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Science INDIA

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What's Inside

COVER STORY

Cover Image Courtesy: Reuters/ Hannibal Hanschke

WHO's South-East Asia Regional Office Inaugurated in New Delhi

The newly constructed World Health Organization (WHO) South-East Asia Regional Office in New Delhi was inaugurated on 19 December by Prime Minister Narendra Modi and WHO Director-General Dr Tedros Adhanom Ghebreyesus, who described the facility as "more than a workplace".

The virtual inauguration coincided with the closing session of the Second WHO Global Summit on Traditional Medicine at Bharat Mandapam, and the new building was constructed with generous support from the Government of India.

Thanking India for hosting the Regional Office and financing the project, Dr Tedros said, "This building is more than a workplace. It is a symbol of shared purpose and cooperation and a platform from which we will continue striving toward WHO's founding goal: the highest attainable standard of health for all."

The new facility comprises three interconnected towers with modern and sustainable features, built on the same Indraprastha Estate land where the original 'WHO House' stood for over five decades.

Designed to meet green building standards, the office incorporates solar energy, rainwater harvesting, water treatment and reuse, indoor and outdoor gardens, and reduced heat gain through its facade. It also features extensive meeting and conference infrastructure, including a large auditorium.

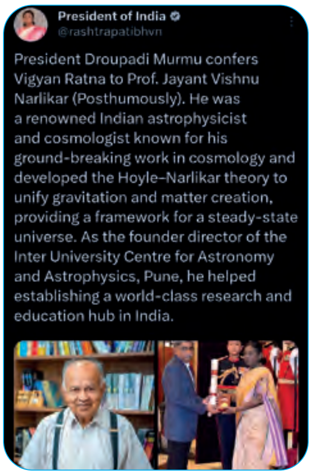
Artworks and artefacts from the old building, gifted by Member States, have been preserved, including the MF Husain mural titled 'The History of Medicine', now installed in the reception hall of the new office with the help of the Indian National Trust for Art and Cultural Heritage (INTACH).

Built at a cost of USD 35 million, the new WHO South-East Asia Regional Office has a total built-up area of over 40,500 square metres, significantly larger than the 10,500 square metres of the old WHO House, reflecting the WHO's expanding role and capabilities in the region.

Prof Shekhar Mande becomes INSA head

Prof Shekhar C Mande, former Director General, CSIR and currently president, Vijnana Bharati, took charge of President of the India National Science Academy (INSA) on 1 January 2026.

A Structural and Computational Biologist, his tenure will be for three years.


President of India
@rashtrapatibhvn

President Droupadi Murmu confers Vigyan Ratna to Prof. Jayant Vishnu Narlikar (Posthumously). He was a renowned Indian astrophysicist and cosmologist known for his ground-breaking work in cosmology and developed the Hoyle–Narlikar theory to unify gravitation and matter creation, providing a framework for a steady-state universe. As the founder director of the Inter University Centre for Astronomy and Astrophysics, Pune, he helped establishing a world-class research and education hub in India.

WRITE FOR SCIENCE INDIA

Do you love science? And do you also love writing about it? If your answer to both the questions is 'yes', *Science India* would like to invite you to write for the magazine.

There are a few points we would like you to take care of before embarking on this journey.

Whether you are an established writer or not, please don't send us unsolicited articles as we get tonnes of mail and it becomes difficult to respond to all. If you have a particular topic in mind on which you would like to write, send us a brief with the subject line: Brief for a Proposed Story.

The brief should describe what you want to write on, in about 100-150 words. It is your proposed story in a capsule, in a manner that should get us excited. We will respond only if your proposal is approved, and then share detailed guidelines.

At the same time, we would also like to remind our prospective writers that the bottom line of *Science India* is Indian science, Indian scientists and Indianness.

We are a general readership magazine on S&T and we don't publish scientific research papers. Do look up the previous issues of the magazine on our website to get an idea of the kind of stories we carry. It will help you plan your proposal better.

Best of luck. Mail us at editor@scienceindia.in

Send your letters to editor@scienceindia.in

We request writers and contributors not to send any AI-generated articles, graphs, diagrams and images to us for publication. Those will be summarily rejected without any intimation. The onus will be on the sender.

Let's Connect

Dear Readers,

As we begin another new year of the Gregorian calendar, Team *Science India* would like to extend the season's greetings to its esteemed readers, who faithfully stand by the magazine by appreciating the efforts we put in to create it month after month. Without your encouragement, we wouldn't have been able to aspire for greater heights with each passing year. We also take a moment to express gratitude to all our contributors who make *Science India* such a rich reading experience.

As the year 2025 drew to a close, a seminal science related bill was passed by the Parliament in December, and it swiftly received Presidential assent as well. Today, we know it as the SHANTI Act, whose importance for India's energy security cannot be overemphasised. It's the acronym for Sustainable Harnessing and Advancement of Nuclear Energy for Transforming India, and it marks a landmark as it opens up the strategic nuclear sector for private participation. That is going to be a gamechanger in the way India will henceforth harness nuclear energy for civil use as a story on the topic in this edition reveals.

The recently formulated SHANTI Act will prove to be a gamechanger in the way India will henceforth harness nuclear energy for civil use

Like all winters, the tail months of 2025 too saw the topic of pollution becoming centre stage as Delhi-NCR again grappled with alarming AQI levels, which pushed the debate on health risks and mitigation efforts required to the forefront. Our news story this month uncovers in depth the real causes and possible solutions to the annual problem of pollution and related smog which refuse to go away. This edition's cover story, in the meanwhile, takes a look at the problem of pollution globally and brings focus on Black Carbon, which is being labelled as the Super Pollutant because of the silent yet catastrophic damage that it is causing all around. The image on the cover of this edition, of an iceberg off Greenland darkened due to soot, should shock us enough to at least understand what this is all about.

