From Volga to Ganga :

The Story of Kudankulam

photo: A.I. Siddiqui

The Padmanabhaswamy temple in Trivandrum

*India's biggest nuclear power station in being set-up at Kudankulam in collaboration with the Russian Federation **A.I. Siddiqui** presents details in this travelogue-cum-technical feature*

The aerial view of Thiruvananthapuram, Trivandrum for short, is mesmerizing – presenting hues of green and blue. As the aeroplane descends further, the verdant Kerala reveals its enthralling landscape. The Trivandrum airport is comfortably devoid of clamours of hotel agents and taximen. Trivandrum, the capital city of the southern State Kerala is also famous for its Padmanabhaswamy temple and the golden beach Kovalam. The temple is a fine example of blend of the Kerala and Dravidian styles of architecture. The internationally renowned Kovalam beach resort, with its three adjacent crescent beaches, is a favorite tourist haunt.

photo: A.I. Siddiqui

An artisan at Kanyakumari beach embossing the sea-shells

The National Highway No.47 (NH-47) connects Trivandrum and Kanyakumari, my sojourn en-route Kudankulam. The continuous habitats along the high-way makes it difficult for the first time visitors to identify where one city ends and the next town begins. But farther from Trivandrum, the rows of houses gradually disappear providing overwhelming views of paddy fields, coconut grooves and banana plants all of which are closely integrated with the lives and culture of the people living in this region.

Kanyakumari, named after Goddess Kanyakumari Amman, is about 80 kms from Trivandrum. Kanyakumari, a small habitat in Tamil Nadu State, is a very popular name among Indians, as a pilgrim and famous tourist spot. It has the distinction of being the southern most point of the mainland India. Here, Bay of Bengal on one hand and Arabian Sea on the other meet the Indian Ocean, presenting captivating shades of mixing waters. Nevertheless, the world famous Vivekananda Rock temple stands tall in the sea. The twin rocks stand amid the sea

photo: A.I. Siddiqui

The dusk and the twin rocks at Kanyakumari - on the left is Swami Vivekananda Rock Memorial and on the right statue of Thiruvalluvar

*** The title of the artical is inspired by the book, 'From Volga to Ganga' by Rahul Sankrityayan. His Excellency, the Vice President of India and Chairman of Rajya Sabha, about the book said, "… many years ago, an Indian writer, Rahul Sankrityayan wrote a travelogue titled "From Volga to Ganga". Even the celebrated author himself didn't know then, that he was providing the most perfect imagery for the Indo-Russian civilisational encounter. The great rivers represent two great civilisations, and their perennial flow symbolises the permanence, the serum and the continuity of our contacts". The Vice President was addressing the meeting of Members of Parliament, addressed by His Excellency Mr. Vladimir V. Putin, President of Russian Federation, on October 4, 2000.*

separated by about 220 feet. The famous philosopher, Swami Vivekananda meditated here on the night of December 25, 1892, a year before his attending the Parliament of Religions in Chicago. The superb rock memorial has been erected to commemorate his visit to the rock. On one of the rocks, stands 133 feet high statue of Thiruvalluvar, one of the most respected poets of Tamil, famous for his work 'Thirukural'. The height (133-ft) of the sulfur-resistant statue is said to correspond to the 133 chapters of his work. Not far from the Rock Memorial is a lighthouse, the Kumari Amman temple and the Gandhi Memorial where the urn containing the ashes of Mahatma was kept before immersion. It has been designed such that the Sun's rays fall on the same spot every 2nd October – his birthday. In fact, the region has a unique landscape dotted with beautiful temples, churches and mosques distilling unity in diversity.

The views of sunrise and sunset from Cape Comorin or Kanyakumari are memorable. It is said that it is the only place in India where sun-set and moonrise can be seen simultaneously on a full moon day.

Nuclear Power Corporation of India Limited (NPCIL) had, until recently, its project office in Nagercoil – the district headquarters of Kanyakumari district. Nagercoil is named after the presiding deity Nagaraja. The Nagaraja temple is about 20 kms from the city. The pillars of this temple, I am told, are adorned by the carvings of Jain Tirthankars, Mahavira and Parshivanath.

National Highway No.7 (NH-7) connects Kanyakumari and Tirunelveli via Nagarcoil. The first leg of the journey from Kanyakumari towards Kudankulam on NH-7 presents, on both the sides of the road, serried banana and coconut trees sandwiched between high hillocks and dancing paddy fields. Clouds floating across the azure sky, Oh! What a land – picture perfect with its surrealistic beauty and eternal mystique.

The journey on NH-7 ends at Kavalkinaru and we divert to a country road to reach Kudankulam. A huge wind-mill park at Kavalkinaru presents a spectacular sight. As we approach Kudankulam, a dramatic change in the landscape can be noticed. Soon after crossing the Anjugramam village, the vegetation becomes thorny and bushy. Coconut and banana trees almost disappear. The soil appears barren. Going little further, the cactus bloom and ant-hills become abundant. Kudankulam region is in the rain shadow area, which means very scanty rains even during thick of rainy season. This semi-arid zone has moderate to severe salinity and alkalinity. All these factors have led to frequent crop failures and very low agriculture productivity. These adverse agriculture conditions have forced the local population to adopt 'beedi' (Indian cigarette) making and fishing that yields low monetary returns. Kudankulam is in Radhapuram Taluka in district Tirunelveli of Tamil Nadu State. The Tirunelveli city is about 75 Kms in north-east direction from Kudankulam.

The Kudankulam site was chosen by the Site Selection Committee (SSC) of the Department of Atomic Energy (DAE) way back in 1987-88. The SSC considered several aspects including the guidelines set by the International Atomic Energy Agency (IAEA). It was one among the many sites considered by the SSC. Several factors related to nuclear safety as also social, economical and environmental were considered by the Committee.

The site is located in low seismic area, zone-II as per the Indian Standards of Classification. The classification divides the whole country in five Zones, with zone-I having the lowest and zone V the highest seismicity. The site does not have any active faults in its vicinity. The site also provides preferable foundation conditions to build the nuclear power plant upon. The site is free form severe cyclonic activities

all photos by: A.I. Siddiqui

Road to Kudankulam: Scenes of paddy fields and coconut grooves gradually dissolve into cactus bloom and barren land as we drive towards Kudankulam site though it lies along the coast of Gulf of Manar, which also provides ample water for the condenser cooling.

Mr. S.K. Jain, Director, Light Water Reactors and Kudankulam (LWR&KK), elaborating site specific features points out that there were no nearby chemical plants, large industries and military installations as also air corridors. "That means", says Mr. Jain, "the possibilities of explosion, fire, release of inflammable, explosive, corrosive or toxic clouds is nil and the chances of loss of flight control does not exist".

Kudankulam site is, nevertheless, well connected by road, railways and sea. NH-7 and broad-gauge rail head at Kanyakumari and the Tuticorin sea port about 100 kms, will be used by the project authorities to transport large equipment and components to the site, informs Project Director (Kudankulam), Mr. S.K. Agarwal. The Kudankulam site itself has been declared, recently, as a minor port.

The site has a potential for setting up to 6000 MWe installed capacity. The first two units of 1000 MWe each are presently being set-up in technical collaboration of the Russian Federation. But a pertinent question is, why did India need an imported nuclear power plant (NPP) when the country has its own indigenous programme? Dr. V.K. Chaturuvedi, CMD, NPCIL clarifies, "the two light water reactors we are importing from the Russian Federation, and the other LWRs that we may import in future are add-ons and will help to increase the installed nuclear capacity rapidly. The project will help to build a larger operating base, which means better profitability and more internal surpluses, which will go in a long way to pursue the indigenous programme more vigorously. In view of huge demand for power the country's nuclear power programme which is poised to expand rapidly will become self sustaining financially too".

Kudankulam project is a Rs.140 billion mega project - the biggest ever undertaken by NPCIL. Explaining on the cost of project, Dr. Chaturvedi says, "this is the cost of the completion of the project in the year 2005-2006, including the interest during construction. It is a firm cost, even the sensitivity of dollar-rupee parity fluctuations have been considered in the unit energy cost". The Russian components of funding is mainly to cover the cost of services and supply of equipment, components and materials being supplied by the Russian Federation.

The Russian Federation is funding almost half the project cost. The soft loan is at an interest rate of 4% per annum. Mr. Jain briefs the arithmetic, "the loan is to be repaid in fourteen equal yearly instalments (EYIs) starting a year after the commencement of commercial operation of the plant". How much does it mean? "Assuming a nominal plant load factor of 68.5%, the two units will generate electricity worth Rs. 33991 million per annum compared to the EYI of Rs. 6530 million", explains Mr. Jain. A financially more relevant indicator is the Debt Service Coverage Ratio (DSCR) which tells whether a borrower has earned sufficient revenue to meet the principal and interest commitments on the outstanding debt after meeting the operating costs. It is the utility's cash flow divided by the sum of all its debt payments. For instance, if DSCR is more than 1, say 1.2, it means to lender that for every rupee of loan debt that the borrower has to service, he/she will have Re. 1.2 with which to make the payment. The average DSCR for Kudankulam project is calculated to be about 1.4. "That shows the economic viability of the project" concludes Mr. Jain.

