WHAT SPEAKS THE SPEAKING TREE?
PERFORMANCE ANALYSIS OF KUDANKULAM REACTOR DURING ITS ONE YEAR OF GRID CONNECTION

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The VVER-1000/412 design, a third generation (Gen-III) pressurized water reactor (PWR) at Kudankulam Nuclear Power Plant (KKNPP), 98 km North-East of Thiruvananthapuram and off Bay of Bengal in Tamil Nadu state of India (8°10′08″N 77°42′45″E) attained criticality on 15 Jul 2013 and was grid connected on 22 Oct 2013. During the year, the reactor 'tripped' 14 times and was off the grid for 106 days. Two maintenance shutdowns lasted for 64 days. On 14th May 14, while in start-up mode, a pipe burst accident occurred in the feed-water system. During 4701 hours of operation, it generated 2,825 million units (MU) of electricity, consumed 538 MU for house-load and supplied 2,287 MU to the Southern Grid. The commissioning crew at KKNPP failed in all the seven attempts for clearing the final leg of the commissioning test. The reactor has been under cold-shutdown since 26 September 14 due to problems in its turbine. This study of the health of the reactor, based on daily data of generation and outages of KKNPP for one year since grid connection, shows that the situation is serious enough and warrants an independent safety audit.

1. INTRODUCTION

Ignoring the warnings from eminent scientists, the first act of criticality (FAC) was initiated at the first reactor at Kudankulam Nuclear Power Plant (KKNPP) on 15th Jul 13, 4150 days after the first pour of concrete. It was grid-connected on 22nd Oct 13. According to the initial plan, the reactor was supposed to start commercial generation on 22nd Apr 2014. This dead line was extended twice to 22nd Jul 14 and to 22nd Oct 14. As the reactor failed in the final test, it entered a long sabbatical since 25th September 14 and is not likely to be operational during the current year. The stated reason for the crisis is turbo-generator. As per media reports attributed to anonymous sources, the damaged components will be replaced with spares from the second reactor under construction at the same site. The question as to why this long-lead time equipment worth more than Rs 100 crores has been damaged during less than 200 days of operation has not been raised. In the meanwhile, according to IAEA's PRIS database (updated as on 29 Oct 2014), this reactor began commercial operation in June 2014.[1]

2. OPERATIONAL DETAILS

2.1. Station outages

Since the reactor's grid connection, the Southern Regional Load Dispatch Centre (SRLDC) has been publishing daily data of electricity generation and station outage. SRLDC reported 21 outages of KKNPP reactor. Of these, two outages for maintenances in November 2013 (for 6 days) and July-August 2014 (59 days) were planned and all others were forced outages. During the commissioning of a nuclear reactor, some tests may lead to shut downs, normally lasting for a few hours. We presume that five turbine-related outages which kept the reactor off line for a total of 580 minutes were test-

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related. During the year, the reactor worked only for 185 full (24 hr) days in 13 episodes. Reactor worked for 57 days during the first ruarter-year, 65 days during the second, 54 days during the third and 9 days during the fourth quarters. Details of work and energy delivered are provided in table 1.

Table -1:

UNINTERRUPTED FULL DAYS (24 HOURS) OF OPERATION

AND ELECTICITY DELIVERED – OCT 2013 TO OCT 2014

Episode No	From	To	Full Days Worked	Delivered Energy MU
1	25-Oct-13	28-Oct-13	4	13.28
2	10-Nov-13	01-Dec-13	22	129.86
3	11-Dec-13	26-Dec-13	16	134.75
4	01-Jan-14	02-Jan-14	2	8.45
5	16-Jan-14	28-Jan-14	13	126.44
6	09-Feb-14	17-Feb-14	9	101.05
7	27-Feb-14	28-Mar-14	30	381.16
8	06/04/14	11-May-14	36	534.12
9	16-May-14	18-May-14	3	41.66
10	28-May-14	29-May-14	2	27.44
11	04-Jun-14	09-Jun-14	6	114.77
12	15-Jun-14	15-Jul-14	31	585.5
	14/Aug	31-Aug-14	0	0
13	16-Sep-14	25-Sep-14	9	17.71
	14/Oct-14	25-Oct-14	0	0
	Total		183	2216

2.2 Shut downs and Trips

All other 14 forced outages responsible for 105 idle days (range 2 to 12) were due to events known as trip or scram in reactor engineering. US Nuclear Regulatory Commission (NRC) defines trip. “Key operating parameters of a nuclear power plant, such as coolant temperature, reactor power level, and pressure are continuously monitored, to detect conditions that could lead to exceeding the plant’s known safe operating limits, and possibly, to damaging the reactor core and releasing radiation to the environment. If any of these limits is exceeded, then the reactor is automatically shut down, in order to prevent core damage. In nuclear engineering terms, the automatic shut-down of a nuclear reactor is called a reactor trip or scram. A reactor trip causes all the control rods to insert into the reactor core, and shuts down the plant in about three seconds."[2] Too many scrams place "unnecessary strain on plant components" according to NRC spokesman Victor Dricks. The KKNPP authorities have been careful not to use this 'dirty' word in their media briefings and they named all trips as shut downs. Details of all outages due to trips and maintenances are given in table 2. While reporting the beginning of an outage, SRLDC also provides the date of anticipated revival. The actual revival was delayed further in all outages, the difference between the anticipated and actual outages was 65 days.