The month of December also saw the successful hosting of the mega 11th edition of India International Science Festival, held in Panchkula. We bring you reports on the festival from the ground and also give its vibrant roundup through pictures that showcase why this festival is so popular among common science enthusiasts and experts alike.

As the space sector remains one of the most popular science subjects among students and general public alike, we take a look at the various CSIR laboratories that play a vital role in India's space odyssey, making vital contributions to ISRO's efforts.

The science luminaries that we bring to the spotlight in this edition are Prof Satyendra Nath Bose and Dr Debala Mitra. Prof Bose, who needs no introduction, remains a tragic case of a genius not winning a highly-deserving Nobel Prize; one half of the sub-atomic particles in our three dimensional world are named after him, which we know as bosons, with the other half being fermions. We remember him on his birth anniversary that falls on 1 January. Dr Debala Mitra, on the other hand, was the Archaeological Survey of India's first woman director general, whose birth centenary was observed last month.

This edition, as always, carries a full bouquet of stories with a mix from different topics, including our regular columns. As our readers continue to enjoy the winter season, we hope they will be able to do so with this wholesome edition in their hands.

Here's wishing all a fruitful and meaningful year ahead with a prayer for India to take giant leaps in its scientific journey!

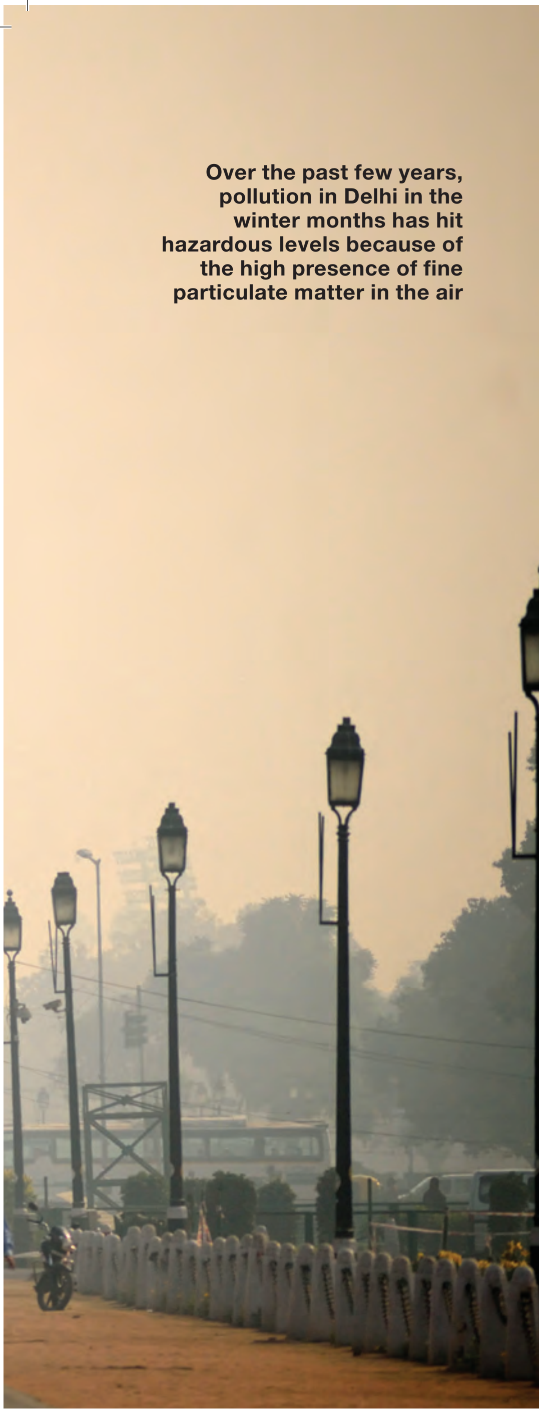
Image Courtesy: Shutterstock

Poison in the Air

Unravelling Delhi's pollution induced health crisis that emanates from a complex cocktail of pollutants of various origins, urban infrastructure deficits, and unfavourable geography

■ Prof P K Joshi

For many living in or regularly visiting Delhi—one of the world's largest urban agglomerations—breathing is no longer a passive act. The city's air has become a toxic mixture of microscopic, suspended particles, reactive gases, and chemical compounds that together constitute one of the world's most severe urban pollution crises. Every winter (and now almost year-round), the dense haze that blankets the capital isn't just smog—it's a complex cocktail of pollutants that harms lungs, hearts, brains, and entire ecosystems. What was once an episodic haze has evolved into a chronic atmospheric emergency,



Over the past few years, pollution in Delhi in the winter months has hit hazardous levels because of the high presence of fine particulate matter in the air

one that silently but relentlessly erodes public health, shortens life expectancy, and burdens future generations with irreversible biological damage.

In late 2025, Delhi's air quality has regularly crossed the 'very poor' to 'severe' category on the Air Quality Index (AQI = 301-400 to 401-500)—meaning pollution levels were not only unhealthy but acutely hazardous for all residents. Often, spikes reached values far above safe thresholds, prompting the government to exercise Stage IV of Graded Response Action Plan (GRAP), which means restrictions on traffic, construction activities, and school hours. This choking pollution that is engulfing Delhi and the National Capital Region (NCR) is not merely an environmental inconvenience or a seasonal nuisance; it is a complex physicochemical phenomenon driven by anthropogenic emissions, geographical constraints, and meteorological conditions that together create one of the most toxic urban airsheds on Earth impacting human health.