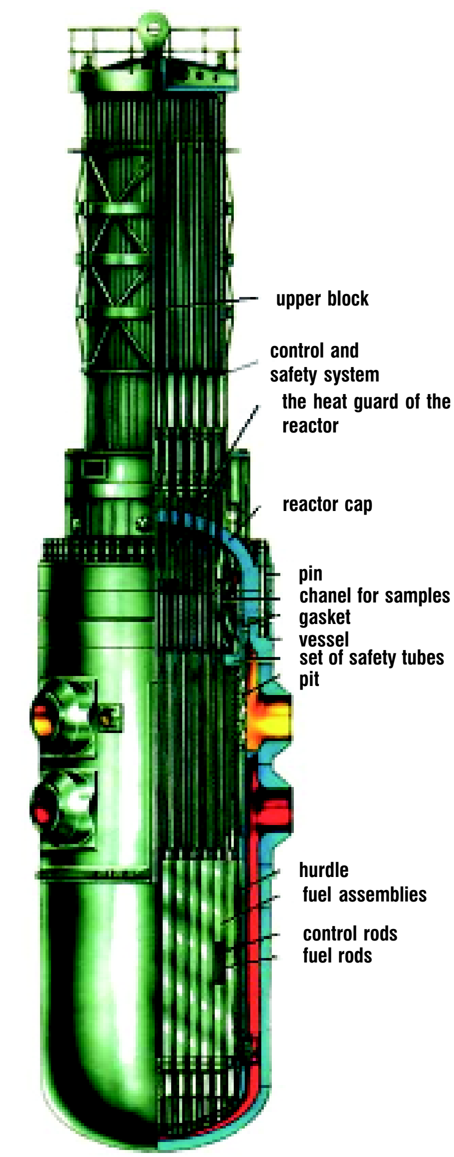
The total project cost is the result of a

series of negotiations Indian side had with their Russian counterparts. “Negotiations have certainly optimised the project cost by an appropriate sharing of the responsibilities by the Indian and the Russian sides. This resulted not only in the reduction of project cost but it will also provide an opportunity to the Indian industry to participate in this mega-project” says Dr. Chaturvedi.

The change in scope of work is explained by Mr. S.K. Agarwal, “Initially, Indian scope was limited to only construction of all plant buildings and erection of equipment except the main steam supply system and the turbo-generator (TG) plant but now it includes the construction, erection and commissioning of the entire plant under the technical supervision of the Russian experts”. Mr. Agarwal informs that the Atomic Energy Regulatory Board (AERB) of India granted construction consent in March - end 2002. However, parallel action was initiated by KK project authorities to float tenders and award major construction contracts necessary at that stage. “This helped,” says Mr. Agarwal “to reduce the mobilisation period”.

The construction, of this biggest nuclear power plant both in terms of its capacity as also investment, commenced with the placement of first pour of concrete on March 30, 2002 (See Indian News, this issue). The two units being set-up at Kudankulam with a gross capacity of 1000 MWe each belong to Pressurised Water Reactor (PWR) family, the dominant type of reactor world-wide. This type of water cooled water moderated reactor, called VVER in Russian nomenclature uses slightly enriched uranium. The fuel for the Kudankulam plant is to be supplied by the Russian Federation. On the fuel arrangements, Dr. Chaturvedi explains, “our strategy is that who so ever supplies the plant enters into a long-term contract for supplying fuel for the designed life of the plant. We are ensuring that we always have adequate fuel for the operation of plant for a five-year duration so that we have sufficient time to locate alternative sources in case of interruption in the supply due to any reason”.

Today, the Kudankulam site is buzzing with hectic construction activity. The movement of construction equipment and machinery – trucks, bull-dozers, mixers, trailers and so on – compose a twenty first century musical note being played against the blue waters of Gulf of Manar. The mood at Kudankulam Directorate and project site is up beat.



The Reactor Pressure Vessel (RPV) is the heart of the plant

all photos by : A.I. Siddiqui

Frequent crop failure and poor soil conditions has left not many options for the people in Kudankulam. Fishing and ‘beedi making’ with low monetary returns are the main occupations

The project schedules are being implemented and monitored meticulously with clock-work precision. The first milestone of completion of raft of the reactor building No-1 has already been achieved well ahead of the schedule. And the raft of the second unit which was scheduled for completion next year has now been preponed to September this year!

Most of the labour force, says Mr. Agarwal, "is drawn from the adjoining areas". Strictly speaking not a single household has been displaced from the Kudankulam site. Moreover, "as per the government norms there is absolutely no project affected population (PAP). However, as per NPCIL's policy preference for the employment is given to the suitably qualified personnel whose land has been acquired and those from the neighbouring areas," Mr. Agarwal informs. He points out that instructions have been issued to the contractors to employ the local labour force to the maximum extent.

"VVER" in Russian stands for "*Voda Energo Reactor*" implying 'water cooled water moderated' reactor which is similar to its counterpart 'pressurised water reactors' (PWRs) in the United States and Western countries. The developmental work of the VVER began way back in 1950s in the erstwhile USSR and the first VVER became operational in 1964. All through these years, spanning over four decades, the design has considerably been evolved with significant improvement in safety features. The design is backed-up by strong research and experiment base in the Russian Federation. These experiments and research are carried-out in the experimental research reactors and several other facilities set-up to validate the design, models and codes. According to the International Atomic Energy Agency, 51 units of VVERs having a capacity of 32834 MWe are operational and eight units with a capacity of 6438 MWe under construction. India has chosen 1000 MWe capacity reactors being set-up at Kudankulam.

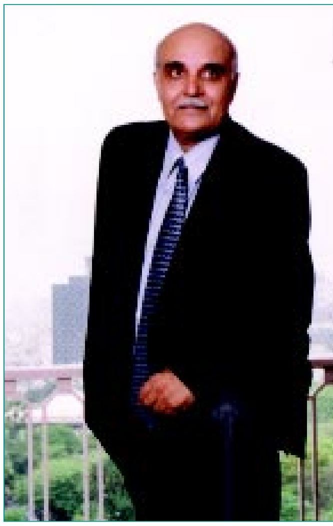


photo: A.I. Siddiqui

The vision is in his sight

"Large capacity reactors like the two VVERs at Kudankulam are add-ons and will help to rapidly increase the installed nuclear capacity in the country."

Dr. V.K. Chaturvedi
CMD, NPCIL

"VVER" has several variants identified by English alphabet 'V' followed by a 3-digit number. For instance, V-187 was the earliest, a pilot design followed by V-338 and V-320. Majority of the operating nuclear plants belong to V-320 category. Then came the advanced designs, V-413, V-392 and V-428. Among these, V-392 has the most advanced design features and it is this design which is being supplied to India and set-up at Kudankulam.

The advanced reactors have evolved from hundreds of reactor-years of operation experience, incorporating features that significantly enhance safety and performance and minimise

Most of the Labour force employed at Kudankulam comes form the adjoining areas to the project.

environmental impacts of the nuclear plants while still maintaining economic competitiveness. Inherent safety features of the plant and passive and active engineered safety features make the advanced reactor top of the rank among the entire gamut of reactor designs (see *additional resources* at the end of this article).

A unique feature of the advanced reactor designs is that they incorporate what are called 'passive safety features', besides the active safety features. The passive safety systems work on the never failing forces of nature like gravitation, convection, conduction, momentum etc. We shall return to these features later in the article.

The heart of the Kudankulam nuclear power plant is a 19.47 meter high and 4.5 meters in diameter, reactor pressure vessel (RPV) (see Figure). The 200-mm thick cylindrical vessel is made of low alloy high strength steel with an inner cladding of austenic stainless steel. The RPV houses the reactor core, the reactor control rods and host of other mechanisms and connections. The coolant entry and exit is through coolant inlet and outlet, respectively, connected to the upper part of the RPV. The coolant, in this case light water, enters through the inlet, removes the heat from the core produced in the nuclear fuel by the fission chain reaction and the hot coolant moves through 'outlet' to the steam generators. The light water is demineralised to eliminate the ill effects of minerals naturally present in the water. A fixed quantity of boric acid is also added to this demineralised water which acts as 'moderator' and also a reflector. The boric acid being a neutron absorber helps to control the reactivity, i.e. the rate of fission chain reaction.

photo: KTM Kumar

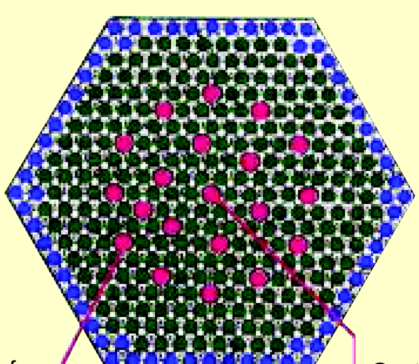
VVER is an advanced design and one of the safest in the world

S.K. Jain,
Director, (Light-Water Reactors and Kudankulam)

The RPV has a detachable top cover. The vessel head is a leak tight chamber facilitating building-up of pressure necessary to inhibit boiling of the coolant. Pressuriser, another equipment cylindrical in shape, is employed to build the coolant pressure up and maintain it within the predetermined margins. The RPV sits inside a strong concrete pit. The outer surface of the RPV is insulated and cooling is provided in the space between the RPV and its concrete housing.