Table -2

KKNPP-1: OUTAGES SINCE GRID CONNECTION

Ser	Reasons	Start Date	End Date	No of Days
1	Tripped on reverse power	22/10/13	25/10/13	4
2	Feed water problem	29/10/13	04/11/13	6
3	Maintenance Work	05/11/13	10/11/13	5
4	Reactor Side Problem	02/12/13	10/12/13	8
5	TG testing	27/12/13	01/01/14	5
6	Power supply failure test	03/01/14	15/01/14	12
7	Turbine Trip	29/01/14	08/02/14	10
8	Reactor Tripped	18/02/14	26/02/14	8
9	Tripped on T-G process disturbances	29/03/14	05/04/14	7
10	Main waterfeeding pump tripped	12/05/14	15/05/14	3
11	To carry TG net load rejection test	19/05/14	27/05/14	8
12	Tripped On De-aerator Problem	30/05/14	03/06/14	4
13	Tripped Control System Problem	10/06/14	14/06/14	4
14	Maintenance Works	16/07/14	13/09/14	59
15	H/T For Exciter Diode Testing	13/09/14	15/09/14	2
16	Turbine side problem (still down)	26/09/14	25-Oct-14	30
	Total days lost			175

The SRLDC reports show that Kudankulam reactor experienced 14 trips during its 4701 hours of its operation. SRLDC data shows only those trips that happen when the generator is delivering electricity to the grid. Trips can also happen during start up, when there is a minimum of 13 hrs between the beginning of criticality and delivery of electricity to the grid. Since the grid will not register the events during the start-up, the actual number of trips may be much more than what is reported by SRLDC. As trip rates are usually calculated per 7,000 reactor hours (which is equivalent to one reactor year), the rate for KKNPP is 20.8. According to the World Nuclear Association (WNA), the trip rate is 0.37 for all the reactors in the world and 0.25 for 10 best performing reactors. Average loss of productivity per trip at KKNPP is 7.5 days as against 1.5 days for all reactors in WNA analysis. In USA a plant with 25 scrams during a 7,000-hour period is issued a "red" citation and will be forced to shut down.

2.3 Trips by system

2.3.1 Feed-water system related trips and an accident.

The three outages related to feed-water system lasted for 13 days (Table-3). Total known events within the FWS is four, including the 14 May pipe burst accident near the high pressure heater. The last three events in this system occurred during a gap of 19 days. Failure of FWS, which is part of the secondary coolant circuit can lead to depletion of water inside the steam generators. Because of its importance in reactor safety, feed-water control systems remain the center of attention for the control system experts and these are classified as systems important for safety. Malfunctioning within the FWS was the underlying cause for the Three Mile Accident of 1979. During the safety assessments performed under the IAEA's Extra-Budgetary Programme for VVER-1000 reactors, high-energy pipeline break and consequential failure of the steam- and feed-water lines was identified as a generic issue.

Table -3

Details of Feed-water system related trips

Start of outage		Expected Date Revival	Actual Revival		Difference in Expected and Actual	No of Days lost
Date	Time		Date	Time		
29/10/13	20:03	01/11/13	04/11/13	16:11	3	6
12/05/14	14:36:	13/05/14	15/05/14	16.23	2	3
30/05/14	21:11	01/06/14	03/06/14	15:04	2	4

The Safety Significance of Feedwater

Water is used as coolant in three processes in a pressurized water reactor. The primary coolant which circulates between the reactor pressure vessel and the steam generator (SG) transports the heat generated during the fissions of uranium atoms to the secondary coolant inside the SG. After running the turbine, the steam generated in SG (the secondary coolant) - now a mixture of water and steam- is cooled down in the condenser, which converts the steam to liquid state. The seawater is the tertiary coolant and it transports the waste heat (about 70% of the total) to the ultimate heat sink. The condensed steam, known as feedwater, is pumped back into the SG. Primary and secondary coolants are demineralized-deionized freshwater.

