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Nuclear Energy — Facts and Fiction

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Early warnings

Two incidents in the recent past come dangerously close to disaster in India. Both involve nuclear power plants.

One occurred at the Narora nuclear reactor in UP on 31 March, 1993. Early that morning, two blades of the turbine of the first unit at Narora broke off. They sliced through other blades, destabilizing the turbine and making it vibrate excessively. The vibrations caused the pipes—which carried hydrogen gas that cools the turbine—to break, releasing hydrogen, which soon caught fire. Around the same time, lubricant oil too leaked. The fire spread to the oil and throughout the entire turbine building. Among the systems burnt by the fire were four cables that carried electricity. This led to a general blackout in the plant. One set of cables supplied power to the secondary cooling systems. When it got burnt, those cooling systems were rendered inoperable.

To make things worse, the control room was filled with smoke and the operators were forced to leave it about ten minutes after the blades broke. Prior to leaving, however, the operators *manually* actuated the primary shutdown system of the reactor. Fortunately, the reactor shutdown systems worked and control rods were inserted to stop the chain reaction. The problem then was similar to that happened at Fukushima: the reactor went on generating heat because the fuel rods in a reactor accumulate fission products which continue to undergo radioactive decay.

The situation was saved by some workers who climbed on to the top of the reactor building, with the aid of battery-operated torches, and manually opened valves to release liquid boron into the core, further absorbing neutrons. Had these workers not acted as they did there could have been a local core-melt and *explosive* fuel-coolant interaction. The names of those heroic workers have never been made public! [1]

Another major disaster would have occurred at Kakrapar in Gujarat but for a stroke of luck. On 15 and 16 June 1994, there was heavy rain in South Gujarat and the water level of the lake began to rise. That resulted in the ducts that were meant to let out water becoming conduits for water to come in. Water began entering the turbine building on the night of 15 June. There was no arrangement for sealing either the cable trenches or the valve pits, both of which also allowed water to enter the reactor building. By the morning of 16 June, there was water not only in the turbine building but also in other parts of the reactor complex.

The workers in the morning shift had to swim in chest-high water, and the control room was reportedly inaccessible for some time. A site emergency was declared and workers were evacuated. The gates of the Moticher Lake could not be opened, even after the management requested help from the district and state authorities.

Finally, *villagers* from the area, who were worried about the security of their own

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homes, made a breach in the embankment of the lake which allowed the water to drain out. Fortunately, the reactor had been shut down for over four months at the time of the flooding and there was no great danger of an accident. Had it been functioning and there had been reason to issue an off-site emergency, the situation would have been disastrous. [1]

It is important to note that common people and workers, who remain unnamed, have come to the rescue of the plants in both incidents—one caused by fire and the other, by water.

No wonder, then, that people elsewhere are deeply worried. The ongoing agitation against the proposed Rs.17,000 crore nuclear power plant in Koodankulam, Tamil Nadu is the latest manifestation of a long series of protests against nuclear technology. Despite this struggle going on for about 500 days, the government is bent upon going ahead with the commissioning of the plant. But the agitation has brought to focus the important questions: Is nuclear technology really safe? Is nuclear energy really the only way to meet the power shortage in India? Most importantly, why is the government so bent upon going ahead at any cost?

A bit of history

Before we delve into these questions, let us look back to get a historical perspective of the issue. A most interesting chapter in the history of nuclear energy in India is the titanic clash between two foremost physicists, Dr. Homi Bhabha and Prof. Meghnad Saha on the future of Indian Nuclear Programme. Saha and Bhabha differed in their notions about the goals of science and technology, and the means for achieving these goals. Saha emphasized large-scale industrialisation, development of competent manpower, judicious and equitable distribution before embarking on a nuclear programme. He advocated participatory democracy even in such highly technical engineering projects. On the contrary, Bhabha argued that nuclear energy is an immediate need for India and he preferred an elitist approach—even if it means secretiveness—over Saha's open and democratically disposed approach. [18,1]

A memorandum sent by Dr. Bhabha to Nehru argued that "In order to keep activities secret, a small, high-powered centralised body controlling atomic energy research has to be set up rapidly reporting only to the Prime Minister." [18] In contrast, Saha wanted to see universities do research on nuclear physics and engineering, and be supported (by the government) in their efforts to do so. [19]

Saha's argument did not find favour with the ruling establishment under Nehru and Bhabha's argument prevailed. Thus, the Atomic Energy Commission (AEC) founded in 1948 just one year after independence is—as historian Ramachandra Guha puts it—the *most secretive* institution in India! The power plants run by AEC do not have to report to the Parliamentary Committee on Public Undertakings. In fact, they have been made exempt from the scrutiny of Parliament itself by an Act of Parliament: the Atomic Energy Act of 1948. [3] This Act clamped secrecy on the entire atomic energy programme of the country. [20]

During the early 1950s, as an elected Member of the Parliament, Saha repeatedly raised this issue on the floor of the Lok Sabha. In the debate in the Lok Sabha on Peaceful Uses of Atomic Energy on 10 May 1954, Saha made an impassioned appeal: "If you read out Atomic Energy Act, you find that it does not tell us what to do but it simply tells us what is not be done. (But) the Atomic Energy Acts of England and America ··· deal with how the efforts of the scientific talents of the country have to be harnessed in one scientific effort." [20] He continued to oppose the secrecy and the exclusivity of the Atomic Energy Commission. [19] But, the nuclear energy programme went ahead on the chosen path of secrecy.

The compulsions behind this secrecy and exclusivity are dealt with later in this article.

The claims on nuclear energy in the Indian context

Let us look at the most important claims of the nuclear programme in India:

a) Nuclear energy is a must to meet India's expanding energy needs

b) In comparison with other sources, nuclear energy is cheap and plentiful

c) Nuclear energy is relatively safe

d) Nuclear energy is more environment friendly than energy based on fossil fuels.

Let us examine each of these claims in the light of experiences of nuclear programmes in India and around the globe.

Claim 1: Nuclear energy is a must to meet India's energy needs

In 1954, Bhabha predicted India would produce 8,000 MW by 1980. In 1969, DAE extravagantly predicted that 43,500 MW of nuclear energy would pulsate the country by 2000. These grand words have failed to materialise. By 2000, India was only able to produce 2,720 MW. [1]

An empirical analysis shows that the nuclear establishment has consistently overstated the amount of electricity it can feasibly generate in the near future. Here, the term 'nuclear establishment' refers to the pro-nuclear bigwigs in politics (including the PM), bureaucracy, media, Department of Science & Technology, the Department of Atomic Energy and various bodies under it namely AEC, AERB, NPCIL, UCIL and others, and most importantly, the domestic and international corporate houses who pull the invisible strings.

In 1984, the Department of Atomic Energy (DAE) drew up a new atomic energy plan that envisioned setting up 10,000 MW of nuclear power by the year 2000. But an audit in 1998 found that the actual additional generation of power under the plan as of March 1998 after having incurred an expenditure of Rs. 5292 crore was NIL. [1]

As of today, India has 19 nuclear reactors with a total electricity production capacity of 4,680 MW. Now, the total installed capacity in India including coal, hydro and other energy sources is 2,07,900 MW. This means, nuclear capacity accounts for a mere 2.3% of the total installed capacity. While thermal and hydroelectric plants together constitute 85% of this capacity, wind-based capacity is more than 3 times the nuclear capacity. [7]

If all the 7 planned nuclear plants including Koodankulam begin operations, nuclear capacity would go up to about 10,100 MW. Add to this, the proposed 9900 MW Jaitapur plant—claimed to be the largest nuclear plant in the world—the total nuclear capacity would reach about 20,000 MW. However, the required capacity to meet the projected electricity demand in 2016-17 i.e., end of 12th five year plan, would be about 2,50,000 MW. [18] So, how can nuclear technology that creates such a pittance in relation to total electricity demand really cater to it?

Claim 2: In comparison, nuclear energy is cheap and plentiful

On the economic side, distinguished energy scientist Prof. Amulya Reddy and others have shown that nuclear power in India is more costly per unit than coal.[2] Based on this work, a study at IIT Kanpur shows that realistically, the cost of one Unit (KWh) of electricity in 2007 was Rs. 2.68 for Kaiga nuclear plant and Rs. 1.90 for Raichur coal plant.[21] A separate study has found that the Unit cost of hydro power in India is 35% lesser than coal (and hence, nuclear).[23]

The United States is a close ally of India in her nuclear quest. But, even in the US, Energy Information Administration (EIA) in Dec, 2010 suggested that Coal, Natural Gas, Hydro and Wind options are cheaper than Nuclear option as shown in Table 1 ($1 = Rs. 55).

Table 1:

Plant type	Average Cost per Unit (Rs./KWh)
Natural Gas	Rs. 3.60
Hydro	Rs. 4.75
Wind	Rs. 4.95
Coal	Rs. 5.20
Nuclear	Rs. 6.25

A prestigious publication like 'The Tech' (MIT's oldest and largest technology newspaper) agreed in Nov, 2011 that the cost of nuclear power is likely to be about twice the cost of natural gas power in the US.? [13]

Indian Nuclear sector has garnered more than 60% of the total budget on energy research despite contributing a mere 2.3% of the country's total capacity. If these priorities are reversed, with clean technologies like solar and wind power getting the kind of support nuclear energy currently enjoys, the energy demands will be better served. [3]

'One of the big problems with nuclear power is the enormous upfront cost. These reactors are extremely expensive to build' says Daniel Indiviglio, Washington-based columnist with Reuters. The work of Dr. M.V. Ramana, nuclear physicist with Princeton University and Senior Fellow at CISED, Bangalore demonstrates that a nuclear plant two times the size of a coal plant costs about four times to build [22] as shown in Table 2. For example, the nuclear plants Kaiga I & II with capacity 2×200MW commissioned in the year 2000 costed Rs.1,816 crore to build while the coal-based plant Raichur VII with capacity 210 MW commissioned in the year 2002 costed Rs.491 crore to build.

Dr. M.V. Ramana goes a step further: 'This illusion (that nuclear energy is cheap) is conjured up by hugely underestimating costs, by hiding subsidies, and most significantly, by limiting liabilities in the event of catastrophic accidents. The nuclear establishment tries to substantiate it through calculations based on estimated costs of future facilities rather than actual costs of existing facilities. Given the huge cost overruns at most facilities when compared to initial estimates, the distortion is significant'. For instance, the actual capital cost of Kaiga plant (reactors I & II) including the construction cost mentioned above was 4 times the initial estimated cost.[2]

Dr. Surendra Gadekar, physicist with a focus on nuclear affairs, adds: 'The huge subsidies paid to the nuclear power plants are in the form of heavy water subsidy, the fuel fabrication subsidy, the insurance and liability subsidy, the security subsidy, the research subsidy, the waste management subsidy, and other hidden and unknown subsidies'.[16]

There is no clear idea of how much it costs to decommission a reactor i.e., make a reactor inoperative, dismantle and decontaminate it keeping the environment safe. The few examples in other countries show that the decommissioning of the reactors has invariably cost much more than expected. Similarly, the cost of radioactive waste management is completely arbitrary (typically, 5 paise per unit of power generated). [1]

India relies on costly uranium imports for its nuclear power industry, with only half of its operating reactors (Kaiga, Narora, Kalpakkam, Tarapur) running on domestic uranium. Last year, NPCIL claimed to have found natural uranium deposits of about 49,000 tons in Andhra Pradesh but mining and milling it would be an expensive and hazardous process if we are to go by the experiences of Jaduguda Uranium mines (discussed later) apart from the well-known issues of impact to the environment and rehabilitation of poorest of the poor.

But, Thorium is plenty in India!

India has the largest reserves of Thorium—touted as a nuclear fuel—in the world. Dr. Bhabha formulated the 3-stage nuclear programme to use Thorium as the fuel, more than 5 decades ago. In this plan, fast breeder reactors running on uranium fuel would bombard thorium with neutrons, converting it into fissile Uranium-233. This will be processed into fuel rods to be used in the next stage as reactor fuel. But it is a dream yet to come true, if at all. There is no reactor existing today which is equipped with Thorium-based power generation technology as there are several serious technical problems.

Consider this. Dr. V.S. Arunachalam, former Scientific Adviser to Defence Minister of India and his colleague at Carnegie Mellon University, Dr. Rahul Tongia, said way back in 1997 that the Thorium-Uranium 233 cycle does not appear attractive and the three stages of the plan appear to be non-realisable even in a timeframe spanning five decades.[62] Other experts point out that Thorium based power generation will be both expensive and unsafe.[12][14]

Even though India has indigenously built nuclear reactors (Pressurised Heavy Water Reactors or PHWRs) based on Canada's CANDU Reactor in Rajasthan and has made some further innovations, almost all the nuclear reactors currently under commissioning are imported. The noted economist I.M.D Little made this farsighted remark way back in 1958: 'As Dr.Bhabha says, electricity is in short supply in India. It is likely to go on being in short supply if one uses twice as much capital as is needed to get more (electricity)'. This remarkable prediction—that an expensive nuclear energy cannot meet the electricity shortage in India—is as true today as it was 5 decades ago.