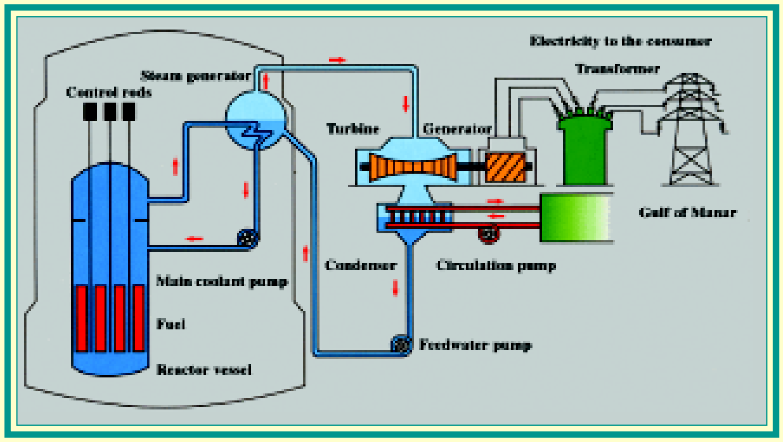
Several components, collectively called reactor internals, are housed inside the RPV. The 'core barrel' accommodates the reactor core. The core barrel has perforations at the bottom. The coolant entering through the upper portion of the RPV is directed downwards and enters the core barrel through these perforations. The coolant circulates through the reactor core before its exit from the RPV. The other reactor internals include, 'Protective Tube Unit' that keeps the core in position and guides the control rods into the core; core baffle - sandwiched between core barrel and core - for shielding the RPV from irradiation, support systems for fuel assemblies, instrumentation and control, provisions for the placement and retrieval of specimen that are irradiated etc.

The enriched uranium fuel pallets encapsulated in Zirconium–Niobium (Zr-Nb) tubes are assembled in a hexagonal array fuel assembly. The fuel assembly has 331 tubes in all. The Zr-Nb tubes loaded with fuel are placed in 311 locations whereas the balance 20 are used to house control rods and instrumentation tubes. One central tube is for structural element of the fuel assembly frame. Such 163 fuel assemblies constitute the reactor core, which itself has a hexagonal array.

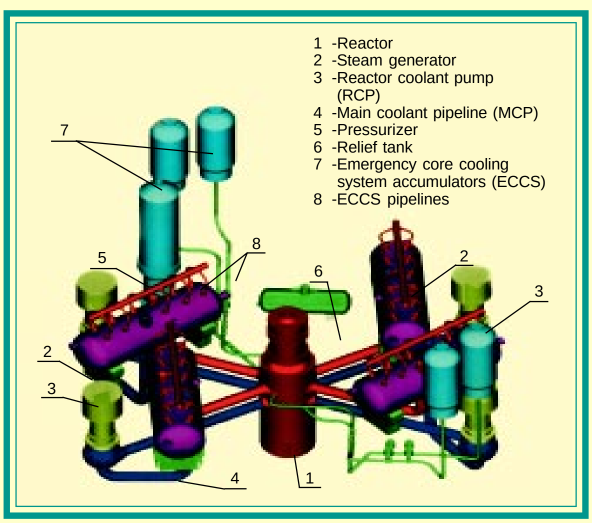


The Fuel Assembly Profile

How Does it Work ?

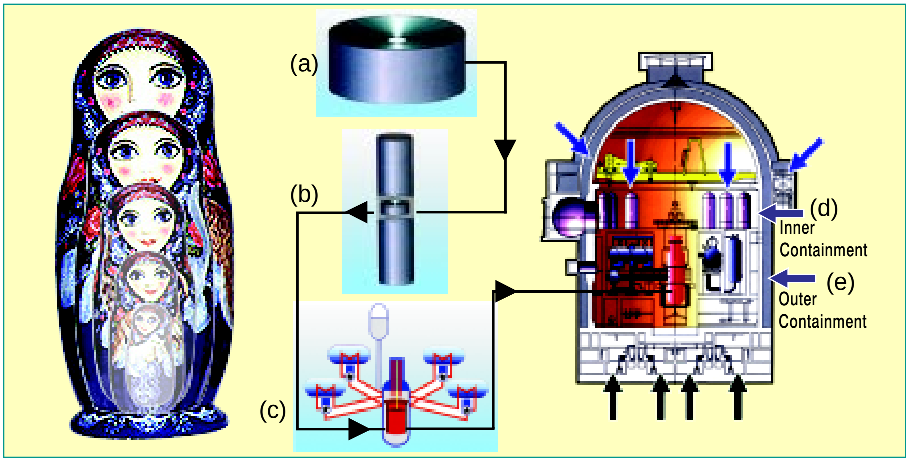


Heat in a nuclear power reactor is produced by the controlled fission chain reaction in the nuclear fuel. The heat is used to raise steam that drives turbo-generator to produce electricity. In VVER, slightly enriched uranium is used as fuel. The fuel bundles are placed in the reactor core, which is housed in reactor pressure vessel (RPV). In VVER, water is used both as coolant and moderator. The coolant removes the heat from the reactor. The reactor plant has three major loops. The coolant circuit, or nuclear steam supply system (NSSS) comprises of the reactor itself, primary coolant pump, steam generator and associated pipes and valves. Four such circuits are connected to the RPV (see figure below). Since the boiling point of water is 100 ºC and the temperature of the coolant rises to 322 ºC in the reactor, the coolant is kept pressurised to inhibit its boiling, by a pressuriser, connected to one of the loops. The water in the primary circuit is slightly radio-active, therefore, the close loop is kept isolated from the environment.



The hot coolant transfers its heat in the steam generator to water circulating in another loop called secondary cycle. Thus, the steam generator has two sides, the primary and the secondary side. The secondary circuit comprises steam generators, turbines, moisture separator and reheater, condenser, feed water pump, dearators, associated pipelines and other equipment. The secondary circuit does not contain radioactivity, though it is also a closed loop and isolated from the environment.

The steam produced in the steam generator is fed to a set of turbines, which drive the generator to generate electricity. The steam from the turbine is exhausted into a condenser where it is cooled and condensed. The condensate is pumped back to the steam generator. The condenser cooling is accomplished by a third loop, condenser-cooling system, which draws cooling water from the Gulf of Manar. It is this (third) circuit which is exposed to the environment.



The Russian Dolls (MATRYOSHKA) (left) and concept of dense-in-depth. The fuel maxtrix (a) prevents release of fission products to fuel element cladding (b) that prevents its release to the coolant of primary circuit (c). The primary circuit (c) prevents release of fission products to inner containment (d) that does not allow its release to the outer outer containment (e) The outer containment is the final barrier to release of fission products to the environment though an exclusion zone and a sterilised zone too exist (see text)

The top of the RPV is crowned with 121-reactor control drives. The control rods containing neutron-absorbing materials control the rate of chain reaction, in other words, the power of the reactor. These rods are held by electro-magnetic clutches, giving the mechanism its name 'electromagnetic control rod drive mechanism'. The control rods can be inserted-in, in a stepped manner, allowing absorption of neutrons by them. It leads to a deficiency in the availability of neutrons in the core to reduce the number of fissions thus reducing the power of the reactor. Conversely, withdrawal of the control rods allows building-up of extra neutrons causing more fissions and increasing the power of the reactor. In case necessity arises to shutdown the reactor in an emergency or failure of power supply that keeps the electromagnetic clutches energised, the clutches are de-energised allowing the control rods to fall freely into the reactor core under the force of gravitation and the reactor becomes sub-critical. The action takes only 2 to 4 seconds to be completed.

Another fast acting system to shut-down the reactor is 'quick baron injection system'. It is a back-up system to 'control rod drive mechanism' and acts on a diverse principle. The system injects highly concentrated boric acid into the reactor coolant circuit. One boric-acid solution tank is connected to each four primary coolant pumps. Once the system receives the signal of failure of the control rod drive mechanism, it is automatically actuated. A unique feature of the system is that it can work even in case of failure of power to the pumps. It has been made possible by the flywheel provided with each pump. The flywheel conserves energy (inertia, to be accurate) and keeps the pumps rotating, as the power fails, for a duration sufficient to inject the boric acid into the circuit.