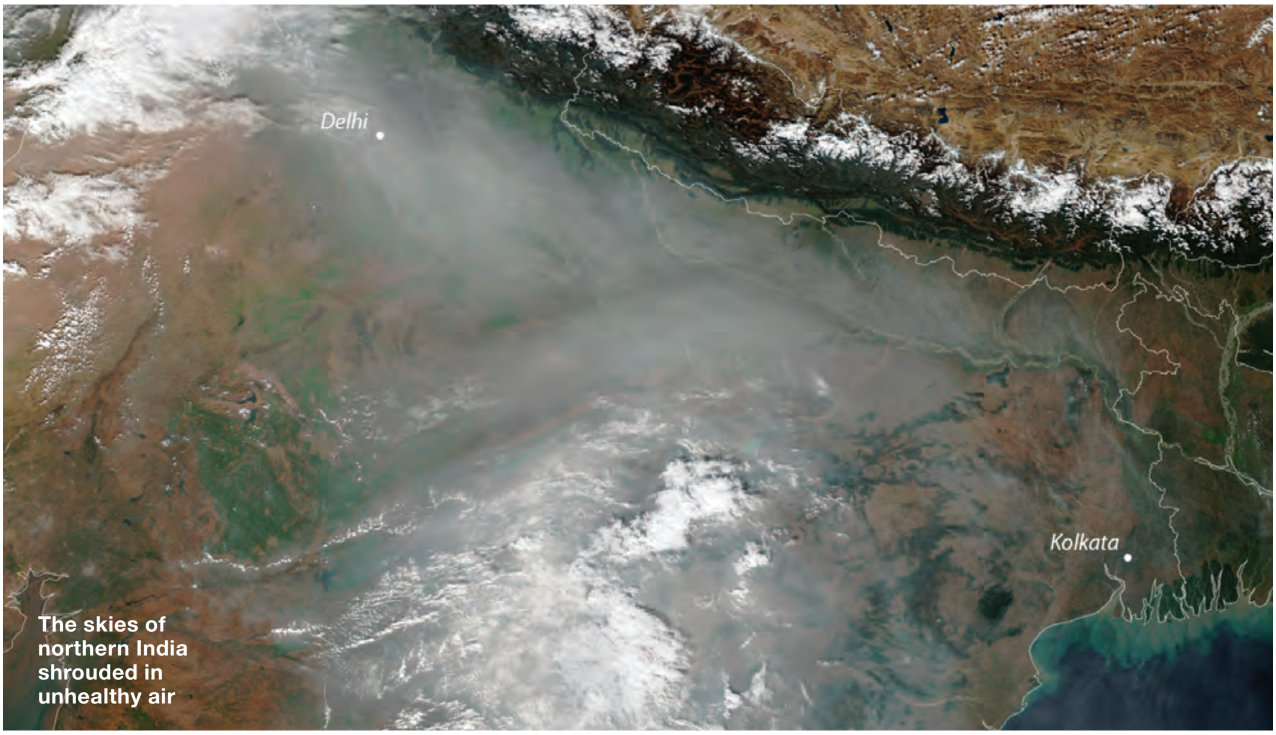
WHAT IS $PM_{2.5}$?

At the centre of this crisis lies particulate matter (PM), particularly fine particles with aerodynamic diameters less than 2.5 µm, known as $PM_{2.5}$. These particles are approximately thirty times smaller than the width of a human hair, and unlike larger particles that are filtered by nose or upper airways, $PM_{2.5}$ penetrates deep into the alveolar regions of the lungs, where gas exchange occurs. From there, these particles can cross the alveolar–capillary barrier into epithelial tissues and enter systemic circulation affecting acute and chronic cardiovascular and pulmonary outcomes and virtually every organ system.

The chemical composition of $PM_{2.5}$ in Delhi is especially dangerous. These particles are not inert dust; they are often coated with heavy metals such as lead (Pb), nickel (Ni), chromium (Cr), and cadmium (Cd), as well as polycyclic aromatic hydrocarbons (PAH), sulphates (SO_4^{2-}), nitrates (NO_3^-), ammonium compounds, and black carbon. Each of these components has its own toxicological profile, but together they create a synergistic assault on human physiology. Fine particles entering the bloodstream can alter endothelial function, promote thrombosis, and destabilise atherosclerotic plaques, thereby increasing the risk of heart attacks and strokes. Chronic exposure to such particulate pollution has been strongly linked to chronic obstructive pulmonary disease, lung cancer, stroke, metabolic disorders, and adverse pregnancy outcomes. Epidemiological studies consistently show that for every incremental increase of 10 mgm/cum in annual $PM_{2.5}$ concentration, the risk of all-cause mortality rises significantly, with cardiovascular deaths accounting for the largest share. Longitudinal studies estimate that residents of Delhi may lose between six to eight years of life expectancy solely due to prolonged exposure to such polluted air. This loss is not

Extremely poor visibility in Delhi in December 2019 due to air pollution

Image Courtesy: Wikimedia Commons



The skies of northern India shrouded in unhealthy air

Image Courtesy: Wikimedia Commons

evenly distributed; children, the elderly, and those with pre-existing respiratory or cardiovascular conditions bear a disproportionate burden of disease.

CHOKING VEHICULAR EXHAUST

Vehicular emissions represent one of the most persistent and technically complex contributors to air pollution. The city hosts around 150 million vehicles, many of which operate under conditions of chronic congestion, low average speeds, frequent idling, and stop-and-go traffic patterns that are known to exacerbate emission rates. Particularly diesel engines emit a mixture of sulphur oxide (SOx), nitrogen oxides (NOx), carbon monoxide (CO), volatile organic compounds (VOCs), and fine PM. These particles are especially toxic due to their high black carbon content and surface-adsorbed organic compounds, many of which are mutagenic and carcinogenic.

Beyond tailpipe emissions, vehicular activity also contributes to non-exhaust particulate pollution. Brake wear, tire abrasion, and road surface erosion generate substantial amounts of both $PM_{2.5}$ and PM_{10}. These mechanically generated particles often contain metals such as copper (Cu), zinc (Zn), and iron (Fe), which can catalyse oxidative reactions within lung tissue. In high density traffic locations, non-exhaust emissions now constitute a growing fraction of total PM pollution, undermining gains made through cleaner fuel standards alone.

