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Hill Containment of Nuclear Power Plants

National Institute of Advanced Studies
Bangalore, India

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Foreward

Electricity for all at affordable costs has been a global aspiration since the beginning of the twentieth century. With the discovery of nuclear fission and the demonstration of nuclear electricity, this aspiration appeared quite close to realization. Unfortunately, over the decades, we could only see a constantly receding goal post. Not only were there no major breakthroughs in the nuclear reactor technologies bringing the costs down, but the industry had also to bear the increasing costs associated with nuclear safety and security. It is not surprising that today, a good fraction of the population actually believes that the nuclear option is no longer a relevant option to address the electricity needs of the global population. At the same, it has to be recognized that there is a mismatch between projected global energy demands and sustainable global energy resources.

The authors, Prof. B. V. Sreekantan and Prof. B. N. Karkera, have been arguing that with innovative siting of the nuclear power plants underground close to large reservoirs at the top of the hills, it is possible not only to bring the costs down but also increase the safety and security of the plants. The idea was discussed in a workshop in National Institute of Advanced Studies, Bangalore. The present monograph is an attempt to formally capture the ideas in print and place them before a larger audience for evaluation.

V S Ramamurthy
Director
National Institute of Advanced Studies

Acknowledgements

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One of us (BNK) would like to thank the National Institute of Technology, Karnataka (NITK) and Sahyadri College of Engineering and Management (SCEM) for giving the necessary facilities while pursing this work. We thank Smt V B Mariyammal for all the help in preparing the soft version of this book and Smt. Sandhya Kamala Alagade of SCEM for language editing.

Contents

Chapter 1:

Introduction

While India, after independence has made tremendous progress in several areas of technology such as – atomic energy, space, electronics, information, communications and so on, it is a woeful fact that in terms of providing basic necessities of life like food, water, health facilities, education and electrical power it is still reeling at atrocious levels. It is a regrettable fact that nearly 40% of the population is still below the poverty level. There is no electricity for a large fraction of the villages. Even in most of the cities nearly 20% of the population is without electricity. The governmental agencies are fully aware of this situation and ambitious plans have been drawn up to remedy this situation. Strategies for long term energy security are shown in Figure 1 [1]. At the present time (2012), thermal and hydroelectric sources dominate the power scenario. While nuclear power is less than 3% (4.78 GWe) today, it is hoped that it will reach about 25% (275 GWe) by 2050 using only the indigenous Uranium. This share will be doubled to about 50% (600 GWe) by strategically importing during the intervening period 2012-2020, 40 GWe LWRs along with requisite uranium fuel.

These projections are discussed in "Strategy for Growth of Electrical Energy in India Document 10, August 2004, DAE" [1], and also in the article by Dr. Srikumar Banerjee, Former Chairman of DAE [2]. There is also an excellent review article by *Prof. Sukhatme,* Former Chairman, Atomic Energy Regulatory Board [3], in which the author has discussed the relative merits and demerits of the energy options before us. There are many who are optimistic about breakthroughs in Solar Energy. Prof. B.N. Karkera himself is promoting 90% efficient 'Solar Bio Electricity' for domestic lighting by peddling dynamo for health, free of tariff and with nominal investment by Electricity Boards for the benefit of remote isolated population for whom it has been impractical to reach electrical supply for decades and for the benefit of poor labour class by diverting the saved electricity to small scale industry.

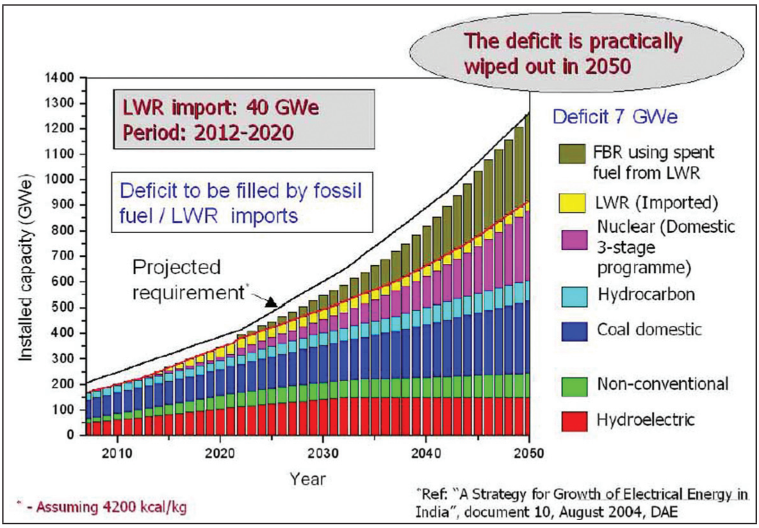

Figure 1. Strategies for Long-Term Energy Security [1]

At the present time, in India, the installed capacity of Nuclear Power is only 4.78 Gigawatt Electrical (Appendix 1, Table 1). The number of Nuclear Power reactors operating is twenty. Out of these, the first two reactors at Tarapur (TAPS-1 & TAPS-2) are the Boiling Water-Reactors using enriched Uranium and MOX fuel element and the rest are all Pressurized Heavy Water Reactors (PHWR) using Natural Uranium (U) (0.7% U^{235}+99.3% U^{238}) as the fuel element. (Further details are available in Appendix 1).

The current Indian three stage strategy for achieving large scale increase of Nuclear Power production is the same as the one spelled out by Dr. Homi Bhabha, the founder of the Indian Atomic Energy programme in the 1950's, as depicted in Figure 2 - "Three Stage Indian Nuclear Programme" and in Figure 3 - "Neutrons Produced per Fission in ^{235}U, ^{233}U and ^{239}Pu". This strategy is based on the following facts on India's strengths and weaknesses:

Stage-1: India has limited Uranium and is used in this stage, in which U^{235} generates fission power while a tiny fraction of the balance fertile U^{238} transmutes into a new fissile material Pu^{239}. U^{235} is natural fissile material and the rest 99.3% is fertile material U^{238}. India uses this naturally occurring nuclear fuel in Pressurised Heavy Reactors (PHWRs) for the best possible thermal neutron fission cross section economy. These are Thermal Reactors using Heavy Water (HW) as moderator to thermalise the fission neutrons and also as coolant to transport the thermal energy from the fuel elements. With the perfection of HW

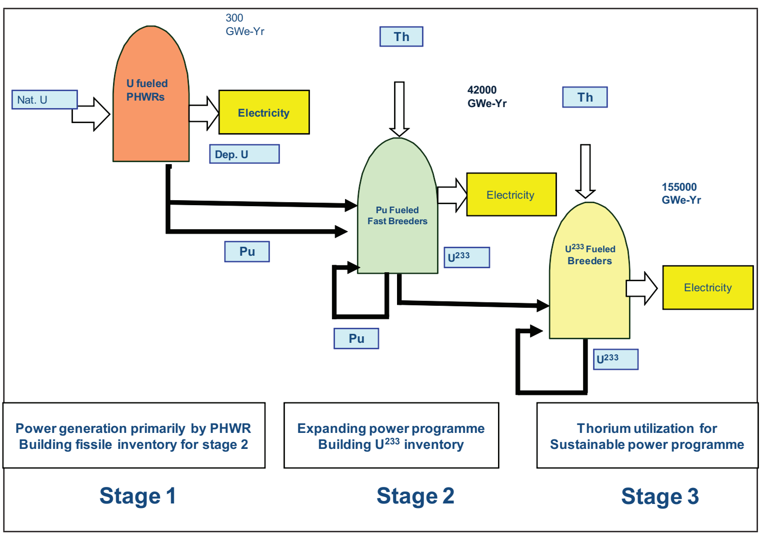

Figure 2. Three stage Indian Nuclear Programme [2]

technology, India has mastered Stage-1 (Figure 2) by using its strengths well. The limited quantity of transmuted Pu^{239} and large quantity of depleted U are essential for the next stage-2. Stage 1 will be wound up with exhaustion of the lean source of Uranium within the country.

Stage-2: India started building Fast Breeder Reactors (FBRs) using limited quantity of transmuted Pu^{239} for (i) highest yield of fission neutrons (Figure 3); (ii) fast neutron economy; (iii) consequential breeding of its own fuel Pu^{239} from depleted U; and (iv) later breeding another fissile material U^{233} from fertile Th^{232}; while generating fission power from fissile Pu^{239}. It has to be pointed out that the breeder reactor technology requires the use of liquid sodium as the coolant, which is a highly sophisticated and difficult technology since handling liquid sodium is a very hazardous problem. This technology too has been mastered at the Kalpakam Reactor Laboratory in Chennai. FBRs use this liquid sodium technology to transport the thermal energy from the fuel elements, now mastered under Stage 2 (Figure 2). This stage will be wound-up eventually with the exhaustion of the supply of depleted U as a consequence of closing of Stage-1. The bred U^{233} is the fuel for the next Stage-3.

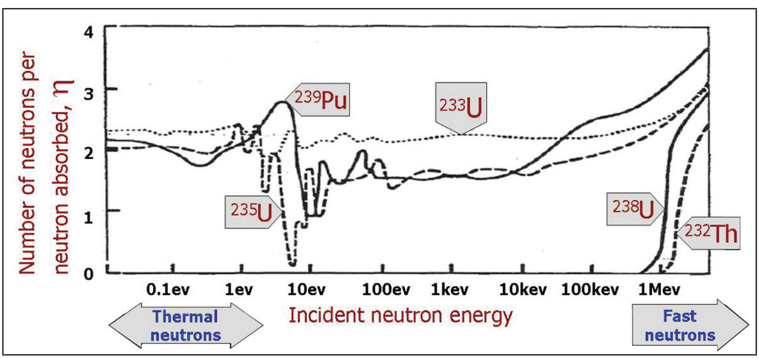

Figure 3. Neutrons Produced per Fission in 235U, 233U and 239Pu as a function of incident neutron energy [2]

Stage-3: India has designed AHWR, a prototype of Stage-3 thermal breeder reactors (TBR). U^{233} is bred from fertile Th^{232}, initially in FBR (Stage-2) and continued in TBR (Stage-3). This is Thermal Reactor using Heavy Water (HW) as moderator to thermalise the fission neutrons and as coolant to transport the thermal energy from the fuel elements. TBR is simpler and breed its own fuel U^{233}.

These three stage strategies (Figure 2) are logical from various angles:

(i) Limited resources of U within the country.
(ii) Mastering ofTechnologies of HW and Liquid Sodium Handling ;
(iii) Ensuring High Thermal Neutron Fission Cross Section
(iv) High Neutron yield per absorption/reproduction Factors
(v) Civil Nuclear Deal.
(vi) Long term energy safety

Short time bottleneck from limited U in-house is being overcome by importing Light Water Reactors under Civil Nuclear Deal.

Interestingly, it is estimated that India has about 225,000 tons of thorium metal and the above third stage technology can yield power to the extent of 1.3 Terawatt hours - enough to serve India for a long time. At IGCAR Kalpakkam, Tamilnadu, a Fast Breeder Test Reactor (FBTR) of 40 Megawatt (thermal) is operating since 1985. A 500 Megawatt (electrical) Prototype Fast Breeder Reactor is under construction with uranium-plutonium mixture which is expected to go into operation soon. Figure 1 is essentially based on the projections made by DAE on the basis of the above 3-stage scenario with PHWR's and

Breeder Reactors becoming operational at the time scales shown.

With all this optimistic and realistic projections and with all the necessary technologies in hand, there is no doubt a great future for the requisite electrical power realization through nuclear power generation in the coming decades, practically wiping out the power deficit by 2050. However, there is one dark cloud which has appeared in recent years, which, if not satisfactorily dispelled, may impede the progress of nuclear power generation, not only in our country, but also elsewhere in the world for the same reason. The reason for the impediment is addressed in the next chapter.

Chapter 2.

Nuclear Power Reactor Accidents – World Over

Since the mid fifties of the last century, 382 nuclear power reactors have been operating around the globe producing 334.169 Giga Watts of electrical power (Appendix 1, Table 4). Another 83 reactors are under construction which are expected to add additional 92 Gigawatts of electrical power. What certainly is commendable and creditable of the designers and operators of the power reactors, is the fact that, despite the large number of reactors operating for such long periods, (~15,000 reactor years) the number of major accidents are few. Nevertheless, some minor and major accidents have taken place which cannot be ignored.

The Table 1, taken from the Wikipedia article on "Nuclear and Radiation Accidents" lists such 23 accidents – their location, date of accident, cause of accident, number of deaths, monetary loss (US$ 16 Billion) and also the level of accident as defined by IAEA. The details and the references are available in the Wikipedia [5] article.

It is to be noted from the table that in most of the accidents no deaths have occurred. We will consider, in some detail, the few serious cases which were at INES level of 5, 6 and 7 (Table 1).