The reactor pressure vessel is connected to four steam generators directly and the coolant returns via main circulating pumps (see the box 'how does it work'). These pumps, four in number, one for each steam generator, evacuate reactor coolant from the steam generators and inject it into the RPV. Once the heat of the coolant is transferred to light water to raise the steam, the coolant is flowed back by the circulatory pumps to the RPV. This makes a closed loop, also

The language that nuclear engineers speak

Atom: *A particle of matter which cannot be broken up by chemical means. Atoms have a nucleus consisting of positively-charged protons and uncharged neutrons of the same mass. The positive charges on the protons are balanced by a number of negatively-charged electrons in motion around the nucleus.*

Chain reaction: *A reaction that stimulates its own repetition, in particular where the neutrons originating from nuclear fission cause an ongoing series of fission reactions.*

Cladding: *The metal tubes containing oxide fuel pellets in a reactor core.*

Control rods: *Devices to absorb neutrons so that the chain reaction in a reactor core may be slowed or stopped by inserting them further, or accelerated by withdrawing them.*

Coolant: *The liquid or gas used to transfer heat from the reactor core to the steam generators or directly to the turbines.*

Core: *The central part of a nuclear reactor containing the fuel elements and any moderator.*

Critical *mass: The smallest mass of fissile material that will support a self-sustaining chain reaction under specified conditions.*

Criticality: *Condition of being able to sustain a nuclear chain reaction.*

Enriched uranium: *Uranium in which the proportion of U-235 (to U-238) has been increased above the natural 0.7%. Reactor-grade uranium is usually enriched to about 3.5% U-235, weapons-grade uranium is more than 90% U-235.*

Fission: *The splitting of a heavy nucleus* called the primary circulation circuit or the nuclear steam supply system (NSSS). It is kept isolated from the secondary system because the coolant in the PHT carries slight radioactivity.

The purification of coolant is necessitated to control its radio-active contamination and various chemical impurities. The later could lead to clogging of system, impairing its heat removal efficiency and possibility of corrosion though the entire primary circuit is made of corrosion resistant stainless steel. The coolant purification system involves a closed loop circuit with a heat exchanger to bring down its temperature and then to 'cationic' and 'anionite' filters before it is pumped back to the primary coolant circuit.

The steam generators to be used at Kudankulam project are horizontal 'shell and tube' type heat exchangers. A nest of u-shaped tubes is housed inside the shell. The reactor coolant flows through the tubes while light water used to raise steam, called secondary side water or feed water remains on the shell side. The horizontal steam generators hold large quantity of secondary side water, which acts like a large reservoir even if the feed water supply is terminated in an unlikely situation. The horizontal layout of the steam generator has another advantage that even with significant reduction in the level of the secondary side, the heat removal capacity of the steam generator is not impaired. These steam generators also have large evaporation surfaces implying low steam velocities. The steam generators have provisions for an auxiallry feed water supply should the main feed water supply is disrupted in an abnormal condition. The emergency heat removal from the secondary side is accomplished by an emergency cool down system powered by Diesel generators. The system comprising of heat-exchangers and pumps and is a closed loop system using the inventory of steam generators thus requiring no feed-water.

The steam so produced is fed to a set of turbines comprising of one high-pressure and three low-pressure cylinders. The steam first passes through high-pressure cylinder and is then routed to equipment called moisture separator and reheater to remove the moisture and reheat the steam. It then enters the low-pressure turbines. The impinging steam on the turbine blades rotates the turbine, which is coupled with a generator to generate electricity.

photo: KTM Kumar

We will make all out efforts to compress the gestation period of the project

S.K. Agarwal
Project Director
(Kudankulam)

The turbine of Kudankulam plant revolves 3000 times in a minute. The turbine is equipped with systems like stress evaluator and an on-line performance monitoring system that keeps a check on its health. The 24-kilo Volt (kV) generator is capable to operate, at full load, at 5% frequency - and voltage variations.

The electricity generated at Kudankulam site will be fed to a switch-yard and then to the Southern Grid through three double circuit lines of 400 kV and a double circuit line of 230 kV

into two, accompanied by the release of a relatively large amount of energy and usually one or more neutrons. It may be spontaneous but usually is due to a nucleus absorbing a neutron and thus becoming unstable.

Fission products: *Daughter nuclei resulting either from the fission of heavy elements such as uranium, or the radioactive decay of those primary daughters. Usually highly radioactive.*

Fuel assembly: *Structured collection of fuel rods or elements, the unit of fuel in a reactor.*

Chain reaction: *A reaction that stimulates its own repetition, in particular where the neutrons originating from nuclear fission cause an ongoing series of fission reactions.*

Cladding: *The metal tubes containing oxide fuel pellets in a reactor core.*

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Coolant: *The liquid or gas used to transfer heat from the reactor core to the steam generators or directly to the turbines.*

Core: *The central part of a nuclear reactor containing the fuel elements and any moderator.*

Critical mass: *The smallest mass of fissile material that will support a self-sustaining chain reaction under specified conditions.*

Criticality: *Condition of being able to sustain a nuclear chain reaction.*

Fission: *The splitting of a heavy nucleus into two, accompanied by the release of a relatively large amount of energy and*

photo: A.I. Siddiqui

A huge ant hill: the Kudankulam area has many like this.

transmission system. The switchyard is made indoors to protect it from the saline atmosphere of Kudankulam. (The switch yard at Madras Atomic Power Station too is indoor for the same reason). The 400 kV lines will be connected to Madurai, Trivandrum and Udhumalpet and 230 kV line to Tuticorin. The system also feeds power supply to the station for both the normal operations as well as to start the shutdown plant up. The southern states benefiting from the grid include Tamil Nadu, Kerala, Andhra Pradesh and Karnataka States. Mr. Jain says that the capacity of the Southern Grid was adequate for the 1000 MWe capacity units. He also points out that the Central Electricity Authority (CEA) has conducted study to examine the grid-related issues before the clearance of the project by it.

The Kudankulam reactor is considered one of the safest new generation designs. It has several inherent and engineered — both active and passive — safety features for normal as well as abnormal conditions, (See the exhibit, 'Implementation of the dirversity principle to ensure main safety functions in VVER-1000 design). Says, Mr. Jain, 'the VVER-392, has a negative power co-efficient. It means that any abnormal increase in reactor power that could affect the safety of the reactor is self-terminating'. Mr. Jain explains that this happens because with an abnormal increase in power, the moderator is also heated and becomes less dense, therefore, loosing its moderation efficiency. He points out another inherent safety feature, called 'negative void coefficient' in reactor physics parlance. It implies that the chain reaction in the reactor core comes to a grinding halt in an unlikely event of the loss of coolant (water) from the reactor (discussed later in the article).

These reactors follow the design philosophy of 'defence-in-depth' and provide successive levels of safety so that failure of one does not impair the overall safety of the reactor (See the exhibit 'Defence-in-depth'). In case of failure of first level, the next protective level comes into force actuating certain safety systems. The reactor protective systems are 100 per cent quadruplicated, i.e. four independent channels for such systems exist though only one was sufficient for the protection of the reactor.

These systems not only have adequate redundancy but also diversity and physical segregation. Diverse systems

usually one or more neutrons. It may be spontaneous but usually is due to a nucleus absorbing a neutron and thus becoming unstable.

Fission products: *Daughter nuclei resulting either from the fission of heavy elements such as uranium, or the radioactive decay of those primary daughters. Usually highly radioactive.*

Fuel assembly: *Structured collection of fuel rods or elements, the unit of fuel in a reactor.*

Fuel fabrication: *Making reactor fuel assemblies, usually from sintered UO2 pellets in zircalloy tubes, comprising the fuel rods or elements.*

Light water reactor (LWR): *A common nuclear reactor cooled and usually moderated by ordinary water.*

Low-enriched uranium: *Uranium enriched to less than 20% U-235. (That in power reactors is usually 3.5 - 4.5% U-235.)*

Megawatt (MW): *A unit of power, = 10^6 watts. MWe refers to electric output from a generator, MWt to thermal output from a reactor or heat source (eg the gross heat output of a reactor itself, typically three times the MWe figure).*

Moderator: *A material such as light or heavy water or graphite used in a reactor to slow down fast neutrons by collision with lighter nuclei so as to expedite further fission.*

Natural uranium: *Uranium with an isotopic composition as found in nature, containing 99.3% U-238, 0.7% U-235 and a trace of U-234. Can be used as fuel in heavy water-moderated reactors.*

Neutron: *An uncharged elementary particle found in the nucleus of every atom except hydrogen. Solitary mobile* are employed to achieve the same safety function to avoid common mode failure. For instance, power supply to safety related systems and equipment is provided by more than one grid feeders which is backed-up by on-site quadruplet (4 x 100) Diesel generators and then again by a battery bank.

The engineered safety features are designed to prevent and limit the accidental conditions and to mitigate the abnormal conditions including highly improbable severe accidents. These safety features for the V-329 plant have evolved from the proven V-320 serial model. The degree of redundancy has been increased in V-392 from triplicated safety systems to quadruplicated safety system, as mentioned earlier. This additional margin provides an opportunity to the plant operators to service and maintain one of the redundant system, according to the procedure, while the plant is in operation that sufficiently relaxes the maintenance intervals.