So, cheap nuclear power is as true as flat earth!

Claim 3: Nuclear technology is relatively safe

The safety concerns primarily arise from human and environmental damage caused due to and expected from nuclear accidents and radiation emission in the nuclear life cycle (from mining till decommissioning) most notably, from nuclear waste. Let us deal with both of them starting with nuclear accidents.

World Nuclear Association (WNA) is an international lobby group that promotes nuclear power with support from global nuclear industry. WNA claims that 'the risks from (western) nuclear power plants, in terms of the consequences of an accident or terrorist attack, are minimal compared with other commonly accepted risks'.[9]

Let us look at the top three incidents considered by WNA to be world's worst civilian nuclear disasters to verify this claim.

Chernobyl disaster, Ukraine – 1986

Chernobyl disaster was a catastrophic nuclear accident that occurred on 26 April, 1986, in the Chernobyl Nuclear Power Plant, Ukraine. An explosion caused by a sudden power surge and consequent fire released large quantities of radioactive materials that even spread to Russia, Belarus and the rest of Europe.

World Health Organisation (WHO) in its April, 2006 report on Chernobyl noted that the clean-up operation undertaken after the accident involved an estimated 350,000 clean-up workers from the army, power plant staff, local police and fire services.

In 2006, the Chernobyl forum—a group consisting of UN agencies and interestingly, governments of Russia, Ukraine and Belarus—estimated the eventual death toll to be 9,000 from among the worst affected workers, residents, evacuees as well as neighbouring nations due to leukemia, thyroid cancer and other radiation-induced cancer as well as acute radiation sickness (ARS). The United Nations considers this report to be most comprehensive report on Chernobyl. The accident resulted in a massive relocation of the population as radiation made human life impossible over 5000 sq. km area.[31] More than 3.3 lakh people had to be relocated.[10]

Three Mile Island Disaster, USA – 1979

The Three Mile Island (TMI) accident—the worst civilian nuclear disaster in the US—occurred on March 28, 1979. Radiation and Public Health Project suggests that infant mortality in the local area increased by 47% in the two years after the accident. It also says that, 25 years on, cancer-related deaths among children under 10 are 30% higher than the national average.

Joseph Mangano, in his study 'Three Mile Island: Health Study Meltdown' revealed that the number of cancers within 10 miles of TMI rose by 64% in the 5-year period after the accident when compared to 5-year period before the accident. In 1997, the National Cancer Institute of the US calculated that radioactive iodine may have caused thyroid cancer in more than 2 lakh Americans.

Fukushima disaster, Japan – 2011

It is now well known that the Fukushima nuclear disaster in Japan occurred due to an earthquake and consequent tsunami in March 2011. The plant had 6 reactors with 3 of them active when the earthquake struck. Immediately after the earthquake, these reactors shut down automatically but the tsunami flooded the emergency generator room cutting power to the critical pumps that circulate coolant water through a nuclear reactor. So, the reactors overheated due to the high radioactive decay heat and the 3 reactors started to melt down. In the intense heat and pressure of the melting reactors, several hydrogen-air chemical explosions occurred even as the workers struggled to cool the reactors.[24]

Significant amounts of radioactive substances were released into air, soil as well as ground and ocean waters. The government had to ban the sale of food grown in the area 30-50 km around the plant. Radioactive material was detected in a range of produce, including spinach, tea leaves, milk, fish and beef, up to 320 km from the nuclear plant. Residents were advised not to use tap water to prepare food for infants. Even a millionth gram of some of these substances, if ingested or breathed in, could seriously raise the cancer risk for individuals, especially in children and infants.

Within a few days, radiation was observed by monitoring stations around the world including the US, Canada, Austria, Russia, Australia and Malaysia. Large amounts of radioactive materials have also been released into the Pacific Ocean and the long-term effect on marine life is not fully understood. A total of 573 deaths have been certified as 'disaster-related' by 13 municipalities affected by the crisis. 300 workers were confirmed to have received high radiation doses. Predicted future cancer deaths go up to 1000.

New evidences are unfolding and the final impact is yet to be fully understood. The 40-year-old plant was built on the assumption that the biggest tsunami that could be expected on the Fukushima coast would be 5.7 metres high. The tsunami that crippled backup power supplies at the plant, leading to the meltdown of three reactors, was more than 14 metres high.[17]

Benjamin K. Sovacool has reported that worldwide there have been 99 accidents at nuclear power plants.[105] An interdisciplinary team from MIT estimated in 2003 that given the expected growth scenario for nuclear power from 2005 to 2055, at least four serious nuclear accidents will occur in that period.[93] And, Fukushima has already happened.

In these circumstances, is it tenable to argue that nuclear energy is 100% safe?

Lack of 'safety culture'

The Japanese government panel that investigated the Fukushima accident pointed to a lack of a 'safety culture' at both the levels of central government and the Tokyo Electric Power Co. (TEPCO) which operates the plant. Astoundingly, in Oct 2012, TEPCO admitted for the first time that it had failed to take stronger measures to prevent disasters for fear of inviting lawsuits or protests against its nuclear plants.[7] TEPCO reportedly has a dubious history of falsifying safety records and changing piping layouts without approval.[4]

South Korea derives 32% of its electricity from nuclear energy. In Nov, 2012, it was found that in two of its reactors, components with fake quality certificates had been used for replacement. They were forced to shut down following public protests.

Let us now ask the question: Can anybody claim this type of malpractice will not happen in India especially when their work is so shrouded in secrecy?

Take for example, the proposed Rs. 1,12,000 crore 9900 MW nuclear plant at Jaitapur in Maharashtra. In April, 2011, the Department of Atomic Energy (DAE) and the NPCIL claimed that Jaitapur plant site is not earthquake prone since the nearest tectonic fault—an area where one underground earth plate meets another—is at least 30 km away.[82] But how was this claim made? The Atomic Energy Regulatory Board (AERB) which reports to the Department of Atomic Energy (DAE) oversees nuclear safety management in India. It is relevant to recall that AERB was severely criticised by the Comptroller and Auditor General (CAG) in August, 2012 on numerous grounds: not preparing a nuclear safety policy despite having had a mandate to do so since 1983, failing to prepare the complete list of safety documents, not having a detailed inventory of all radiation sources and failure to adopt international practices.

Now, let us hear from Dr. A. Gopalakrishnan, himself a former chairman of AERB: 'Disaster preparedness oversight of AERB is mostly on paper and the drills they once in a while conduct are half-hearted efforts which amount more to a sham. NPCIL strategy is to have their favourite consultants cook up the kind of seismic data which suits them, and there is practically no independent verification of their data or design methodologies. AERB has become a lap dog of DAE and PMO. A captive AERB makes the overall nuclear safety management worthless'.[8]

It is ironic that AERB was set up by DAE to review safety measures at its own plants. Dr. Gopalakrishnan lays bare the ridiculous situation: 'About 95% of the technical personnel in AERB safety committees are officials of the DAE, whose services are made available on a case-to-case basis for conducting the reviews of their own installations'![22]

An impact assessment report by Tata Institute of Social Sciences (TISS) came down heavily on the proposed plant stating that the project will have a huge negative impact on social and environment development as it is sitting on a high to moderate severity earthquake zone.[6]

An independent study by the team of Prof. Roger Bilham of the University of Colarado and Prof. Vinod K. Gaur of CSIR suggests that the site may be vulnerable to an earthquake with a magnitude of 6 or more on the Richter scale in close vicinity. They lament that reliable geological studies are unavailable to characterize seismic activity of the region and data is insufficient to conclude that the site is not earthquake prone. Prof. Bilham has even said 'the absence of such data's availability raises suspicion'.[5]

The reason for this suspicion is not difficult to see. The Latur earthquake in 1993 which killed at least 9000 people had its epicenter in Killari which was considered to be seismically inactive!

Dr. A. Gopalakrishnan further points out that the Evolutionary Pressurized Reactors (EPRs) to be built in Jaitapur, are not commissioned anywhere in the world so far. Its potential problems are totally unknown even to Areva, its French developer, let alone India's NPCIL.

While NPCIL boasts of zero nuclear accidents in India, Dr. Gopalakrishnan had said that AERB had prepared a list of 130 incidents in Indian installations and has charged that the DAE had uniquely failed in meeting its responsibilities. In 1999, the 'Outlook' magazine listed 9 major accidents some of which had the potential to lead to a partial or total meltdown.[104] But the real causes behind these 'incidents'—the soft word used by DAE for accidents—may never be known. For example, in Nov 2009, more than 55 workers fell sick after consuming water contaminated with radioactive Tritium in Kaiga power plant in Karnataka and the NPCIL attributed it to an insider's mischief. Dr. M.R. Srinivasan, former Atomic Energy Commission chairman, promised an investigation but nobody knows the outcome till date. Interestingly, the same man headed the expert panel which declared in Feb, 2012 Koodankulam plant to be safe!

As the Department of Atomic Energy is not obliged to reveal details of ongoings at these nuclear plants to the public and reports directly to the Prime Minister, there is possibly many other accidents that we do not know about.

Finally, out of the world's three worst nuclear disasters, two were caused by human error and third, though caused by a natural calamity, was aggravated by human error. The French Atomic Energy Commission (CEA) has concluded that technical innovation cannot eliminate the risk of human errors in nuclear plant operation.[92] How is this factored in, when Dr. Kalam gave an 'all is well' certificate to Koodankulam?

Dr. Gadekar summarises the 3-stage process of misinformation of the nuclear establishment to handle public concerns on nuclear safety. First, say nothing. Next, if forced to say something, give out a very low figure which can be termed a 'mistake' if caught. Finally, if the lies are detected, apologise and keep repeating a variation of the lie such as? increase? ¿safe?'? radiation limits twenty times. The whole plan is to keep the people in ignorance? ?through misinformation.?

So, can we safely rest assured on the official claims that nuclear energy is safe?

Nuclear waste and radiation – perpetual threat

The nuclear disasters and accidents constitute a sudden spurt in the damage to life and environment that are unexpected, unguarded and largely uncontrolled. However, radiation emitted during various stages of the nuclear fuel cycle namely mining, milling, enrichment, transportation, processing, reprocessing, waste disposal, and decommissioning constitute perhaps, a bigger threat to health and environment. Exposure to radiation leads to ailments, deformities, birth defects, life threatening diseases and in some cases, deaths, and the effects extend across generations. Hence, this is no less a concern than nuclear accidents.

Let us look at the impact of radiation on the health of the people as well as the dangers posed by nuclear waste.

In France, around 30,000 workers dubbed as 'nuclear nomads' are subcontracted annually in the 58 nuclear reactors operated by Electricity of France (EDF) group, the largest energy company in France. EDF subcontracts over 1,000 companies, who employ the 'nuclear nomads', sometimes of foreign origin, to do the dangerous maintenance, repair and clean-up work in these plants.[26]

French Sociologist Annie Thébaud-Mony is the author of 'Nuclear Servitude: Subcontracting and Health in the French Civil Nuclear Industry' that investigates the effects of the radiation on these workers, and how the practices of the Nuclear industry exposes them to large amounts of radiation further endangering their health. It is worth noting that she refused to accept her country's most renowned civil award, the Legion of Honour, to protest against the failure of French courts to condemn those responsible for industrial crimes to the true degree of their responsibility. She found that subcontracting has 3 clear benefits: it is cheaper; it makes it hard for the nomads to get organised; and, most importantly, these nomads are temporary staff who are made to work in high radiation zones for brief periods only to be discarded after they reach their radiation limit. So, these nomads move around from plant to plant, often staying at campsites, with the constant threat of job loss hanging on their head like Damocles' sword. [25]

Since the 1970s, Japan has had a dubious track record of subcontracting maintenance work of reactors to outside companies which hire workers on a short-term basis who remain employed till they reach their radiation exposure limit. In that sense, they become the part of nuclear waste![11]

88% of the workers in Japan's nuclear power plants are contract workers who handle the bulk of the dangerous maintenance work for less pay, less job security and fewer benefits. These temporary workers were exposed to levels of radiation about 16 times higher than the levels faced by TEPCO permanent employees. But they work under the constant fear of getting fired, trying to hide injuries to avoid trouble for their employers, carrying skin-colored adhesive bandages to cover up cuts and bruises.[27]

Prof. Gabrielle Hecht from the University of Michigan brings up a very important point while dealing about nuclear waste. Uranium-producing African countries—which supplied between 25-50% of the West's uranium—remain contaminated from uranium mine debris. Today, regional poverty is so extreme that in Niger—the largest producer of uranium—people modify radioactive trash barrels into basins for collecting water. Such instances—though large in number—never make into any of the official statistics on the risks of nuclear waste.[11]

Dr. Surendra Gadekar and Dr. Sanghamitra Gadekar extensively studied the adverse health impact of Jaduguda Uranium mines in Jharkhand, Rawatbhata Nuclear Plant in Rajasthan, Kakrapar Nuclear Plant in Gujarat among others. Here is what they have to say: 'Contract workers do the dangerous and most dirty jobs but are not entitled to any benefits. They do not (even) get admission to plant hospital. Tarapur Annual Performance Report in 1985 says the radiation levels in various parts of the reactor were 10 to 500 times higher than what was expected during design. Emergency evacuation plan is to transport 15,000 residents of Mandvi into a primary school in Mangrol that cannot take more than 200 people. In Jaduguda Uranium mines area, the cases of congenital deformities have increased by over 7 times when compared to nearby villages. There are also high incidence of TB and chronic lung disease leading to 78 deaths'.