Table 1
(Source: http://en.wikipedia.org/wiki/Nuclear_and_radiation_accidents#cite_ref-critev_4-0)

Nuclear power plant accidents and incidents with multiple fatalities and/or more than US$100 million in property damage, 1952-2011					
Date	Location	Description	Deaths	Cost (in millions 2006 $US)	INES level[17]
January 3, 1961	Idaho Falls, Idaho, United States	Explosion at SL-1 prototype at the National Reactor Testing Station. All 3 operators were killed when a control rod was removed too far.	3	22	4
October 5, 1966	Frenchtown Charter Township, Michigan, United States	Partial core meltdown of the Fermi 1 Reactor at the Enrico Fermi Nuclear Generating Station. No radiation leakage into the environment.	0		
January 21, 1969	Lucens reactor, Vaud, Switzerland	On January 21, 1969, it suffered a loss-of-coolant accident, leading to a partial core meltdown and massive radioactive contamination of the cavern, which was then sealed.	0		4
1975	Sosnovyi Bor, Leningrad Oblast, Russia	There was reportedly a partial nuclear meltdown in Leningrad nuclear power plant reactor unit 1.			
December 7, 1975	Greifswald, East Germany	Electrical error causes fire in the main trough that destroys control lines and five main coolant pumps	0	443	3

Nuclear power plant accidents and incidents with multiple fatalities and/or more than US$100 million in property damage, 1952-2011					
Date	Location	Description	Deaths	Cost (in millions 2006 $US)	INES level[17]
January 5, 1976	Jaslovské Bohunice, Czechoslovakia	Malfunction during fuel replacement. Fuel rod ejected from reactor into the reactor hall by coolant (CO_2). [http://cs.wikipedia.org/wiki/Havárie_elektrárny_Jaslovské_Bohunice_A-1]	2		?
February 22, 1977	Jaslovské Bohunice, Czechoslovakia	Severe corrosion of reactor and release of radioactivity into the plant area, necessitating total decommission	0	1,700	4
March 28, 1979	Three Mile Island, Pennsylvania, United States	Loss of coolant and partial core meltdown due to operator errors. There is a small release of radioactive gasses. See also Three Mile Island accident health effects.	0	2,400	5
September 15, 1984	Athens, Alabama, United States	Safety violations, operator error, and design problems force a six year outage at Browns Ferry Unit 2.	0	110	
March 9, 1985	Athens, Alabama, United States	Instrumentation systems malfunction during startup, which led to suspension of operations at all three Browns Ferry Units	0	1,830	
April 11, 1986	Plymouth, Massachusetts, United States	Recurring equipment problems force emergency shutdown of Boston Edison's Pilgrim Nuclear Power Plant	0	1,001	

Nuclear power plant accidents and incidents with multiple fatalities and/or more than US$100 million in property damage, 1952-2011					
Date	Location	Description	Deaths	Cost (in millions 2006 $US)	INES level[17]
April 26, 1986	Chernobyl, Ukrainian SSR	Overheating, steam explosion, fire, and meltdown, necessitating the evacuation of 300,000 people from Kiev and dispersing radioactive material across Europe (see Chernobyl disaster effects) *["IAEA Report". In Focus: Chernobyl. Retrieved 2008-05-31]	56 direct; 4,000 cancer *	6,700	7
May 4, 1986	Hamm-Uentrop, Germany	Experimental THTR-300 reactor releases small amounts of fission products (0.1 GBq Co-60, Cs-137, Pa-233) to surrounding area	0	267	
March 31, 1987	Delta, Pennsylvania, United States	Peach Bottom units 2 and 3 shutdown due to cooling malfunctions and unexplained equipment problems	0	400	
December 19, 1987	Lycoming, New York, United States	Malfunctions force Niagara Mohawk Power Corporation to shut down Nine Mile Point Unit 1	0	150	
March 17, 1989	Lusby, Maryland, United States	Inspections at Calvert Cliff Units 1 and 2 reveal cracks at pressurized heater sleeves, forcing extended shutdowns	0	120	

Nuclear power plant accidents and incidents with multiple fatalities and/or more than US$100 million in property damage, 1952-2011					
Date	Location	Description	Deaths	Cost (in millions 2006 $US)	INES level[17]
March 1992	Sosnovyi Bor, Leningrad Oblast, Russia	An accident at the Sosnovy Bor nuclear plant leaked radioactive gases and iodine into the air through a ruptured fuel channel.			
February 20, 1996	Waterford, Connecticut, United States	Leaking valve forces shutdown Millstone Nuclear Power Plant Units 1 and 2, multiple equipment failures found	0	254	
September 2, 1996	Crystal River, Florida, United States	Balance-of-plant equipment malfunction forces shutdown and extensive repairs at Crystal River Unit 3	0	384	
September 30, 1999	Ibaraki Prefecture, Japan	Tokaimura nuclear accident killed two workers, and exposed one more to radiation levels above permissible limits.	2	54	4
February 16, 2002	Oak Harbor, Ohio, United States	Severe corrosion of control rod forces 24-month outage of Davis-Besse reactor	0	143	3
August 9, 2004	Fukui Prefecture, Japan	Steam explosion at Mihama Nuclear Power Plant kills 5 workers and injures 6 more	5	9	1

Nuclear power plant accidents and incidents with multiple fatalities and/or more than US$100 million in property damage, 1952-2011					
Date	Location	Description	Deaths	Cost (in millions 2006 $US)	INES level[17]
March 11, 2011	Fukushima, Japan	A tsunami flooded and damaged the 5 active reactor plants. Loss of backup electrical power led to overheating, meltdowns, and evacuations. [Worker dies at damaged Fukushima nuclear plant". CBS News. 2011-05-14] *[Martin Fackler (June 1, 2011). "Report Finds Japan Underestimated Tsunami Danger". New York Times]; #[IAEA Briefing on Fukushima Nuclear Accident (12 April 2011)]	3 *		7 #

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The Three Mile Island Accident (USA)

A nuclear accident of INES level 5, occurred at the Three Mile Island in Pennsylvania, USA, on 28 March 1979. Investigations revealed that the accident was due to operator error and failure of monitoring instrumentation.

A small valve in the plumbing system opened to relieve the pressure in the reactor but failed to close. This caused the cooling water to drain off which led to the overheating of the core. The monitoring instruments provided false information which made the plant operator shut down the emergency water supply that would have cooled the reactor. The core temperature rose to 4300°F. The plant designers who were contacted, stepped in at this stage and controlled further damage. There was a small release of radioactive gas. No one died. The estimated damage was 2.4 billion dollars. It is suspected that one person, exposed to radiation might die of cancer.

The Chernobyl Nuclear Accident (Ukrainian SSR) April 26, 1986

Till the more recent Fukushima accident, the Chernobyl accident of INES level 7, was regarded as the worst accident in the history of nuclear power. Not all the details and the extent of damage are fully available yet.

What is known is summarized as follows in [6]:

"During a routine test, the plant's safety systems were turned off to prevent any interruptions of power to the reactor. The reactor was supposed to be powered down to 25 percent of its capacity, and this is when the problems began. The reactor's power fell to less than one percent, and so the power had to be slowly increased to 25 percent. Just a few seconds after facility operators began the test, however, the power surged unexpectedly and the reactor's emergency shutdown failed. What followed was a full-blown nuclear meltdown.

The reactor's fuel elements ruptured and there was a violent explosion. The fuel rods melted after reaching a temperature over 3,600°F. The graphite covering the reactor then ignited and burned for over a week, spewing huge amounts of radiation into the environment.

About 200,000 people had to be permanently relocated after the disaster. The International Atomic Energy Agency (IAEA) reported in 2005 that 56 deaths could be linked directly to the accident. Forty-seven of those were plant workers and nine were children who died of thyroid cancer. The report went on to estimate that up to 4,000 people might die from long-term diseases related to the accident. Those numbers are a subject of debate, however, as the Soviet Union did much to cover up the extent of the damage. The World Health Organization reported the actual number of deaths related to Chernobyl was about 9,000."

Fukushima Daiichi Nuclear Disaster (Scale 7)

The Fukushima Nuclear Disaster happened on 11 March 2011 following a major earthquake that triggered a Tsunami in the Pacific Ocean. The nuclear power plant at Fukushima comprised of six Boiling Water reactors designed by General Electric and maintained by the Tokyo Electric Power Company. Out of them, reactors 1, 2 and 3 were in operation, reactor 4 was undergoing periodic inspection and reactors 5 and 6 had been shut down for maintenance. Reactors 1, 2 and 3 suffered full melt down since the Tsunami had resulted in tripping the grid, flooding of emergency generators, and consequential failure of the coolant water circulation. Further, the efforts to use sea water to cool the reactors resulted in completely ruining the reactors. In the first instance, an evacuation of all people within a radius of 20 kms was effected.

According to Japanese Government estimates the amount of radioactivity released was one-tenth of what had been released during the Chernobyl accident. It is feared that significant amount of radioactivity has entered the ground as well as the sea. Radioactive Cesium which can cause cancer has been located upto distances of 30-50 kms, and sale of food grown in this area has been prohibited.

No immediate deaths, but six workers had been exposed to very high levels of radiation. Three hundred others also have been exposed but to a lower level of radiation. The estimate of those who may die of cancer ranges from 100 to 1000.

An investigation commission was set up by the Japanese Government to determine the causes of the Fukushima Nuclear accident and make recommendations. The commission report is now available on the web [7]. According to the report of the commission while the earthquake of March 11 in the Pacific Ocean and the resulting Tsunami contributed to the disaster happening, these are secondary causes; the *primary cause* is "Human Error" and the failure of the back-up power system. The report is critical about the functioning of the Tokyo Electric Power Corporation and the concerned government bureaucracy. The message from the chairman of the commission Kiyoshi Kurokawa is a very frank appraisal of the whole incident from which valuable lessons can be learnt. This message is presented in the Appendix 4.

As has been pointed out by Prof. Atul H Choksi [4] it is really difficult to know the extent of damage that these nuclear accidents can cause in the long term. Prof. Choksi points out that, in the case of the Chernobyl accident different International organizations have given wide ranging estimates of likely cancer deaths that may occur over long periods of time. While the United Nations Scientists Committee on the Efforts of Atomic Radiations gives the number as 62, the UN Chernobyl Forum and WHO give the figure as 4000 and the committee of 52 scientists commissioned by Greenpeace places the number of cancer deaths at 93,000 and the group of three scientists from Russia and Belarus give the number as 985,000. These wide disparities in the projected number of cancer deaths are essentially due to lack of agreement on the correlation of the level of radiation exposure and the occurrence of cancer.

Chapter 3.

Underground Siting of Nuclear Power Stations

From what has been presented in the previous chapters, it is clear that the future of Nuclear Power for electricity is at cross roads in all the countries in the world. On the one hand, it is abundantly clear that nuclear power is the best choice for enhancing the power needs of many countries, particularly in India which as we have seen is at a miserably low level to-day. The Fast Breeder Technology, in which considerable technological development has been made in India in addition to the standard technologies (PHWRs), has provided the scope for solving the power problem for hundreds of years. One does not have to wait for breakthroughs in solar power technologies or fusion power which may take a long time to be on production scale to become feasible. Neither can we count on the "Solar Bio Electricity" being promoted by Prof. B.N. Karkera, as it is for self powering of small pockets of population isolated from power grids and is unfit for industrial usage. While the entire nuclear scenario looks so optimistic, the recent Fukushima accident in Japan has made it necessary to rethink on the large scale expansion of nuclear power. One is forced to proceed with caution since radioactive spill out from explosion of nuclear reactors can cause serious damage to civilian population in terms of health, food, water and can take a long time to remedy the ill effects. Taking serious cognizance of this aspect, several advanced countries like Germany have closed down their nuclear reactors while some other countries have decided not to go ahead with the construction of further nuclear power stations. These are countries that have adequate access to alternative sources of power like thermal or hydel and also do not have such dire and urgent necessity of additional power like India.

In this context, the question arises whether there is any alternative by which one can have nuclear power, and also ensure mitigation of the dangers of radioactivity to a large extent, if not complete elimination.

Immediately after the Fukushima accident last year in March 2011, one of the authors of this book (BVS), based on his forty years of experience (1951-1991) of operating large scale experiments on cosmic rays underground up to depths of 8000 ft below ground level in the 10,000 ft deep Kolar Gold Fields in India, and also because of his familiarity with various neutrino underground observatories in Japan (Kamiokande, and Super-Kamiokande), Italy-Switzerland (Mont Blanc), USA (Home Stake Salt Mine), and Canada (Sudbury) which are operating very large scale installations, and the Large Hadron Collider operating under 300 to 500 ft rock depending on the over head terrain in the Alps, realized that there should be no technical difficulties in installing and operating nuclear reactors underground, which will certainly minimize to a large extent the damage that can be caused by a core meltdown and consequent explosion of the nuclear reactors. In case of such a mishap, the entire spilled radioactivity will be contained within the ground and could be vitrified.

While discussing this possibility with the other author (BNK) who is a reactor engineer and has thirty five years of hands-on experience (1968-2005) at the Bhabha Atomic Research Centre (BARC), the latter pointed out that the idea is good for perfect safety of public under every conceivable threat; but expressed, at first serious concern about the economical cum logistic problems and engineering viability of underground high capacity nuclear power stations, with current nominal standard capacity of 1 GWe per reactor unit and few such units per station. His reservations were on multiple counts – vertical decent for men and materials, lack of natural drainage and ventilation; requirement of large volume of water for cooling and seepage of underground water etc.

Further discussion led to a novel way of meeting all the requirements and providing economical benefits and operational efficiency; which will be presented in the next chapter.

At this stage of discussion the authors surfed the web to see whether similar ideas had occurred to others. They were surprised and relieved to find that installations of underground nuclear reactors was not an absurd idea and had been practiced in a small scale in many other countries for a long time for a variety of reasons one of which may be for greater secrecy.

During the course of the web search the first thing they came across was the following statements by two top nuclear scientists Andrei Sakharov from Russia and Edward Teller from USA; made immediately after the Chernobyl reactor accident in April 1986.

Andrei Sakharov (Memoris, P. 612)

"Plainly, mankind cannot renounce nuclear power, so we must find technical means to guarantee its absolute safety and exclude the possibility of another Chernobyl. The solution I favor would be to build reactors underground, deep enough so that even a worst case accident would not discharge radioactive substances into the atmosphere"

Edward Teller (Memoris, P. 565)

My suggestion in regard to [the containment of nuclear material in case of an accident] is to place nuclear reactors 300 to 1000 feet underground …" I think the public misapprehension of risk can be corrected only by such a clear-cut measures as underground siting.

Figure 4. Statements by Two Top Nuclear Scientists

The first set of three underground reactors was set up in Russia in 1958, 1961 and 1964 in Central Siberia. Out of them, the first two were for production of Plutonium and the third one was to provide electricity and hot water to the city of Zheleznogorsk. These were water cooled uranium-graphite reactors. The turbine and the Yenisey River which supplied the water for cooling are also shown in the photographs. (Photographs from a brochure published by the Mining and Chemical Combine, Zheleznogorsk, Krasnoyarsk, Kray.)

Yenisey River　　Early construction operations

Figure 5. The first underground reactor was set up in 1958, in Central Siberia.

