THE MYSTERY OF A REACTOR DISAPPEARANCE:

SAFETY ISSUES AND GEN-III NON-COMPLIANCE OF AES-2006 VVER 1000 REACTORS IN FINLAND

VT Padmanabhan, R Ramesh, Joseph Makkolil

Society of Science Environment and Ethics (So-SEE)
Karippai,Western Bazaar
Aranattukara, Thrissur
Kerala, India - 680616

Email: soseekerala@gmail.com
vtpadman@gmail.com

Synopsis

Finland's parliament has recently approved a joint venture with Russia to build a VVER 1200 MWe, design AES-2006 pressurized water reactor which according to the vendor 'complies with the IAEA and EUR requirements' of a generation-III (Gen-III) reactor in northern Finland. However, design AES-92, which was certified as Gen-III in 2007, is missing in the genealogy of AES-2006 given in a presentation by the vendor, Rosatom. We propose that there are strong reasons to believe that this disappearance is due to the dismal performance of the AES-92 reactors at Kudankulam (KK) in India. KK Reactor I took about 12 years for construction and failed in the commissioning tests seven times. AES-92 received Gen-III certification in 2007 on the basis of fictitious and fabricated data. Since neither AES-2006, nor any other design in the pedigree, has undergone the Gen-III compliance test, the vendor's claims are contentious. Considering the substandard performance of AES-92 reactor at Kudankulam since its grid connection in October 2013, its Gen-III certification needs to be canceled. It is mandatory that the vendor will also need to prove the Gen-III compliance of AES-2006 before going ahead with the ongoing deals in India, Finland, Vietnam and Bulgaria.

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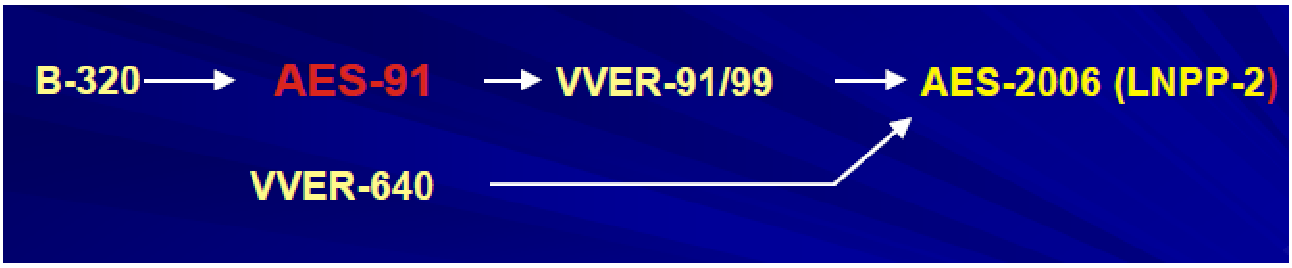
1. Introduction

Nuclear vendors and utilities claim that the so-called generation-III (Gen-III) fission reactors are inherently safer, more economical and eco-sensitive than the earlier designs. Gen-III certification of reactors is done on the basis of drawings, designs and probabilistic safety analysis reports (PSAR)- on virtual reactors and not on the real ones. Dr. Helmut Hirsch, Scientific Consultant for Nuclear Safety from Germany states that "reactor types of Gen III with more innovative features exist – but only on paper, so far".[1] In this article, we will chart out the genealogy of the AES-20056 reactor, the history of EUR (European Utility Requirement) certification process of AES-92, performance of the real AES-92 reactor at Kudankulam Nuclear Power Plant (KKNPP) in India and the attributes of its predecessor AES-91 reactor under operation in China since 2007. We will demonstrate that the reason for the deletion of the AES-92 reactor design from the AES-2006 genealogy is the real-world underperformance of the only AES-92 reactor at KKNPP.

2. Finland-Russia Deal and Falsification of the Genealogy of Reactor

The Finnish Parliament has recently approved a joint venture by the Finnish consortium, Fennovoima and the Russian energy firm, Rosatom for construction of a Gen-III reactor (design AES-2006) at the Pyhäjoki site in northern Finland. This is the latest design Water-Water-Energy-Reactor (WWER), which is the Russian equivalent of the Pressurized Water Reactor (PWR). Construction is expected to start in 2015. In a power point presentation, entitled "Introduction to the AES-2006 NPP design intended for Loviisa", Vitaly Ermolaev, Technical Director of Marketing and Business Development Department of the Atomstroyexpert (ASE) describes the main features and backgrounds of the reactor.[2] All the 42 slides in the presentation have a prominently displayed footer "AES-2006 INTENDED FOR LOVIISA", which indicates that the presentation is an education materials aimed at the Finnish people. The following diagram showing the evolution of the Russian VVER-1000 reactor is from a slide that appears three times in their presentation.