Industrial emissions, both within Delhi and in surrounding regions, further compound the problem. Biomass, biofuel and coal-based power plants, brick kilns, small-scale manufacturing units, and industrial boilers emit a combination of these pollutants. SOx is a potent respiratory irritant that contributes to bronchoconstriction and aggravates asthma. In the atmosphere, it undergoes oxidation to form sulphate aerosols, which are a major component of $PM_{2.5}$. NOx, a key component of vehicular exhaust, is itself a respiratory irritant that damages airway epithelium and increases susceptibility to infections, while also acting as a precursor to secondary particulate formation and ground-level ozone (O_3).

OTHER TOXINS EXPLAINED

CO, another by-product of incomplete combustion, binds to haemoglobin in red blood cells forming carboxyhaemoglobin (COHb) with an affinity far greater than oxygen. Although acute CO poisoning is rare in open environments, chronic low-level exposure increases cardiovascular stress, particularly in individuals with ischemic heart disease. VOCs emitted from fuel evaporation and exhaust systems further complicate by participating in photochemical reactions that generate secondary pollutants such as oxygenated VOCs (formic acid, formaldehyde, acetone, ethanol, etc.), O_3 and secondary organic aerosols (SOA). Benzene, ethylbenzene, toluene, xylene, collectively known as BTEX, a set of well-documented human carcinogens commonly detected in urban air, is of particular concern due to their association with leukaemia and bone marrow suppression. Though some of the common impacts include respiratory (lung tissue damage, decreased lung function, inflammation, and asthma), cardiovascular (arrhythmias, heart failure, and myocardial infarction), digestive, urinary, hematologic, hematopoietic, hepatic and genetic toxicity, immune dysfunction, reproductive effects, and nervous systems (alterations in brain structure, neurotransmitter levels, cognitive function, anxiety, impulsivity, and depression).

Dust represents another major but often misunderstood component of Delhi's pollution. The city's rapid urban expansion, continuous construction activity, unpaved or poorly maintained roads and road construction mechanism, and sparse green and blue cover create ideal conditions for dust generation and re-suspension. Importantly, these dust particles are rarely pure soil; they are frequently coated with vehicular exhaust residues, industrial emissions, and biological material, effectively transforming them into toxic carriers rather than benign mineral particles. Construction dust is particularly problematic because it is generated continuously and often in close proximity to residential areas. The mechanical crushing of concrete, bricks, and stone releases silica-rich particles, which when inhaled over long periods can contribute to silicosis and chronic lung inflammation. Workers exposed occupationally face high risks, but ambient populations are also affected due to widespread dispersion. Road dust re-suspension by moving vehicles further amplifies exposure, creating a feedback loop in which traffic generates as well as redistributes particulate pollution.

STUBBLE BURNING AND METEOROLOGY

Seasonal agricultural residue burning in neighbouring states adds another dimension to Delhi's pollution burden. During the post-monsoon months, large-scale burning of rice stubble releases enormous quantities of smoke containing $PM_{2.5}$, CO, NOx, and organic aerosols. While the contribution of stubble burning to Delhi's annual pollution load is lower than that of local sources, its impact during specific weeks can be dramatic, triggering acute pollution episodes that push air quality into the 'severe' category. The health implications of such short-term spikes are significant.

Meteorology plays a critical role in transforming emissions into a public health crisis. Delhi's geographical location in the Indo-Gangetic Plain, combined with its distance from the coast, limits natural ventilation. During winter, temperature inversion layers frequently form, trapping cold, dense air near the ground beneath the warmer air aloft. This inversion effectively seals pollutants within the breathing zone, preventing vertical dispersion. Low wind speeds and high humidity further enhance pollutant accumulation and promote secondary aerosol formation. As a result, even moderate emission rates can lead to extreme pollution concentrations under unfavourable meteorological conditions.

THE TRUE SCALE OF HEALTH CRISIS

The health consequences of this polluted atmosphere extend far beyond coughing and eye irritation which is generally reported by adults. At the cellular level, inhaled pollutants generate reactive oxygen species that overwhelm the body's antioxidant defences, leading to oxidative stress and inflammation. Children represent one of the most vulnerable populations in this pollution landscape. Their lungs are still developing, they breathe more air per unit body weight than adults, and they often spend more time outdoors.

Delhi's geographical location, combined with its distance from the coast, limits natural ventilation

Exposure during critical developmental windows can permanently impair lung growth, reducing maximal lung function in adulthood and increasing susceptibility to chronic respiratory disease. Evidence also suggests associations between prenatal pollution exposure and low birth weight, preterm birth, and impaired immune development. Neurological studies increasingly suggest links between air pollution exposure and cognitive decline, dementia, and adverse neurodevelopmental outcomes in children.

The mortality burden attributable to air pollution in Delhi is staggering. A significant fraction of all deaths in the city each year can be linked to long-term exposure to fine $PM_{2.5}$. These deaths are not immediately visible as pollution-related fatalities; they manifest as heart attacks, strokes, lung cancer, and respiratory infections, masking the true scale of the crisis. This invisibility makes polluted air a particularly insidious killer, as its victims often succumb years after exposure, far removed from the smog-filled days that initiated the disease process. Though the government has no conclusive data establishing a direct correlation between higher AQI levels and health disorders, it acknowledges that air pollution is one of the triggering factors for respiratory ailments and associated diseases. Accordingly, comprehensive and targeted training modules on air pollution have been institutionalised, empowering programme managers, medical officers, nurses, nodal officers, sentinel sites, frontline workers such as ASHAs, as well as vulnerable populations—including women and children—and occupationally exposed groups such as traffic police and municipal workers.

