Technical Cooperation project, is also providing assistance to Pakistan in reviewing the Preliminary Safety Analysis Report of CHANSUPP-2. This will not only help both the owner/utility and the regulator but also increase confidence of the international community in Pakistan's nuclear program. The IAEA is also helping Pakistan in conducting missions for operational safety, such as OSART. It is also funding several TC projects on annual basis to enhance safety.

iii Owner/Operating organization fora

KANUPP is benefiting from the cooperation with CANDU Owners Group, and sometimes World Association of Nuclear Operators. Similarly CHASNUPP-1 is also benefiting from WANO.

Iv Role of technical support organizations

Both KANUPP and CHASNUPP-1 have access to a large pool of experts, which is sufficient to meet their respective requirements. The PNRA has, moreover, just started developing its own extensive technical support organizations, in addition to those which were previously available to its predecessors.

v. Regulatory research

The US NRC, an alternative source of guidance on regulatory affairs, put considerable resources into regulatory research. We hope PNRA is gearing up to get involved in regulatory research directly as well as through its TSOs. We have identified the following major areas in this regard:

- To improve the technical analysis to review the permissible upper limit on reactor channel power both in CHASNUPP-1 and KANUPP
- Adaptation of risk-informed decision making.

6. Conclusion

Nuclear power technology has been developed over the past five decades, reaching a stage where it is now an acceptable, reliable, safe and competitive source of electricity production. Economically attractive fuels like oil and gas are insufficient to meet Pakistan's development needs. Therefore Pakistan has planned to increase installed nuclear power generating capacity to 8,800 MWe by 2030. Pakistan's track record in nuclear safety is exceptionally good. By achieving nuclear power targets and maintaining an excellent safety record, Pakistan can meet its growing energy needs.

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