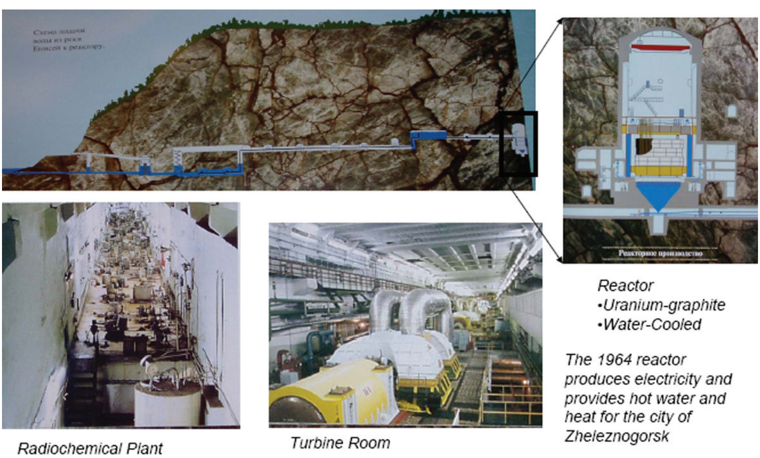


Figure 6. The Underground Reactors set up in Russia in Central Siberia.

The next set of underground reactors came up in Europe and some details regarding these are given in Table 2. None of them have leaked any radio activity and radiation to cause any hazard to the public, even under worst accidents .

Table 2. Underground Nuclear Reactors besides the three reactors in Russia

Name and location	Size	Purpose	Configuration/ Location		Status	Reactor Chamber Dimensions (feet)
			Turbine Generator	Reactor		
Halden Norway (BHWR)	25 MWt	Experimental	None	Rock Cavern	Operational (1959-2020)	98′ long 85′ high 33′wide
Agesta Stockholm, Sweden (PHWR)	80 MWt/ 20MWe	Heat Production	Above ground at grade level	Rock Cavern	Operated from 1964-1974. Shutdown since 1974.	88′ long 66′ high 54′wide
Chooz Ardennes, France (PWR)	266 MWe	Power	Above ground	Rock Cavern	Operated from 1967-1991. Shutdown since 1991.	138′ long 146′ high 69′wide
Lucerne, Switzerland	30 MWt/ 8.5 MWe	Test Reactor	Rock Cavern	Rock Cavern	Operated from 1968 to 1969. Shutdown since 1969.	--

The underground reactor at Lucerne, Switzerland generated 30 Megawatts of heat and 8.5 Megawatts of electricity with heavy water as the moderator. In 1969 the loss of coolant resulted in partial core melt down and there was heavy radioactive contamination of the cavern which was immediately sealed and not opened for a few years. There was no effect of any radioactive leak that affected the workers or the population in the surrounding areas. Later, the cavern was opened, and decontaminated.

The experiences of the European Laboratories in operating, for several years, Nuclear Reactors of various types underground not only confirmed the main advantage of effective shielding against radioactive fall out in case of an accident,as it did happen in one case and the cavern effectively shielded radioactive leaks, but also brought to focus how such installations can provide safety against several other features like terror attacks, air craft crashes, sabotage, vandalism etc., which are becoming more serious now a days. Such locations also provide better protection against natural disasters like Tsunamis, Volcanoes, Earthquakes, etc. There have been several large scale studies on all aspects relating to the siting of nuclear power stations underground particularly by US groups. These ideas have been discussed in several International Conferences on Nuclear Engineering; several symposia have been held exclusively to discuss the underground siting of nuclear reactors. There is a very detailed paper by C.W. Myers and N.Z. Elkins [8]. This paper gives exhaustive references to all the earlier work, and highlights the unique UNDERGROUND NUCLEAR PARK (UNP) concept which has emerged out of efforts to collocate nuclear power reactors and nuclear waste management facilities close to each other in a specially designed underground station. Figure 7 shows the very ambitious general plan of UNP under an overburden of 200 ft of salt in a salt mine, planned to house more than a dozen nuclear rectors in separate cavities well shielded from each other and a separate cavity for the generation of both electricity and hydrogen and, yet another separated chamber for storing the waste nuclear fuel and reprocessing it in the under ground station itself. It is a futuristic plan with envisaged time frame 2025-2030. In their paper Myers and Elkins project a hypothetical growth scenario leading to the generation of 1000 GWe Nuclear Energy in the US by 2050 which they think will be ~25% of the global projection of 4000 GWe nuclear power. The present rate of production of nuclear energy is an order of magnitude lowers.

The concluding paragraphs of the paper by Myers and Elkins which are very significant and instructive are as follows:

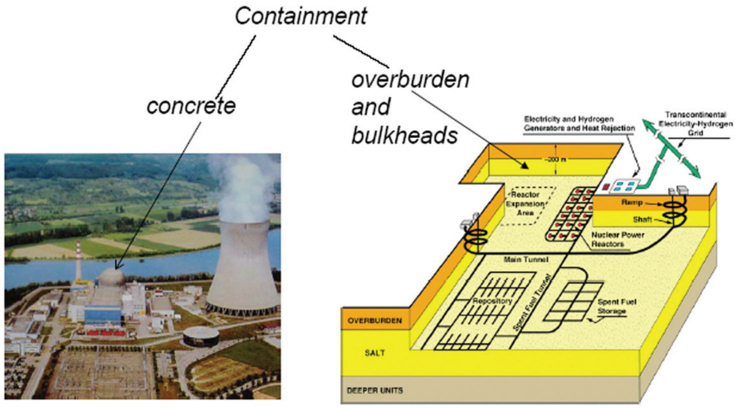


Figure 7. Elimination of need for conventional containment structure (L) by underground Nuclear Power Station (R)

"If high-growth-rate nuclear energy scenarios in the U.S. for the 21st century should materialize, then the continuation of the conventional approach of installing one or a few new reactors at the earth's surface at widely dispersed locations, and having their HLW repository and LLW disposal sites located at a great distance from the reactors, will probably mean a continuation of controversies regarding capital cost, nuclear waste, physical security, and safety. If so, the high-growth-rate scenario could be jeopardized, with the result that even less than the current level of 20% of U.S. electricity would be nuclear generated in the future.

This unfortunate situation could perhaps be avoided in part by an alternate approach that, beginning ~2025-2030, would involve deployment of underground nuclear parks, each consisting of an array of reactors with a collective multi-giga-watt capacity. Collocated with the reactors would be the nuclear waste management and other facilities that support those reactors. Deployment of UNPs could significantly reduce environmental impacts and facilitate public acceptance of new nuclear power plants. This combined with the probable reduced cost and increased margins of safety and physical security for UNPs would increase chance that a high growth trajectory for nuclear power in the U.S. would be achieved.

The UNP approach should be examined in detail to assess its merits relative to conventional siting".

Chapter 4.

Hill Contained Hydel Powered Nuclear Plant – Our Proposal

The UNP project required the construction of a large vertical shaft going to a depth of 100 m and creation of various underground laboratories at this depth. All the equipment and materials and operating personnel have to be taken down by large size elevators with high loading capacity. Personnel for operation, servicing, maintenance, repairs, renovation and up-gradation have to traverse through these deep vertical shafts day after day for long periods similar to what are followed in gold and coal mines. A more attractive alternative that is economical, engineering-wise feasible and operationally more efficient, and with many other novel features has been figured out by Prof. B N Karkera, which he calls "Hill Contained Hydel Powered Nuclear Plant", (HCHPNP) which is presented below. This layout is distinctly different from the earlier underground nuclear reactor layouts in tunnels presented in Chapter 2 IN MANY RESPECTS.

In all the present Nuclear Power Systems the most vulnerable and worrisome component is the reactor core itself which is loaded with the highly radioactive partially depleted uranium in fuel rods. It is the explosion of this assembly with molten fuel rods that can result in the radioactive contamination of the surrounding air, earth and water. Depending on the magnitude and extent of leakage, evacuation of people and cattle over an 800 sq.km area (of radius 16 km) or more becomes essential as did happen in the case of the Fukushima accident. This area is designated as Emergency Evacuation Zone with regular mock evacuation drills for all the occupants of this area as a safety measure.

To minimize the risk caused by radioactive exposure and also to save the locked up land for civilian use, our proposal is to locate the reactor in a cavity at the end of a 100 m long horizontal Zig Zag tunnel of opening say 12m height, 12m width, with multiple air locks, specially dug out at the bottom of a hill, so that there is a minimum of hundred meters of impervious rock (granite) all round the reactor. The hill should have a perennial source of water at the top (river or lake). This will avoid making a 100m deep vertical shaft from the surface and will also eliminate the construction of an exhaust chimney. There will be no engineering and office buildings at all around the reactor and the associated equipments. The other components of the power system – the steam generator, and the HP/LP turbines and the electricity generator, and the condenser- will all be located in a second tunnel leading to the reactor cavity. These will be located conveniently in the side cuttings of the second tunnel at a distance of ~15 meters from outside. The advantage of having these at a short distance from the mouth of the tunnel is that in case of a reactor accident these systems will not get damaged, and also will have easy and quick access while providing safety from external air attacks, natural disasters, earthquakes, etc. Safety of equipments from earthquakes is realized by the absence of buildings, substituted by cavities in the hill itself. A second tunnel is mandatory to serve as an additional escape route for the operating personnel in case of an emergency.

In all thermal power generating systems – nuclear, oil, natural gas, bio-gas or coal – it is recognized that the over all efficiency of electricity generation is of the order of 33%, determined by the poor efficiency of steam turbine in converting the thermal energy into energy of rotation. Because of this net poor efficiency, to generate one Gigawatt of electrical power, the heat that is generated in the nuclear reactor is three Gigawatts and so there has to be a provision in the cooling system to throw out two Gigawatts of heat energy. This will require enormous quantity of water – millions of gallons of water per hour – to flow though the condensate cooling system of a standard power reactor. It is precisely this large requirement of water that forces the proximity of the sea or lakes for locating the reactors. Alternatively to provide for this large quantity of water one has to build dams across perennial rivers to store enough water, as at Kaiga, and create artificial lakes.

To meet the large quantity of water required for the cooling system of the condenser associated with the reactor, our proposal is to build the reactors in tunnels at the bottom of the hill which has a huge water reservoir at the top of the hill from which through pen stacks water can be brought to the reactor at sufficient speed (because of potential energy) so that no separate electrically operated pumps are required to force the water through the condenser. Hydel pumps are also used for the rest of the pumping de-mineralized water through the Steam Generator and heavy water through the Reactor Core. A small portion of the water rushing down from the top is used to generate low capacity hydel electric power sufficient for the reactor operation, control systems and all lightings, ventilation and other service systems, etc.

Obviously, all those hilly locations which have water at the top, with inadequate quantity and height for large scale hydel power generation, qualify eminently for this purpose. This opens up many more possible interior locations, away from sea. This same source of water can be used for other purposes also. The water at the top of the hill will be cooler by a few degrees which will help the condensate cooling with better thermal efficiency and hence higher power generation. The temperature of the outlet water will be higher by 4 to 5^0 C which will cool off as it is let out. Due to the cooler hill-top water, the discharge temperature is also less in comparison, facilitating quicker cool off to match with ambient temperature. It is to be emphasized that there is no possibility of this water becoming radioactive since it flows only through the condenser system and has no direct connection with the reactor core or the heavy water circuit in the PHWR type reactors. Further, condenser system is located in a separate tunnel, isolated from the reactor tunnels. Survey reports of these marginal water bodies not suitable for installing hydel stations must be available with Hydrological Survey Departments and could be used for initial studies of possible locations for Hill Contained Nuclear Power Stations.

Any one who has visited the world's deepest Kolar Gold Fields and seen the underground facilities created there up to depths of 10,000 ft below ground for various mining operations some of them more than a hundred years ago, will realize immediately that making caverns of suitable dimensions for housing a nuclear power reactor system is no big deal. The same confidence we get if we visit any of the neutrino laboratories in the world – the Super-Kamiokande in Japan, the Mont Blanc tunnel laboratory in the border of Italy and Switzerland or the newly developed under ground facility in the Salt Mines Ohio in USA. The Large Hadron Collider Accelerator Laboratory (LHC) in CERN, Geneva which is inside an underground tunnel of 35 kms periphery, whose depth ranges from 300 to 500 ft depending on the surface hilly terrain is another supreme example.

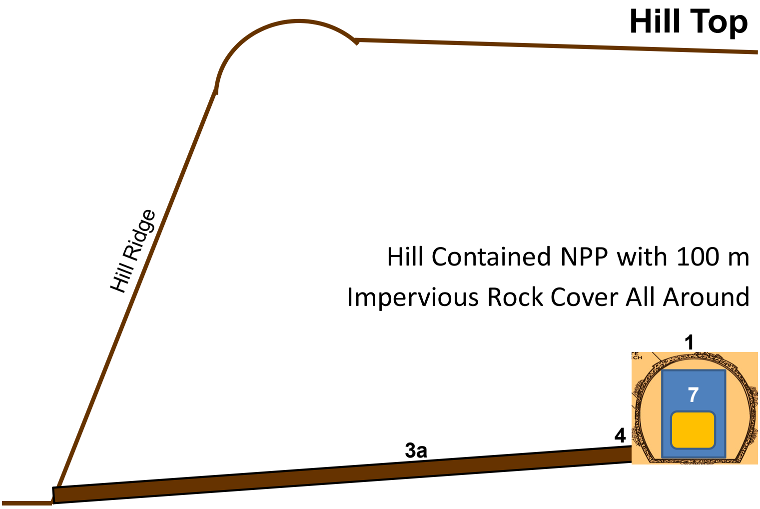
The question is whether there are any insurmountable difficulties in constructing the proposed type of Hill Contained Nuclear Power Stations in India for technical reasons or for economic reasons?