AN INEXCUSABLE LAPSE

The choking pollution of Delhi is the result of a convergence of high emission intensity, toxic pollutant composition, unfavourable geography, and climatic conditions that together create an environment hostile to human health. It is driven by vehicles, dust, industrial activity, biomass burning, and urban infrastructure deficits, but sustained by atmospheric chemistry and meteorology. Scientifically, there is little ambiguity about the danger it poses, and evidence linking air pollution to disease, disability, and premature death seems irresistible. Addressing this crisis requires not only technological interventions and regulatory enforcement but a recognition that clean air is fundamental to public health, economic productivity, and human dignity. Without decisive, sustained action, the city risks normalising an atmosphere that quietly steals years of life from its people, one breath at a time. In an age defined by information and artificial intelligence, the failure to safeguard and manage a city's environmental assets stands as one of humanity's gravest moral and civic failures—it is inexcusable!

**The writer is Professor with the School of Environmental Sciences, Jawaharlal Nehru University (JNU), New Delhi. The comments here are personal.*

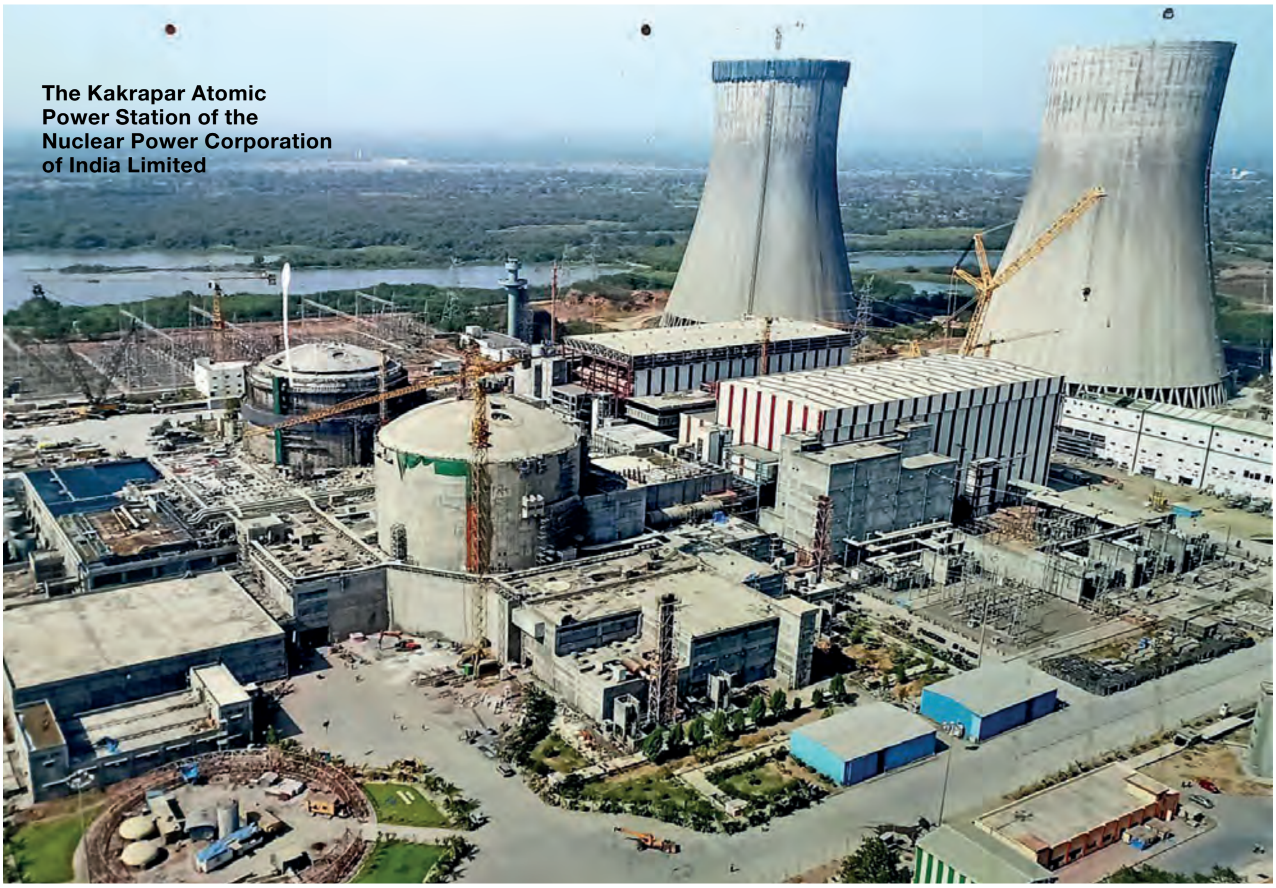

The Kakrapar Atomic Power Station of the Nuclear Power Corporation of India Limited

Image Courtesy: Nuclear Power Corporation of India Limited

■ Prof Punit Kumar

SHANTI Act 2025
Nuclear Science at the Core of India's Green-Energy Transition

The Act, which received Presidential assent on 20 December 2025, replaces previous laws on the subject, and opens up the nuclear sector for private participation

India stands at a defining moment in its energy journey. Rapid economic growth, expanding digital infrastructure, urbanisation, and rising aspirations have led to an unprecedented surge in electricity demand. At the same time, climate change, environmental degradation, and geopolitical uncertainties linked to fossil fuels have made the existing energy paradigm increasingly unsustainable. It is within this complex scientific, environmental, and policy landscape that the SHANTI Act 2025 (Sustainable Harnessing and Advancement of Nuclear Technology for India) assumes critical importance, it was introduced in the Lok Sabha on 15 December 2025 and passed on 17 December, passed by the Rajya on 18 December, and received the President's assent on 20 December, becoming an act.

The SHANTI Act is not merely a legislative reform, it represents a scientifically informed rethinking of nuclear energy's role in India's green transition. By modernising outdated legal structures, strengthening safety governance, enabling carefully regulated private participation, and aligning nuclear power with climate goals, the Act places nuclear science firmly within India's clean energy strategy. For a country striving to balance development with sustainability, this marks a decisive shift from viewing nuclear power as an isolated technology to recognising it as a systemic solution.