One can conceive several apocalyptical scenarios of a nuclear accident but the worst considered by the nuclear engineers is an accident called 'loss of coolant accident' or its acronym LOCA. In such an accident engineers consider a double ended guillotine break in the largest pipe line of the nuclear steam supply system, the system that removes fission heat from the reactor core through coolant. A nightmare for the designers, the very low probability accident, can further be compounded with other misfortunes like non-availability of power or a few operator's mistakes. LOCA could trigger a series of imaginative disasters no less than a Hollywood horror film. For instance, Zirconium present in the Zirconium-Niobium tubes has high affinity for oxygen and it may react with steam, under certain conditions. The chemical reaction will remove oxygen from steam water liberating hydrogen. The hydrogen so produced could catch fire or explode, depending on its concentration in the air. Thus, at the end we have a scenario like this - a double ended guillotine break in the coolant line with coolant draining from the core, the rising temperature of the fuel, radioactive materials including fuel melting and flowing on the reactor floor like magma and zirconium liberating hydrogen from steam which catches fire or detonates. The molten uranium has a higher temperature than most of the materials that it encounters in its passage. As a result, all these materials are damaged too. At the same time, perhaps, there is no power supply available, of what so ever kind - that is, we have a station black-out.

The loss of coolant will impair the removal of fission heat from the core. However, water being both coolant and moderator, loss of coolant also means loss of moderator. Therefore, the chain reaction is terminated immediately. However, heat continues to be generated by the radioactivity of the fuel. The heat could be large enough, if no alternative safety system exists, to meltdown the reactor core and escape of radioactivity into the environment in absence of adequate reactor containment. The radioactive cloud emanating from the core could travel miles and miles with no respect to political boundaries.

Is n't it a very imaginative script? Engineers have tried to map such scenarios through complex calculations and computer modeling. The chance of such an accident-involving core melt down but with no release of radioactivity to public domain is no more than '10^{-5}' per reactor-year and that of release of radiation beyond the reactor, involving mass evacuation still lower, '10^{-7}' per reactor-year, to be precise. Numbers like '10^{-5}' and '10^{-7}'

neutrons travelling at various speeds originate from fission reactions. Slow (thermal) neutrons can in turn readily cause fission in nuclei of "fissile" isotopes, e.g. U-235, Pu-239, U-233; and fast neutrons can cause fission in nuclei of "fertile" isotopes such as U-238, Pu-239. Sometimes atomic nuclei simply capture neutrons.

Nuclear reactor: *A device in which a nuclear fission chain reaction occurs under controlled conditions so that the heat yield can be harnessed or the neutron beams utilised. All commercial reactors are thermal reactors, using a moderator to slow down the neutrons.*

Pressurised water reactor (PWR): *The most common type of light water reactor (LWR), it uses water at very high pressure in a primary circuit and steam is formed in a secondary circuit.*

Radiation: *The emission and propagation of energy by means of electromagnetic waves or particles. (cf ionising radiation)*

Radioactivity: *The spontaneous decay of an unstable atomic nucleus, giving rise to the emission of radiation.*

Reactor pressure vessel: *The main steel vessel containing the reactor fuel, moderator and coolant.*

Spent fuel: *Fuel assemblies removed from a reactor after several years use.*

Uranium (U): *A mildly radioactive element with two isotopes which are fissile (U-235 and U-233) and two which are fertile (U-238 and U-234). Uranium is the basic fuel of nuclear energy.*

Waste:

High-level waste (HLW) *is highly radioactive material arising from nuclear fission, requiring both shielding*

photo: A.I. Siddiqui

'The lonely survivor : a huge banyan tree is the only one at Kudankulam site. Project authorities are trying to preserve this 'exception'

are extremely small, difficult to comprehend through day-to-day experience. Let's draw an equally imaginative analogy to understand the remoteness of such an event.

On a clear night sky, on a no-moon day and away from the city lights one can observe 'shooting stars' or meteors. The number of such events is so high on some particular days during the year that the phenomenon is called a 'shower', a meteor shower. The meteoroids, the small debris, mostly of the size of grains or small pebbles, hit the earth's atmosphere in hundreds and thousands every day. But they burn as they pass through the earth's resisting atmosphere leaving behind a trial of fire and presenting a spectacular celestial show. However, a fraction of large meteoroids reach the earth and many such pieces can be seen in museums. Then, there are asteroids orbiting the Sun between the orbits of Mars and Jupiter, and the comets that follow a highly elongated orbit around the sun. There are hundreds and thousands of such objects that endanger life on the earth. Moreover, the earth's orbit passes through the orbits of several such objects.

The impact of such bodies hitting the earth could be varying from almost negligible to mass destruction, even extinction of civilization, depending on the size of the object hitting the earth. The probability of such large-scale impacts in a year or in our lifetime is very slim. Dr. Clark R. Chapman, of Southwest Research Institute in US Congressional Hearings on May 21, 1998 stated, "those chances are small that they are difficult to comprehend…"

Returning back to our query, how significant (or insignificant) is the number 10^{-5}? Well, C.R. Chapman and D. Morrison in their study published in 1998 calculated that the chance of dying from an asteroid or comet impact is 1 in 20,000 or 2×10^{-4} which is five fold more than the frequency of reactor core melt down and 500 times more than the frequency (10^{-7}) of the reactor accident involving evacuation of

and cooling. It can be recovered from reprocessing spent fuel, though some countries regard spent fuel itself as HLW. It requires very careful handling, storage and disposal.

Intermediate-level waste (ILW) *is sufficiently radioactive to require shielding, some is categorised as long-lived ILW and this may be disposed of with HLW.*

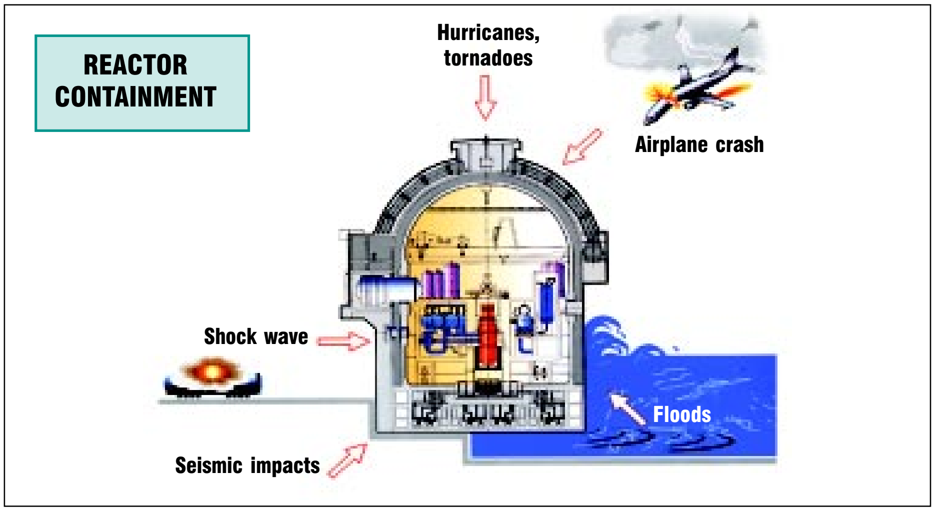
Low-level waste (LLW) *is mildly radioactive material which does not require shielding in handling or storage, and is usually disposed of by incineration and shallow burial.*

Zircaloy: *Zirconium alloy used as a tube to contain uranium oxide fuel pellets in a reactor fuel assembly.*

(Source: World Nuclear Association, reproduced with permission)

population. Clearly, these are highly improbable events. Let's now examine how is this safety level achieved?

To begin with, a nuclear power reactor should have a sound design based on proven technology like VVER-392. The safety margins in reactor design are so large that it is said that an aeroplane designed on such safety margins will never be able to fly. Second, nuclear industry follows exacting quality standards and these standards are maintained through all phases of reactor design, manufacturing, construction and operation. Third, nuclear power plants are operated by well-qualified operators trained and qualified on simulators where situations like LOCA are also simulated. The skills of the operators are tested and an operation certificate is granted by the regulatory body. The operators are periodically re-trained and re-qualified to hone their skills, responses and reflexes. These operators follow well-



laid procedures even for emergency situations, that is, in abnormal conditions the operators don't panic and know the course of the action. In nutshell, an extreme event like 'LOCA' in itself is highly improbable.

Coming back to the sequence of events, the fission chain reaction is stopped immediately, as mentioned earlier, with the draining of the coolant which also acts as moderator. However, the heat due to radioactive material in the fuel must be removed. The job is accomplished by an 'emergency core cooling system' (ECCS) by pumping and re-flooding the reactor core with water. But, one may ask that recharging core with water (i.e. moderator) could resume the chain reaction. To avoid this, boric acid, 16 grams per litre, is added to the ECCS water.

The ECCS has two major categories, the passive ECCS and active ECCS. The passive ECCS does not require any pump or power supply and can function during the station black out condition also. It is the passive part of ECCS which comes into action first, to tide over the initial period of an accident like LOCA. Four accumulator tanks, each with a total volume of 60 m^3 are directly connected to the RPV through independent nozzles. The accumulator tanks located within the reactor building and at an elevation above the RPV, have a capacity two times the volume of water in the RPV. Each tank is pressurised with nitrogen gas occupying about 10 m^3 of the total volume of tank and connected to RPV through a check valve and associated piping. The moment, the pressure of coolant falls below a pre-determined value (that is, less than the tank pressure) the check-valve opens up and borated water gushes into the core.