They also conclude that Rawatbhata atomic plant neighbourhood is no different with increased number of cases of congenital deformities, tumours, miscarriages, stillbirths and life expectancy falling by a staggering 11 years. They show workers carrying nuclear waste on bare hands and feet into lorries.

'U.S. reactors have generated about 65,000 metric tons of spent fuel, of which 75 percent is stored in pools, according to Nuclear Energy Institute. The spent fuel rods give off about 10,000 sieverts of radiation per hour at a distance of one foot (sievert is the unit to measure biological effects of nuclear radiation)' says Robert Alvarez, who served as Senior Policy Advisor to the Secretary for US National Security and Environment. To get the point across, he adds that this is 'enough radiation to kill people in a matter of seconds'. There are more than 30 million such rods in U.S. spent fuel pools. No other nation has generated this much radioactivity from either nuclear power or nuclear weapons production.[15]

In France, Greenpeace says that since the origins of the French nuclear industry some 50 years ago, the management of nuclear waste has been largely neglected. In 2006, France's iconic sparkling wine, Champagne, was threatened by radioactive contamination leaking from a nuclear waste dumpsite in the region. Low levels of radioactivity have already been found in underground water less than 10 km from the famous Champagne vineyards. In another incident, French laboratory ACRO said that radioactive waste from a storage facility in Normandy, France was leaking into groundwater and was being used by local farmers for their dairy cattle.[35]

The French Nuclear establishment touted reprocessing as the way to reduce nuclear waste but the Union of Concerned Scientists (USC) busted the myth. In a study released in Mar, 2011, USC found that reprocessing of spent nuclear fuel would increase, not decrease, the total volume of nuclear waste. The study concluded that reprocessing is not a sensible answer to the nuclear waste problem.[36]

Advocates D.Nagasila and V.Suresh disclosed a chilling point in *The Hindu* on 5 Nov, 2012: As per the 1988 agreement between India and erstwhile Soviet Union on the Koodankulam plant, the highly dangerous and toxic 'Spent Nuclear Fuel' (SNF) would be shipped back to the Soviet Union. However, in 1997 India signed another agreement—this time with Russia—contrary to the original proposal to ship out the SNF to Russia, the highly radioactive SNF from the nuclear power plant was to be stored, transported and reprocessed within India. Right now, secrecy shrouds the fate of the radioactive spent fuel, its reprocessing and transportation in Koodankulam.

No safe way to dispose nuclear waste

The fundamental problem is that there is absolutely no known way to dispose nuclear waste in a manner that ensures permanent safety. A March 2006 report by the UK government's Sustainable Development Commission (SDC) identified that 'No safe long-term solution to the problem of radioactive waste from nuclear plants is available, let alone acceptable to the general public'.[28]

According to International Atomic Energy Agency (IAEA), a 1000 MW nuclear power station produces approximately 30 tons of high level solid waste per year. High level waste consists of spent fuel rods which can no longer be used for power production as well as waste materials after processing. High-level waste contains highly radioactive fission products, and so, must be handled and stored with extreme care. Since the only way radioactive waste finally becomes harmless is through decay, which can take lakhs of years for high-level wastes, the waste must be stored and finally disposed of in a way that provides adequate protection of the public for a very long time.[89] But, a group of physicists at the School of Physics, University of Melbourne have pointed out that currently, no country has a complete system for storing high level waste permanently though many have plans to do so in the next 10 years.[29]

Even the available technologies such as storing in deep rocks by vitrification (converting to glass) or destroying the spent fuel using high energy incinerators, are very costly affairs and hence, are very unlikely to be included as part of safety measures in the upcoming nuclear plants in India.

How should any sensible man, whether a poor fisherman or an educated urbanite, react when he is forced to live under the constant threat of an evidently unsafe technology?

Claim 4: Nuclear technology is environment friendly

This is indeed a hotly debated topic because most experts agree that the routine health risks and greenhouse gas emissions from nuclear power are small relative to those associated with coal. Pro-nuclear advocates have offered nuclear power as a solution to global warming. Let us examine this claim.

Firstly, it is true that nuclear power plant operation emits no or negligible amounts of carbon dioxide during fuel processing. However, all other stages of the nuclear fuel chain—mining, milling, transport, fuel fabrication, enrichment, reactor construction, decommissioning and waste management—use fossil fuels and hence emit greenhouse gases notably, carbon dioxide. Dr. Benjamin K. Sovacool, Director of Energy Security & Justice Program at the Vermont Law School says that the largest part of the greenhouse emission (nearly 40%) in the nuclear fuel cycle comes from mining, milling and enrichment. He concludes that the total carbon emission in the nuclear life cycle is twice as much as solar and six times as much as wind farms. So, nuclear energy, though cleaner than coal in terms of carbon dioxide emission, is not as clean as other clean energy sources.

Secondly, there are incidents of commercial nuclear power plants releasing gaseous and liquid radiological effluents into the environment. A leak of radioactive tritium at Vermont Yankee in 2010 which contaminated ground water, along with similar incidents at more than 20 other US nuclear plants in recent years, has kindled doubts about the reliability, durability, and maintenance of aging nuclear installations. In France too, in July 2008, 18,000 litres of Uranium solution containing natural uranium was accidentally released at the Tricastin plant forcing the authorities to ban drinking well-water, and swimming or fishing in two local rivers.[34]

So, seen in the context of the catastrophic risks involved with nuclear accidents, waste and radiation hazards in the nuclear fuel cycle, the overall risks to environment far exceed the marginal contribution in terms of limited green house emission in one specific stage—namely power generation—of the entire nuclear fuel cycle.

Cleanup and compensation - at what cost?

When the estimates are made, the accident costs are not factored in. While the Nuclear Safety Commission in Japan is grappling to come up with the enormous economic cost of the Fukushima disaster, Jan Haverkamp—a Greenpeace nuclear energy expert—puts the total cost of the Fukushima catastrophe, including compensation and clean up, at over Rs.5 lakh crores. Kazumasa Iwata, president of the Japan Center for Economic Research, thinks the estimate ranges from Rs.3.5 lakh crores to Rs.12.5 lakh crores (however, the cost of compensation to affected people is less than 10% of the total cost).

India appears to have learnt a 'clever' lesson from the big brother, the US, when it comes to indemnifying the nuclear reactor vendors against accidents. The US enacted a cap on the damages that could be passed on to the private operator as early as in 1957 through Price-Anderson Act. Thus, today in the US, while the cap is at $12 billion, the actual cost of a nuclear meltdown as shown by a Nuclear Regulatory Commission study (adjusted to current inflation level) would be about $720 billion—60 times more than the cap.[31]

On same lines, as part of the Indo-US Nuclear deal, followed by similar bilateral deals with the other nuclear equipment manufacturing countries, the Indian Central Government enacted a law on capping the liability that could be passed on to the reactor suppliers in the event of an accident. The cap so fixed is a mere Rs.1,500 crores! If you look at the massive liability incurred in a nuclear mishap as in Fukushima, this only means that if a disaster were to occur in India, an exceedingly large part of the cost would be borne by the ordinary Indian tax payers. This point has been conveniently covered up by the nuclear establishment.

The meager value of the cap raises another disturbing question. A Public Interest Litigation (PIL) filed in the Supreme Court in Mar, 2012, represented by advocate Prashant Bhushan, has argued that the low cap on liability would make nuclear plants more unsafe as operators would prefer to bear the burden of an accident rather than going for safety installations.[33]

Nuclear power phase-out

Austria was the first country to begin a nuclear phase-out in 1978 to close down all its nuclear plants in a phased manner. It is followed by Sweden (1980), Italy (1987), Belgium (1999), and Germany (2000). Switzerland and Spain have enacted laws not to build new nuclear power stations. The United States has not built any new nuclear plants since the TMI accident in 1979.

Japan has 55 reactors and following Fukushima disaster, all nuclear reactors have been shut down by May 2012. Interestingly, CNN Japan reported that 'the trains ran exactly on time, the elevators in thousands of Tokyo high-rises efficiently moved between floors, and the lights turned on across cities without a glitch even though none of the energy is derived from a nuclear reactor for the first time in 4 decades'. So, obviously, skys don't open up if there is no nuclear power!

Two reactors have restarted in Japan since July this year. Tens of thousands of people have protested the decision and recent polls showed that majority of people favoured abandoning nuclear power entirely. Thanks to the public pressure, Japan government has announced a plan to completely phase-out nuclear plants.[30]

Sweden and Denmark have already given

up nuclear power. Germany has already shut down eight reactors and plans to close the rest by 2022. Japan was forced to announce a planned phase-out by 2040 following a bigger-than-nuclear explosion of public anger.

(*To be concluded in the next issue.*)

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History of Modern Chemical Industries

Asoke P. Chattopadhyay *

In an earlier edition, a history of chemical technology was presented from ancient times till about 1900. Much of this history is inseparable from history of alchemy, of chemical magic, and traditional practices. Ancient witch doctors, shamans, could treat sick people and cure some of them through their knowledge of special chemicals obtained from botanical and other sources. What we usually refer to as modern science originated in Europe during the 17th century, and continued with the Age of Reason (18th Century) till the birth of the New Sciences (Quantum Mechanics, Relativity, New Biology etc.). Many of the stalwarts during this period, esp. Davy, Lavoisier, Faraday, Priestley, Scheele, Berzelius, Ostwald were motivated by the need to produce materials which may provide food, clothing, shelter and better health to mankind. Removed as we are by at least one century from these persons (in some cases, by more than a century), we cannot even imagine the hardships they had to overcome, to meet the challenges they set before themselves—usually always with the idea that their work will benefit humanity. I say 'usually' because there were, again, always a few individuals who were driven more by the prospect of personal (monetary or otherwise) gain.

Let us recall very briefly the situation from early days of the industry till about 1900. Most of the changes that are really important happened during the 18th Century, in the latter half of it to be precise. The first chemical industry happened with the Leblanc process for making caustic soda (NaOH). Nicholas Leblanc (1742-1806) was the physician of Duke of Orleans. He devised this method in 1787 and obtained a patent for it four years later. In 1874, the world production of caustic soda was 0.525 Mtonnes, more than 94% of it made by the Leblanc process. However, in 1902, the world production was 1.8 Mtonnes, but only about 8.3% of it was made by this process. By then other processes e.g. electrolytic process were invented (1875-1900). An important point is that the Leblanc process was never important in the New World, as it was cheaper to import European NaOH in North America, and by the time chemical industry developed there, the electrolytic process was already invented.

Ironmaking was in existence since prehistory. Even now, there are tribes making iron tools using ground iron ore, coal etc. in bamboo and other containers. By 16-17th Century, people in Europe were using batch process, with small blast furnaces in outhouses, with charcoal as the burner and reducing agent. Around 1773, Abraham Darby in West England developed a process for making coke from coal, and used this instead of charcoal in his blast furnace in Shropshire. Charcoal making was time consuming. The new method revolutionised ironmaking, and in succeeding decades iron from this area was used

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in making steam engines, rails, boats and ships, building structures etc. for the first time. The method was still primitive. Traditionally, the output or pig iron from these foundries was made into wrought iron by manually mixing with iron ore and charcoal. Steel making was essentially small scale and expensive, using either the cementation or crucible processes, where the iron was mixed with charcoal and impurities burnt out. These were batch processes. Only from mid 19th Century, steel-making became a major industry because of the Bessemer and Open Hearth processes. In both, air and silica or other lining in the furnace was used to lower the carbon content, and remove impurities as acidic or basic slag. The slag was used to make cement, among other items. These processes have been superseded by Electric Arc (1878, Siemens) and Basic Oxygen (1952) processes. Major producers of iron ore are China, Brazil, former USSR, Australia, India and USA, roughly in that order, whereas major steel producers are Western Europe, North America, Japan, China, former USSR and South America, again in that order. These change somewhat due to mergers and acquisitions of multinational corporations.

No discussion on chemical industries is complete without mentioning two (or three) chemicals, which together constitute 90% of the industry. These are (1) sulphuric acid, (2) ammonia, and (3) superphosphate or phosphatic fertilisers. Sulfuric acid is the world's most important industrial chemical, i.e., the largest chemical produced by weight per year. Concentrated sulphuric acid, called "oil of vitriol" earlier, was made by distillation of green vitriol, hydrated ferrous sulphate. This was replaced by a process patented by Joshua Ward in England in 1749, where sulphur and Chile saltpetre (sodium nitrate) was burnt together in vessels with water. Although the method was used in Europe much earlier, the new method became popular and the price came down from 2/lb to 2 shillings/lb. John Roebuck replaced glass jars by lead chambers in 1755. This brought price down further. Clement and a co-worker discovered in 1793 in France that if air is admitted, less nitrate is needed in the process. This reduced the cost even further. However, the modern method uses contact process, patented by Philips in 1831, where SO_2 is converted to SO_3 by platinum catalyst, and purity can be improved beyond the 78% limit earlier. Today, K_2SO_4 promoted vanadium oxide catalyst is used.