There is a missing link – AES-92, which is the first and the only 'certified Generation-III' VVER reactor. Besides, there are far-fetched claims on the features of AES-91, the 'parent' design of AES-92.

3. VVER- Design Development in Russia

3.1 AES-91 and AES-92

The standard design of 1000 MW pressurized water reactor (VVER) is V-320 and its prototype is in the Balakowa Plant in Russia. The Russian Federation has been working towards EUR certification for VVER-1000 reactors since the 1990's in co-operation with the Finnish, German and French experts. This resulted in AES-91 design (VVER-1000/V-428) reactor which was sold to China in 1997. Its improved version AES-92, with more passive safety features, was developed for India. “The AES-92 incorporated what one Finnish nuclear expert called 'radically simplified' plant systems that included active safety systems, a reduced-power reactor core, and a double containment structure surrounding the nuclear reactor.”[3] Construction licences for AES-92 were issued by the Russian regulator GAN and the Indian regulator AERB in April 1999 and March 2002 respectively. The construction of two reactors in India started at KKNPP in 2002 and they have not even been commissioned so far. These are the only reactors of AES-92 design worldwide.

3.2 AES-2006

AES-2006 (also designated as VVER-1200), with a thermal output of 3300 MW and net electric output of ~ 1200 MW, was developed within the framework of the Federal Target Program: “Development of nuclear power industry in Russia in 2007-2010 and up to 2015”. The stated design improvements are (a) preferential use of passive safety systems for 'Beyond Design Based Accident' (BDBA) management, (b) location of water storage tanks inside the containment and (c) plant independency (operation irrespective of power supply sources) during a 72 hour period. (*Ref 2*) According to the designer Atomproect, the references for the AES-2006 design are “NPP with VVER-1000/428 and NPP-91/99 for the tender in Finland, updated based on the experience of operating power units VVER-1000/320 and on the design solutions of NPPs with VVER-640 and *AES-92*.”[4] In an external review of AES-2006, J. G. Marques stated that the “the inner vessel diameter of the AES-2006 will be 10 cm larger than the one of the AES-92.”[5] The World Nuclear Association (WNA) also underlines the role of design AES-92 in the evolution of the AES-2006 plant: “It is an evolutionary development of the well-proven VVER-1000 in the AES-92 and AES-91 plants.”[6] The genealogy of AES-2006 is given below:

REAL REACTORS — VIRTUAL REACTORS

V320 ---→ AES-91---→ AES-92 --→ VVER-91/99 --→ VVER-640 --→ AES-2006

4. Certification of reactors

After the accidents of Three Mile Island (1979) and Chernobyl (1986), the US Electric Power Research Institute (EPRI) started working on the utility requirement document (URD) – a technical foundation for the design of advanced PWR and BWR. It provides a set of plant functional requirements, primarily for nuclear utilities in USA. The URD is claimed to be 'one of the base documents for the newest generation of nuclear plants'. The URD classifies the reactors into three generations (Gen-I, Gen-II and Gen-III.)[7] More than 97% of all the commercial reactors in the world belong to Gen-II.

4.1 Certification in Europe

The European Utility Requirements (EUR) Club, a consortium of operators and vendors in Western Europe set up in 1991, has been working on a URD for Europe. The EUR URD document is structured in four volumes. The reactors that comply with Gen-III requirements are listed in volume 3, *Application of EUR to Specific Designs*. As of 2014, the volume has eight subsets, including one for AES-92, each dedicated to a specific design, which "includes a description of the design and an analysis of compliance vs. the generic requirements." The document contains detailed design information provided by the vendor and answers to hundreds of questions raised by the utility experts. Certification takes 2 to 3 years and 3 to 5 man-years of a team of engineers from the EUR, the utilities and the vendor.[8] The following pressurized water reactors have been certified by EUR as compliant with Gen-III requirement.