India's electricity demand is projected to more than double over the next two decades. While renewable energy, particularly solar and wind, has expanded rapidly, these sources alone cannot meet the requirements of a stable, resilient power grid. Their inherent intermittency, dependence on weather conditions, and current limitations in large scale energy storage present structural challenges. From a systems engineering perspective, an electricity grid dominated by intermittent sources requires a firm, non-carbon emitting backbone. Nuclear energy, by contrast, offers high energy density, continuous power generation, and near-zero operational carbon emissions. The SHANTI Act recognises this scientific reality. It situates nuclear power not in opposition to renewables, but as their essential complement providing the stability that allows large-scale solar and wind integration without compromising grid reliability.

Image Courtesy: PIB

nuclear power generation to Indian private entities. This reform reflects a growing global consensus that complex technological systems benefit from diversified expertise, capital infusion, and competitive efficiency. Importantly, the Act maintains strict state control over strategically sensitive domains such as uranium enrichment, fuel fabrication, reprocessing, and strategic materials. Private participation is permitted only in non-sensitive areas, under rigorous li-

Above: Dr Jitendra Singh, Minister of State (Independent Charge), Science & Technology, has called SHANTI Act a 'significant policy shift'; Right: A PHWR (pressurized heavy-water reactor) under construction at Kakrapar, Gujarat

Image Courtesy: Wikimedia Commons

REPLACING OLDER ACTS

India's nuclear sector has long been governed by the Atomic Energy Act of 1962 and the Civil Liability for Nuclear Damage Act of 2010, both of which have now been replaced by the SHANTI Act. Both these laws were products of their time. The 1962 Act reflected an era when nuclear technology was strategic, centralised, and limited to state actors. The 2010 liability law emerged from a global environment shaped by nuclear accidents and public concern, emphasising ethical responsibility. However, nuclear science and engineering have evolved dramatically since then. Modern reactors incorporate passive safety systems, advanced materials, real time monitoring, and probabilistic risk assessment tools that significantly reduce accident likelihood and impact. Yet the regulatory ecosystem did not evolve at the same pace, resulting in procedural rigidity, investment uncertainty, and slower capacity growth. The SHANTI Act addresses this mismatch between scientific advancement and legal structure. It acknowledges that contemporary nuclear technology, when governed by transparent and evidence-based regulation, can meet the highest safety standards while contributing meaningfully to climate mitigation.

One of the Act's most important contributions is the consolidation of nuclear governance into a single, coherent legal framework. Fragmented regulations often create ambiguity across the nuclear lifecycle from site approval and construction to operation, waste management, and decommissioning. The SHANTI Act introduces clarity by explicitly defining institutional roles, technical responsibilities, and compliance mechanisms at each stage. For long duration infrastructure projects with high safety margins, such predictability is not merely administrative convenience, it is a scientific necessity. Clear governance reduces systemic risk, improves accountability, and facilitates long term planning grounded in engineering realities.

OPENING UP NUCLEAR SECTOR FOR PRIVATE PARTICIPATION

A transformative element of the SHANTI Act is the conditional opening of censing, inspection, and safety oversight. This hybrid model balances national security with scalability. It allows India to accelerate nuclear deployment without compromising sovereign control, while also fostering innovation, project management efficiency, and financial sustainability.

Safety is the cornerstone of nuclear science. Public trust in nuclear energy depends not on assurances, but on institutions capable of enforcing rigorous, independent oversight. Recognising this, the SHANTI Act enhances the statutory authority and autonomy of the Atomic Energy Regulatory Board (AERB). Under the new framework, the AERB is empowered to conduct legally binding inspections, mandate safety upgrades, enforce emergency preparedness protocols, and operate independently of nuclear operators. Parliamentary accountability mechanisms further strengthen transparency. From a scientific governance perspective, this institutional separation between promotion and regulation aligns India with international best practices. It ensures that safety assessments are driven by data, peer-reviewed standards, and risk analysis rather than administrative or commercial pressures.

PUBLIC INTEREST V/S PROJECT VIABILITY

The question of liability has historically constrained India's nuclear expansion. The SHANTI Act introduces a balanced liability regime that protects public interest while ensuring project viability. Operator liability is clearly defined and capped, mandatory insurance mechanisms are enforced, and government liability applies beyond prescribed limits. Crucially, the Bill removes open-ended supplier liability, bringing India closer to international conventions and facilitating global technology collaboration. This approach does not dilute accountability. Instead, it embeds compensation within a framework informed by actuarial science, probabilistic risk assessment, and international legal norms ensuring both justice for victims and feasibility for operators.

From a lifecycle perspective, nuclear power ranks among the lowest carbon electricity sources. Its greenhouse gas emissions, when measured across construction, operation, and decommissioning, are comparable to wind and significantly lower than coal or gas. The SHANTI Act explicitly recognises nuclear energy as a climate solution. In a grid increasingly dominated by renewables, nuclear power provides frequency stability, inertia, and continuous output, functions that are critical for avoiding fossil fuel backup. By integrating nuclear energy into India's net-zero pathway, the Bill reinforces a science-based approach to decarbonisation.

The SHANTI Act also creates regulatory space for advanced reactors and Small Modular Reactors (SMRs). These next generation systems incorporate passive safety, modular construction, and improved fuel efficiency. SMRs are particularly well suited for remote regions, industrial hubs, desalination plants, and hydrogen production facilities. Their smaller size, lower capital risk, and enhanced safety features make them attractive for diverse applications beyond conventional grid electricity. By enabling these technologies, the Act signals India's intent to remain aligned with global nuclear innovation rather than confined to legacy systems.