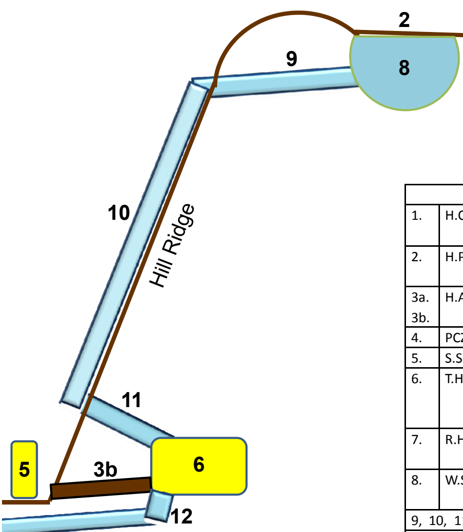
To answer this question, fortunately we have a report entitled "India Based Neutrino Observatory (INO) Project". This project is under the Department of Atomic Energy. Several leading research institutions like TIFR, BARC, Saha Institute, VEC and many universities are part of it. The Detailed Project Report on INO Site vol. 1, prepared by the Tamil Nadu Generation and Distribution Corporation Ltd., recently in December 2010, gives complete details regarding the civil and engineering works involved in the construction of the INO Laboratory at a depth of 1000 meters in Bodi West Hills / Pattipuram in Village, Thenai District, not far from Madurai, the cultural capital of Tamil Nadu. INO has horizontal access similar to the one specified in our proposal HCHPNP Report. It is far simpler in construction than underground stations like KGF, LHC, Neutrino Laboratories, etc. listed in the previous paragraph.

What is of interest and relevance to us in this INO report is that for housing the two Neutrino Magnetic Calorimeters each weighing 50 kilotons (mostly iron plates), the concerned engineers have designed a huge cavern laboratory of dimensions 132 meters x 26 m x 25 m at the end of a tunnel 2 kilometers long inside the hill. There are three other caverns of smaller dimensions for housing the required instrumentation and services. The approach tunnel is 2 kms x 7.5 m x 7.5 m. While the total cost of the civil and engineering works is Rs. 141 crores, the cost of the approach tunnel with a front portal is ~36 crores and of the main neutrino detector laboratory cavern is 38 crores and engineering services is Rs. 70 crores. In their design and costing they have taken care of all the services – electrical substation and distribution, water, air conditioning, fire alarm and fire fighting, communications, passenger lift, crane, side cuttings in the approach tunnel for movement and reversal of vehicles by turning around, etc. These cost figures tell us that the cost of making an underground cavern for installing a high power nuclear reactor (say 1 Giga watt electrical) will not be a deterring factor and is small compared to the cost of the overall project of approximately Rs 10,000 crores for the present day reactor units at the surface. On the contrary, our preliminary estimates show that the scheme proposed here of locating nuclear power plants in caverns inside hills should turn out to be far cheaper than constructing multi-storied concrete buildings with access roads, safety barriers etc. in the surface reactor installations. A saving of approximately 800 sq.km of land area by eliminating Emergency Evacuation Zone is a bonus and a cost saving factor. Also a one Gigawatt power generator requires 0.1 Gigawatts of electrical power as Station-Operation-Power, including the major cost of electricity for operating the pumps that draw water from the sea. In our system this requirement is not there since the water comes down by gravity from the hill top and the potential energy is utilized for pumping the water through the cooling system. Thus there is a saving of 0.1 Gigawatt of electrical power to the National Grid per 1 GWe reactor unit which is again a considerable cost saving factor. These hill top reservoirs otherwise discounted as of no use for making hydroelectric power stations, will now find a nationally relevant use.

The figures 9(a), 9(b) and 9(c) illustrate a rough sketch of our plan to house 1 to 4 nuclear power reactors in the same hill depending on the site as well as water supply. While the main tunnel leads us to the reactor cavern, the second tunnel also is connected to the main cavern and will have a series of caverns as side cuttings for locating the control electronics, the steam turbine, the electrical generator condenser and other services water, electricity, ventilation, etc.

In principle a single tunnel of length about 100 m is enough for all purposes. However, it is advisable and convenient to have one or more additional tunnels for housing control gear, steam turbine, electrical generator, condenser, etc., and also for the to and fro passage of services – water, steam, electricity, etc. The second tunnel connects to the reactor cavern. The different caverns in the tunnels will be sufficiently shielded from each other such that the effect of an explosion in one cavern will seal off itself and will not affect the reactor assembly in the other. Each reactor chamber has an air-lock safety door and two additional air lock doors at the external exit mouth of the tunnel. The side cuttings in the services tunnel will house the steam generator, steam turbine, steam condenser, and the electricity generator, as shown in the sketch. A second service tunnel may be made in case there is a possibility of putting many more reactors, as shown in Figure 9b. The steam generator because of its heavy water involvement could also be, alternatively in a cavern closer to the reactors. Along with the electrical substation the administration will be outside the hill edge, shown in the figures 9a & 9b.





Twelve Features of HCNPP Layout		
1.	H.C.	Hill Contained NPP with 100 m Impervious Rock Cover All Around
2.	H.P.	Hydel Powered; Hydel Source @ 100m Height for 100% Station Power
3a. 3b.	H.A.	Horizontal Accesses; 3a. RT @ 100m & 3b. ET @ 15m 1:50 Water-Drain-Slope;
4.	PCZ	Progressive Crumble Zone; Seal Explosion
5.	S.S.	Sub-Station & Grid @ Foothill
6.	T.H.	Technical Hall, @ 15m Depth within Hill Housing Steam Turbine, Condenser and Electrical Generator
7.	R.H.	Reactor Hall Cavern with Air Lock @ 100m Impervious Rock Cover All Around
8.	W.S	Water Source to Cool the Steam Condensate ; Adequate for 5°C ΔT.
9, 10, 11		Water Down Comers {WDC}
12.		Water Discharge with 5°C ΔT {WD}

Figure 9a. HCHPNP - Front Sectional Elevation

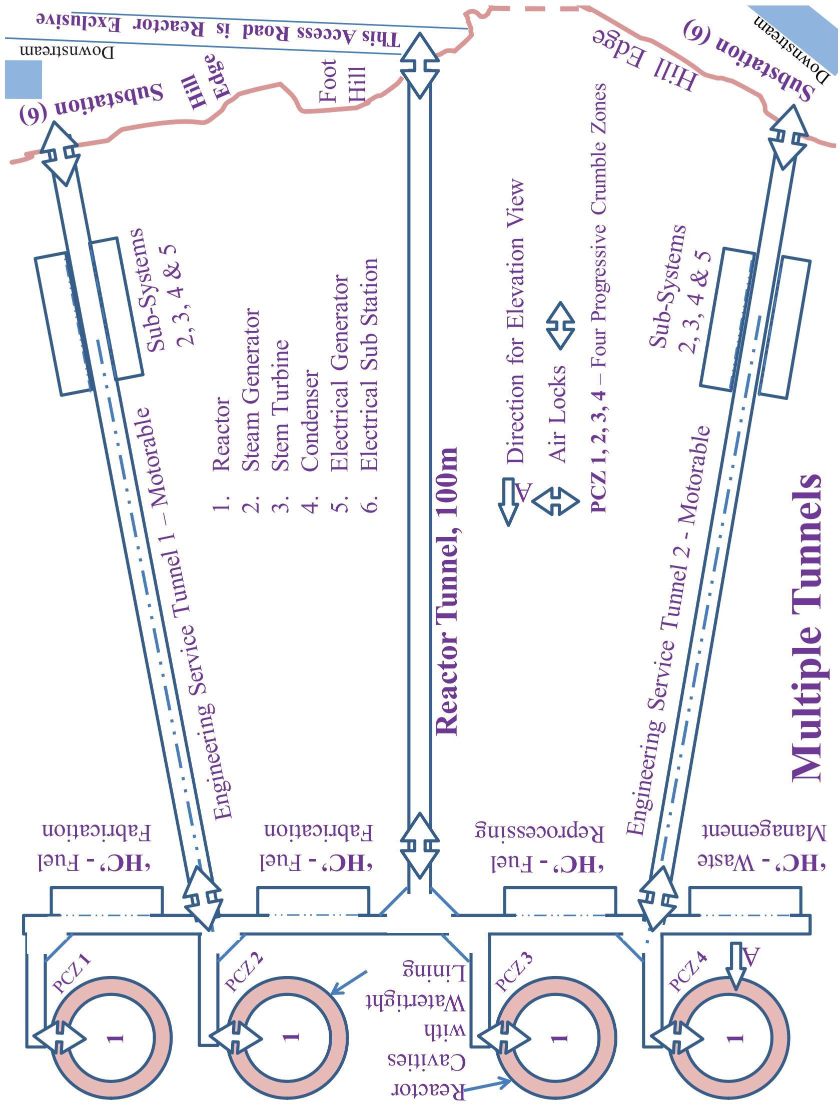


Figure 9b. HCHPNP - 4 Reactors, a Reactor Tunnel and 2 Separate Service Tunnels

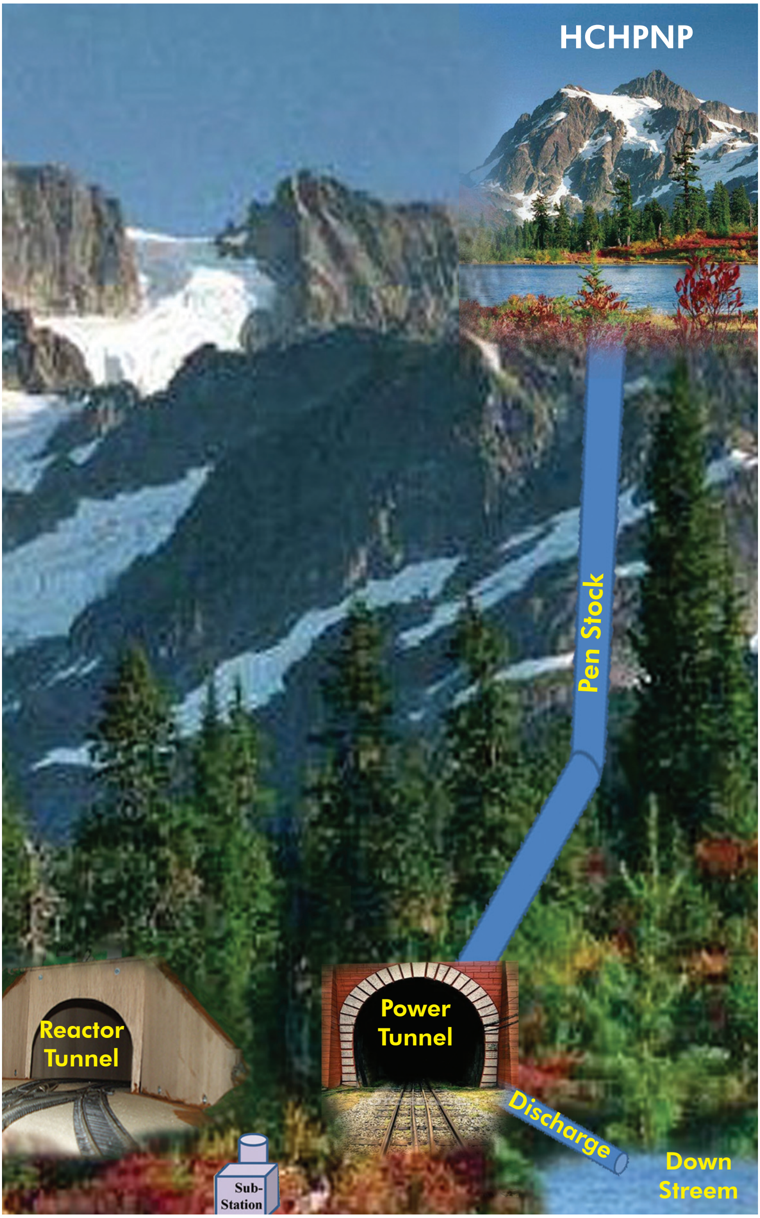


Figure 9c. HC HP NP @ Mountain Foothill

Our proposal is economically viable even with one single reactor unit per nuclear site/station, unlike the surface located nuclear stations. This is because of the minimum infrastructural needs; such as 800 sq.km locked up land, long approach roads, and huge buildings with earth quake immunity.

Chapter 5:

Discussion Meeting At NIAS

On 10 March 2012, exactly one year after the Fukushima Nuclear Disaster, a Discussion Meeting was held at the National Institute of Advanced Studies on the topic "Underground Siting of Nuclear Power Reactors – Pros and Cons". The list of participants with their affiliations is given in the Appendix 3.

The discussion was initiated by the authors of this book highlighting some of the important issues from the various chapters of this book:

(i) the current status of the electrical power generation in the country which leaves no option but to enhance the nuclear power production at a much faster rate
(ii) the perception of high risk with the nuclear programme by the general public because of the recent accidents like the ones at Fukushima and Chernobyl and the resulting opposition to NPPs
(iii) the feasibility and advantages of locating nuclear power stations underground
(iv) the experience of the European Groups in Russia, France, and Netherlands in this regard
(v) the grandiose Nuclear Power Park plans that have been drawn up by the United States of America in this regard with time scale 2025-2030 as realizable
(vi) the problems associated with nuclear waste transport and disposal and how the underground locations solve this problem by having additional shielded caverns.

(vii) the advantages and the feasibility of the new proposal "Hill Contained Hydel Powered Nuclear Plants".

Following the presentations by the authors of the book, one of the participants of the meeting Dr A K Ghosh summarized the contents of an internal report entitled "Underground Siting of Nuclear Reactors" prepared by a team of BARC (Bhabha Atomic Research Centre) scientists (Appendix 2). This report brought out some of the critical issues and problems that have to be faced in the implementation of underground siting of nuclear reactors in India.

The basic questions raised by Dr. Ghosh at the Discussion Meeting were:

i. The stability of underground structures
ii. Effects of underground water
iii. Accessibility of underground installations
iv. Construction of the vertical approach pits and tunnels at the bottom for housing the reactor and accessories
v. Coping up with natural and man made accidents even in underground installations.
vi. Large quantity of water, millions of gallons per hour required for cooling since our reactors in India are water cooled.
vii. Problems connected with transmission of high power, may be Gigawatts, to the National Grid.