Westinghouse European Passive Plant	December 1999
KERENA (SWR-1000, the predecessor design)	February 2002
VVER AES 92	June 2006
Westinghouse AP1000	June 2006
AREVA EPR	Dec 1999 & June 2009

4.2 Criteria for Generation-III reactors

The main criteria used for assessment of reactors are listed below. Of these, as detailed by Stephen Solly, the core damage frequency is not a dependable index of the reactor's health.[9]

- A design service life of 60 years compared with 30-40 years of Gen-II reactors,
- Lower likelihood of severe accidents, with *core damage frequencies (CDF)* ranging from 4.2×10^{-7}/a to 2.5×10^{-6}/a,
- Improved fuel technology and thermal efficiency,
- Passive safety systems,
- Standardized design,
- Improved capabilities to manage severe accidents,
- Reduced construction time – less than 60 months.

4.3 AES-92 and Gen-III Certification by EUR

The developments inside the design laboratories of Russia were not known to the outside world until the 2000s. Construction of AES-92 reactors at Kudankulam started in March 2002. Key documents like the detailed project report (DPR) and preliminary safety analysis report (PSAR) are still treated as confidential. There was no independent review of anything that was developed inside the atomic complex. The first description of the AES-92 reactor was provided by a senior official of the Nuclear Power Corporation of India (NPCIL), SK Agarwal and two of his colleagues in an article published in 2006 in an international journal, *Nuclear Engineering Design*. The article was based solely on data supplied by the designer, Gidropress, as part of the Rosatom-NPCIL deal. One wonders as to why the designers did not write the paper.

In 2005, Rosatom submitted its application for EUR certification, showing the two Kudankulam reactors as the prototype. The paper by Agarwal *et al* which revealed that the KKNPP's reactor pressure vessel (RPV) "has *no weld joints in the core region*" and the reactor's CDF is "10^{-7}/reactor-year"[10] was also part of the documentation submitted. In the concluding EUR seminar in Milan in May 2007, AES-92 was certified as complying with the EUR requirements for Gen-III reactor.[11]

4.4 Equipment Defects in the AES-92 Reactors at Kudankulam, India

The reactor pressure vessel (RPV), known as the heart of a reactor, determines both the safety and the life time of a reactor. RPVs of Gen-II reactors had welds on the beltline (around the middle portion), which increases the risk of RPV failure, leading to release of radioactivity to the environment. RPVs of Gen-III reactors are claimed to have no weld. According to the West European Nuclear Regulators' Association (WENRA) "the main safety concern regarding the VVER-1000 plants lies with the quality and reliability of individual equipment, especially with the instrumentation and control equipment. Also the embrittlement of the reactor pressure vessel needs continuous attention and action will need to be taken if it approaches a hazardous level."[12]

The RPV of the first reactor arrived at Kudankulam in India in January 2005. NPCIL requested Rosatom to speed up the delivery of the RPV for the second reactor which was received in India in June 2005. The RPV was installed inside the first reactor in April 2007, two years after its arrival. A year after the erection, in 2008, the Atomic Energy Regulatory Board (AERB) revealed that "the KKNPP RPV has welds in the core region"[13] and in 2011, the NPCIL announced that the reactor's "core damage frequency is 10^{-5} /reactor-year and its life time, 30 Yrs (40 yrs for RPV)."[14] In other words, the real reactor was 100 times more unsafe than the virtual one described in the paper and certified as Gen-III by EUR.

NPCIL's quality assurance (QA) team, camping in St Petersburg since 2002 should have seen the welds of the RPV well before Agarwal *et al* wrote the first manuscript. RPV had arrived at the site well before the final revision of the manuscript (26^{th} September, 2005). The first author was in the Indian team that negotiated the deal with Rosatom and was also the Station Director of the site. He had access to confidential documents like the DPR, the PSAR and the inspection reports. It is a mystery that the authors did not refer to the inspection reports before describing the equipment. India did not complain to the vendor or inform the EUR Club about the equipment defects. The issue of counterfeit equipment at KKNPP, reported earlier[15] has a whole catalogue of such discrepancies which warrant serious attention by experts as well as the broader civil society.

4.5 Real-world Performance of AES-92 Reactor

The URD classification of all reactors is based on drawings, designs and probabilistic safety assessment reports and not on the actual performance of the real reactors. There is no Gen-III PWR under commercial operation anywhere in the world. The reactor at KKNPP in India was fuel-loaded 12 years after the first pour of concrete as against the vendor's claim of six years made before the EUR assessment team. Milestones for six 1000

MWe reactors commissioned during the past 10 years are given in table 1.