According to Pavlin Groudev and Malinka Pavlova from the Institute For Nuclear Research And Nuclear Energy, Sofia, Bulgaria, "total loss of feed water will lead to depletion of water in the Steam Generators (SG) water levels, loss of natural circulation in primary circuit and increase of core exit temperature. Following SG dryout, if there is no alternative supply of feedwater, "the core residual heat would heat the primary system water resulting in a substantial loss of water from the Reactor Coolant System. Total loss of feedwater will lead to switching off all Main Coolant Pumps (MCPs); actuation of the Reactor Protection System, signaling the drop of all control rods to the bottom of the core in four seconds." According to the IAEA, loss of feedwater, coolant and internal and external electric power supply are "Beyond design basis accident", which needs to be factored during the preliminary safety analysis.

2.3.2 Trips due to Reactor side problems

The reasons given for five trips in SRLDC report are vague or confusing. In two cases, the reasons shown are reactor side problems, without mentioning the system or sub-system involved. Reactor could mean the pressure vessel, the steam generator and the primary coolant circuit, which are parts of the nuclear steam supply system. In a broad sense, the reactor could also mean the entire system including the turbo-generator and the transformer. The reason for 10 Jun 14 trip which kept the generator off the grid for four days is given as control system problem. This happened seven days after the reactor trip due to deareator problem and less than a month after the two events including the accident (May 14). There are several control systems in the reactor related to (a) Reactor coolant (b) chemical and volume control (c) main steam line system (d) main feed-water system, (e) auxiliary feed-water system etc. Outages due to ill-defined reasons are listed in table-4.

Table – 4:

Outages Due to ill-defined reasons – KKNPP

Ser	Reasons	Start Date	End Date	No of Days lost	Difference in Expected and Actual
1	Reactor Side Problem	02/12/13	10/12/13	8	6
2	Reactor Tripped	18/02/14	26/02/14	8	6
3	Power supply failure test	03/01/14	15/01/14	12	5
4	To carry TG net load rejection test	19/05/14	27/05/14	8	4
5	Tripped Control System Problem	10/06/14	14/06/14	4	2

The reasons given for two trips which kept the reactor off-line for 20 days are power supply failure test and net load rejection test. In reality, the actual reasons would have been some defects. These tests are described below.

The Net Load Rejection Test – 19 to 27 May 2014

Nuclear power plants have been mainly seen as a base-load source of electricity. Today's reactors have to improve the manoeuvrability (load following) capabilities, to be able to adapt the electricity supply to daily or seasonal variations of the power demand. Load rejection tests are conducted to assess this manoeuvrability. The VVER-1000 version (V-392) at Kudankulam is a 3rd generation (Gen-III) reactor[3,] which must be capable of daily load cycling operation between 50% and 100 % of its rated power in about 10-15 minutes. Load rejection test can only be conducted when the reactor is grid connected and this test can be conducted several times over in a day! Forty five days after the failed attempt, the net load rejection test was successfully conducted at KKNPP on 03 Jul 2014 and the reactor was disconnected from the grid from 1638 to 1657 hours.[4]

Loss of Off Site Power Events (LOSP).

Availability of alternating current (AC) power is essential for safe operations and accident recovery of NPPs. LOSP is a simultaneous loss of electrical power to all unit safety buses, requiring the emergency power generators to start and supply power to the safety buses. LOSP events are caused by plant-related problems or by external causes that occur beyond the plant switch yard like lightning strikes, hurricanes, and transmission line faults. According to a US study of LOSP events at NPPs during 1980-96, the mean duration of outage was 85 minutes (range 2 to 1675 minutes) for plant-related LOSP and 1258 min (range 37 – 7929 min) for weather-related LOSP.[5] At KKNPP, this test is reported to have kept the plant idle for 12 days.

The underlying causes for the above trips could have been some other defects. The exact system/subsystem involved in the event cannot be known for sure from the SRLDC reports. Each trip is followed by an analysis to identify the root-cause and suggest remedial measures. At KKNPP, all such documents are properties of the Russian company Atomstroyexport, Russia and NPCIL holds them in a fiduciary capacity - even though these involve safety and right to life of Indian workers and people!

2.3.3 Trips due to Turbine-generator system defects

The turbine system was involved in five out of the 14 trips reported. The first trip immediately after the grid connection and the last one of 26 September, were due to faults in the turbo-generator. The official releases and also our analysis show that as of now, the turbine system is the weakest link at KKNPP. Alexander Uvarov of the Moscow-based nuclear think tank Atominfo said that "the Unit is at the stage of the *pre-*commissioning tests. The purpose of this stage is to check the functionality of the systems and equipment. In the course of the conducted tests some *minor* malfunctions of the turbine work have been observed. However all safety systems activated reliably and malfunction was diagnosed and observed promptly and rectification measures were elaborated in due time".[6]

According to a media reports attributed to source inside KKNPP preferring anonymity, "some component inside the turbine turned loose and damaged the turbine blades."[7] Damages to turbine from foreign particles, very frequent till the 1990's have been minimized by chemical manipulation of the secondary coolant and by control of base and weld metals for pipes and equipment in the secondary coolant circuit (SCC). The origin of the foreign particles could be any part of SCC- the feed-water system, the steam generators or the turbine system all the pipes that connect these. According to the Nuclear Threat Initiative (NTI) "a broken pump had caused small metal particles to infiltrate the Iranian Bushehr reactor's cooling system, and it was feared that the particles might have made their way into the fuel assemblies".[8] Subsequently, the reactor was de-fueled.