Professor Karkera pointed out in reply that it is precisely these very issues that led the authors to the idea of:

i. Approach through a convenient 100 m long horizontal tunnel to the caverns where the reactor is located.
ii. Reactor cavern to be surrounded by about 100 meters of impervious rock all round, adequate

for containing even MCA (maximum credible accident).

iii. Reactor cavern to have PCZ (progressive crumble zone) to seal of the tunnel by a wide range of explosive accidents.

iv. Reactor cavern and tunnels to have a set of standard Air Locks to isolate the cavern and tunnel volumes from the outside atmosphere.

v. To have the Nuclear Power Plant tunnel/s within a hill having perennial water source at the top in the form of a river or a lake from which water can be flown down through pen stacks.

vi. This arrangement will save lot of electrical power required for pumping the condensate coolant water.

vii. It also propels the hydro-turbine-pumps to circulate primary and secondary coolants (de-mineralized water) through steam generators and coolant heavy water through reactor core.

viii. Large quantity of cold water with potential energy from hill top to flow through the condenser, cooling the steam condensate.

ix. The power required for other purposes can be generated in small hydel units (or drawn from the general electric power supply from the grid).

x. No additional backup emergency power will be needed in the form of Diesel Generator that will be continuously kept on along with the thousands of battery packs in surface installations. All this results in cost saving and protects the environment around.

A question was raised whether sufficiently tall structures can be made in the caverns to accommodate the nuclear reactor with its control rods at the top. Prof. Sreekantan replied that based on his experience with the underground facilities in KGF and the various neutrino observatories in the world there is no problem in having caverns as tall as 30 to 40 m or more. In fact the one that is proposed in the INO project report itself has the main lab roof as high as 25 m. Prof. Karkera supplemented Prof. Sreekantan that all the civil enclosure such as double containment, reactor building, technological building, tall exhaust chimney, etc. are replaced by caverns and rock-cut surfaces with appropriate linings. These would necessarily made water proof.

Professor Rajaraman enquired whether it is safe to have several reactors next to each other in the light of the Fukushima tragedy where presence of 4 reactors next to each other made matters worse.

Prof Karkera replied that if one has to have several reactors in the same site, it is very necessary that they are well shielded from each other as suggested in our proposal. The caverns will be designed such that there is sufficient rock in between the caverns for the different reactors Any accident in one cavern should not affect the other. In the US proposal of the Nuclear Park also this aspect has been stressed. Also their plan provides for storage, in the same location, of large quantity of used waste fuel which is still radioactive, in neighboring shielded caverns. Our proposal is economically viable even with one single reactor unit per nuclear site/station, unlike the surface located nuclear stations. This is because of the minimum infrastructural needs, such as 800 sq.km locked up land, long approach roads, huge buildings with earth quake immunity, etc.

One of the participants suggested that the Power Reactor could be located in a cavern in a hill close to the sea so that water may be pumped from the sea itself.

Prof. Sreekantan said this is a possibility, but it should be remembered that in the case of the Tsunami that affected the reactor assembly in Japan, the reactor building had been built such that waves of water even 10 meters high will not affect, but in that particular Tsumani the waves rose to 13 meters and flooded the reactor buildings, which led to all the damage. Prof. Karkera supplemented this by stating that such layouts with water drawn from sea will not have the advantage of saving the Station Operation Power, close to staggering 10% of the power generated.

Prof. Ahuja raised the following questions:

1. Since hydro-stations which are typically only for peaking loads frequently run out of water during the lean seasons, will there be enough water for continuously operating the nuclear plant?
2. Does the design of underground nuclear stations trade off ambient (explosion in the case of an accident) by increased occupational exposure?

Prof. Sreekantan replied that of course, one had to choose locations where water supply was perennial. However, it is to be noted that the quantity of water required for generation of hydel power is ten times more than what is required for a Nuclear Reactor producing the same output of electrical power. Also for hydel station the height from which water comes down should be large enough and is also important for its economical performance. Whereas height of water source of the nuclear condensate coolant needs to be marginal, just about 100m so that it can force itself through the condenser and operate the pumps pumping coolants through the steam generator and reactor core, by replacing electrical pumps and resulting in saving huge station power.

There is no reason why the occupational exposure is any more than what happens in the usual surface reactors. In all underground tunnel operations it is mandatory to have always an additional escape route, in case of any emergency. Much of the operation is increasingly remote controlled, anyway.

Chapter 6.

Conclusions

Based upon the information that has been collected from different sources and presented in the various chapters of this book in a condensed form, and also on the basis of the new proposal by the authors for locating future nuclear power reactors within the hill, the main conclusions that can be drawn are as follows:

1. India needs a drastic high exponential rate of growth of electric power to ensure a reasonable quality of life for the large majority of people and to step up the pace of growth of industry, agriculture and other nationally relevant activities.

2. Among the various options hydel, thermal, nuclear, solar and other non-conventional sources, today the hydel and thermal are contributing the maximum with nuclear being less than 3%. The technology and the material resources for enhancing the nuclear contribution to 50% by 2050, if not earlier exist, and this advantage should be fully exploited.

3. Unlike oil and coal, nuclear energy is free from the blemishes of carbon contamination of the atmosphere. However, accidents like Chernobyl and Fukushima have brought focus on radioactive contaminations and the disastrous consequences on the civilian population in the event of an accident – man made or natural. This has led to a certain hesitation and even negative attitude towards nuclear power among various

sections of the civil society and even among some intellectuals.

4. All this has led to the necessity of reinventing a strategy for the continuation of the nuclear power programme, not only for India, but also for other countries too.

5. There is no technological way of reducing or eliminating the radioactive contamination if an accident does take place. As a precautionary measure what has been done so for is to locate the nuclear reactor core within a single walled or a double walled containment concrete structure designed such that no radioactivity escapes. Provision is made to douse the entire system with large quantity of water, specially stored, when the core-melt down happens due to over heating and when the conditions of maximum credibility accidents (MCA) are reached. The real problem with this is that a continuous monitoring has to be done to ensure that there are no cracks in the walls of the containment structures. The question also remains how to dispose off, this highly radioactive contaminated water inside the containment structure after the accident.

6. The authors of this book have proposed an alternative method for locating future nuclear reactors, which ensures much greater safety from radioactive leaks even if an accident takes place. The suggestion is that the reactor be located in a deep cavern inside a hill with at least 100 meters of rock all round. The cavern is accessed through a zig-zag tunnel (Figure 9b) at the bottom of the hill with several air-lock doors at various stages. In case of an accident and core-melt down, the enormous heat naturally melts all the rock around, upto some length, which collapses and everything

gets vitrified including the radioactive materials (Figure 9c).

In an extreme case the cavern can be abandoned for ever without any worry of radioactive leaks since it is buried with at least 100 m of rocks all around.

7. Such a hill contained nuclear station provides straight away many other advantages: better protection against vandalism, terrorist attacks, air crashes, Tsunami, volcanoes, and sabotages by agents during a war. (Figure 10) One of the greatest benefits to the civilian society is that there is no need for reservation of an area of ~800 sq. kilometer to serve as Emergency Evacuation Zone at the foot of the hill and on the top of the hill as is the case with reactor stations located on the surface. Normal activities like agricultural operation, housing, factories, etc. can go on at the foot of the hill and the top of the hill. No special concrete structure for housing the reactor equipments is necessary since all of them will be in the caverns inside the hill. All these factors result in cost reduction also – both construction cost and operational cost (Figure 11).

Figure 10. HC HP NP @ Dam Foothill

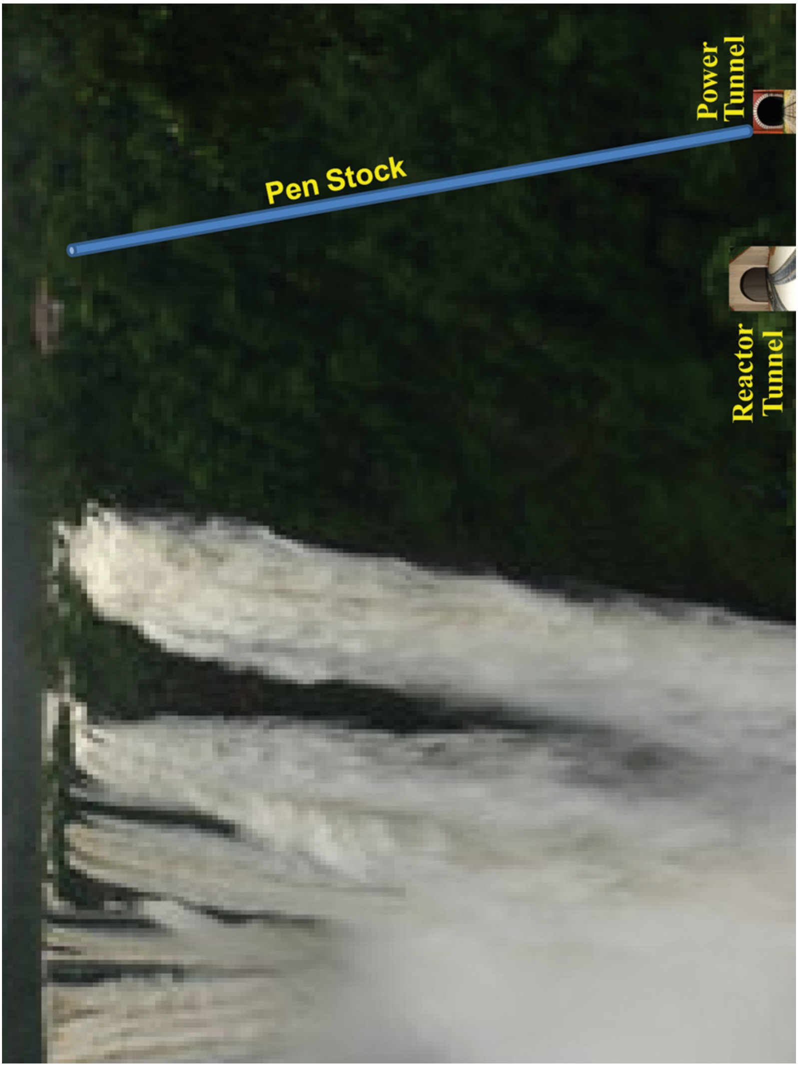


Figure 11. HC HP NP @ Waterfall Foothill

Chapter 7

Recommendation

In the light of the above, our recommendation is that since the Hill Contained Hydel Powered Nuclear Stations hold the promise of a much higher safety for the public and since the preliminary analysis shows that it is a feasible one and also cost effective, a Senior National Committee consisting of nuclear experts, geologists, geophysicists, hydel specialists, and social scientists should examine this proposal in depth in the long range interests of continuing publicly acceptable Nuclear Power Programme in India.

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Appendix 1

Nuclear Power In India

We have in India 20 Nuclear Power Plants having capacity of 4780 Megawatts of power. Six more are under construction which will provide 4800 Megawatts of power when completed. Except the first two reactors at Tarapur which are Boiling Water Type (BWR), all the others are pressured Heavy Water Cooled Reactors (PHWR). There is one Test Fast Breeder Reactor operating at Kalpakkam (See Table below):

Table 1: Plants Under Operation

Unit-Location	Reactor Type	Present Capacity (MW Electrical)	Date of Commencing Commercial Operation
TAPS-1, Tarapur, Maharashtra	BWR	160	October 28, 1969
TAPS-2, Tarapur, Maharashtra	BWR	160	October 28, 1969
TAPS-3, Tarapur, Maharashtra	PHWR	540	August 18, 2006
TAPS-4, Tarapur, Maharashtra	PHWR	540	September 12, 2005
RAPS-1, Rawatbhata, Rajasthan	PHWR	100	December 16,1973
RAPS-2, Rawatbhata, Rajasthan	PHWR	200	April 1,1981
RAPS-3, Rawatbhata, Rajasthan	PHWR	220	June 1, 2000
RAPS-4, Rawatbhata, Rajasthan	PHWR	220	December 23, 2000
RAPS-5, Rawatbhata, Rajasthan	PHWR	220	February 4, 2010
RAPS-6, Rawatbhata, Rajasthan	PHWR	220	March 31, 2010
MAPS-1, Kalpakkam, Tamilnadu	PHWR	220	January 27,1984
MAPS-2, Kalpakkam, Tamilnadu	PHWR	220	March 21,1986
NAPS-1, Narora, Uttar Pradesh	PHWR	220	January 1,1991
NAPS-2, Narora, Uttar Pradesh	PHWR	220	July 1,1992
KAPS-1, Kakrapar, Gujarat	PHWR	220	May 6, 1993
KAPS-1, Kakrapar, Gujarat	PHWR	220	September 1,1995

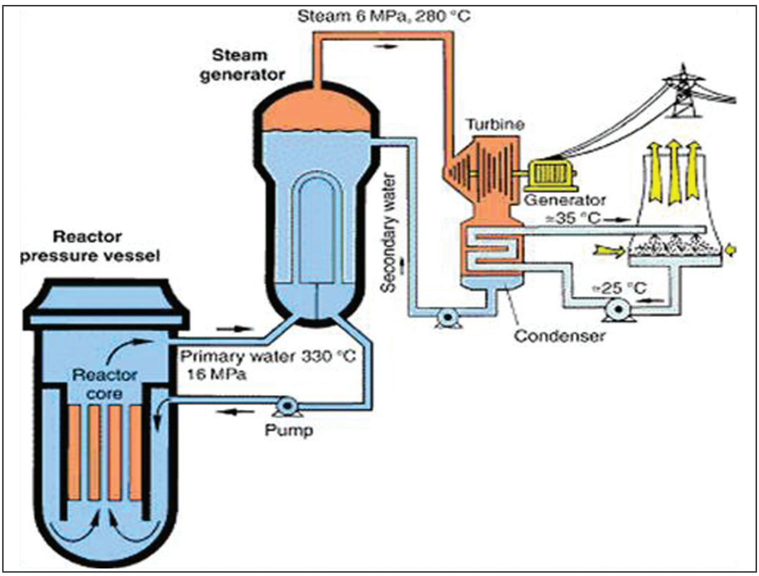
Kaiga-1, Kaiga, Karnataka	PHWR	220	November 16, 2000
Kaiga-2, Kaiga, Karnataka	PHWR	220	March 16, 2000
Kaiga-3, Kaiga, Karnataka	PHWR	220	May 6, 2007
Kaiga-4, Kaiga, Karnataka	PHWR	220	January 20, 2011
Total		**4780 (4.78 GWe)**	

Table 2: Projects Under Construction

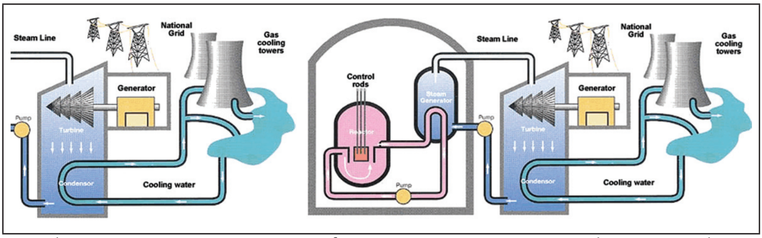
Project	Capacity (MW)
KKNPP-1&2, Kudankulam, Tamil Nadu	2x1000 LWRs
KAPP-3&4, Kakrapar, Gujarat	2x700 PHWRs
RAPP-7&8, Rawatbhata, Rajasthan	2x700 PHWRs
Total	**4800 (4.8 GWe)**
PFBR @ Kalpakkam	1x500 FBR

THE COMPONENTS OF PHWR

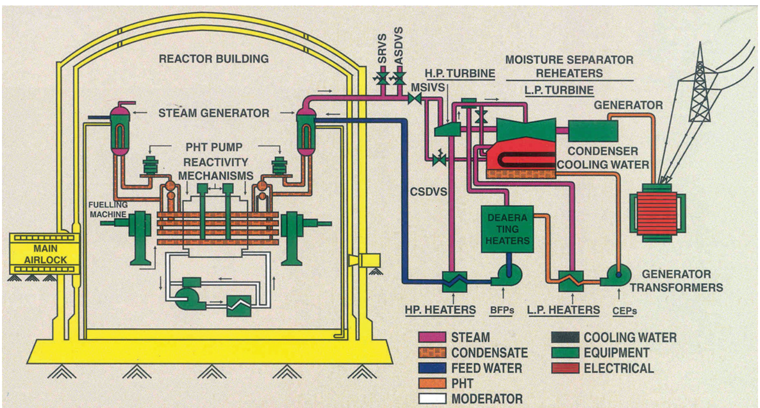
The main components of Pressurized Heavy water Reactor (PHWR) are shown below.