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

Ser	Reactor Name	Country	First Pour Concrete	Initial Fuel Loading	First Act Criticality	Grid-conn-ection	Commer-cial Opera-tion	FPC IFL	IFL-FAC	FAC-GC	GC-CO	FPC-CO
1	S.Wolsong 1	S. Korea	20/11/07	02/12/11	06/01/12	27/01/12	31/07/12	1473	35	21	186	1715
2	Hanul -5	S. Korea	01/10/99	01/10/03	28/11/03	18/12/03	29/07/04	1461	58	20	224	1763
3	Hongyanhe-2	China	18/08/07	26/11/12	16/01/13	17/02/13	06/06/13	1927	51	32	109	2119
4	Tianwan -2	China	20/09/00	01/03/07	01/05/07	14/05/07	16/08/07	2353	61	13	94	2521
5	Tianwan -1	China	20/10/99	18/10/05	20/12/05	12/05/06	17/05/07	2190	63	143	370	2766
6	KKNPP-1	India	01/03/02	02/10/12	15/07/13	22/10/13	22/10/14	3868	286	99	365	4618

FPC = First Pour of Concrete. FAC= First Act of Criticality GC = Grid Connection CO = Commercial Operation

(The last column gives the number of days between the first pour of concrete and commercial operation. 4618 days shown for KKNPP is based on the assumption that it will be commercially commissioned on 31 December 2014 which is unlikely.)

During the 14 months of its grid connection in October 2013, KKNPP- I worked for only 4701 hours. All the seven attempts to clear the final commissioning tests failed. The reactor has been lying idle for more than half the time due to serious problems in different reactor systems. During the first 10 months of its grid connection, the reactor experienced 14 scrams due to the problems in the feed-water system, the reactor and the turbine-generator.[16] There was also a serious pipe burst accident in the feed-water system, leading to the hospitalisation of workers with serious musculo-skeletal and burn injuries.[17]

4.6 Core Damage Frequency (CDF) of AES-91 Reactor in China

In the Ermolaev presentation, the average core damage frequency for internal initiating events for the AES-91 reactor in China is 3.4 per million reactor years ($3.39x10^{-6}$a) (*Ref 2*). In a paper presented at the NEA/CSNI Workshop (Paris, in June 2011) on PSA for New and Advanced Reactors, Bo Z of the Chinese Nuclear Agency, says that the CDF of

Table -2 : Core Damage Frequencies of Select reactors

– Olkiluoto Units 1 & 2 (Asea-Atom BWR) (STUK, 2010)[18]	$1.3×10^{-5}$ /a
– Temelín 1 & 2 (VVER-1000/320) (Czech Republic, 2010)	$3.3×10^{-5}$ /a
– VVER-1000/320 PWRs in Russia, low end (Rosatom, 2010)	$4.4×10^{-5}$ /a
– D.C. Cook (Westinghouse 4-loop PWR) (I&M, 2003)	$4.8×10^{-5}$ /a
– Loviisa Units 1 & 2 (VVER-440-213 with containment)	$6.0×10^{-5}$ /a
– South Ukraine- 1 (VVER-1000/302) start up 1982	$6.0×10^{-6}$ /a

Tianwan reactor is 13 per million reactor years ($1.3×10^{-5}$/a).[19] CDF for select reactors are given in table 2: (*Ref 9*)

The CDFs of the Chinese Tianwan (AES-91) reactors and the Finnish Olkiluoto reactors are similar. The former is only marginally better than the VVER-440-213 reactors at Lovisia in Finland. At the same time, the CDF of VVER 320 at South Ukraine which was grid connected in 1982, is two times lower than that of AES-91. In short, the AES-91 reactors at Tianwan, China are comparable to the Gen-II reactors worldwide. The only difference is the availability of a core catcher below the Tianwan reactors. The core catcher does not reduce the chances of core meltdown; it only mitigates it – theoretically.