But then there is another passive system holding about 1000 m^3 water which slowly discharges the water. Thus, it keeps the core flooded and cooled, in case of station black-out, for 24 hours. The system called second stage hydro-accumulator system, comprises of eight tanks placed inside the reactor building at an elevation above the RPV.

Besides, the passive ECCS is backed-up by an active ECCS comprising of 4 channels of high pressure (HP) and 4 channels of low pressure (LP) subsets. A set of one HP and one LP is connected to one Diesel generator. The system is designed to remove the residual heat for a longer period. The HP system is operated in case of a small and LP system in case of large size rupture in the coolant pipe line. These pumps draw borated water from the spent fuel tank and spent fuel pond in the reactor building. As this water is drawn from the pond and pumped into the reactor core it is discharged through the break on to the reactor building floor. It is collected in the floor sump and re-circulated by the active ECCS.

In our LOCA scenario, we also envisaged flow of molten uranium fuel and liberation of hydrogen that may either detonate or deflagrate. In VVER a 'melt-fuel catcher' has been provided at the bottom of the RPV pit. The main purpose of the 'fuel catcher' is to bring down the temperature of uranium fuel (the melting point of uranium is 2800 °C, which is, more than the melting point of steel) and to contain it. The fuel catcher, a tank, is made of steel surrounded by water. Bricks of ferrous oxide and aluminium oxide are filled in the tank. These bricks absorb most of the heat from uranium, though they themselves are melt during the process. Over a period of time, the molten fuel and the bricks form a lump. The composition of these bricks and the design of the 'melt fuel catcher' has been decided after extensive research at the world's one of the largest experimental facility at Kurchatov Institute in the Russian Federation. Millions of dollars are spent to carry out such experiment at this facility by a group of countries.

The hydrogen formed by chemical reaction of zirconium with steam is managed by another system. The Kudankulam reactor is equipped with 'hydrogen recombiners'. The recombiners use 'palladium' metal, which acts as a catalyst to recombine hydrogen with oxygen. The hydrogen recombiners, fixed inside the upper portion of the inner-containment dome, are also a passive feature that does not need any power and remain 'on' all the time.

It can be visualised that a considerable quantity of water must have been converted into steam, exerting pressure on the inner containment. The steam so produced will also be contaminated. The reactor at Kudankulam has the provision of containment spray system. Essentially it has two redundant channels of sprinklers that spray water, mixed with chemicals to bind the fission products. The sprinkler system is automatically activated the moment pressure inside the containment transgresses the predetermined value. The sprinklers are placed in such a manner that the entire containment is covered evenly.

Another feature of the Kudankulam plant is a system dedicated to venting of steam from the containment. It also helps in keeping the steam pressure released inside the reactor building within the design limits of the containment system during an accident. The 'system of vented containment' releases the steam-gas mixture in a predetermined and controlled fashion through pipelines into high efficiency scrubber filters that remove the radioactive products from the mixture before its release into the environment through stack and maintains the integrity of the containment.

To seal the fate of any release of radioactivity into the environment the entire nuclear steam supply system (NSSS) is housed in the double containment. The reactor building containment system acts not only as the final physical barrier to prevent any release of fission products into the environment during accident conditions but it also protects the inner containment and the nuclear system from the external hazards (See the exhibit, "Reactor Containment"). The containment system based on 'dome-inside-dome' concept comprises of an inner and an outer containment. The inner containment with a spherical dome is made of pre-stressed cement concrete and houses the entire nuclear system. The inner containment has a liner of 6 mm thick carbon steel sheet and designed to withstand extreme internal pressure and temperature effects arising during accident conditions.

The outer containment is made of reinforced cement concrete (RCC). The outer containment is designed to protect the inner containment from natural and man-made external hazards like tornado, hurricane, air shock wave, air-craft crash etc. The space between the two containments as also inside the reactor building is kept below the atmospheric pressure to ensure prevention of any leakage into the environment. Radiation level, temperature, humidity etc. inside the reactor building is maintained within the acceptable limits by a reactor building ventilation system.

photo: A.I. Siddiqui

Kavalkinaru junction is a very windy spot where stands this windmill park

However, it can be argued that the penetrations through the reactor containment system could become vulnerable in accident conditions. The Kudankulam reactor is equipped with containment isolation system which isolates the penetrations (like pipeline transporting steam to turbine) used during normal plant operation. This containment integrity is achieved by automatic closure of isolating valves under accident conditions.

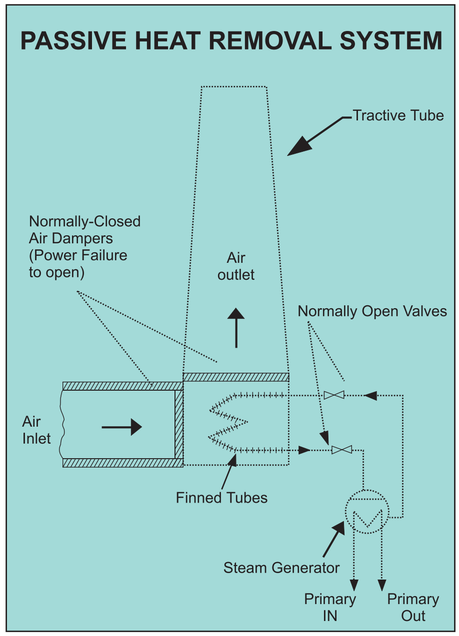
In short, all the disastrous events arising from the highly improbable double ended guillotine break in the largest pipe of primary heat transport system have been fully addressed in the design of the reactor.

Most of these features, in all its probability, will never be used during the life time of the plant, though they are always kept intact and up-to-date by way of regular high quality maintenance and periodic inspection and testing. The presence of such or similar systems or their absence could have profound impact on the safety of a nuclear reactor. For example, existence of such or similar systems and the sound reactor design ensured that not an iota of radioactive substance released into the environment during the partial core melt down accident at Three Mile Island plant in the USA in the year 1979. On the contrary, bad design and absence of similar systems led to release of radioactive substances into the environment in 1986 Chernobyl accident. Such Chernobyl type reactors are gradually being phased out and safety systems in the existing reactors have been significantly upgraded.

Besides, all these hi-tech safety features, the Kudankulam plant has an exclusion zone of 1.6 km. radius, as an abundant precaution. A well-laid emergency preparedness programme, with the review and approval of the regulatory body, exists to meet any such eventuality.

Let's now return to some other innovative features of the Kudankulam plant. One such feature is a 'passive heat removal system' (PHRS) useful to remove the heat from the steam generators during a station blackout situation. Imagine that there is no break in the primary heat transport system or small or large LOCA but for some reason the power supply including the back-up system fails. In such a situation, the heat from the reactor core will be removed by 'thermo-syphoning' and actuation of the passive ECCS.

The 'thermo-syphoning' is based on the principle that hot fluid moves upwards and cold fluid downwards. The hot coolant from the reactor core moves upwards into the steam generators which are kept at higher elevation and the cooler coolant downwards to the core, thus establishing a natural circulation cycle. However, it is essential to remove heat from the steam-generator to keep thermal differential and the thermo-syphoning functional. The secondary side of the steam generators in Kudankulam plant is connected to air-heat exchangers in which the tubes are finned to reject heat to the air. The lower and upper part of



the rectangular shaped heat exchangers are connected to air-ducts(See the exhibit, ''Passive Heat Removal System''). The upper duct is a chimney like structure to facilitate natural draft. Both air ducts remain closed during normal operation. The increase in steam pressure above the set value leads to the opening up of the dampers. Now, cool air can enter through the inlet duct and hot air exits through the outlet duct. The primary side of the heat exchangers is connected to the steam generators via valves, which are kept always open except during the maintenance of heat exchanger. A set of four such heat exchangers connected parallely to one another is in turn connected to one of the four steam generators. These heat exchangers are placed circumferentially out-side the outer containment. The PHRS with passive ECCS can remove the residual heat from the core for 24 hours or longer during station blackout situations and also during LOCA with station black-out for 24 hours.