Industrial ammonia was produced from 1913 in Germany, using the then new Haber-Bosch process of high pressure catalytic conversion of N_2 and H_2. Hydrogen was then obtained by electrolysis of water, but is now made by coke and water vapour, or from natural gas, or from naphtha. Most of the ammonia produced is used in fertilisers, either directly (28.7%), or as urea (22.4%), ammonium nitrate (15.8%), ammonium phosphates (14.6%) and ammonium sulphate (3.4%) Rest of it is used to make explosives and polymers, in refrigeration and wood pulping, as rubber stabiliser, to control pH, in food and beverages and in pharmaceuticals. Although by weight, ammonia produced per year is less than sulphuric acid (by a factor of nearly half), the amount produced in moles is about 4 times, as the molecular weight of ammonia is much less vis-a-vis H_2SO_4.

Phosphates are ubiquitous as industrial and domestic chemicals, but are often overlooked. Only a few of their applications are listed here. For example, sodium phosphate is used as a strong cleaning agent; in combination with NaOCl, it is used as a bleach, antibacterial and dishwashing chemical. Sodium hydrogen phosphate is used as a buffer, as a cheese emulsifier, for picking of meat, in instant pudding and gels, and in breakfast cereals. Sodium dihydrogen phosphate is used as a laxative, in pH adjustment, for treating surfaces before painting. Potassium phosphate is used to absorb H_2S, to control stability of latex. Potassium hydrogen phosphate is used as a buffer. Potassium dihydrogen phosphate is a piezoelectric, and a fertiliser. Ammonium phosphates (including hydrogen phosphates) are used as fertilisers, nutrients, flame retardants. Calcium phosphates are used in food and as fertilisers. Their other varieties are used as baking powder, toothpastes (except when fluoride is used), stock feeds, mineral supplements, etc. The use of calcium phosphates as fertilisers started from around 1830 when Liebig found that acidified bones act as good fertilisers. The world production of rock phosphate increased from around 500 tonnes in 1847 to 500 Ktonnes in 1880 to 150 Mtonnes in 1998, mainly to feed a growing world population.

We have not touched upon cosmetics and such other fast moving consumer goods (FMCG) items, which are also various chemical products, and demands for which has been on the rise. But more of that later.

Before we take up the historical development of chemical industries since 1900, we have to keep in mind the inequalities that exist between the producers and the consumers, even among different categories or classes of consumers. For example, towards the end of 19th Century (1880), coal replaced wood as the worlds main supplier of energy. Wood now accounts for only about 2% of energy supply of the world. Again, coal itself was superseded in 1960 by oil. Coal now accounts for about 30% of total energy of the world (vis-a-vis oil, which supplies about 33% of the latter, vide International Energy Agency data). Nuclear power did not exist before 1950, but now accounts for about 16% of world's power. This would not mean that in rural West Bengal or Karnataka, 30% of the households use coal, and about 16% use nuclear power. While nuclear power use is rather restricted in India, one would find wood as being a major energy source in such rural households. The percentage would be more in sub-Saharan Africa, or among indigenous population in Central or South America. However, nuclear power meets about 70% of electricity demands in France, including in several rural areas. Consumption of chemicals thus differ much between nations, and even between regions inside a nation, depending on availability of monetary resources over and above satisfaction of basic human needs.

Our discussion of the period from mid-19th Century till date, especially in relation to chemical industry, can be carried out on two different aspects of it viz. technological (and scientific), and economic, the latter side including all facets of trade and commerce as well. Let us deal with the scientific and technological aspect first. Scientific and technological changes related to chemical industry during 1850-2012 may be broadly classified into three groups viz. making natural compounds artificially, improving upon older / existing methods of making chemicals, and creating completely artificial molecules. The Haber-Bosch process and synthetic indigo are examples of the first type, whereas Solvay process of making soda is of the second kind. Perkin's synthesis of dye, or making of polymers such as Bakelite (and many other) plastics are examples of the third category.

In 1850, Great Britain was the biggest economic and political power in the world, and the largest producer of chemicals. In late 1860s, 304 Ktonnes of soda and 590 Ktonnes of sulphuric acid was produced in Britain, vis-a-vis 33 Ktonnes of soda and 43 Ktonnes of H_2SO_4. USA produced only 93.7 Ktonnes of sulphuric acid in 1970, and imported most of soda from Europe. But German and US industries grew much faster than their British counterparts. After the first decade of the 20th Century, Germany was producing 0.5 Mtonnes of soda (comparable to that in Britain) and 1.6 Mtonnes of sulphuric acid (350 Ktonnes more than in Britain). The USA was producing 2.2 Mtonnes of sulphuric acid, the largest in the world, by 1914. Even though synthetic dye was first produced in Britain, by 1914 Germany was producing nearly 28 times as much dyestuff. Even Switzerland was producing more than double the amount of dye produced in Britain. By this time, Germany was controlling 85% of the dye industry, most of the new pharmaceuticals, and in effect, about 40% of the chemical industry of the world. It is interesting that for most of the British chemical industry, Englishmen had to rely on the knowledge and expertise of French chemists, France could never become a major player in the world in this area. Some experts have suggested the socio-political developments in England and France were responsible for the difference between these two countries. While education and research in England was traditionally in the hands of learned societies and private enterprise, in France, the economic blockade following the Revolution forced the government to control these two activities. Also, almost everything in France is based in Paris, not distributed as in England.

Germany was kind of intermediate between England and France, there being several centres of learning and industrial enterprise, although not as ubiquitous as in England. However, the perseverance of German research in organic chemicals paid off in the 20th Century. Japan, the only other country to become a part of world capitalism, was still in its infancy in the early 20th Century. Her contribution to the world's chemical trade was around 1% by 1914. The chemical industry in the USA was started by a few individuals. An important contributor was E. I. Du Pont de Nemours, who fled with his father to the US to escape the French Revolution in 1799, to set up the first du Pont factory (producing ammunition) in 1802 in Delaware. He was an assistant of Lavoisier. By 1951, the USA was producing 43% of the world's chemicals, followed by Britain (9%), Germany (6%), France and Japan (4% each). Half a century later, world's production had increased about 10 times, the share of the US has declined to 28%, that of Britain only 3%, and those of Germany and France had remained at 6% and 4% (i.e., in their 1951 levels), but the share of Japan had increased to 13%. Germany remains the second largest chemical exporter after the USA in the first decade of the 21st Century.

One should not forget that A. W. Von Hoffman, an assistant of Justus Liebig, was recruited from Germany to Britain in 1845 to lead the newly formed Royal College of Chemistry. Liebig was a student of J. L. Gay-Lussac, who was a student of Berthollet, who in turn was trained by Lavoisier himself. Leibig started his teaching and research in the 3rd decade of the 19th Century in Germany. Hoffman, a leading chemist of his day, had to return to Germany as the British chemical industry was not prepared to invest in R&D at that time. However, Perkin, one of Hoffman's students in Britain, had synthesised the first artificial dye in 1856, which was to initiate the dye industry in Britain. In Germany, there was more interaction between industry and academia. Thus, the early exploration of individuals (entrepreneurs) in mid to late 18th Century gave way to consolidation and exploration about hundred years later. We must remember that Adam Smith's famous book on economics was published in 1776. The picture changed again half a century later, during and after the First World War.

The USA, deprived of European imports, especially of dyes etc., started to build its own organic chemical industry. It is not a coincidence that the most important British and German chemical companies, Imperial Chemical industries and IG Farben, were formed in 1926 and 1925 respectively. In the USA, there was competition and consolidation among companies such as du Pont, Union Carbide, Allied Chemical and American Cyanamid.

While the European industries were largely affected by the Second World War, those in the USA were not. The soldiers returned home to educate themselves and get jobs. The Depression years were over. The petrochemical industry in the USA developed quickly, based on demand for automobiles and allied petroleum products. An abundant supply of native oil and gas reserves helped. By 1950s, about 50% of production of organic chemicals in the USA was from natural oil and gas. A decade later, the ratio was nearly 90%. Another decade later, i.e., by the 1970s, European countries especially Britain and Germany were able to compete with the USA in terms of chemical output. Japan was the last major power to enter the world chemical market, around this time. Previously, its industry served domestic demands only. However, in around 1969-70 came the oil crisis, and the major players had to restructure their chemical industries to tackle this new challenge. Polymer products multiplied tremendously. Pharmaceuticals claimed an increasing fraction of chemical products in the market. Fast moving consumer goods (FMCG) articles also started their foray in the market from around 1970s and 1980s. Right now, polymers constitute about 33% of the total chemical output, and are the largest segment of the latter. Bulk petrochemicals and intermediates constitute 30% of total chemicals. Life science products, drugs and health products of humans and animals, diagnostics, pesticides etc., also make up 30% of total chemicals. Derivatives and basic industrial chemicals, synthetic rubber and rubber products, resins, dyes and pigments, turpentine, surfactants, explosives, carbon black etc. make up about 20% of total chemical products. Inorganic chemicals, salts, chlorine, caustic soda, soda ash, acids, etc. constitute 12% of total chemicals. Fertilisers (ammonia and nitrates, phosphates and potassic chemicals) make up about 6% of total chemical products. Speciality chemicals and FMCG products are rapidly increasing segments, and include electronic materials, industrial gases, adhesives, sealants, coatings, cleaning chemicals, catalysts, soaps, detergents and cosmetics.

In terms of employment, in the European Union, chemical industry generates over 3 million jobs in about 6,000 companies, and accounts for over 2/3 of the entire trade surplus of EU. In the USA, chemical production per year is around 750 billion dollars, employing over one million persons. The European Union remains the largest chemical producer, followed by the US and Japan. However, emerging countries and regions such as China, India, Korea, the Middle Eastern and South East Asian countries, and Brazil are making rapid progress. With the latest trend of outsourcing in the developed nations, production processes are moving to less developed (and emerging) countries, where labour is cheaper. But everywhere, the emphasis is on cutting costs and finding alternate (more efficient and cheaper) pathways to the same products. Also, newer chemicals such as nanomaterials, biomaterials, nano-bio composites, materials with pre-designed properties etc. are appearing in the markets. But throughout the period, i.e., 1850 till date, research and innovation has played a major role in the industry. W. H. Carrother's making of the first synthetic fibre, nylon, in the 1930s in Du Pont and Winfield and Dickson's synthesis of polyester, the most important artificial fibre, in 1941 are probably the most significant works for the industry. There have been other such contributions with products, catalysts, processes etc. With increasing use of computers, design and theoretical work has also become important. This is especially true of drugs. About a century ago, there was no testing of drugs; production was simultaneous with its introduction in the market. Today, a putative drug has to undergo rigorous testing at several levels before it can be brought to the market. Even then, action of previously unknown side effects may force the drug to be withdrawn within decades of its introduction. Refecoxib and celecoxib are examples of non-stereoidal anti-inflammatory drugs which were designed over years, and had to be withdrawn following harmful effects on patients with cardiac problems.

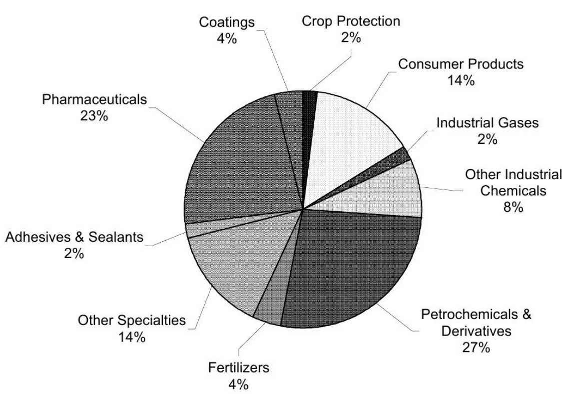

Figure 1: Global chemical production by segment, 2000. Source: American Chemical Council, Guide to the business of chemistry, 2001. Source: Ref [1].

Right from the early days, it was found that the HCl fumes polluted the atmosphere near the alkali plants. Towers were built which could absorb the fumes and the Alkali Act of 1861 was passed in Britain to make the towers compulsory for alkali plants. Also, much of the byproducts and solvents were often thrown unprocessed into rivers and ponds nearby, causing much environmental hazard. These had to be tackled and proper laws enacted. It was the constant investment in R&D that kept BASF, ICI and such companies as market leaders for over a century. Environmental degradation, however, continued, notable among them being the 1976 dioxin leak in Italy, the Love Canal incident in the USA in 1980, the Bhopal gas disaster from a Union Carbide plant in 1984, and two years later, fire in a Sandoz plant in Switzerland (1986) causing pollution in Rhine water.