The designer of the AES-2006 reactor, St Petersburg Atomenergoproekt (SPAEP), a Rosatom affiliate, makes even taller claims on the performance of the Tianwan reactor. Performance details given in a brochure[20] and from data published by IAEA PRISM[21] are given in columns 2 and 3 of table below:

Table 3: General Parameters of Tianwan Reactor
According to Rosatom and IAEA PRISM

Parameters	**SPAEP**	PRISM
Guaranteed net power output MWe	1007	933
Effective number of hours (nominal power/year)	7900	7278
Overall availability factor	92%	83%

5. **Summary**

Of the six reactors in the family tree of AES-2006, the first three are real. Of these three real reactors, AES-92 has worked for 4,701 hours during 13 months and were made idle due to scram and defects for more than half of this period. The performance of the second real reactor, AES-91, has not been any different from an average Gen-II VVER reactor. Similarly, the overall performance of V-320 reactors has not been better than other PWRs. The real AES-92 reactor lying idle in India is nowhere near the "radically simplified" virtual model, and the first largest technological marvel, created by the finest minds from the Soviet Union/Russia and France, Germany and Finland. We have no evidence against the design, but even the designer will refuse to buy the real AES-92 reactor at Kudankulam for half its price.

REAL REACTORS   VIRTUAL REACTORS

V320 ---→ AES-91---→ AES-92 --→ VVER-91/99 --→ VVER-640 --→ AES-2006

So, the family tree of AES-2006 has two real, one still-born and three virtual reactors. The Rosatom has deleted the still-born AES-92 design from the family for reasons based on their 'non-performance' at Kudankulam. None of the remaining reactors, the real ones and the virtual ones, has been subjected to any independent assessment. The performance of AES-91, presented by the vendor is fictitious. Hence, the claim that AES-2006 is a Gen-III reactor has not been validated. The following assessment of VVER-1000 reactors by WENRA is equally applicable for AES-2006:

> "The VVER-1000 plants were designed to similar safety requirements as Western plants and have equivalent safety systems. However, compared to the VVER-440/213 plants, the overall safety level of the VVER-1000 plants seems to be lower. The reason is that the higher power VVER-1000 plants have lost nearly all the inherent safety features of the smaller VVER-440 plants."[22]

In response to the proposed Ostrovets NPP in Belarus, the Belarusian Anti-Nuclear Campaign had correctly pointed out that AES-2006 is "an as-yet untested design" and "the known incidents and deficiencies in the operation and construction of Russian-built NPPs in Russia, Iran, and China" [as well as the containment building collapse at Leningrad on 17th July 2011] "are evidence that Rosatom and its structures have serious problems of a systemic nature and cannot guarantee the quality of their sites."[23]

6. Conclusion

In 2007, Antonia Wenisch of the Austrian Institute of Ecology in a paper entitled "Mystery Reactor" asked "what exactly is the AES-92? It is difficult to get reliable technical facts about this reactor, which is not being publicly advertised by the Russian nuclear industry. There is no operational experience with this reactor."[24] Seven years down the line the mystery deepens and spreads from India to faraway lands like Finland. In 2004, Kakha Bendukidze, the then CMD of OMZ the biggest atomic manufacturing complex in Russia, revealed to a Finnish journalist that in China, India, and Iran, "the selection is made as a compromise of politics, price, and quality" and the Finnish contract "is the first time that the process is completely transparent; the power plant is being built by a private company with private funding."[25] Private company and private funding do play an important role in reducing corruption so long as it is profitable. The ultimate guarantor of environmental safety and inter-generational justice is an autonomous government regulator, accountable to the people and to the Parliament alone." The fall-out of the accident at the construction site of Leningrad-2 in 2011 in the Finnish regulatory establishment STUK is not reassuring.

The EUR certification of AES-92 reactor as Gen-III, the inaction of the operator and the regulator in India about this fraud, Rosatom's efforts to erase it from the genealogy and the traumatic experience of the commissioning crew with an untameable machine at Kudankulam in India are not isolated events, unworthy of remembering. They have global implications, especially for countries of Asia, Africa and Central Europe, which are the niche market for the stepped-up drive to sell Russian reactors.

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Abbreviations

Atomic Energy Regulatory Board (India) -	-AERB
Atomstroyexpert (Russia)	-ASE
Beyond Design Based Accident'	-BDBA
Boiling Water Reactor	-BWR
Core Damage Frequency	-CDF
Detailed project report	-DPR
European Utility Requirements	-EUR
Generation-III	-Gen-III
International Atomic Energy Agency	-IAEA
Kudankulam Nuclear Power Project	-KKNPP
Nuclear Power Corporation of India	-NPCIL
Preliminary safety analysis report	-PSAR
Pressurized Water Reactor	-PWR
Quality assurance	-QA
Reactor pressure vessel	-RPV
US Electric Power Research Institute	-EPRI
Utility requirement document	-URD
Water-Water-Energy-Reactor	-WWER
West European Nuclear Regulators' Association	-WENRA
World Nuclear Association	-WNA

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