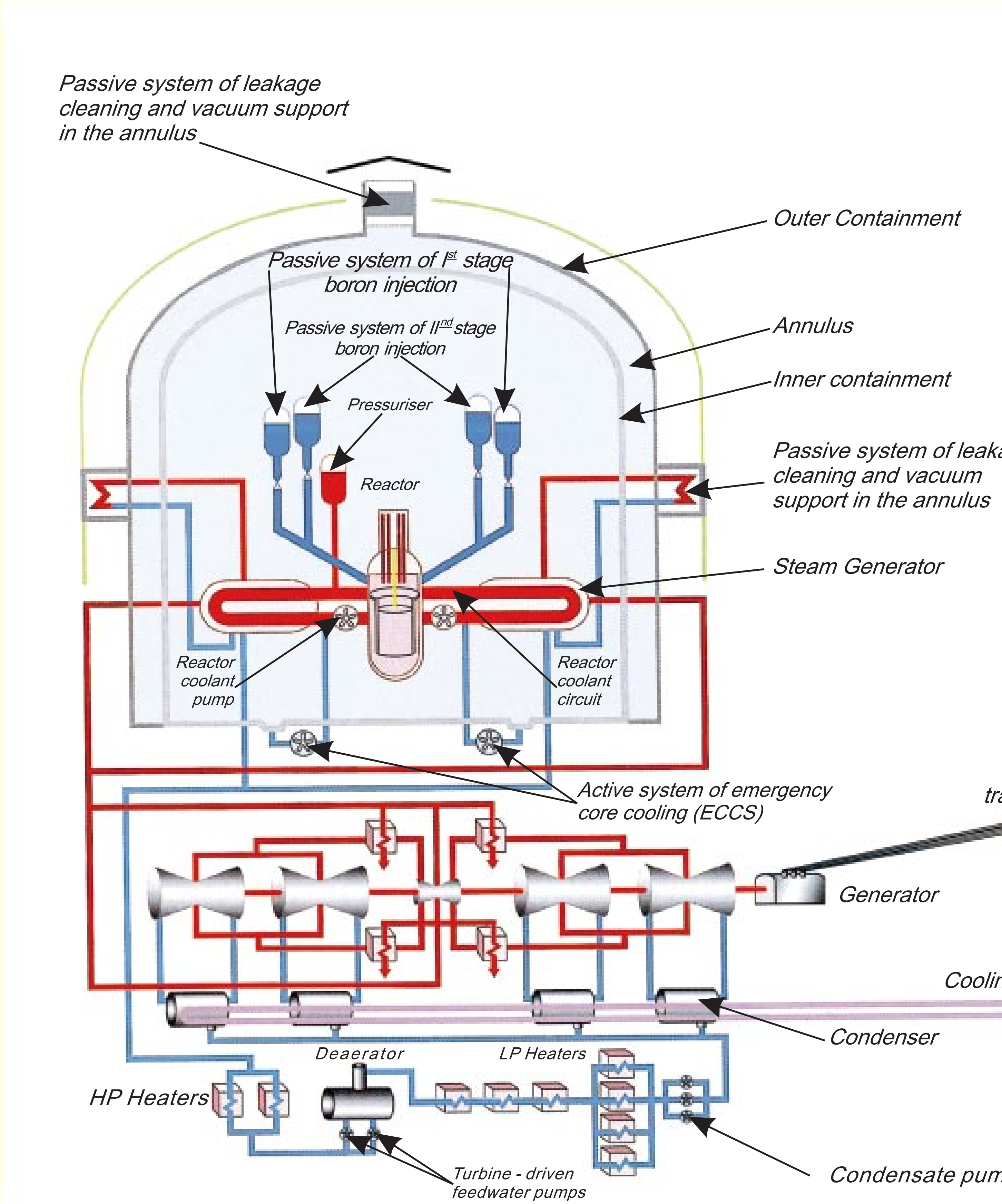
Operators' intervention is not required for the first thirty minutes of an accident by the provision of these safety features both passive and active. Therefore, though highly qualified and trained, the operators get sufficient time for relaxed decision making under these adverse circumstances.

A unique feature of the design is a passive system to maintain negative pressure in the annulus between inner and outer containments. This is achieved by connecting the annulus space to the chimney at the top of the containment. The chimney is heated by the hot air coming from the PHRS described above. A draft is created by the heating, which maintains the necessary vacuum without involving any active components.

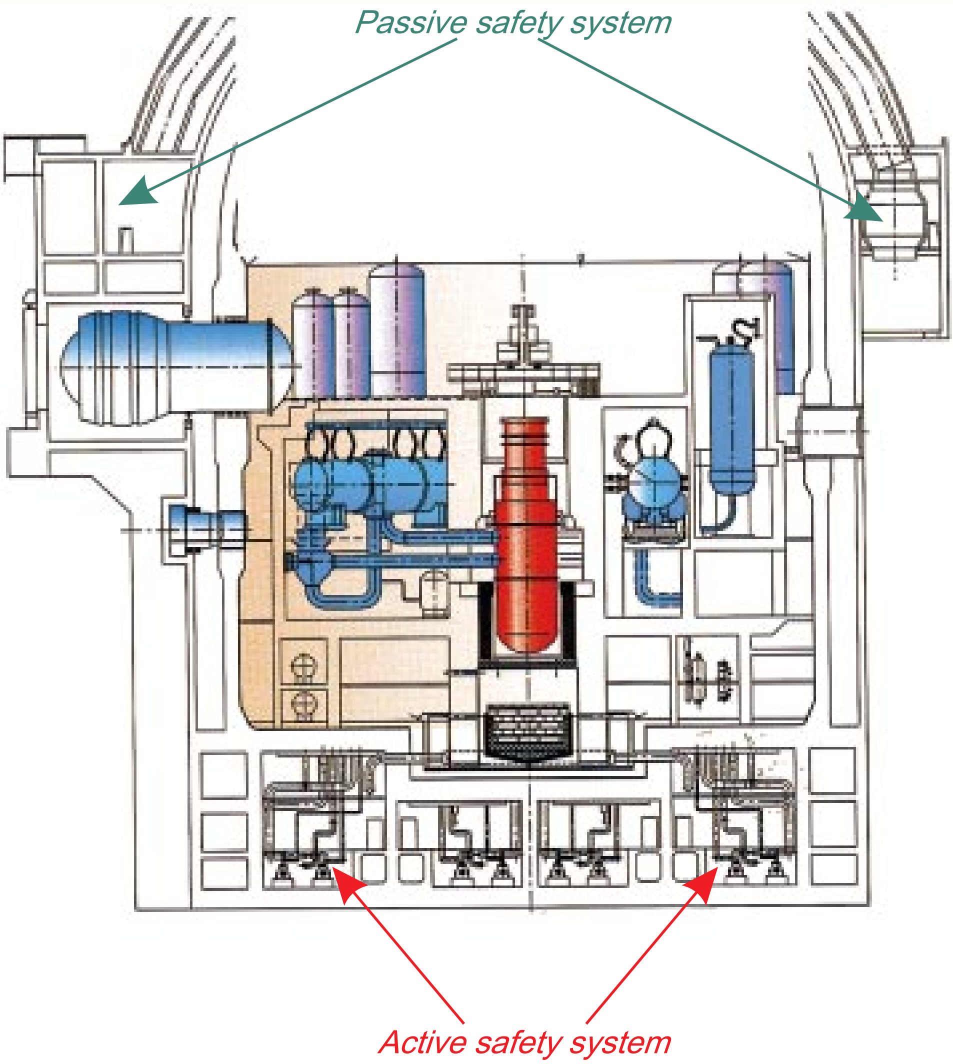
The fire hazards have been considered and adequately addressed in the design, selection of material and operation procedures of the Kudankulam plant. The reactors are

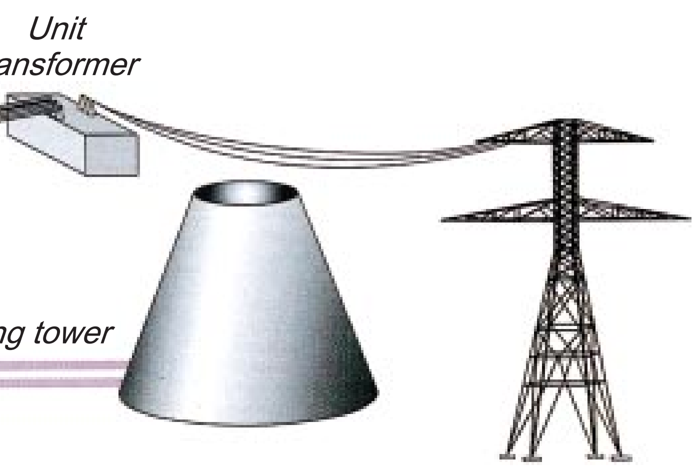
Ground Reality : The Project work at Kudankulam begins with a bang.