2.3.4 Turbine History and arrival

According to the Russian website nuclear.ru, "on February 27, 2004 Silovye Mashiny Concern steam-tested 1000-MW turbine manufactured for the Indian Kudankulam nuclear power plant under construction. This is the first of two turbines Silovye Mashiny is to manufacture for the Indian plant as part of "about USD 200 million-contract for supply of equipment"'.[9] In response to the media reports of defects in the turbo-generator, "the NPCIL official said that the Russians have, in fact, supplied an upgraded rotor in place of earlier version. The Russians actually test their turbines in a test bed to check whether it functions as per specifications before they are shipped out. ...Around 120,000 tonnes of power plant equipment have landed in Kudankulam, and during transit some got damaged. The Russians have replaced the damaged items free of cost. It is normal for technical personnel from the equipment suppliers to come to the project site and there is nothing unusual about it".[10] Erection of Turbine & Generator was completed during Sep-2008,[11] 55 months after its arrival.

Table – 5

TURBINE RELATED OUTAGES

Ser	Nature of the problem	From	To	Days lost
1	TG testing	27/12/13	01/01/14	5
2	Turbine Trip	29/01/14	08-Feb-14	10
3	Tripped on T-G process disturbances	29/03/14	05-Apr-14	7
4	Exciter Diode Testing	13/09/14	15/09/14	2
5	Turbine side problem	26/09/14	Still Out	30
	Total days lost			59

2.3.5 Media briefings on turbine generator

About the malfunctioning of the rotary engine in Nov 13, the 'sources' in KKNPP *confided* to the correspondent of a newspaper that "this is only a routine procedure as any nuclear reactor, prior to attaining commercial power generation stage, will have to undergo a series of mandatory tests, which are being conducted at KKNPP also."[12] After the January 29 turbine trip, which idled the reactor for 10 days, a senior engineer (of KKNPP) said: "turbine tripping is a normal phenomenon in a new plant when the power levels are being increased. Other maintenance activities are also being carried out while the turbine issue is being addressed."[13] In a study about the Role of PRA in the Safety Assessment of VVER Nuclear Power Plants in Ukraine for the period 1990-95, Kot and colleagues from the US Department of Energy reported 8 turbine trips, which is equivalent to 1.5 per reactor-year (RY).[14] The turbine trip at KKNPP is 4 per reactor year.

3. C3 COMMISSIONING

On 1st May 2014, AERB gave its consent for the final, C-3 commissioning tests, in which the reactor power could be raised to 90% full power (FP) from the earlier level of 75% FP. After the review of test results by AERB, "the reactor power can be raised up to 100% FP for a limited duration of time to conduct tests as per commissioning programme" and "subsequently, reactor power should be brought down to 90% FP and stabilized. Stable operation at 90% FP for at least 7 days shall be demonstrated... and after satisfactory completion of above activities, Site shall submit application for raising reactor power up to 100% FP for sustained operation and only after clearance by AERB"[15].

3.1 Seven failed attempts at C3 Commissioning

1. The site moved into C-3 phase on 3rd May, registering a peak output of 739 MW. It crossed 800 MW on 4th May and remained stagnant at around 850 MW till 9th May morning. At 1930 hrs that day, the output declined to 550 MW. After staying around this level for two more days, the reactor tripped at 14.36 hours on 12 May 14 due to 'feed water problem'. According to the Russia&India Reports, the reactor achieved 900 MW on 5th May 14[16], whereas the SRLDC report shows a maximum of 876 MW for the day.

2. By early morning of 14th May, the site thought they had solved the problem, as according to the Station Director, the reactor attained criticality in the morning. It takes a minimum of 13 hours to raise the coolant temperature level to 321 C – the temperature of the hot leg- after a cold shut down, if the reactor does not fall into an 'iodine pit'. Less than 12 hours after attaining criticality, the accident in which six workers received burns and skeletal injuries occurred at noon on 14th May. The pipe burst accident mid-way between the deaereator and the high-pressure heater (known in official circle as the 'warm-water event') has been analysed in detail earlier[17].