Expansion of nuclear energy under the SHANTI framework is expected to generate significant economic benefits. High-skill employment will be created across reactor engineering, materials science, radiation safety, construction, and operations. Domestic manufacturing will receive a boost under the 'Make in India' initiative, particularly in high precision components, control systems, and instrumentation. These capabilities have spillover benefits for other advanced sectors, including aerospace, defense, and medical technology.

A modernised nuclear sector strengthens India's position in international climate and technology forums. Nuclear cooperation enhances scientific diplomacy, enabling collaboration in safety research, fuel cycles, waste management, and advanced reactor design. By aligning nuclear policy with climate commitments, India reinforces its credibility as a responsible technological power contributing to global decarbonisation.

Modern nuclear plants occupy relatively small land footprints and produce negligible air pollution. The SHANTI Act emphasises lifecycle responsibility, including waste management, long term storage, and decommissioning. This approach reflects an important scientific ethic that green energy must be environmentally accountable from inception to closure. Embedding sustainability into regulation, the Bill aligns nuclear science with ecological responsibility.

Despite its promise, the success of the SHANTI Act will depend on effective implementation. Public concerns about radiation, waste, and accidents must be addressed through transparent communication, data driven risk explanation, and institutional trust. Investment in human resources, regulatory science, emergency preparedness, and public scientific literacy will be essential.

**The writer is Professor, Department of Physics, University of Lucknow.*

DR JITENDRA SINGH ON SHANTI ACT

The legislation marks a significant policy shift by opening parts of the nuclear energy sector to private participation for the first time. The Act is intended to modernise India's nuclear framework in line with contemporary technological, economic and energy realities, while retaining and strengthening core safety, security and regulatory safeguards that have been in place since the Atomic Energy Act of 1962. The Bill enables responsible private and joint venture participation to bridge resource constraints, shorten gestation periods and support the national goal of 100 GW nuclear capacity by 2047, without compromising national security or public interest. Nuclear energy has applications beyond power generation, including cancer care, agriculture and industry, and the Act for the first time explicitly recognises environmental and economic damage within the definition of nuclear harm. India's nuclear contribution to the energy mix remains modest compared to global peers, and scaling it up is essential to meet rising demand from sectors such as data processing, healthcare and industry, alongside renewables. The act aims to create an enabling ecosystem for clean, reliable energy as India approaches the centenary of Independence, while upholding the long-standing commitment to peaceful use of atomic energy.

KEY POINTERS

* Target of 100 GW
* Private Sector Participation
* Unified Legal Framework
* Strengthened Regulation
* Focus on Modern Technology

IISF 2025 TAKEAWAYS

IISF 2025 in Panchkula: A National Churning of Ideas

The 11th edition of India International Science Festival underscored that science is not confined to laboratories but actively shaping national policy

■ Science India Bureau

The 11th edition of the India International Science Festival (IISF) 2025 concluded in Panchkula (Haryana) in December 2025 with a resounding message: Science in India is no longer confined to laboratories, but is increasingly shaping national policy, societal transformation and India's civilisational journey towards becoming a developed nation. Held at the Dussehra Ground in Panchkula from 6 to 9 December, IISF 2025 emerged as one of the largest science outreach events in the country, drawing scientists, policymakers, students, innovators, start-ups and citizens from across India and several foreign delegations.

Organised by the Ministry of Earth Sciences in collaboration with other science ministries and departments of the Government of India, and Vijnana Bharati, IISF 2025 was anchored around the theme "Vigyan Se Samruddhi: For Aatmanirbhar Bharat", underlining the government's vision of science-led prosperity and inclusive development.

The festival was inaugurated in the presence of Union Minister of State (Independent Charge) for Science and Technology, Earth Sciences and MoS, PMO, Dr Jitendra Singh, along with Dr M Ravichandran (Secretary, MoES), Prof Ajay Sood (Principal Scientific Adviser to GoI), Dr Shekhar C Mande (President, VIBHA), and NITI Aayog members Dr VK Saraswat and Dr VK Paul.

In his inaugural address, Dr Singh emphasised that IISF was conceived not merely as a scientific conference but as a mass movement to democratise science.

Union Minister of State (Independent Charge) for Science and Technology, Earth Sciences and MoS, PMO, Dr Jitendra Singh inaugurating the 11th IISF at Panchkula in December 2025

Image Courtesy: Vijnana Bharati

"Science must move from institutions to households, from journals to janata," he said, reiterating that IISF rests on three core pillars—Celebration, Communication and Career. He highlighted that India's scientific ecosystem has undergone a fundamental shift in the last decade, marked by indigenous innovation, start-up culture, and policy-driven research aligned with national priorities.

Dr Singh underlined how India's achievements in space technology, biotechnology, deep ocean research, nuclear science and digital public infrastructure reflect the country's growing scientific self-confidence and its commitment to global good.

A HUB OF SCIENTIFIC CHURNING

Over four days, the IISF venue transformed into a vibrant science city, hosting more than 150 thematic sessions, exhibitions, workshops and outreach programmes. The festival witnessed the participation of tens of thousands of students, teachers, researchers and citizens, making it one of the most inclusive science festivals held in India to date.

The event brought together scientists from premier institutions such as ISRO, DRDO, CSIR, IISc, IITs, AIIMS, ICAR and several universities, alongside start-ups, industry leaders and policy experts. Special focus was laid on engaging school and college students through hands-on demonstrations, interactive exhibits and science communication sessions.

Addressing the festival, Haryana Chief Minister Nayab Singh Saini described Students' Science & Technology event as a 'New Nalanda', reflecting India's ancient tradition of knowledge centres adapted to modern scientific needs.

A special session featured Group Captain Shubhanshu Shukla, India's Gaganyaan astronaut-designate, whose presence drew immense interest among students and young science enthusiasts. Shukla spoke about India's human spaceflight ambitions, the rigorous training process undertaken by astronaut candidates, and the larger significance of the Gaganyaan mission in establishing India as a frontline space power.