A Schematic diagram of VVER - 10

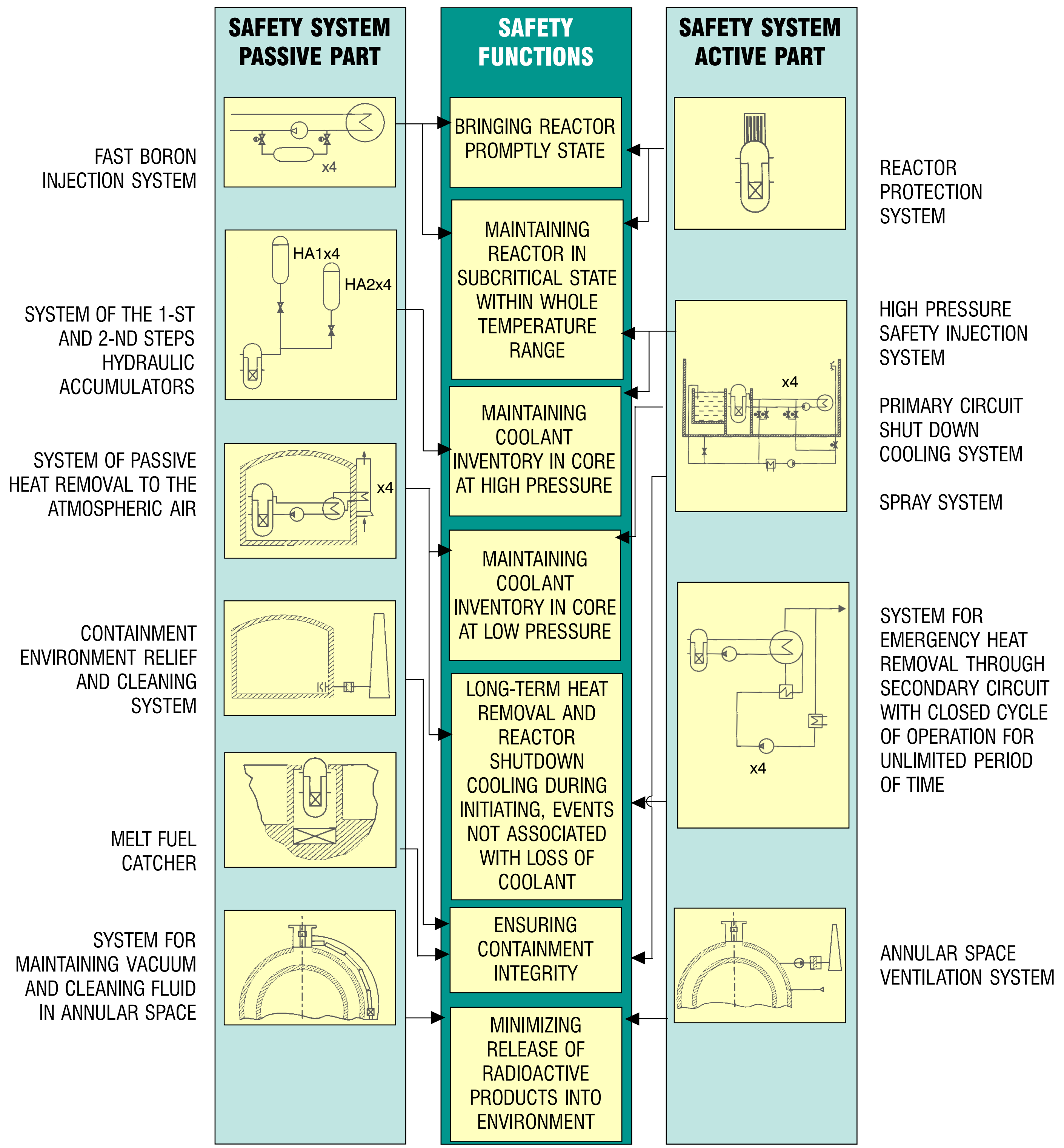


00 and a cross-section of the reactor





Implementation of the Diversity Principle to Ensure Main Safety Functions in VVER-1000 Design



equipped with an automatic fire fighting system having four independent channels, though one was sufficient. The water in the supply tank of fire fighting system is replenished by the main fire water storage reservoir.

A large number of parameters of various systems are monitored by different instrumentation and control sensors. These parameters include, for example, temperature, pressure, flow rates, neutron flux, humidity, vibrations, etc. The instrumentation and control system transmits all normal and abnormal conditions to the state-of-the-art centralized monitoring system in the control room of the plant. In most cases, automatic regulation is accomplished in accordance with the design parameters. In some other cases, particularly those related to nuclear safety systems, the safety system is automatically activated with information to the control room as described in our LOCA example above. These functions in Kudankulam plant are performed by a computerised system.

The refuelling of these reactors is done once in a year by replacing one-third of the core with fresh fuel. In the refuelling process the top cover of the RPV is removed after reactor shutdown and bringing down its pressure to atmospheric pressure and temperature of the coolant to about 60 - 70°C. The connections to the top cover are also removed. The protective tube assembly is also detached. The tope cover of the RPV is lifted by an overhead crane and shifted to an assigned place within the reactor building. The spent fuel from the core is transported to the cooling ponds after ascertaining their leak tightness. In case the fuel assembly is found leaking it is first hermetically sealed before its transportation to the pond. The remaining two-third fuel assemblies are re-arranged in the core as per the design intent. The fresh fuel which has already been shifted from fresh fuel storage area to the holding pond is lowered into the vacant positions.

The entire operation is carried out under a protective layer of borated water. The reactor pit or cavity is filled with borated water providing more than 3 meter thick layer of water above the fuel assemblies. The spent fuel from the reactor core is stored within the reactor building for a period of seven years. It is shifted to spent fuel bay, outside the reactor building after this initial cooling period.

photo: A.I. Siddiqui

Train from Kanayakumari passing through green landscape.

Radioactive wastes generated during the operation of plant could fall in solid, liquid or gaseous categories or low, intermediate or high-level waste categories (see glossary of terms in this article). The bulk of radioactivity is contained within the spent fuel. The liquid waste is first evaporated in a steam heated evaporator and then compacted as a solid. The vapour so produced is condensed and the water used during the process is recycled within the plant. The solid residue is treated with other solid waste generated in the plant. Most of the solid waste is the contaminated apparel, tools, scrap etc. Mr. Jain informs that hardly any radioactivity thus will be discharged in the Gulf of Manar. The burnable solid waste is burnt in an especially designed incinerator. The flue gases from the incinerator are passed through high efficiency filters, which remove all the particulate activity from them. The gases are than discharged in the atmosphere through a 100 m high stack. The radiation dose released though the stack is also accounted for the calculations of total radiation discharge from the plant. The non-burnable waste and the residues from the incinerator are compacted and fixed in non-leachable medium like epoxy and specific type of cement cocrete. It is then encapsulated in leak-proof, high integrity containers and then placed in especially designed trenches within the premises of the nuclear power plant. The surrounding area is closely monitored to ensure isolation of the waste from the environment.

Mr. S.K. Agarwal says that cooling water for the condenser will be drawn from the Gulf of Manar and discharged back. The temperature difference between the intake and out-fall will not exceed more than 7 °C at the point of discharge, the limit set by the Ministry of Environment and Forest (MOEF). "The temperature gradient (rise) rapidly diminishes in a large body of water like Gulf of Manar and will not affect the marine life or fishing activity in the region" says Mr. Agarwal.

Evidently, the Kudankulam plant maximizes the utilization of water through its closed loop cycles. However, some fresh water is required, called make-up water, to compensate the loss of water through the system, as also for holticulture and domestic use. This small quantity of fresh water is provided by a reverse osmosis plant. The reverse osmosis plant, converting sea-water into fresh water has been set-up at the residential township of the Kudankulam Project. The first phase of plant is already operational.

Mr. Agarwal says that a constant vigil on the discharge of radiation in air, water and land is kept by the Environmental Survey Laboratory (ESL). The laboratory collects samples and surveys in an area of 30 km surrounding the plant to check variations, if any, in environmental parameters to ensure its safety. These samples for example, include flora and fauna, water and air samples etc. In fact, says Mr. Agarwal, the first phase of ESL has already started functioning and collecting meteorological and various other base-line data. Studies on the background radiation have already been completed. An epideomological survey of the population living in the adjoining areas has also been completed.

According to Mr. Jain, the total radiation release to the environment, permissible by the regulatory body, is 25 x 10^{-5} sieverts per year (sieverts is a radiation dose). However, says Mr. Jain, "the actual release from the plant is estimated to be much less than 1 x 10^{-5} sieverts per year". This release is much less than the natural variation and so small in magnitude that it can not be measured by the state-of-art instruments and is estimated, rather theoretically.

I am impressed by the design of VVER-392 no less than the beauty of land. The twin rocks of Kanyakumari and the statue of Thiruvalluvar can be seen from the Kudankulam site, more clearly with a pair of binoculars. I am lost in comparing the ancient wisdom with the modern technological innovations. In either case, it is the prowess of human mind which leaves an imprint on the sands of time. I return to Mumbai via Trivandrum. As the aeroplane takes off the 'God's own country' gradually disappears. Flying high in the sky, I realize that perhaps I will receive more radiation dose between Trivandrum and Mumbai than the population living in close vicinity of the plant in one year. I murmur, three Cheers to Kudankulam!

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I sincerely thank-

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- I am thankful to ATOMSTROYEXPORT, ATOMENERGOPROEKT, OKB GIDROPRESS and ROSENERGO
- My sincere thanks to the World Nuclear Association to allow me to reproduce glossary of nuclear terms.

Additional Resources:

1. Mr. S.K. Jain – "*Advance Light Water Reactors At Kudankulam*", Nu-Power, Vol.12 No.1, 1998.
2. Mr. Novak Valery et al – "*Development of Improved Safety Reactor Plant with VVER-1000*", Nu-Power, Vol.12 No.3, 1998.
3. Mr. R.K. Sinha and Dr. Anil Kakodkar – *"Advanced Heavy Water Reactor"*, Nu-Power, Vo.13 No.3, 1999.
4. Mr. J. Kupitz and J. Cleveland – "*Overview of Global Development of Advanced Nuclear Power Plants, And the Role of the IAEA*", Nu-Power, Vol.14 No.1, 2000.
5. Mr. Bouteille Francois - *"European Passive Reactor"*, Nu-Power, Vol. 14 No. 3, 2000

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