The current picture can be better understood from the following figures. Fig. 1 shows global chemical production segment-wise, by 2000. Table 1 shows the evolution of chemical industry between 1850 and 2000. The data are given wherever available. The striking features that immediately draw attention are (1) the near constancy of US and France in terms of contribution to global chemical industry, (2) the fall of Britain as a major player in this field, (3) the rise of Japan as a major player in the same period, and (4) the fall of Germany upto 1950 and near constant ratio of global chemical output since then. Please note that in 1913, these 5 countries together contributed 80% of the global chemicals, while in 2000, their total contribution is only 54%. In other words, contributions from China, India and other countries have become important in the new Millenium. This becomes clear in Table 2, which gives the data for chemical exports from 1899 till 2000. This shows the European Union as the largest chemical exporter in the world by far, with US coming second by a large gap. It also shows that other countries, such as China, India, Brazil etc., not named in Table 2, have be-

Year	USA		Britain		Japan		Germany		France		World Total
1850	0.005										
1860	0.0047										
1870	0.0194										
1877							0.6	20%			3
1880	0.0386										
1890	0.0594										
1895							1				
1900	0.0626										
1905	0.0921										
1913	3.4	34%	1.1	11%	0.15	2%	2.4	24%	0.85	9%	10
1927	9.45	42%	2.3	10%	0.55	2%	3.6	16%	1.5	7%	22.5
1935	6.8	32%	1.95	9%	1.3	6%	3.7	18%	1.6	8%	21
1938	8.0	30%	2.3	9%	1.5	6%	5.9	22%	1.5	6%	26.9
1951	71.8	43%	14.7	9%	6.5	4%	9.7	6%	5.9	4%	166
1970	49.20	29%	7.60	4%	15.30	9%	13.60	8%	7.20	4%	171
1980	168.34	23%	31.77	4%	79.23	11%	59.29	8%	38.60	5%	719
1990	309.10	24%	44.70	4%	162.80	13%	100.50	8%	66.30	5%	1248
2000	460.00	28%	50.70	3%	218.40	13%	100.00	6%	73.00	4%	1669

Table 1: Production of chemicals in billion US$ and country shares (given as %). Source: Ref [1].

Exports from	**1899**	**1913**	**1929**	**1937**	**1950**	**1959**	**1990**	**2000**
United Kingdom	19.6	20.0	17.5	16.0	17.9	15.0	8.4	6.6
France	13.1	13.1	13.5	9.9	10.1	8.6	9.1	7.8
Germany [1]	35.0	40.2	30.9	31.6	10.4	20.2	17.7	12.1
Other Western Europe [2]	13.1	13.1	15.3	19.4	20.5	21.1	31.7	32.0
United States	14.2	11.2	18.1	16.9	34.6	27.4	13.2	14.1
Canada	0.4	0.9	2.5	2.9	5.2	4.4	1.8	1.6
Japan	0.4	1.0	1.8	3.0	0.8	3.1	5.4	6.1
Other	4.2	0.3	0.4	0.3	0.5	0.2	12.8	19.8
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Total in billion $ U.S.	0.26	0.59	1.04	0.98	2.17	5.48	309.2	566.0

Table 2: Chemical exports by country of origin from 1899 till 2000. Source: Ref [1].

come important globally. Fig. 2 analyses global chemical output by region, and by nature of countries themselves. The phenomenal rise of China can be clearly understood from Fig. 2. This is brought out more forcibly in Fig. 3 and Fig. 4. From Fig. 3, which shows global chemical production by region, the chemical production in Asia equals the total chemical production of Europe and America combined. NAFTA stands for North American Free Trade Association, including USA, Canada and a few other countries. Fig. 4, which compares the chemical production by regions between 2000 and 2010, clearly shows that emerging economies such as China far outpace the developed countries in chemical production in the second decade of the new millennium. Fig. 5 compares chemical production among countries in 2010, among both developed and less-developed countries. Here again, China emerges as the world leader, followed by USA. Japan and Germany are close together, behind the US. Other countries follow after them. It is interesting to note that Brazil and Korea come after Germany and Japan, ahead of India, Italy, and Taiwan. This also explains why

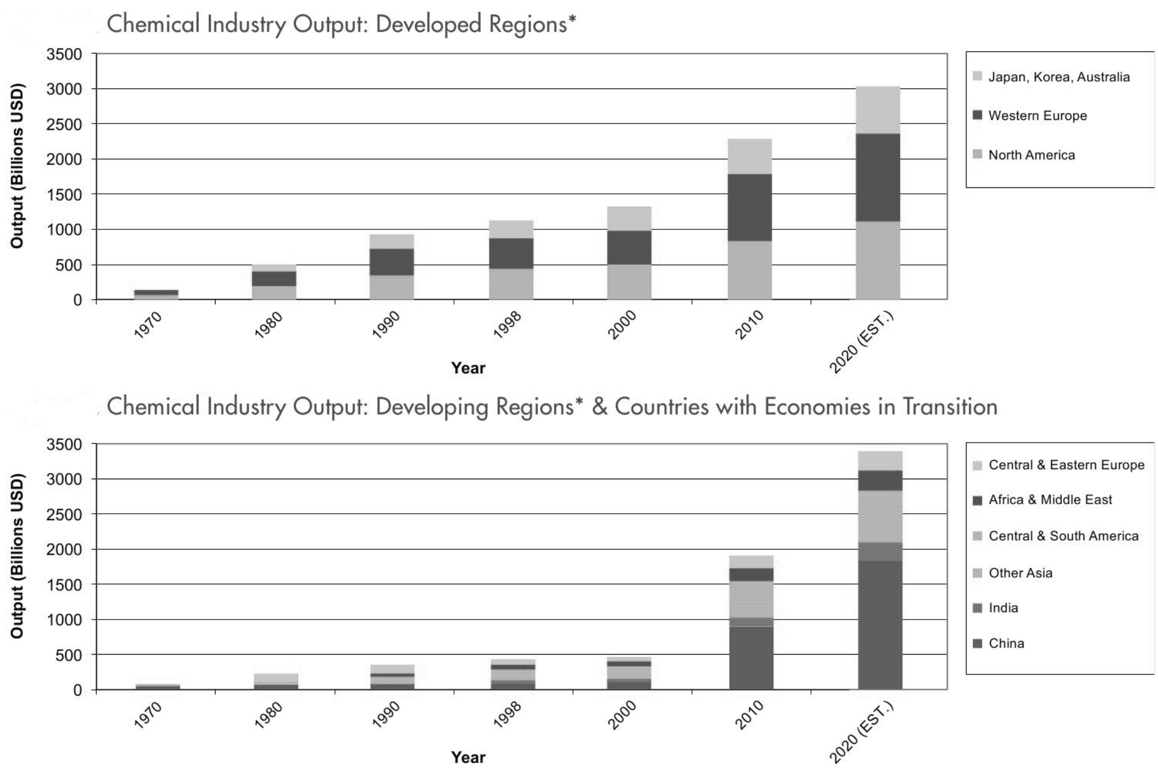

Figure 2: In each column on the top figure, the 3 units are for (a) Japan, Korea and Australia, (b) Western Europe and (c) North America, from top to bottom, in that order. Similarly, in the bottom figure, the different parts in each column signify data for (a) Centra & Eastern Europe, (b) Africa & Middle East, (c) Central & South America, (d) Other Asia, (e) India and (c) China, from top to bottom, in that order. Source: Ref [2].

the country-wise breakup of global chemical exports, shown in Table 2, is misleading as it does not indicate the production or sale of chemicals produced in a country, only chemical exports from it. In Asia, most of the chemicals produced within major chemical producers such as China or India are consumed within the country, demand being very high. Japan is the only exception, earning a lot from its exports.

Finally, one should be able to comment on future trends based on past history and current indicators. First, what will happen to traditional chemicals? We know that the older or heavy chemicals were superseded by newer ones such as pharmaceuticals or consumer products over the last couple of decades. Maybe nanomaterials or nanocomposites with biochemicals or other materials will become important in the coming decades. Already patents are being filed in this area at a tremendous pace.

Environmental issues are also important. More and more attention is being paid to environmental damages, as we are slowly becoming aware of exactly how much and how dangerously human industry has brought the environment to a “tipping point”. Hence, more R&D efforts, and

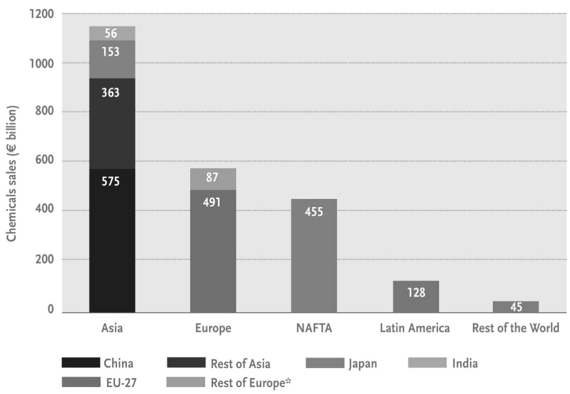

Figure 3: World chemical sales by region. In the column for Asia, the numbers are for China, Rest of Asia, Japan and India, serially from bottom upwards. In the column for Europe, it is EU-27 and Rest of Europe, from bottom to top. Source: Ref [4].

more money, is expected to be spent on this aspect across the various chemical production units. Also, there is an interesting face-off between the economy of scale and tendency to miniaturise in chemical industry today. Attempts are being made, through outsourcing and R&D efforts, to reduce the number of steps in a chemical plant. At the same time, China has shown how large-scale production by cheap labour can catapult a country quickly into a position of global leadership. Increasing complexity of global socio-political scenario, combined with greater environmental disturbances, widespread water scarcity in large parts of Africa, Asia and Latin America, may make any long term prediction about the trends in chemical industry very difficult. □

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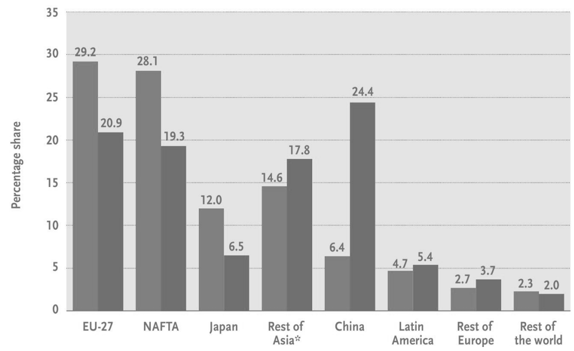

Figure 4: Comparison of world chemical sales between 2000 and 2010. For each pair of columns, the left one is for 2000 (total of Euro 1437 billion), and the right one is for 2010 (total Euro 2353 billion). Source: Ref [4].

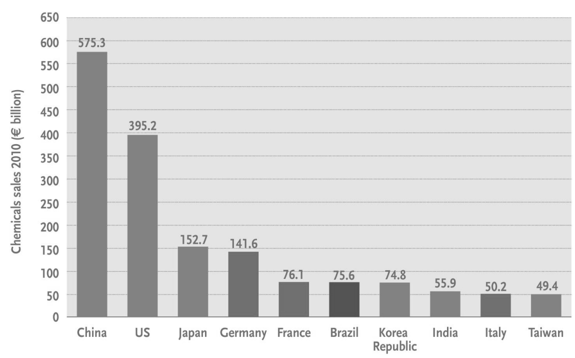

Figure 5: The top 10 chemical producing countries in 2010. Source: Ref [4].

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A Brief History of Science
Part-2: The Upsurge of Greek Intellect

Soumitro Banerjee*

The advent of the iron age saw large-scale warfare and redistribution of the empires. Out of the ashes of that chaotic period sprang a civilization that was to have enormous influence on the intellectual development of mankind. It happened in a land somewhat removed from the older civilizations like Babylon, Egypt, Persia, India, etc., to be free from the conservative influences. On the other hand it was not too isolated, so that it could adopt and build on the knowledge created in those cultures.

A few factors were responsible for this great intellectual upsurge. By the time of the advent of Greek civilization, slavery had taken roots in the society. As a result of that, for the first time, some people—the slave owners—had free time to engage in thinking alone. By then quite a few scientific and technological advancements had happened (for example, wheel, pottery, metallurgy, astronomy, number system etc.). The Greeks built on that ground, and took it to a far higher level of abstraction.

Secondly, for most part of the Greek civilization, there was no large monarchy (the first Greek empire was built by Alexander, which disintegrated after his death). The Greek society was mostly centred around small city-states, where the separation between the ruler and the ruled was rather small. As a result, most citizens were able to take part in political life. In most of the city states there was no king, and a council of citizens took the political decisions. As a result of this political environment, great importance was attached to one's ability to argue. The cultivation of logic had its impact on the way the Greeks tried to answer questions that naturally came to their mind.

The historians divide the Greek period into three phases: the Ionian phase, the Athenian phase, and the Hellenistic phase—each with its characteristic social factors and contributions to science.