PHWR nuclear power plant



Schematic representation of PHWR components with HW as the coolant
(Source: http://www.hiroshimasyndrome.com/the-nuclear-cooling-tower.html)



Safety Barriers in Indian PHWR, including double containment, raft foundations and earthquake immunity.

1. Reactor vessel calandria with natural uranium fuel rods surrounded by one loop of heavy water for moderating and also the primary loop of heavy water for carrying the heat to the Steam Generator from the nuclear fuel.
2. Steam Generator
3. Demineralized water as secondary loop, carrying the heat from the steam generator to the steam turbine
4. Turbine operated by the hot high pressure steam
5. Condenser to cool and condense the steam

6. Liberal supply of water from outside (Sea, or Reservoir)
7. Generation of electricity and connection to the power grid.

The fuel assembly consists of few fuel bundles, each with many fuel pencils; which in turn are a stacked up series of U pellets in a Zircalloy ZrO_2-DyO_3 tube that is surrounded by the coolant heavy water. This assembly is immersed in the moderator which is also heavy water (**Figures).** The moderator slows down the neutrons released in the fission reaction and sets a chain reaction of further fission interactions. The fission of each Uranium 238 nucleus results in an energy release of ~200 MeV (~3.2 x 10^{-11} joule) which is million times greater than the energy release in any chemical reaction of a combustible process. Though it is conversion of mass to energy according to the Einstein Equation $E = mc^2$, the converted energy is only 0.09% of the mass, being the differential mass defect of the nuclide fissioned and nuclides of fission fragments. This energy appears as kinetic energy of the fission fragments (85%) and a small part (~15%) as the kinetic energy of other particles. All this is converted to heat which is conveyed by the heavy water in a pressurized non-boiling condition and is transferred to the ordinary water and converted to steam in the Steam Generator.

Then the steam passes though the turbine and generates electricity as shown in Figure 3. The light water steam is cooled by the Condenser and re-circulated.

A large quantity of ordinary water has to pass through the Condenser system to cool the steam and the heavy water. This quantity of outside water for cooling could be as large as passage of a million gallons per hour in the case of a power reactor generating a Gigawatt of electricity. As pointed earlier the heat generated is three Gigawatts. This is the main reason why the Nuclear power reactor has to be located by the sea coast or near a large resource of water.

Some times a dam has to be constructed specifically for this purpose.

'Safety in Depth' of Nuclear Power Plants

A number of precautions are taken in the engineering design of nuclear power plants since they are potentially dangerous source of radiation hazards in case of any failure or accident. Generally an area of 8 sq. kms is reserved for housing the nuclear plant with all its components. This area is restricted and entry allowed only for the reactor operation and maintenance personnel staff. Around this there is the sterilization zone of area 80 sq. kms where agricultural operations are not allowed so that consumption of contaminated food by radioactive spill over, either by animals or humans, is completely prevented.

Around this is an area of 800 sq.kms which is called the Emergency Evacuation Zone which will have to be completely evacuated of all humans and animals whenever an accident of class Maximum Credible Accident (MCA) does take place. To ensure that people in this area are ready for evacuation at any time, occasional surprise emergency evacuation drills are conducted. No industrial or commercial activities are allowed in this emergency zone at any time, once the reactor starts operating. The fenced boundaries of these three zones are naturally manned by security agencies, whose responsibility is also for facing situations like vandalism, terrorist attack, war like situations and other emergencies arising out of natural disasters like volcanoes, Tsunami, floods, earthquake, etc.

Thermal power stations release large quantities of obnoxious gases like SO_2, NO_2, CO_2, fly-ash, etc. Nuclear stations are completely free of this kind of emissions. The only serious problem is the release of radioactive nuclei and radiations in case of an accident. Thus Nuclear Power Stations do not contribute to acid rain, Ozone hole, etc., which result in the degradation of the quality of air, global warming, and long term climate change.

It is estimated that if the electricity produced by nuclear reactors world wide (327 of them) is replaced by coal power plants the additional contributions of CO_2 world wide would be 26000 million tons each year.

The world wide distribution of Nuclear Reactors and the net installed capacity of them and the relative percentages are given in the Table A1.

Table A1. Nuclear Reactors Operating in the World

Country	No. of Reactors	Net Installed capacity(MWe)	% of nuclear power
Spain	8	7,450	22.9
Sweden	10	8,958	51.8
China	11	8,438	2.2
Ukraine	15	13,107	51.1
Germany	17	20,470	32.1
India	20	4,780	2.9
Canada	18	12,577	15.0
United Kingdom	19	10,097	19.4
Korea, Republic	20	17,647	37.9
Russian Federation	31	21,743	15.6
Japan	53	45,957	29.3
France	59	63,260	78.1
USA	104	1,00,683	19.9

In India at the present time there are 19 Nuclear power stations which are operating. Their locations are given in the **Figure A1.** The photographs of a few power stations in India are given in **Figures A2.**

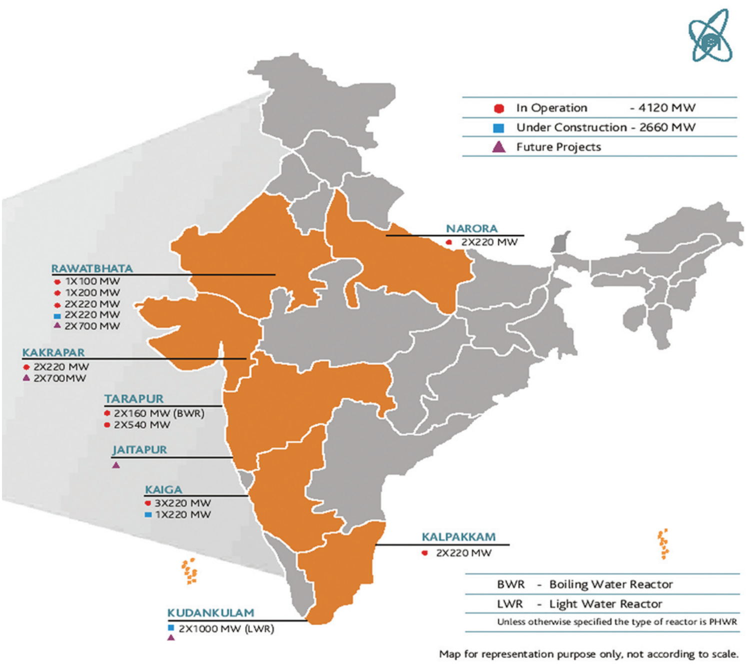
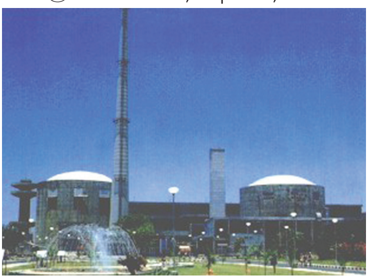


Figure A1. Nuclear Power Plants in India

RAPS 1 to 4 + 2 + 2; PHWR Reactors @ Rawatbhata, Rajastan, India

NAPS 1 & 2; 2 X 220 MW PHWR Reactors in Operation @ Narora, UP, India



2 x 220 MW PHWR Reactors in Operation & 2 x 700 MW PHWR future projects @ Kakrapara, Gujarath, India

TAPS 1 & 2 (cont.+2); 2x160 MW BWR Reactors in Operation, Tarapur, Maharashtra, India

TAPS 3 & 4); 2 x 540 MW PHWR Reactors in Operation, Tarapur, Maharashtra, India

Kaiga 1 to 4; 4 x 220 MW PHWR Reactors in Operation

Figures A2. A few photographs of Power stations in India.

The power capacities of these are given in the **table A2**

Table A2. Nuclear Power Plants in India
As in the Source: http://www.mapsofindia.com/maps/india/nuclearpowerplants.htm

Power station	State	Type	Operator	Units	Total capacity (MW)
Kaiga	Karnataka	PHWR	NPCIL	220 x 4	880
Kalpakkam	Tamil Nadu	PHWR	NPCIL	220 x 2	440
Kakrapar	Gujarat	PHWR	NPCIL	220 x 2	440
Rawatbhata	Rajasthan	PHWR	NPCIL	100 x 1 200 x 1 220 x 4	1180
Tarapur	Maharashtra	BWR (PHWR)	NPCIL	160 x 2 540 x 2	1400
Narora	Uttar Pradesh	PHWR	NPCIL	220 x 2	440
Total				**20**	**4780**

Some of the nuclear power plant projects which are under construction can be listed below:

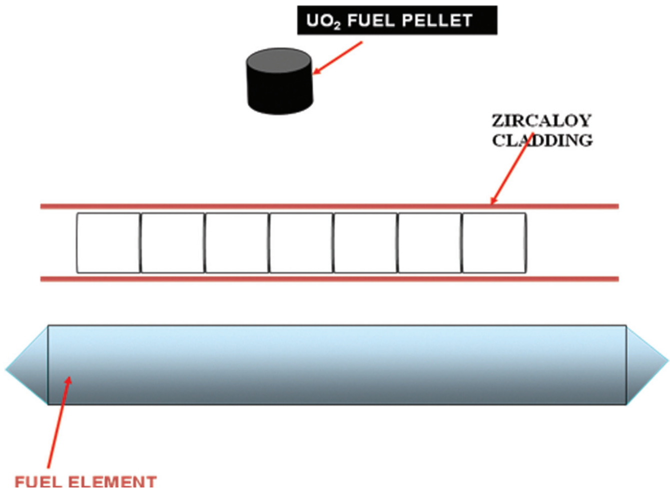
Power station	State	Type	Operator	Units	Total capacity (MW)
Kudankulam	Tamil Nadu	VVER-1000	NPCIL	1000 x 2	2000
Rawatbhata	Rajasthan	PHWR	NPCIL	700 x 2	1400
Kakrapar	Gujarat	PHWR	NPCIL	700 x 2	1400
Total				**6**	**4800**

Some of the nuclear power projects which are planned up for the future are as follows:

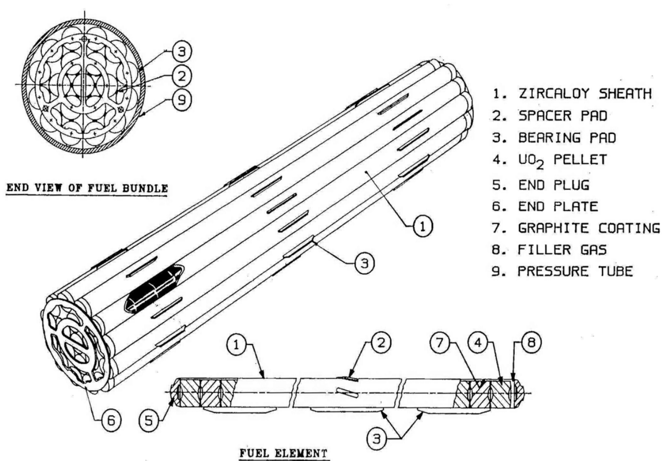
Power station	State	Type	Operator	Units	Total capacity (MW)
Jaitapur	Maharashtra	EPR	NPCIL	1600 x 4	6400
Kudankulam	Tamil Nadu	VVER	NPCIL	1000 x 2	2000
	Haryana	PWR	NPCIL	700 x 4	2800
	Madya Pradesh	PHWR	NTPC	700 x 2	1400
Total				**19**	**12,600**

Multiple Safety Barriers: Safety linked design starts right from fuel pallet. The fuel is in oxide form to withstand a high temperature at the pallet core, without softening / melting. It is encapsulated as fuel pencil with zercaloy clad and its end plug for keeping it segregated from erosion into high velocity coolant heavy water. Such few fuel pencils are held together end plate as fuel bundle, separated by bearing pads, avoiding hot spots, resulting in melting and unwanted spillage of fuel. Such bundles are housed within thick walled coolant pressure tubes, prevented from burst opening. These coolant pressure tubes are housed within calendria tubes with thermal isolation by 5 mm Helium cover. The calendria tubes are submerged within coolant boundary within the calendria and surrounding Gamma shielding concrete. This system is covered by primary containment followed by secondary containment. Thus the designed reactor is within 1.6 km radius exclusion zone, within 5 km radius sterilization zone, within 16 km radius emergency evacuation zone.