3. After the repair of the damaged pipe, the reactor was revived again and started generating electricity at 16.23 on 15th May. The power level rose to 775 MW on 18th May and on next day at 15.54 hrs the reactor tripped again due to "net load rejection test".

4. The reactor was brought online on 27th May. On the fourth day (30 May 14) at 1900 hrs, the reactor achieved the much awaited milestone of 900 MW. Two hours and eleven minutes later, it tripped again due to problem with the deaereator, located downstream the location of the pipe burst accident (14 May 14) in the feed-water system.

5. Revived again at 15.04 hrs on 3 June. Peak output was 331 and 702 MW on 3rd and 4th June respectively. On 8th June, the Hindu reported that the unit attained its maximum capacity of 1,000 MW at 1.20 pm. on 7th June,[18] whereas the maximum generation for the day according to SRLDC was 991 MW. Three days later, on 10th June, the maximum output of 1004 MW was registered at 0300 hrs. Fifteen hours later, the reactor tripped due to 'Control system problem'.

6. The reactor was revived on 14 Jun and registered 934 MW at 1900 hrs on 16 June and was stable for the next four days with output above 90% FP. On 20 June 14, the output dropped to 437 MW and increased to 900 MW two days later. At 1300 hrs on 16 Jul, the reactor was shut down for long-time maintenance lasting for 59 days. This was in response to the turbulence of the system during the 25 days between 22 June and 16 Jul when the generation was below 90% FP MW on 12 days.

7. The generator came on line at 16:57 on 13 September 14, after the 59 day-long maintenance. Three and a half hours later, it tripped and vanished for two days for exciter diode testing. It came on line at 10:10 on 15 September 14 and recorded a maximum generation of 309 MW at 22:29 hrs. During the next 12 days, it could not reach the 900 MW mark, the highest achievement was 850 MW on 21 September 14. According to Alexander Uvarov of the Moscow-based nuclear think tank Atominfo, the generator “faced 830 MW inclinations of certain operating figures of the turbo-alternator”. The reactor tripped again on 27th September. The expected date of revival was 06 October, which has been extended to the end of the year.

Between the beginning of the C-3 phase on 5th May 14 and 25 Oct 14 (173 days) the reactor’s operation was punctured by 5 trips and one 59 day long maintenance. Since the final leg of the phase requires uninterrupted generation of 900+ MW for 7 days, this could have been done only during 15 June to 15 Jul 14. The generator was extremely turbulent during this period:

- After staying at 90%+ MW level during 17 to 19 June 14, the output dropped to 437 MW at 1900 hrs on 20 Jun 14.
- 90+% FP was achieved on 22nd and 23rd June and dropped to 556 MW on 24th June.
- 991 MW was generated on 27th June, dropped to 453 on 28th June. For the next 9 days, reactor could not reach 90%FP.

We studied the differences between the generations at three time points of the same day during 20 June to 6 Jul 14. On 12 out of 17 days in this analysis, the fluctuations within the same day ranged from 115 MW to 615 MW. Of these, the fluctuation was between 100-200 MW on three days, 200-500 MW during six days and above 500 MW on three days.

4. COMPARISON OF KKNPP REACTORS WITH OTHER SIMILAR REACTORS

4.1 Generation-III reactors

The reactors currently under operation and construction have been classified into four – Gen 1, Gen-2, Gen-3 and Gen 3+. This classification is done by Electric Power Research Institute (EPRI) Utility Requirement Document (URD) in USA and the European Utility Requirements Forum (EUR), a consortium of vendors in Europe. Most NPPs in operation today built in the 1970s and 1980s belong to Generation II type, as they are based on the experience gained with the Generation I plants built in the early days. Construction of Generation III NPPs was started in the early 1990s. According to the industry, Gen-3 reactors are based on advanced designs featuring improved safety and economics. A list of gen-III reactors now under construction/operation is given below:[19]

Table 6: Gen-3 reactors under construction/operation

Reactor[1]	Developer(s)	Net Electric Output (MW_e)	Type[2]	Status
ABWR	General Electric, Toshiba, Hitachi	1315	BWR	Start of operation in Japan, 1996
ESBWR	General Electric Hitachi	1333	BWR	Design certification on-going in the United States
AES-92	Gidropress	1000	PWR	Start of operation in India, 2013[3]
AP1000	Westinghouse	1117	PWR	In construction. Start of operation in China, 2013[3]
APR-1400	Korea Hydro & Nuclear Power	1350	PWR	In construction. Start of operation in South Korea, 2013[3]
APWR	Mitsubishi	1600	PWR	In construction. Start of operation in Japan, 2016[3]
EPR	Areva	1600	PWR	In construction. Start of operation in China, 2013[3]
ACR-1000	Atomic Energy of Canada	1082	PHWR	Design certification on-going in Canada. Start of operation in 2016[3]
EC6	Atomic Energy of Canada	690	PHWR	Design certification on-going in Canada

[1] AP1000 is a trademark of Westinghouse Electric Company, LLC; APR1400 is a trademark of Korea Hydro & Nuclear Power Company; EPR is a trademark of the Areva Grou
ACR-1000 and EC6 are registered trademarks of Atomic Energy of Canada Limited.
[2] BWR, boiling water reactor; PWR, pressurized water reactor; PHWR, pressurized heavy water reactor.
[3] Expected.