The Ionian period

The first burst of intellect happened in the sixth century BC, not in the mainland Greece, but in the cities of Asia minor and the islands in the Mediterranean sea, populated by Greek people. Trade routes established a link between these cities and the older civilizations, and at the same time these cities were not rich enough to be target of invasion. Thus shielded, the Ionian Greeks of these city-states started building on the science and technology of the earlier cultures.

The first spark was ignited by Thales (624-547 BC) of Miletus (a coastal city in West Asia), which was followed by people like Anaximander (610-545 BC), Anaximenes (585-528 BC), Pythagoras (572-497 BC), Empidocles (494-434 BC), Hippocrates (460-370 BC), Archytas (428-347 BC), etc. Their tendency was towards

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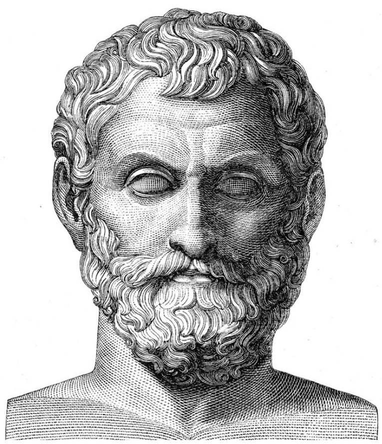
Map of ancient Greece

giving a theoretical structure to the science and technology developed till that time.

The people of Egypt had built the pyramids; but **Thales** invented a method of measuring the height of a pyramid based on geometry. Traders and sailors had travelled to distant lands; but **Anaximander** (610-545 BC) was the first to put together a map of the then known world based on the accounts of travellers and sailors. The ancients knew the construction of a cube; but **Archytas** (428-347 BC) solved the problem of building a cube twice the volume of a given cube. From these, one can easily see the inclination towards developing a theoretical solution to a given problem.

That tendency of abstract thinking was taken to an altogether different height by **Pythagoras** (572-497 BC), the man famous for his "theorem". He founded a brotherhood of mathematicians who practised mathematics as a secret sect, keeping their findings within themselves (we know about the work of the Pythagoreans through the writings of a later mathematician, Philolaus). They worked with numbers and found many of their properties now known in number theory. For example, they identified 1,3,6,10,15 etc. as "triangular numbers" and 1,4,9,16,25 etc. as "square numbers" (you can form a triangle with 10 dots and a square with 16) and proved that two consecutive triangular numbers give a square number. By analyzing the length of the hypotenuse of a right-angled triangle of side 1 (which is $\sqrt{2}$), they came to



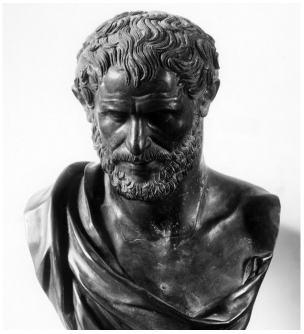
Thales of Miletus (624-547 BC)

the conclusion that all numbers cannot be expressed as ratios of integers, and gave birth to the concept of irrational numbers. In fact, it was the Pythagoreans who developed the method of deduction from known "axioms" which is at the basis of much of mathematics even today. One of the major contributions of the Pythagoreans is to demonstrate the relationship between music and numbers: The notes Sa, Re, Ga, Ma etc. (of the Indian system) on a string instrument always occur in whole-number ratios of the lengths. In spite of such great contributions, their work had a mystical character: they attached mystic properties to numbers, each number having a specific character. They analyzed various geometric shapes and concluded that the circle and the sphere are the most "perfect" shapes. That led to their belief that all celestial objects are spheres, moving in circles. They pictured the universe and the movement of the celestial objects as a "harmony of numbers" much like the harmony in music.

One of the basic issues that pervade much of Greek philosophy concerns the question: What is everything made of? **Thales** thought that water is the basic constituent of the world; all the things we see around us emerge out of water and in the end go into the water. In contrast, in the view of **Anaximenes**, air is the basic constituent of everything. It is air that produces water and soil upon condensation, and produces fire upon expansion. On the other hand, **Empidocles** said that everything around us is made of four constituents: earth, water, air, and fire. And then there is the atomic theory of **Leucippus** and **Democritus** (first half of 5th century BC), which says that everything is made of minute particles, called atoms.

The Ionian period also saw great advancement of medical science in the hands of **Hippocrates**, who tried to free the medical science from the ancient superstitions and "magic cures." He stressed on meticulous observation of patients to learn the nature of the diseases. The code of conduct in medical ethics—the so-called *Hippocratic Oath*—is still in use today.

Another question concerned the structure of the universe. **Anaximander** thought that the Earth is at the centre of the universe, that the sky is a hemisphere surrounding the Earth, and that the stars revolve round the north star. According to **Anaximenes** (who thought that air is the basic constituent) the earth, the sun, and the moon float in a sea of air. He thought that the stars are hot bodies attached to the celestial hemisphere; they are not as bright as the sun because this hemisphere is placed at a far distance than the sun. The Pythagoreans imagined that the earth, the sun, the moon, and other celestial objects revolve round a central fire (this is *not* the sun). Not only that. Based on their belief that the number 10 is a perfect number, they argued that there must be 10 celestial objects. At that time nine objects were known: Earth, Sun, Moon, Mercury, Venus, Mars, Jupiter, Saturn, and the celestial hemisphere containing the stars. So, to make up the number 10, they imagined that there is also a "Counter Earth" revolv-



Left: Democritus of Abdera (460-370 BC), right: Pythagoras of Samos (572-497 BC)

ing around the central fire, which is not visible from the northern hemisphere.

Thus we see that in the Ionian period, people considered the natural questions that comes to one's mind, and tried to answer them. But in answering the questions, they resorted to speculation and personal realization. In most cases the answers they arrived at were wrong. But one noticeable feature was that the answers were wholly in terms of the material things we see around us, that is, their ideas were in content materialistic. Idealism as we know it was not yet born. Historians have attributed this aspect to the fact that, in this early phase of the Greek society, slavery was not yet so strongly entrenched to create a hard division between the doer and the thinker.

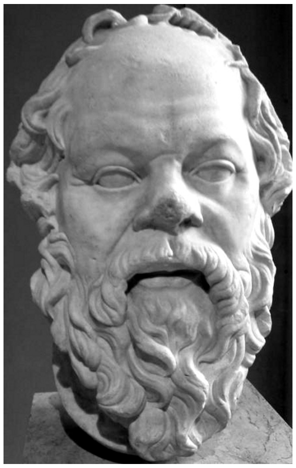
The Athenian Period

Towards the end of the Ionian period there was warfare with Persia and between the Greek states (called the Peloponnesian war) which suppressed many of the city states, but Athens stood up to the enemy under the leadership of the able statesman Pericles. As a result, Athens emerged as the Greek intellectual centre, and remained so over the period from 480 BC to 330 BC, culminating in the suppression of the city-states by Alexander.

In this period, in spite of the great advancements in the intellectual pursuits, we begin to see the effects of a society strongly based on slavery: the slaves who did all the work were not engaged in thinking, and the thinkers who came from the class of slave masters, had no connection with work, that is, the actual manipulation of natural objects. In this period the interests shifted from the explanation of the material world to that of the nature of man, his ideals, etc. Three great figures of this period are Socrates, Plato, and Aristotle.

In the city-state of Athens, a kind of democracy prevailed (albeit a democracy of the slave-owners) in which disputation and oratory skills had ever greater importance. In the words of J. D. Bernal, "The control of people by words became more rewarding than the control of things by work." In this situation **Socrates** (469-399 BC) developed and taught a method of argumentation in which, by asking a series of questions directed at the opponent's own knowledge, he would demonstrate that his opponent did not know what he was talking about. In essence, Socrates was introducing a method of logic in which great importance was attached to the rigorous definition of each term, which was to have great influence on the development of science in future.

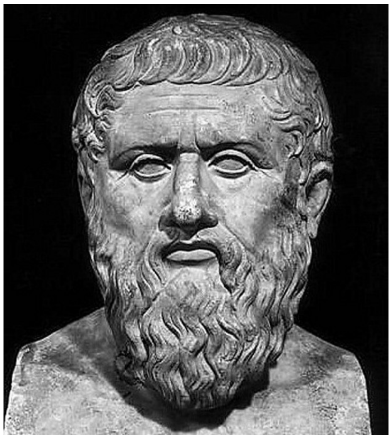
In those times there was a tussle between the followers of democracy and those of monarchy. Socrates himself was not a supporter of democracy. In the middle of the 4th century BC, there was a war with Sparta, in which Athens was defeated. Then in 403 BC, there was a popular revolt that restored democracy. Socrates' death was a consequence of the fact that some of his disciples—young men of aristocratic families—went against Athens during the war with Sparta, due to which Socrates was accused of "corrupting the minds of young men".


Bust of Socrates (469-399 BC)

Plato (427-347 BC), son of a wealthy aristocrat and a disciple of Socrates, was also a supporter of monarchy. In his youth, he dabbled in politics, but decided to devote himself to philosophy after his political ambitions were thwarted by the re-installation of democracy. He opposed the materialistic position of the Ionian philosophers like Democritus, but absorbed the mathematical mysticism of Pythagoras. He then went a step further to argue that the ideas taking shape in human mind are the perfect things; these are the actual reality. The *idea* of the 'circle' is actually the reality, and the circular shapes that we see in nature or can draw on a piece of paper are only imperfect approximations to this idea. He argued that since any beautiful thing has some imperfections, the idea of "beauty" is more powerful and more real than any beautiful thing. The philosophical trend he gave birth to is called *idealism*. It places idea in a higher position than matter, and holds that idea is primary and matter is secondary. It was only a small step from there for the later philosophers to declare that the material world is an illusion, and only ideas represent reality.

Plato then tried to speculate what should be the "ideal" things in every sphere of life and society. He used Pythagorean mathematics to create a peculiar kind of astronomy which tried to figure out how the motion of the heavenly bodies *should be* rather than how they really are. In politics he developed the concept of a "perfect State". According to Plato, the citizens of such a perfect state would be divided into four grades: the guardians, the philosophers, the soldiers, and the people—a division similar to the caste system in India (slaves did not come into any of these categories, because he did not consider them as citizens). He argued that these divisions are permanent because men are *created* in four constitutions—gold, silver, brass, and iron. He also imagined an "ideal" ruler, one from the category of the guardians, who would have no family life, no commitment other than that to the state. He would be a cultured person, highly educated in philosophy and mathematics, and should have a taste for music and the arts. Plato even tried to train Prince Dionysius of Syracuse in his ideal form, and failed (this boy could not stand the rigours of a training in mathematics, and did not want to remain a bachelor lifelong). He then returned to Athens, and created a school called the *Academy*, where he taught to a very select group of pupils. Over the gate was written "Let no one ignorant of mathematics enter here." The Academy survived more than a thousand years, and acted as the precursor of all modern universities and scientific societies.

Thus we see the birth of a mature form of idealism in the hands of Plato, expressed in such beautiful and persuasive language that it influenced generations of intelligent people into philosophical idealism, utopian thoughts, and mysticism. As we shall see later, this trend blocked the advancement of scientific thought for a long time. In the realm of politics, his ideas regarding the af-



Statue of Plato (427-347 BC)

fairs of the state were essentially to give a philosophical justification to a permanent rule of the aristocracy.

Aristotle (384-322 BC) was a disciple of Plato and later a rival who broke away from the Academy and started his own school—the *Lyceum*. He was truly an intellectual giant who had tremendous influence on human thought for more than 2000 years. He absorbed all the knowledge created till that time in different areas of human enquiry, and gave it a structured form as separate disciplines like physics, biology, humanities, etc., which continues to this day. He adopted the logic expounded by Socrates, and developed it into a system of thinking, called "formal logic".

The theoretical structure he created in physics is worth mentioning. He adopted Empidocles' idea that water, air, fire, and earth constitute everything, and gave it a structured form as a system of "elements." To this he added "ether" as the substance of the heavens—an idea that survived until the early 20th century. According to him, all these elements have specific "nature". Why does water flow downwards? Because it is the *nature* of water to flow downwards. Likewise, it is the *nature* of fire to go upwards. According to Aristotle, everything has a natural place in the order of things, and tries to move towards that natural state when moved away from there.

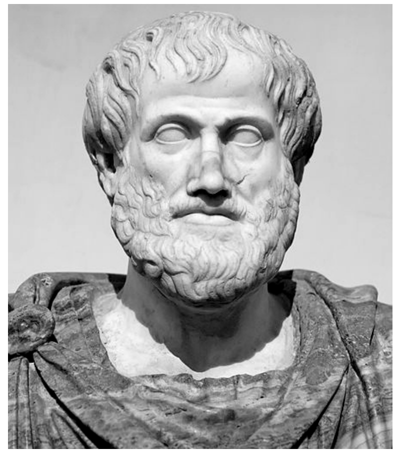
Much of his ideas actually stem from common sense. He saw that the cart moves when pulled by the horse. So he theorized that "force produces motion." A logical corollary of this statement is that a greater force will produce a greater motion. That is what he said: "a heavier body will fall faster than a lighter body." This intuitive idea was so powerful that it prevented generations of scientists from checking it until Galileo Galilei did that in the fifteenth century.