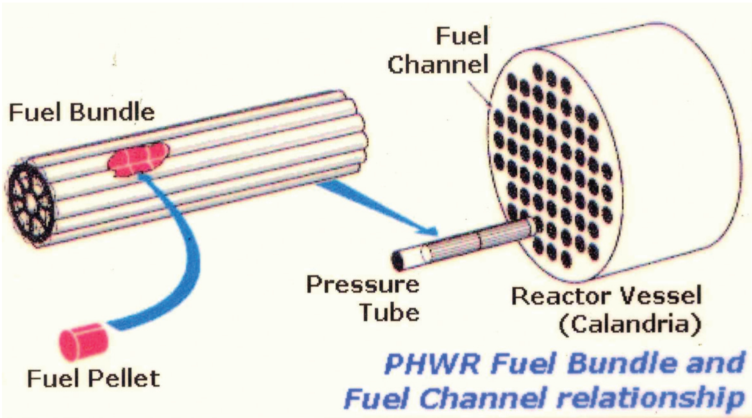
Thus formed power station is safe against seismic effects, tsunami water flooding, shock wave, tornado and air plane crashes.



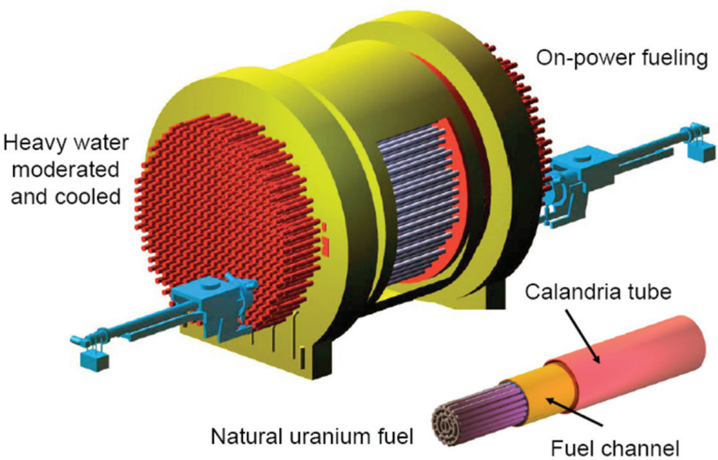
Multi level primary safety barrier within PHWR Fuel Pencil on flexibilities on and containments.

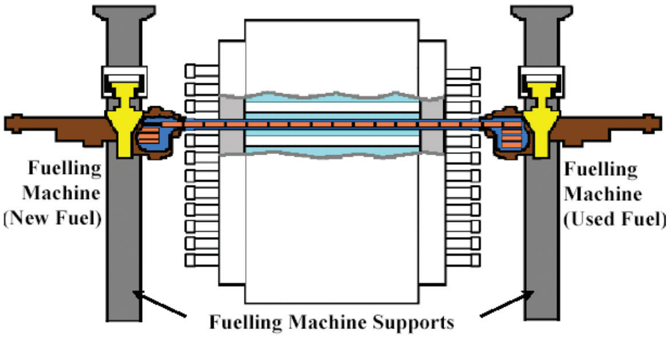


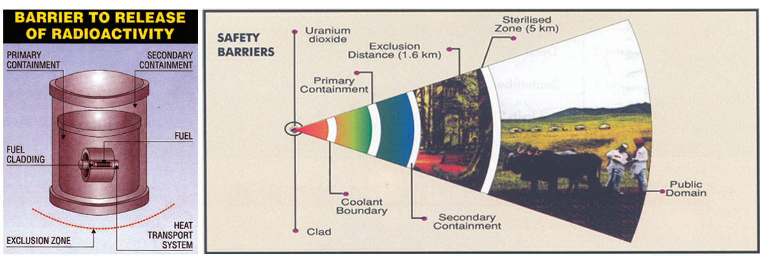
Safety barriers of PHWR Fuel Buldle.



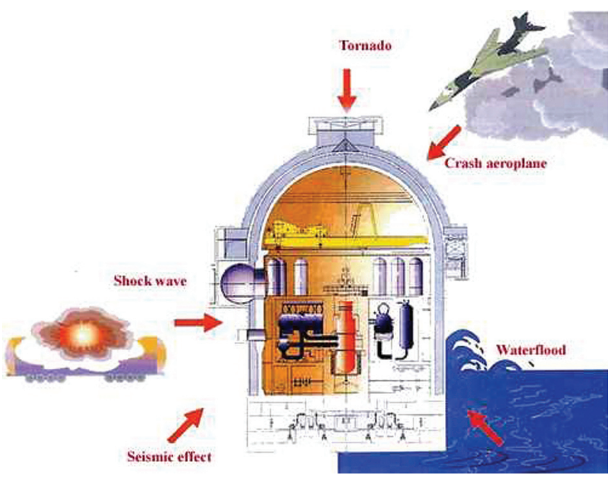
Safety barriers within PHWR reactor vessel calendria.







Multiple safety barriers



Immunity to safety threat built in

APPENDIX 2

UNDERGROUND SITING OF NUCLEAR REACTORS

(Note prepared by: Dr. A.K. Ghosh, Shri V. Bhasin, Shri P.A. Jadhav, Dr. A.K. Nayak and Shri K.K. Vaze and Dr. P.K. Vijayan; BARC;)

1. INTRODUCTION AND GENERAL BACKGROUND

Globally, as on date, 433 nuclear power reactors are operating in 30 countries. They produce 366.5 GW of electric power. In addition 65 nuclear power reactors, having the capacity to produce 62.5 GW of electric power, are under construction. A Nuclear Power Plant (NPP) offers a clean, reliable and affordable electric power. Nuclear power plants produce about 18% of the global electricity supply.

The nuclear power reactors are housed inside the building called Reactor Building (RB). Till date almost all the RBs have been located on the ground surface. The founding level of RBs is selected based on geotechnical properties at the site. As a result the grade elevation of reactors (housed inside the RBs) could vary from ground level to slightly below the ground level.

Generally, the NPPs have an excellent safety record. This is owing to extensive safety measures taken during site selection, design, fabrication / construction, installation and operation. All the credible accident initiating events are postulated during the design stage and several layers of defensive measures are incorporated to mitigate the consequences of these events. In addition, the site selection criteria are such that the severity of external events is minimized. However, in the past there have been three incidences in which the integrity of the reactor core was affected to a significant extent, followed by release of radio-nucleoids in to the environment. These are the accidents at Three Mile Island (1979; in USA), Chernobyl (1986; in USSR) and Fukushima (2011;in Japan).

The initiation of accidents could be from internal events or external events. These events may adversely affect the primary coolant flow or reactor control/shutdown system or primary heat sink or other engineered safety systems. The internal events are those which originate within the reactor systems like malfunction of mechanical, process, electrical, or electronics equipment, failure of primary boundary, operator error, internal fire etc. The external events are those which originate from external sources like earthquake, cyclone, tsunami waves, storm surges or heavy rain/snow fall; or external electrical grid disturbances, nearby external accidents, etc. The external events like accidental aircraft crash or neighboring industrial accidents, etc. are ruled out by site selection criteria and providing adequate exclusion zone around the NPPs. Some of the new generation NPPs also take into account, to a limited extent, the events related to insider malevolent act or external terrorist / disruptive acts like intentional aircraft impact, etc. Generally, the power reactors are located above ground or they have a small portion with a shallow embedment. This note discusses some of the past experiences and proposals with respect to underground siting of nuclear reactors. It discusses various aspects of this proposition.

In the past there had been several propositions to build underground power reactors. The prime reason for such propositions was based on the feeling that this measure would help in significant reduction of radioactive burden to open atmosphere, even during severe accidents. In addition the adverse impact of some of the external events like disruptive acts by terrorists/ adversaries or cyclones can be precluded. As a result, several studies have been carried out by experts in different countries. In general, the proposals converged to a configuration in which the primary nuclear part of NPP (that is, nuclear reactor and primary coolant boundary components) is under earth cover while the secondary part (that is, turbine-generator, condensers, cooling towers etc.) are over-ground and near the water reservoir. The construction could be either under the plain ground or under the rocky hill. It calls for boring tunnels, in sound rocky media having competent rock mass. These tunnels in turn would house the primary nuclear systems and components. The underground construction under the soil media or moderate / weathered rock may not be feasible owing to the fact that a large space is required to house the power reactor components.

2. Actual Experience with Underground Nuclear Reactors

Till date only two underground power reactors, of small capacity, have been built. One of them is in France and the other in Russia. The French reactor started power production in 1967 and was stopped in 1991. Since then it has remained in shutdown state. However, a few small sized underground research or test reactors have been built in Europe and Russia [1,2].

The world's first underground nuclear reactors were constructed and operated in central Siberia, Russia. Russian reactors were commissioned in 1958, 1961, and 1964. The first two reactors were for Plutonium production. The 1964 reactor produces electricity and provides hot water and heat for the city of Zheleznogorsk, [1]. These reactors were water-cooled, Uranium-graphite reactors.

Four small European reactors have been constructed in tunnels bored in rocky media, [2]. These are listed in Table 1.

Table 1: Underground Nuclear Reactors*

Name and location	Size	Purpose	Configuration/ Location		Status	Reactor Chamber Dimensions (feet)
			Turbine Generator	Reactor		
Halden Norway (BHWR)	25 MWt	Experimental	None	Rock Cavern	Operational (1959-2020)	98′ long 85′ high 33′wide
Agesta Stockholm, Sweden (PHWR)	80 MWt/ 20 MWe	Heat Production	Above ground at grade level	Rock Cavern	Operated from 1964-1974. Shutdown since 1974.	88′ long 66′ high 54′wide
Chooz Ardennes, France (PWR)	266 MWe	Power	Above ground	Rock Cavern	Operated from 1967-1991. Shutdown since 1991.	138′ long 146′ high 69′wide
Lucerne, Switzerland	30 MWt/ 8.5 MWe	Test Reactor	Rock Cavern	Rock Cavern	Operated from 1968 to 1969. Shutdown since 1969.	--

* These are besides the three reactors in Russia

The Lucens reactor at Lucens, Vaud, Switzerland, was a small pilot test nuclear reactor destroyed by an accident in 1969. The heavy-water moderated, carbon dioxide gas-cooled, reactor was built in an underground cavern and produced 30 megawatts of heat (which was used to generate 8.5 MW of electricity). It was intended to operate until the end of 1969, but during a startup on January 21, 1969, it suffered a loss-of-coolant accident, leading to a partial core meltdown and massive radioactive contamination of the cavern, which was then sealed. No irradiation of workers or the population occurred, though the cavern containing the reactor was seriously contaminated. The cavern was decontaminated and the reactor dismantled over the next few years, [http://en.wikipedia.org/wiki/Lucens_reactor].

3. Summary of Past Studies

The 1970s studies revealed several probable advantages in underground siting [3]. These are listed below:

(a) Higher resistance against the following:
- Terrorist attack
- Aircraft impacts
- Proliferation
- Sabotage and vandalism
- Conventional warfare effects

(b) Higher Levels of Protection against severe weather effects

(c) Greater containment capability relative to a surface-sited plant and hence reduced public health impacts from extreme hypothetical accidents.

(d) Somewhat reduced seismic motion.

(e) In smaller countries where adequate surface land is not available and safe distances from population cannot be maintained, underground siting of reactors offers a distinct advantage.

It is reported that there have been a few positive results from studies in the 1970s in the U.S., Canada, Japan and Switzerland, [1]. Scope of one of the studies included technical feasibility, safety, security, cost, advantages and disadvantages, [3]. However, in this study the key issues like seismicity, leak-tightness of containment, penetrations and traps, design of liners, installation sequence and access sizing were either not included or were studied with gross idealizations.

These studies brought out the perceived advantages of underground siting as well as the costs and other possible penalties associated with this novel approach to siting. However, the plans for large size commercial plants do not seem to have progressed to a significant extent. In the recent years again there are a few publications on the subject, [2,4]. These deal with founding of such plants on various rock formations, co-location of various associated facilities like chemical processing and waste storage and underground nuclear parks hosting several reactors.

In some recently reported studies the concept of Underground Nuclear Park has been introduced [2,4]. Features of the Underground Nuclear Park Concept are the following:

- Array of high-temperature (>900^0 C reactors suitable for electricity and/or hydrogen production;

- Non-water cooled reactor designs; underground, passive air-cooling of spent fuel; use of ramps for entry of wheeled vehicles; use of seals and bulkheads to isolate individual reactors, sectors of the underground nuclear park, and the entire underground nuclear park from the surface.

- Co-locating several reactors and nuclear facilities appears to be an economically viable option.

Many of these studies have focused on idealized concepts and brought out overall advantages and limitations of underground construction. The feasibility has been examined based on certain assumptions but there is no critical examination on validity of these assumptions.

In fact none of the studies (available in open domain) explores the feasibility from the point of actual engineering, satisfying all the safety and regulatory requirements. There has been no commentary on how to overcome the technical challenges related to construction, installation/ erection, in-service inspection, repair/replacement of aged components / equipment, etc.

Several geotechnical experts point out that underground construction generally carries a perceived greater level of risk (uncertainty) than its elevated, at-grade or cut-and-cover counterpart. In the case of underground construction, ground doesn't just serve as a part of the foundation and/ or sidewall structures but it is the structure. In assembling a project team for an underground program it is important to combine structural engineering skills with the expertise required to reliably identify and mitigate the particular challenges of underground construction.

Constructing an underground facility will involve the usual complexities of any underground construction, for example, mines, etc., and will have to contend with the challenges in material transport and handling any ground collapse (especially during the seismic activities) and occasional problems during ground water spouting. The advantages are assured shielding and confinement of activity in case of any release/spillage etc.

The challenges listed above can only be addressed if there is an appropriately qualified and experienced team on site to manage the work.