EUR Forum certified the VVER-1000 AES-92 reactors as Gen-III in 2006, showing KKNPP reactors which were in their mid-stage of construction, as the prototype. The main document presented in the proceedings for this classification by the Russian design organization Gidropress was a paper by SK Agarwal et.al, published in the the journal Nuclear Engineering International.20

According to Steven C. Sholly, of the Institute of Safety/Security and Risk Sciences, University of Natural Resources and Life Sciences, VIENNA, KKNPP reactors are among half a dozen Gen-3 PWRs under operation/construction.[21] According to an advanced review published in the journal Energy Environment (2013), AES-92 (VVER-392) has a core damage frequency (CDF) of 6.2x10-7 reactor years.[22]

In their 2006 paper, Agarwal et al had underlined that the pressure vessel KKNPP reactors did not have weld joints in its beltline and its core damage frequency was less than one in a million years. Two years after publication of this paper, the AERB revealed that the RPVs received by KKNPP from Russia had four welds on its beltline. According to the NPCIL, "the estimated CDF of the KKNPP reactor is 10^{-5} reactor years and the design service life is 30 years for the reactor and 40 years for the RPV"23.

4.2. Gen-III certification of VVER-392 Reactor – An international fraud

The reactors with welds on the beltline of pressure vessel and a CDF rate of 10^{-5} reactor years do not qualify to be considered as a Gen-3 by the industry's definition. Incidentally, the reactor pressure vessel for KKNPP-1 had arrived the Indian site, months before Agarwal et.al submitted the revised draft of their paper. It appears that the NPCIL opened the consignment only after the EUR proceedings.

There are a couple of questions which may haunt the nuclear establishment in India and Europe. These are:

(a) What was the purpose of the publication of this paper, which was essentially based on the database of Gidropress by engineers (not academics) employed by NPCIL?

(b) Why there was a delay of several months for pointing out the features of the received RPV and also recalculating the CDF of the reactor?

(c) Why the West European Nuclear Regulators Association (WENRA) and the US Nuclear Regulatory Commission (NRC) do not recognize AES-92 (VVER-392) as a Gen III reactor?

The proponents of nuclear energy argue that besides being inherently safer than the earlier versions, Gen3 reactors are eco-friendly as they consume less uranium and other resources and are more economical due to lower construction time and higher availability factor. Here, we will examine if the KKNPP reactor meets any of these criterion. Incidentally, all the reactors which fare better than KKNPP listed in the international comparisons belong to Gen-2.

The European Utility Forum certified VVER-392 as a Gen-3 reactor on the basis of an academic paper. The owner of the only completed Gen-3 VVER reactor has correctly described the features of the reactors and it is clear that it does not qualify to be considered as Gen-3. Moreover, we also have the construction/commissioning milestones of the reactor. Will the EUR Forum reconsider their 2006 decision? And what about the purchase decisions which could have been influenced by this unfair practice? Milestones of KKNPP and other reactors in the world are given below.

4.3 Construction milestones

Major construction milestones of six 1000 MW pressurized water reactors commissioned during the past decade is shown in table 7. Days between the first pour of concrete and commercial commissioning of KK is more than two and a half times that of the Chinese reactor, Shin Wolsong.

Table -7

TIMELINES – OTHER 1000 MW(E) REACTORS COMMISSIONED AFTER 2000

Ser	Reactor Name	Country	Date of Commercial Operation	Number of days for				
				FPC -IFL	IFL-FAC	FAC-GC	GC-CO	FPC-CO
1	S. Wolsong 1	S. Korea	31/07/12	1473	35	21	186	1715
2	Hanul -5	S. Korea	29/07/04	1461	58	20	224	1763
3	Hongyanhe-2	China	06/06/13	1927	51	32	109	2119
4	Tianwan -2	China	16/08/07	2353	61	13	94	2521
5	Tianwan -1	China	17/05/07	2190	63	143	370	2766
6	KKNPP-1	India	31/12/14	3868	286	99	435	4688

4.4 Productivicity during commissioning

Four other 1000 MW pressurized water reactors -Hongyanhe (China), Kalinin-3 & 4 and Rostov-2 -(Russia) commissioned during the past 10 years had a gap of 250+ days between the grid connection and the commercial production. According to International Atomic Energy Agency's PRIS database, Kudankulam reactor's productivity is less than half of other three Russian reactors. (see table-8)