In astronomy, he adopted the view that the Earth is at the centre of the solar system, around which moves the moon and the sun. Around that, there are transparent crystal spheres on which the planets are embedded. The planets move because these concentric crystal spheres move. Then there is the static, unchanging, dark hemisphere—the sky—on which the stars are embedded. That ends the universe, which, according to Aristotle, is finite.

But there is one field—biology—in which Aristotle did real scientific work. For a few years he lived close to the sea. When fishermen brought ashore various types of sea-creatures, he would collect them and would study their anatomy. In many cases he did dissection by his own hand (in this case he deviated from the slave-master attitude). In those days bee-keeping was an important activity, because honey was the only known sweetener. Aristotle made many important studies on such social insects. He even used his own resources to employ people to collect biological samples from distant lands. It is unfortunate that people after him did not continue this line of work, which was practically lost until the modern times. However, the limitations of his time show up at places in his biological studies also. For example, in the book "History of Animals" he said that human males have more teeth than females. Historians of science later commented that, had Aristotle bothered to actually count the teeth of one of his wives, this error would not have occurred. But the tone of the time was to arrive at an answer through personal realization, and Aristotle arrived at this conclusion based on the prevailing belief that women are inferior to men!

In Aristotle, we find the first in-depth treatment of the idea of causality. People before him had the notion that there must be a cause behind every event, but it was Aristotle who first gave it a theoretical form. He defined four types of causes behind every event: material cause, formal cause, efficient cause, and final cause. Consider a bronze sculpture, and ask what is the cause behind it? Aristotle says that the cause can be searched in four different ways. First, it is made of bronze. Hence the material, bronze, is a cause in the sense that the sculpture would be impossible if the bronze were not there. This is the material cause. Second, the sculpture has a form, and the sculptor had that *form* in mind when he worked on the bronze. This is the formal cause. Third, the sculptor is the external agency that acted in order to produce the sculpture. Hence the sculptor is also a cause—the efficient cause. The final cause is that for the sake of which a thing exists, or is done—including both purposeful and instrumental actions. The final cause, or *telos*, is the purpose, or end, that something is supposed to serve. This final cause had an obvious religious underpinning, and in the middle age the Church authorities made it their credo, thus making Aristotle their undisputed authority on every question.

Aristotle's contribution to the theory of logic is really momentous, and in this article we shall be able to give only a glimpse



Statue of Aristotle (384-322 BC)

of his ideas. Picking up the thread left by Socrates, he developed a structured way of logical thinking that rested mainly on deduction, called *syllogism.* According to him, a deduction is speech in which, certain things having been supposed, something different from those supposed results of necessity. Each of the "things supposed" is a *premise* of the argument, and what "results of necessity" is the conclusion. Syllogisms are structures of sentences each of which can meaningfully be called true or false: "assertions" in Aristotle's terminology. According to Aristotle, every such sentence must have the same structure: it must contain a subject and a predicate and must either affirm or deny the predicate of the subject.

He then introduced the style of writing statements compactly in terms of algebraic variables, a, b, c, etc., which allows one to write a statement like "tigers are mammals" as "every b is a", where a represents the category of mammals and b represents tigers. He further compacted the notations by using letter symbols to represent the kind of statement one is making. For example, one would write the statement "every b is a" as Aab, where the first capital letter represents the Greek for "every" or "all", the second letter represents the predicate, and the third the subject. Using this, one can form abstract assertions like "every b is a" (abbreviated as Aab), "No b is a" (abbreviated as Eab), "Some b is a" (abbreviated as Iab) and "Not every b is a" (abbreviated as Oab). Then he outlines what are the logically correct deductions starting from a given premise (for example, $Aab \to Iba$: "every tiger is a mammal" implies "some mammals are tigers"). Thus, one would derive a series of such deductions, finally arriving at a conclusion quite different from the premise. He gives many more ways of such structured reasoning, which guided logical thinking for millennia. Much of Euclid's theorems in geometry follow this style of logical reasoning in their proof.

Euclid of Alexandria (325-265 BC)

Following Socrates, he laid stress on proper definition of the things one is talking about. If you are talking about a tree, first define what a tree is. Take care to distinguish it from a sapling, a shrub, a bush, or a vine. For this purpose he proposed three principles of formal logic. First, the "law of identity" which says if you have defined an entity A, then A is A and nothing but A (abbreviated as $A = A$): A tree is a tree, and nothing but a tree. Second, the "law of negation" which says that no other thing is the same as A (abbreviated as $B \neq A$): A shrub is not a tree. Third, the "law of excluded middle" which says the nothing can be A and B at the same time: Nothing can be a tree and a shrub at the same time. For a long time scientific enquiry was guided by this style of reasoning, so long as scientists were studying "things as they are". It proved inadequate when scientists turned their attention to "things in motion and change". We shall come to this aspect later.

Even though Plato failed in his pursuit of grooming a prince, Aristotle succeeded. He taught the Macedonian prince Alexander (356-323 BC), who became the king of Macedon in 336 BC. In 334 BC he started his military campaign to spread the empire. He quickly subdued the city-states of Greece and invaded Persia. In a series of decisive battles, he defeated King Darius III of Persia, and spread his empire up to the river Indus. Then in 326 BC he invaded India. Even though he won battles, this terrain proved difficult for him, and he was forced to turn back at the demand of his exhausted troops. He died of disease in Babylon in 323 BC on the way back to Greece.

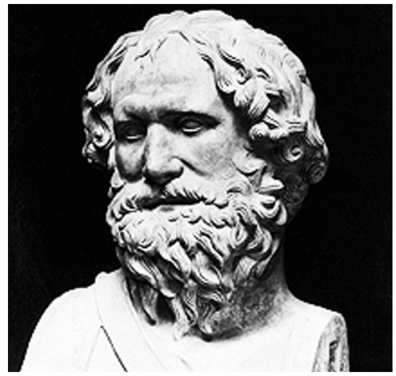
Before we move on to the Hellenistic period, we have to discuss the contribution of Theophrastus (373-288 BC), who studied in Plato's Academy and Aristotle's Lyceum, and became the head of the Lyceum after Aristotle's death. Under his leadership Lyceum became a famous centre of learning. He also made original contributions in botany and chemistry. Noticeable are the facts that in his writings he opposed some of Aristotle's doctrines including that of "final cause," and argued that fire cannot be an "element".

The Hellenistic period

After Alexander's death, the empire was divided among his generals. Seleucus occupied West Asia up to Punjab, while Egypt, Cyprus, Palestine and a part of today's Syria came to be ruled by Ptolemy. Civil war started for the occupation of Greece, and as a result the centre of intellectual activity shifted from mainland Greece to the other parts of the empire. This is called the Hellenistic period. The Egyptian coastal city of Alexandria, founded by Alexander the Great in 331 BC, became prominent in this period. The Alexandrian rulers, called the *Ptolemies*, patronized learning and scholarship, and founded a library which had the largest collection of books in the world of that time. Prominent figures of the Hellenistic period are Euclid, Archimedes, Aristarchus, Hipparchus, Claudius Ptolemy, and Galen.

Euclid (330-275 BC) worked in Alexandria during the reign of Ptolemy I (323-283 BC), and was the curator of the mathematics section of the library. He inherited a rich tradition of geometry, created and enriched by Thales, Anaxagoras, Pythagoras, Plato, etc. Euclid gave it a structured form, where the axioms were clearly stated, and theorems were proved based on Aristotelian deductive logic. His 13-volume treatise "Elements" is so comprehensive, that most of the theorems remained unchanged and form the backbone of school-level geometry even today.

Archimedes (287-212 BC) of Syracuse was another genius of that time. Though he is mostly known for the "Archimedes Principle" of hydrostatics, he was also a mathematician, an engineer, a physicist, and an inventor. He was educated at the library of Alexandria, and then returned to the island of Syracuse. His main interest was in geometry, in which he invented a method of obtaining the value of π, and developed the methods of measuring the volumes of various solid objects like sphere, pyramid, cylinder and cone. He overcame the limitations of the primitive number system of Greece (they did not use a place-value system and did not know the use of zero) to conceive large numbers, and used algebra to solve problems. Apart from discovering the "Archimedes Principle" which provided a theoretical basis for shipbuilding and maritime transport, he invented the "Archimedes screw" to pump water for irrigation, and gave a theoretical grounding to the theory of simple machines like levers and pulleys. Legend has it that he moved a whole ship using multiple pulleys in front of the ruler of Syracuse. Archimedes is said to have remarked of the lever: "Give me a place to stand on, and I will move the Earth."



Archimedes of Syracuse (287-212 BC)

At that time the Romans was at war with Syracuse, and the Roman ships laid siege of Syracuse a number of times. But each time Archimedes came up with ingenious methods to destroy the ships—some time with catapults that threw large boulders on the ships, some time using mirrors to concentrate sunlight to burn the ships. It appeared as if the Roman army was fighting against the mechanical inventions of a single man. But finally the siege of Syracuse in 212 BC succeeded in breaching the wall.

Claudius Ptolemy of Alexandria (90-168 AD)

Archimedes was killed by a Roman soldier while he was solving a geometrical problem.

Aristarchus of Samos (310-230 BC) was one of the greatest observational astronomers. He measured the distances to the sun and the moon, and estimated their diameters, and was the first to show that the moon is much smaller than the Earth, and the sun is much bigger. His observation that the sun is much bigger than the Earth made him doubt the prevalent belief that the sun revolved round the Earth, and he imagined a sun-centric picture of the solar system. But nobody at that time supported this idea.

About a century later **Hipparchus** of Nicaea (190-120 BC) further enriched this line of observational astronomy using the method of trigonometry. He is considered the founder of trigonometry, who compiled the first sine-table. He invented the astrolabe, an instrument used for measuring the position of celestial bodies. With its help, he compiled the first comprehensive star catalog, containing a record of 1008 stars. But he is most famous for his discovery of precession of the equinoxes in 127 BC. He measured the diameters of the moon and the sun to a greater accuracy than achieved by Aristarchus, through the use of trigonometry. Through his observations, he almost arrived at a heliocentric picture of the solar system, but abandoned it because his calculations showed that, if the sun were at the centre, the orbits of the planets would not be perfect circles, as was believed at that time due to the influence of Pythagoras and Aristotle.

We thus see that through the Greek period various philosophers and astronomers contributed to the conception about the nature of the universe, which reached its pinnacle through the publication of *Almagest* by **Claudius Ptolemy** (90-168 AD) of Alexandria. Ptolemy adopted the Aristotelian conception of an Earth-centric universe, but attempted to explain the detailed observations of Aristarchus and Hipparchus regarding the complex motion of the planets. In his conception, the Earth is at the centre of the universe, and the moon and the sun revolve around it. Beyond that revolve the planets, but not in circles. Their motions are on circles whose centres themselves move in circles around the Earth. The orbits of the planets, called epicycles, are thus given by circles moving over circles. At the far end of the solar system there is the dark canopy of the “sky” containing the fixed stars.

Conclusion

The Greek period spanning about 700 years from the time of Thales until the time of Ptolemy, defined the agenda of science—the basic questions to be probed. But the method of science was not developed at that time. As a result we see great thinkers engaging in speculation regarding the possible answers to these questions. Even though the method was speculative, in the initial Ionian phase the questions and their answers were by nature materialistic. But

The famous fresco "School of Athens" by the renaissance painter Raphael, at the Vatican museums. Plato and Aristotle are shown as the central figures, Plato pointing to the heavens, and Aristotle pointing to the earth. Pythagoras in shown seated, to the left. Euclid is to the right of the picture, bending down to draw a geometrical figure on a slate. Claudius Ptolemy is standing behind him, holding the sphere of the Earth.

during the Athenian phase, the division in the society was more entrenched, the separation between the doer and the thinker more complete, and the thinkers had very little link with the material world. In this situation, even though the groundwork of logical reasoning was laid, the foundation of idealism was also laid—which retarded the advancement of science for many centuries. In the last phase we saw the beginnings of proper scientific pursuit through elaborate astronomical observations and advancement of mechanics, but for the most part these pursuits could not break away from the belief systems created in the Athenian period.

In the next phase we see the ascent of the Roman empire, the transition of the society from slavery to feudalism, and the dual rule of the king and the church over the population of Europe. That required a belief system, and for that they turned to Plato, Aristotle and Ptolemy. Thus the ideas of Aristotle became, in the hands of the Church, the mainstay of the Christian worldview. We shall come to that chapter of world history in the next part of this essay. □

(To continue in the next issue.)