Many issues associated with the underground concept require further study. An example is the power transmission cost associated with moving multi-gigaWatt levels of electricity to distant users. Another is safety risks [5] (e.g., fire, rockfall, and ventilation) common to all underground construction and operations, and their impact in the context of underground nuclear operations. Host-rock-specific issues need to be examined; an example is to determine measures needed to control introduction of water and movement of airborne salt particle in a salt UNP. A safety analysis is needed to evaluate underground reactor and waste management facility accident scenarios. Water requirements could be a significant issue in regions with limited surface and ground water resources, given the number of reactors in an underground nuclear plant. First-of-a-kind economic and technical risks are associated with the start-up. None of these issues are viewed as sufficient to preclude further study of the underground concept, but all are important and require analysis and resolution [2]. Lack of engineering for constructability when tunneling in weak or brittle rock at depth often leads to unnecessary delays and extra costs. Furthermore, brittle failing rock at depth poses unique problems as stress-driven failure processes often dominate the tunnel behaviour. Such failure processes can lead to shallow unravelling or to strainbursting modes of instability that cause difficult conditions. It also follows that fractured rock loses its self-supporting capability (reduced stand-up time) and thus is more difficult to control during construction. Consequently, the features of underground power plant siting are not well understood. Gross physical features such as depth of burial, number and size of excavated galleries, equipment layout, and access or exit shaft tunnels must be specified. Structural design features of the gallery liners, containment structure, foundations, and gallery interconnections must also be identified. Identification of the nuclear, electrical, and support equipment appropriate to underground operation is needed. Operational features must be defined for normal operations, refueling, and construction. Several magazine articles have been published addressing underground concepts. But adequate engineering data is not available to support an evaluation of the underground concept [3].

These uncertainties resulted in reduced interest by nuclear industry.

4. Overall Safety Assessment of Underground Nuclear Power Reactors

As of now one of the possibilities is underground construction of small and compact reactors [4], which are passively cooled and require minimum operator interference. Such reactors require lesser space owing to small size and reduced number of components/ equipment. These can be located in pits or rock tunnels lined by impermeable clays of adequate thickness. The impermeable clays like bentonite retards the leaching out of radio-nucleoids should they be released following a severe accident.

Currently the Reactor Buildings (RBs), housing the primary nuclear side, of NPPs are of 40 to 60 m in diameter and 50 to 60 m high. In underground constructions creating a pit of this diameter and height is not feasible, at most of the rocky sites. It may be feasible only in extremely good quality rock formation. Apart from strong and hard rock, one of the important requirements is that joint spacing in overall rock mass should be very sparse. All over the world only few such sites are available.

The second option is to bore an array of tunnels to house the reactor systems, components and structures. Considering Indian Pressurized Heavy Water Reactors, the required size of tunnels would still be of the order of 25 m width and 25 m height. This is to accommodate the nuclear cavity which in turn house reactor core components. The control rod drives would require clear height of no less than 10 to 15 m above the core. In addition the existing layout has to be linearized to accommodate the primary pumps, moderator flow systems, fuel handling machine and fuel handling system, purification systems, shutdown systems, emergency core cooling systems, and a host of other engineered safety systems. All these systems comprise of pump-motor sets, heat exchangers, accumulators/pressure vessels, compressors and circuitous piping network. It may not be possible to linearize the layout of all these systems, hence it would call for creating additional neighboring tunnels, to accommodate some of these systems with piping running (through rock ducts) from one tunnel to other. Housing steam generators itself would call for a separate array of tunnels or vertical shafts. Some of the issues foreseen are as follows:

(a) Boring tunnels of size 25 m require good quality and stable rock mass systems. In India such systems are present mostly in the Deccan or Western Ghats region. Such construction is not feasible in Northern, Ganges, or Trans-Himalayan Plains. The rock formations in Aravalis, Shivalik, Central India, or Eastern Ghats may not permit rock caverns/ tunnels of such large sizes. The Himalayan region is ruled out owing to high seismic activities and Indian regulations prohibit construction in such regions. This in turn implies that it may not be technically feasible to construct NPPs in all the regions of India.
(b) By virtue of being installed inside the rock tunnels, the protection against some of the external events is undisputedly enhanced. These are aircraft crash, cyclone, harsh weather effects and disruptive acts of terrorists / adversaries. This is one of the unanimous conclusions, from studies conducted by other countries.
(c) As far as earthquake effects are concerned there may not be any major gain in terms of reduction in seismic loading or its probability of occurrence.
(d) The contribution of internal events to accident

initiation will definitely not reduce. On the contrary there may be some increase. Some of the reasons for increased contribution are uncertainties in the stability of the rock, excessive welds in piping systems owing to its increase in length etc.

(e) Several systems of nuclear reactors are enclosed in the concrete vaults. This feature enhances the accessibility during inspections, repair/ replacement or maintenance work. Although such cavities / vaults can be built inside the tunnels, their presence would infringe the installation or replacement of heavy equipments/components, in a linearized layout. This will lead to higher downtime of the reactor.

(f) The In Service Inspection (ISI), which is mandatory to ensure safety, would be difficult or practically infeasible for pressurized piping running through rock ducts.

(g) Economies of scale are possible through co-locating numerous reactors.

(h) One of the biggest challenges in construction inside the tunnels is overcoming uncertainties in structural and stability behaviors of large diameter tunnels[5,6]. One of the issues is the changes in redistribution of rock load with time, which may be significant for large sized openings. In order to overcome this challenge the tunnel support would call for excessive strengthening possibly with reinforced concrete encastered steel girders. Till date very few tunnels of such sizes have been bored and hence the operational experience is not readily available. It may be noted that several of the roadways, railways, or hydroelectric plant tunnels are operating since several decades but their diameter is considerably less. Moreover, the stability of such tunnels is periodically monitored and frequent corrective measures are taken. However, this strategy in NPP tunnels would call for frequent down time of the reactor since the tunnels in general would be accessible only during shutdown.

(i) The efficiency of the plant is also affected owing to a large piping system and hence increased pumping power particularly from underground primary system to over-ground secondary system.

(j) The water flooding would be an added hazard in case of underground tunnels. However, in case of tunnels under the hill, this may not be an issue.

(k) In case of some of the beyond design basis severe accidents there are chances of large scale damage of nuclear core and primary boundary, leading to release of radio-nuclides. This has been observed in accidents at Chernobyl and Fukushima power reactors. In such cases housing reactors in tunnels obviously minimizes the immediate release to the environment due to enhanced confinement. However, it may be noted that this gives only relief against short-lived radio-nuclides. As far as long lived radio-nuclides (some of them having half life greater than 100 years) this relief is of transient nature since the spread by diffusion and ground water transport cannot be ruled out. Locating sites in totally arid zones is not feasible since reactor cooling requires abundant water supply. In this regard it may be noted large scale international efforts are on for deep underground repository of nuclear waste; however, some of the key issues related to environment safety (ground water contamination) are yet to be fully resolved.

The efficacy of enhanced confinement, in underground constructions, has been critically examined by several experts. In this regard the conclusion of a publication by International Atomic Energy Agency [7] is worth quoting:

"Although siting reactors underground seems to offer additional environmental protection from accidents leading to large radioactive releases, it does not normally have significant safety advantages. Clearly, putting a reactor plant into a cavern or otherwise entrenching it into the ground does nothing to avoid an accident. The most it could achieve would be to provide a more complex path for radioactive releases resulting from an accident, which could, under some but not all circumstances, lessen the consequences of the accident. In fact, building a reactor underground could well make a power plant less safe. This is because construction, operation, and maintenance would be made more difficult by the extra complications of design and especially, access to an underground plant.

Moreover, seepage of groundwater could cause additional complications. Unless it is in caverns in solid rock, underground siting raises complicated environmental problems about the protection of groundwater. It would be necessary to dig a pit at least 60 metres in diameter and in depth to put the reactor building in. In most places, this would necessitate very carefully engineered isolation of groundwater, since it would probably be used for local drinking water. Even so, if underground siting would achieve an appreciable gain in safety, the additional engineering and operating difficulties and cost certainly could be met. However, underground siting can only be expected to provide additional safety if the surrounding rock or soil can be made to act as an additional containment to reduce radioactive releases in the unlikely case of grave reactor accidents. The efficiency of a containment, however, depends mainly on the tightness and reliability of many points at which it has to be pierced for pipes, venting, electrical cables, and access of power plant workers, to enable the reactor to be connected with other systems and buildings of the nuclear power plant outside the containment. The tightness of the containment structure itself is much less of a problem. Since a reactor needs the same connections whether it is above or below the ground, the reliability of its overall containment system cannot be markedly improved by underground siting. Apart from some extra protection against extreme outside influences, such as aeroplane crashes, missile attacks, or warfare, underground siting of nuclear power plants does not offer any additional safety worth the extra complications and cost.

5. Regulatory Issue

USNRC does not have regulatory framework for underground reactors. The position with respect to other regulatory bodies is not known.

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Appendix-3

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Mr. Ashok Chauhan
NCPIL, New Delhi

Appendix-4

The Official Report of the Fukushima Nuclear Accident Independent Investigation Commission

(Source: http://publicintelligence.net/fukushima-report/)

Message from the Chairman

THE EARTHQUAKE AND TSUNAMI of March 11, 2011 were natural disasters of a magnitude that shocked the entire world. Although triggered by these cataclysmic events, the subsequent accident at the Fukushima Daiichi Nuclear Power Plant cannot be regarded as a natural disaster. It was a profoundly manmade disaster – that could and should have been foreseen and prevented. And its effects could have been mitigated by a more effective human response.

How could such an accident occur in Japan, a nation that takes such great pride in its global reputation for excellence in engineering and technology? This Commission believes the Japanese people – and the global community – deserve a full, honest and transparent answer to this question.

Our report catalogues a multitude of errors and willful negligence that left the Fukushima plant unprepared for the events of March 11. And it examines serious deficiencies in the response to the accident by TEPCO, regulators and the government.

For all the extensive detail it provides, what this report cannot fully convey – especially to a global audience – is the mindset that supported the negligence behind this disaster.

What must be admitted – very painfully – is that this was a disaster "Made in Japan." Its fundamental causes are to be found in the ingrained conventions of Japanese culture: our reflexive obedience; our reluctance to question authority; our devotion to 'sticking with the program'; our groupism; and our insularity.

Had other Japanese been in the shoes of those who bear responsibility for this accident, the result may well have been the same.

Following the 1970s "oil shocks," Japan accelerated the development of nuclear power in an effort to achieve national energy security. As such, it was embraced as a policy goal by government and business alike, and pursued with the same single-minded determination that drove Japan's postwar economic miracle.

With such a powerful mandate, nuclear power became an unstoppable force, immune to scrutiny by civil society. Its regulation was entrusted to the same government bureaucracy responsible for its promotion. At a time when Japan's self-confidence was soaring, a tightly knit elite with enormous financial resources had diminishing regard for anything 'not invented here.'

This conceit was reinforced by the collective mindset of Japanese bureaucracy, by which the first duty of any individual bureaucrat is to defend the interests of his organization. Carried to an extreme, this led bureaucrats to put organizational interests ahead of their paramount duty to protect public safety.

Only by grasping this mindset can one understand how Japan's nuclear industry managed to avoid absorbing the critical lessons learned from Three Mile Island and Chernobyl; and how it became accepted practice to resist regulatory pressure and cover up small-scale accidents. It was this mindset that led to the disaster at the Fukushima Daiichi Nuclear Plant.

This report singles out numerous individuals and organizations for harsh criticism, but the goal is not—and should not be—to lay blame. The goal must be to learn from this disaster, and reflect deeply on its fundamental causes, in order to ensure that it is never repeated.

Many of the lessons relate to policies and procedures, but the most important is one upon which each and every Japanese citizen should reflect very deeply.

The consequences of negligence at Fukushima stand out as catastrophic, but the mindset that supported it can be found across Japan. In recognizing that fact, each of us should reflect on our responsibility as individuals in a democratic society.

As the first investigative commission to be empowered by the legislature and independent of the bureaucracy, we hope this initiative can contribute to the development of Japan's civil society.

Above all, we have endeavored to produce a report that meets the highest standard of transparency. The people of Fukushima, the people of Japan and the global community deserve nothing less.

CHAIRMAN:

KIYOSHI KUROKAWA

Prof. B V Sreekantan, Former Director of the Tata Institute of Fundamental Research, Mumbai is currently a Visiting Professor at the National Institute of Advanced Studies at Bangalore. While his expertise has been in the field of High Energy Physics and High Energy Astronomies, in recent years he has been working in the area of Philosophy of Science and Scientific and Philosophical studies on Consciousness. As an Editorial Fellow of PHISPC he has edited a volume on "Foundations of Sciences" which is under publication by the Centre for Studies on Civilization. He is the Chairman of the Gandhi Centre for Science and Human Values of the Bharatiya Vidya Bhavan.

Prof. B N Karkera is Reactor Engineer, Adjunct Faculty at NIAS, Visiting Professor and the consultant to BRNS project on HLC at NITK, Research Director, SCEM; was a BARC Senior Scientist for over 34 years, Deputy Director, CSIO/CSIR for 3.5 years, Faculty of Nuclear Engineering, Manipal University, consultant to DRDO on 'BodyPhone', member international / national Technical Boards for Super Conducting Tokomak of IPR and National Optical Telescope Project and holds several patents. Six of his projects were recognized through Prime Minister, President of India and awards at national / international levels. They include India's first fast reactor PURNIMA-I, FBTR and DHRUVA Reactor, TAPS SRM/IRM System, LCA--HUD, LINAC and MC-PET Project for cancer care, and PHWR PT Gauging. He is the recipient of Life Time Achievement Award form NITK AAB.

Hill Containment of Nuclear Power Plants

In this booklet, the authors have pointed out that to overcome the abysmally low level of electrical power availability in India, which is affecting the quality of life, there is no option but to enhance Nuclear Power Production at an exponential rate.

However, they have proposed as a long term measure, future nuclear power stations should be located in specially made deep caverns within hills with atleast a 100 meters rock cover on all sides, which can be approached through long zig zag horizontal tunnels. Such locations of the Nuclear power plants will ensure absolute safety for the public from radioactivity in case of any accidental explosion of the reactor.

Such Hill Containment Nuclear Power Stations circumvent the necessity of locking up hundreds of square kilometers of precious land for emergency evacuation as in surface installations. No civil buildings are needed around the reactor and plant equipments. They also provide better protection against terrorist attacks, vandalism and air crashes.