Table – 8

GENERATION STATISTICS BETWEEN GRID CONNECTION AND

COMMERCIAL OPERATIONS VVER-1000

Reactor	Country	Capacity Mw	Grid Connected	Commercial Operation	Total Days *	Million Units **	MU per day
KKNPP	India	917	22/10/13		365	2287	6.3
Kalinin-3	Russia	950	31/12/04	08/11/05	365	4346	11.9
Kalinin-4	Russia	950	24/11/11	25/12/12	365	5166	14.2
Rostov-2	Russia	950	18/03/10	10/12/10	288	4304	14.9
Hongyanhe	China	1061	17/02/13	06/06/13	318	5683	17.9

http://www.iaea.org/PRIS/CountryStatistics/ReactorDetails.aspx?current=75

http://www.iaea.org/PRIS/CountryStatistics/ReactorDetails.aspx?current=904

4.5 Trip rates – KKNPP and Global

Can the trips and the problems which led to long term maintenances and the accident experienced at KKNPP-1 be considered as the normal birth pangs of a reactor? During the 4701 hours of its operation, it experienced 14 trips which is equivalent to 20.8 per 7000 reactor years. This more than 30 times the trip rates reported during the past two decades. A comparison of trip rates of KKNPP and other reactors are given table-9.

Table 9

TRIPS PER 7000 REACTOR HOURS – KK AND GLOBAL

Total reactor hours -	4701
No of trips KKNPP	14
Trips per 7000 hrs PWRs France 2013	0.60
Trips per 7000 hrs PWRs USA 2004	0.80
Trips per 7000 hrs Best performers – World Nuclear Association	0.25
Trips per 7000 hrs All reactors – WNA	0.37

5. DISCUSSION

5.1. Counterfeit equipment and nuclear safety

A study by an international team of authors based on official documents from the Atomic Energy Regulatory Board (AERB), NPCIL and their Russian counterparts had concluded that major equipment like the reactor pressure vessel (RPV) and the polar crane are obsolete and counterfeit.[24]. The study also reveals that the polar crane, a safety related equipment has only 80% of its name-plate capacity. Several equipment rendered surplus due to post-Chernobyl and post-Soviet cancellation of over 25 VVER-1000 reactors have been incorporated in Kudankulam, China, Iran and also in Russia's Kalinin and Rostov power stations.

During the first decade of this century, Russia's nuclear manufacturing complex and the design organization were under the grip of the Russian underworld. The following statement from the umbrella organization of all firms under the Rosatom is relevant for nuclear safety in Russia's clients including India. "In 2011, a case of large-scale fraud regarding the inferior quality of a supplied raw materials for the products produced at OJSC ZiO-Podolsk was uncovered during 2011. The Procurement Director, "turned a blind eye" to the quality of incoming steel was taken into custody. The case of fraud was exposed as a result of quality examination at the NPP Kozloduy (Bulgaria) upon acceptance of the equipment supplied by OJSC ZiO-Podolsk".

Quality of equipment manufactured during the last decade has been in doubt, also due to large scale corruption cases within Russia's nuclear manufacturing complex. Even the main design organization of nuclear reactors and warheads -OKB Gidropress – was affected. The AEM-Group, an umbrella organization of all nuclear production companies in Russia admits the crisis in their organization: "At the end of April 2012, the Interior Ministry instituted a criminal case against the management of OJSC OKB Gidropress for "large-scale fraud". During 2011, the Director of OJSC OKB Gidropress is suspected to have "signed a 26 million RUB contract for the implementation of a number of works related to the design of the nuclear power plant elements with a third-party commercial organization, which deliberately had no intention to carry out the contract. The criminal scheme was uncovered during the internal audit held by specialists from the Rosatom economic protection department. On April 13, 2012 the OKB Director (being also the part-time chief designer) and his Deputy for Information Technology were detained".[25]

Besides designing reactors, Gidropress also manufactures several items of I&C System. An important safety related item- control rod drive mechanism, which facilitates smooth fall of control rods during a trip – manufactured by Gidropress was found defective at KKNPP. The item was replaced in Feb 2013, months after the loading of dummy fuel in the second reactor.[26]

5.2 Kanyakumari meet of VVER Regulators

The 20th annual meeting of the nuclear regulators from countries with VVER reactors was held at Kanyakumari on 11-13 Dec 2013. The participants reported on the most significant safety-related occurrences in operation of the nuclear power plants with WWER reactors. During a brief period of 50 days of grid connection, the AERB scientists had rich experience of four trips and probably many more transients, which did not lead to trips. AERB Secretary R. Bhattacharya told a news agency that "regulators who attended the conference submitted a report on the VVER reactors in their countries. India too submitted its report. The reports are not public. The reports basically deal with policy related aspects".[27] The Russian regulator, Rostechnadzor (RTN) reported a few serious problems they encountered in Balakov and kalinin reactors. Details of these problems and remedial actions (replacement of defective items by manufacturers) taken are available on the web.[28]