Organizational News

Campaign against the 2012 doomsday rumours

For the past 4 years there has been a consistent propaganda in the print and electronic media trying to make people believe that the world was coming to an end on 21st December 2012 as per the prophesy of the ancient Maya people of South America. As a result, an atmosphere of fear and frenzy was created in many places, particularly among the school students. The *Breakthrough Science Society* took up the campaign against this ill-motivated unscientific propaganda. Booklets were published in English, Bengali, Kannada, and other state languages, and numerous slide-shows and seminars were organized in schools, colleges and localities across the country. In the final month before the stipulated day, the campaign accelerated through the production of a video CD (in Bengali) containing the opinion of eminent scientists and social workers. In most states Press Conferences were held and press releases were given. For the week before the 21st of December, the campaign was taken to public places and the CD was shown publicly. The campaign met with success, as most people earlier affected by the fear psychosis, remained calm and went about their usual business on that day.

Tamil Nadu

Madam Curie Memorial Day: As part of the observance of Madam Curie Memorial Day (July 4), a documentary on her life was shown to the children at the SOS Children's Village, Tambaram, Chennai on July 8, 2012. Before screening the movie, the Village Director, Mr. Nambi Varatharajan gave a brief introduction and Mrs. Malini Sudhakar spoke to the children about the difficult struggles that Marie had to undergo in her life.

Dr. Venkatesan from BSS Tamilnadu was invited by the Associationof Geography Teachers of Tamilnadu to give a guest lecture at their Annual Association Meeting on 30th July 2012. He talked on 'Science of Atmosphere, Weather and Monsoon' and in the evening session, construction of a "One-Rupee Weather Station" for school children using house hold throw-away materials was demonstrated.

A talk on "The Quest for Fundamental Particles and the Higgs Boson" was organized at CLRI, Chennai on 2-8-2012. Dr. Soumitro Banerjee was the speaker. Dr.Soumitro Banerjee also gave a popular science talk on "Isaac Newton and 325 Years of Principia Mathematica" at Bala Vidya Mandir Senior Secondary School, Chennai on 13-9-2012.

Uttar Pradesh

The *Breakthrough Science Society* Allahabad Chapter organized a seminar on "Higgs-boson or God-particle?". The speaker was Prof. Soumitro Banerjee, General Secretary, BSS. The program was presided by Prof. M. C. Sharma, Head of the Physics Department. The 500-strong audience included students and professors of the Allahabad University, four degree col-

A portion of the audience at the seminar on Higgs boson at Allahabad University.

leges and five inter-colleges.

On 10th of October 2012, two schools of the Gonda and Bahraich districts organised discussions on the need for a new science movement. The discussions were conducted by State BSS organisers Shailesh Rao and Jai Prakash Maurya.

Haryana

Tauru, Haryana: On 19-8-12, a science program was held in the Chandrawati B.Ed. College, Tauru, Haryana, in which science experiments, anti-superstition shows, and a science film were shown. The programme was conducted by Chanchal Ghosh, a BSS organizer. On 20-10-2012, a science quiz competition was held in the Hind High School Tauru. Five teams with 3 students each participated in this programme.

Bihar

Darbhanga: A programme was organized to commemorate the legendary scientist Acharya Prafulla Chandra Ray on 10 October 2012. The National Chemistry Day was observed on 10th December. A quiz contest was organized on 22 December on the occasion of the birth anniversary of Srinivasa Ramanujan. The Vice Chancellor of the L.N.M.U was the Chief Guest on the occasion.

Andhra Pradesh

The Hyderabad district unit of BSS organized a seminar on "Higgs boson particle" at the Nizam College, Osmania University, on 7th September 2012. Dr. Soumitro Banerjee of BSS was the main speaker. Prof. Naidu Ashok (Principal), Prof. P. V. Rao (HOD, Chemistry), Dr. Parimal Mishra (Scientist), and Mr. R. Gangadhara (In-Charge, BSS Andhra Pradesh) were present.

The Hyderabad district unit of the BSS organized a study class and miracle exposure programme on 22nd September 2012. It was conducted by Mr. Gangadhar, Mr. Murahari, and Mr. Praful. Another miracle exposure programme was organized on 8 November at Khairatabad (Hyderabad) by Mr. Praful.

On October 10th a seminar was organized

A portion of the audience in the seminar on Higgs boson at the Nizam College, Hyderabad.

by the Hindupur BSS chapter at LRG Junior College. Mr. Gangadhar was the main speaker.

The Hyderabad BSS chapter organized an awareness programme in Himayath Nagar(Hyderabad) Girls' Orphan Hostel, and established a science library at the Uppal (Hyderabad) Boys' Orphan Hostel.

Karnataka

The Bangalore district conference of *Breakthrough Science Society* was organised on 1-12-2012, at the Raman Research Institute. Around 75 delegates participated in the conference, which included software professionals, research students, engineering students, lecturers, teachers, post graduate students, degree students and school students. Prof. Soumitro Banerjee, was the chief guest. Mr. G. Satish Kumar the state Convenor of the organisation gave the inaugural talk on 'Crisis in science'. Two resolutions—one demanding promotion of science programmes in both visual and print media, and the other on scientific disposal of garbage in the city were unanimously passed. A new district committee was elected with Rajani. K.S. as the President, Mr. Niranjana Murthy as the Secretary, Mr. Shivkumar and Mr. Manoj as Vice-presidents, Mr. Chandresh and Dipti as Joint Secretaries, Amruth.K.K, Rajitha, Moksha, Prathibha, Kiran, and Nandeesh as executive committee members along with a 15 member council. Prof. Mahadevan (IISc), Prof. Vidyanand Nanjundaiah (IISc), Prof. Bala Iyer (RRI), and Mr. Nagesh Hegde (Popular Science Writer) sent messages wishing the conference and science movement a success.

Other programmes from Karnataka include an origami workshop, regular study classes and many school and college level programmes during the preparation for the conference.

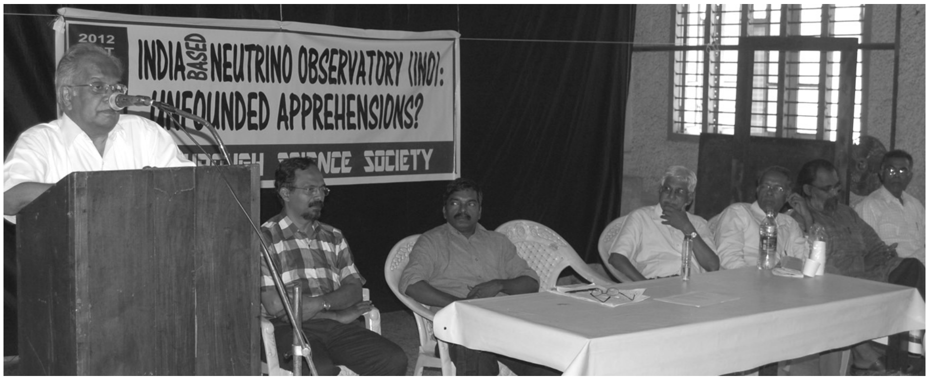
Madhya Pradesh

There were two discussion sessions on the discovery of Higgs Boson—one on 24 October at Guna, and the other on 25 October at Gwalior. Both were addressed by Prof. Soumitro Banerjee.

Winter science camp in Guna:

The BSS Guna Chapter organized a two-day science camp at the Divyansh college Guna on 25th and 26th December. Around 200 students from various schools and colleges participated. On the first day, senior BSS activist Mr. Panchanan Hiramath from Banglore conducted the miracle bust-

An event during the winter science camp at Guna, MP.



Prof. Babu Joseph speaking at the seminar on the India-based Neutrino Observatory, at Ernakulum, Kerala.

ing session. On the second day a session on learning science through experiments was conducted by Mr. Chandresh, a senior BSS activist also from Bangalore. A discussion on the method of science in one session and in the another session a discussion on the science and scientific outlook was conducted by Mr. Sunil Gopal from Gwalior BSS chapter.

Kerala

ERNAKULAM DISTRICT CHAPTER

July 4: Organised a talk by Prof. Gopalakrishna Panickar at Thrippunithura on the "Life and work of Issac Newton" to commemorate the 325th year of publication of Principia Mathematica.

August 11: Shri K.S. Harikumar of Breakthrough Science Society conducted a talk at 'CHILD', Thrippunithura to commemorate Hiroshima Day. Shri C Jayaraman and Shri P.P. Sajeevkumar spoke.

October 13: Arranged a panel discussion by eminent personalities at K. G. Bose Bhavan, Ernakulam on the "India based Neutrino Observatory" to be set up in the western ghats in the Theni district of Thamilnadu. Dr. K. Babu Joseph, Dr. Moncy V. John, Shri C. Ramachandran (Retd. scientist ISRO), Shri G S Padmakumar (state coordinator, BSS), Prof. Gopalakrishna Panickar, Dr. Shibu S. and Prof. P.N. Thankachan spoke. The programme was the first of its kind in the state and sparked off a series of discussions in many other forums.

November 10: Organised a discussion and documentary on the 'Life and work of Madom Curie' at 'CHILD' Thrippunithura. Shri C. Jayaraman and Smt. K. K. Sobha led the discussion.

December 8: Arranged a talk and power point presentation by Dr. Abey George (Tata Institute of Social Sciences, Mumbai) on Koodamkulam Nuclear Power Project in the light of the painful experiences of the three mile Island, Chernobyl and Fukushima experiences. Shri Francis Kalathumkal and P. P. Sajeevkumar spoke.

KOTTAYAM ASTRONOMY CLUB

September 08: Conducted a Class on "Learning Mathematics through Experiments" at Jawahar Balbhavan, Kottayam. Prof. O.S. Sebastian took the class.

October 13 : Organized a talk by Prof. Jain P George at Jawahar Balbhavan, Kottayam, to commemorate the 125th birth anniversary of Sreenivasa Ramanujan.

November 10: Mathematical Model Making at Jawahar Balbhavan, Kottayam. Sri. Jyothi took the classes.

West Bengal

All Bengal Science Conference: The state-level conference of the *Breakthrough Science Society* was organized on 10-11 November 2012 at the Kanthi town in East Midnapur District. This place is close to Haripur—the proposed site for a nuclear power plant—which had to be shelved temporarily in the face of people's opposition. The town is also close to Junput, the proposed site for a missile launch facility of the army—which also has faced stiff opposition from the people.

On 10th afternoon, the participants of the conference staged a march through the town in protest against the two projects, and reached the venue of the open session, the Kanthi Town Hall. The open session was presided by Prof. Dhrubajyoti Mukhopadhyay, the President of BSS. In that session, the agricultural scientist Dr. Safique Ul Alam discussed the problems of GM crops, the former Director of the Bose Institute Prof. Meher Engineer discussed the problems of nuclear power generation, the Vice Chancellor of the Bengal Engineering and Science University Prof. Ajay Ray discussed the need for science in the service of the common people, and the General Secretary of BSS Dr. Soumitro Banerjee discussed the need for a new science movement.

The conference felicitated three people: Mr. Saranan Panda, a school teacher from the remote area of Sabang who took lead in propagating a scientific bent of mind among the people and has reflected a true scientific spirit in his own life, Dr. K. C. Saha, who first brought the problem of arsenic contamination in West Bengal to the notice of the people, and Prof. Palash Baran Pal, who has taken a leading role in popular science writing in the medium of Bengali.

The next day in the delegate session was conducted by a Presidium composed of Mr. Debasis Ray, Dr. Mridul Das, and Dr. Soumitro Banerjee. Four resolutions were placed, discussed and accepted: on the danger of arsenic and fluoride pollution, on the belief in witches and reported killings of tribal women, on the propagation of unscientific beliefs like astrology and fengshui by the media, and on the proposed nuclear power plant and missile launch facility.

The conference elected a new state committee and pladged to intensify the struggle to build a sceince movement in the state. The newly elected State Committee is as follows. President: Prof. D. Mukhopadhyay, Working President: Prof. Pradip K. Ray, Vice Presidents: Dr. Ashoke Prasun Chatterjee, Dr. Katick Ghanta, Dr. Safique Ul Alam, Dr. Damodar Maity, Mr. Subrata Gouri, Mr. Tamal Nanda, Mr. Asta Daskhan, Mr. Gopal Sahu, Dr. Bijoy Dolui, Mr. Chanchal Ghosh. Secretary: Dr. Nilesh Maity, Assistant Secretaries: Dr. Tapan Si and Dr. Radhakanta Konar, Treasurer: Mr. Dinesh Mohanta, Office Secretary: Mr. Ashish Samanta, Secretariat: Dr. Debabrata Bera, Mr. Chandan Santra, Ms. Namita Pal, Mr. Dilip Das, Mr. Kumaresh De, Mr. Anup Manna, Mr. Ramkumar Mandal, Mr. Apurba Senapati, Mr. Anirban Akhand.

Other programmes:

September 2: A seminar was organized at Durgapur on the “Discovery of Higgs Boson” jointly by the Acharya P.C. Ray Science Society, Durgapur, and the The Institution of Engineers (India), Durgapur Local Centre.

October 10: The first “Acharya P. C. Ray Memorial Lecture” was organized at the Bengal Engineering & Science University. Prof. Ashok Mallik, former Professor of IIT Kanpur spoke on “From Natural Numbers to Numbers and Curves in Nature”, and Prof. Pradipta Banerjee, Dean of the Indian Statistical Institute spoke on the life and work of Ramanujan.