On 11 Dec 13, The Hindu reported that a "team of Russian scientists reached Thiruvananthapuram airport on Tuesday, and came to Kanyakumari by road amidst tight security" (*sic*) and the "experts of the AERB would hold talks with them "on a range of issues"[29] .*(emphasis ours)* On the same day, the paper also published a report from the Press Trust of India (PTI) quoting official sources that senior officials of DAE and AERB Chairman visited KKNPP on Wednesday, "but they are not here for the first unit. The sources declined to comment on the purpose of the visit."

5.3 Other safety issues in a nutshell.

Several safety related issues have been raised against Kudankulam nuclear campus. The site selection committee did not consider the cases of four small volume volcanic eruptions, two events of karst and other geologic anomalies during the past two decades, within less than 50 km from the reactor on the NE-SW trending fault line which is known be undergoing reactivation.[30] The risk of tsunamis from the tectonic anomalies within the Gulf of Mannar has also not been addressed. The campus which is wholly dependent on desalination for its fresh water supply has only reserves for one and a half days only. If two of the desalination plants trip for a long period, the reactors will also have to be shut down.[31] Earlier studies have revealed deficiencies and defects in safety equipment like polar crane and reactor pressure vessel. To cap it all, the primary and secondary containment walls were broken and re-sealed to accommodate the missing cables.

6. CONCLUSION

At this juncture of their

biggest crisis, Rosatom and NPCIL are trying to underplay the turbine trouble, besides trying to limit the crisis to the TG system. Though the T-G is blocking the reactor from operation, other systems also experienced problems during 180 days of operation. The total collapse of the quality assurance regime of NPCIL-AERB is a well-known issue. Gopalakrishnan commented that: “the fact that a high-cost, high-risk nuclear reactor is facing defects and deficiencies in its components and equipment even before it is started up is highly unusual, and this indicates gross failures at several levels in the DAE-AERB-NPCIL-ASE combine. If designs have been checked and followed , procurement of materials and fabrication have been done as per technical specifications, testing and quality control at the manufacturer's shops were comprehensive, and NPCIL's Quality Assurance (QA) before acceptance of supplies at site were strictly as per nuclear norms, these problems could not have arisen at the commissioning stage.[32]

Dr BK Subbarao, nuclear physicist who had designed a pressurized water reactor for Indian Navy's nuclear submarine had written a year ago that “the substandard components allegedly supplied by a Russian Company for the KKNPP caused the Nuclear Plant to become a Speaking Tree. What it speaks now contains salient lessons for India and Russia for the good of people of both the countries.”[33] Since her marriage with the grid, Gen-3 has spoken for 4701 hours in 14 episodes, asserting that being a Russian, she is not bound by the confidentiality clause in the Indo-Russian agreement. She spoke for 56 days during the first ninety days and only 11 days during the last quarter. Her eloquence is being replaced by silence. The first outage at KKNPP was due to reverse power, a condition in which the generator which is supposed to produce and supply electricity to the grid behaves like a motor– a consumer, and draws electricity from the grid.

The KK- commissioning crew is battling with an un-tamable machine which has failed to meet the deadline repeatedly for over a year, risking their own and their dear ones' lives. Unmindful of this ground reality, the top brass of NPCIL and Rosatom are negotiating the deal of the fifth and the sixth reactors at Kudankulam site. For them, the problem is only a minor one, limited to T-G system alone and they hope to solve it by borrowing the turbo-generator from reactor No 2. There were nine trips and a serious accident caused due to defects in other systems. The safest thing to be done at this juncture is to suspend the commissioning drill and remove the fuel from the reactor core and keep the irradiated assemblies in the spent fuel pool. This will have to be followed by a safety audit by a team of international scientists with representation from civil society and a thorough financial audit by the Comptroller and Auditor General of India. Kudankulam has all the ingredients for a perfect disaster, a global catastrophic risk, which could break the record of all previous nuclear nuclear disasters. This can be prevented if there is political will.

The authors are independent analysts working on nuclear safety and other environmental-health issues.

Post-script

The Commander of the KK-commissioning crew and the Station Director and their team of scientists, engineers and technicians have all experienced emergencies lived through by a senior reactor operator in Europe during the past two decades of his services. We appreciate these brave men's professionalism, courage and commitment to nuclear safety, which has saved the planet from a major nuclear disaster.

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