The event 'Matsya-6000' showcased India's first indigenous crewed deep-sea submersible, developed under the Deep Ocean Mission. The scientists explained how deep-sea research is critical for understanding climate change, marine biodiversity, mineral resources and disaster preparedness.

One of the most widely attended segments at IISF was 'Operation Sindoor: An Untold Story', in which Lt Gen Rajeev K Sahni (DG, EME, Indian Army) highlighted the role of indigenous defence technologies, scientific preparedness and inter-agency coordination in national security operations that led to the success of this operation.

The EXPO as ever was a major attraction for the visitors at IISF.

PHOTO FEATURE

Snapshots
IISF 2025 @ PANCHKULA

The 11th India International Science Festival 2025 (6-9 December) concluded successfully at Panchkula in Haryana. The four-day festival saw enthusiastic participation by people from all age groups, especially the young, and from all walks of life. With a packed melange of workshops, lec-dems, discussions, deliberations, Matsya 6000 of Deep Ocean Mission, Expo and more, peppered with a medley of cultural performances, the festival became an affair to remember. These pictures provide a delightful walkthrough for readers to absorb its grandeur.

Left: Dr Jitendra Singh, Union Minister of State for Science & Technology (independent charge) at the inauguration of IISF 2025

All Images Courtesy: Vijnana Bharati

Right: Dr Jitendra Singh (centre), releasing the brochure of IISF 2025 along with other dignitaries

Clockwise from top left: Prof Anil Sahasrabudhe (left), Chairman NAAC, with Sunil Ambekar, RSS Akhil Bharatiya Prachar Pramukh; Nayab Singh Saini (left), Chief Minister of Haryana, with Dr Shiv Kumar Sharma (right), National Organising Secretary of Vijnana Bharati; Group Captain Shubhanshu Shukla, the first Indian astronaut to visit the International Space Station, speaking at a session; a display at the venue; a model of Matsya 6000, India's first manned submersible vehicle as part of the Samudrayaan Mission

Above: Praveen Ramdas (right), National Joint Organising Secretary of Vijnana Bharati, welcoming the Haryana Chief Minister Nayab Singh Saini at IISF 2025. In the centre is Dr Rajesh S Gokhale, Secretary, Department of Biotechnology

Below: Children attending the Expo

Right: Manohar Lal Khattar (centre), Union Minister of Housing and Urban Affairs, flanked by ISRO Chairman Dr V Narayanan (second from left) and IITM Pune Director Dr Suryachandra A Rao (third from right) along with other dignitaries

Punjabi pop singer Jasbir Jassi (far left) and singer-composer Akriti Kakar (left) helming the cultural performances in the evening. Above: CSIR's tractor-tiller on display

Above: CSIR stall; above right: Lt Gen Rajeev Sahni giving presentation on Operation Sindoor at Media Conclave; above, far right: A model of gamma ray telescope

Clockwise from above, extreme left: Dr Abhay Karandikar, DST Secretary; Dr M Ravichandran, Secretary, Ministry of Earth Sciences; Prof Ajay Sood, Principal Scientific Advisor to GoI; Vivekananda Pai, Secretary General, Vijnana Bharati; Dr S Somanath, former ISRO Chairman; Dr Shekhar Mande, former DG CSIR

BLACK CARBON
The Super Pollutant We Must Be Wary Of

Black carbon, a key component of unwanted byproducts of incomplete combustion, is making our environment darker and dirtier, and more vulnerable than ever before

Image Courtesy: istock

■ Dr Chhavi Pant Pandey

A Atmospheric aerosols are tiny solid or liquid-covered particles suspended in the air. Aerosols (particulate matter) play a very crucial role in the dynamics of the atmosphere. Almost every weather event in the troposphere is mediated by aerosols, either directly or indirectly. Aerosols serve as nuclei for cloud condensation and precipitation, and also control the tropospheric temperature by absorbing or scattering solar radiation.

However, these life-supporting aerosols can become harmful when their natural equilibrium in the environment is disturbed. One such problematic aerosol is Black Carbon (BC). BC refers to carbonaceous, polycyclic organic aerosols found in the atmosphere and is commonly referred to as 'soot'. BC is produced through incomplete combustion and consists primarily of polycyclic carbon structures with high molecular diversity. Although the terms 'soot' and 'BC' are often used interchangeably, soot is a general term. It refers to a complex mixture of particles and gases that are unwanted by-products of incomplete combustion, with BC being one of the key components

The Serbian physicist Tihomir Novakov first used the term 'BC' in the 1970s when he discovered that aerosols contained fine particulate matter.

In contrast to other greenhouse gases present in our environment, BC is complex in nature and it is not a single molecule or gas. The term BC usually indicates a group of chemicals that substantially absorb the solar radiation on earth. BC also includes light-absorbing organic carbon as well as elemental carbon. Although these aerosols have a relatively shorter lifetime in our atmosphere, they significantly impact climate directly as well as indirectly.

BLACK CARBON: CHARACTERISTICS AND SOURCES

BC exhibits significant variability in particle size, structure, and morphology. BC aerosols are often spherical, and their dynamic shape factors suggest that their particle morphology evolves during atmospheric ageing. Typically, BC aerosols have aerodynamic diameters ranging from 200 500 nm, with particles consisting either predominantly of BC or BC internally mixed with aerosol components. However, to understand the optical properties and radiative forcing due to BC aerosols, one need to measure the effective density and mass size distribution of BC in view of its dynamic behaviour. It is noteworthy that the freshly emitted BC aerosols are mainly hydrophobic in nature. However, the acquisition of soluble coating materials during atmospheric aging increases their hygroscopicity, thereby influencing their ability to act as cloud condensation nuclei affecting their atmospheric longevity. BC has complex optical properties as well as complex morphology. Fresh BC typically aggregates as small spherical monomers, while the atmospheric aging can lead to further particle restructuring, resulting in more compact and uniform morphologies. As a result, BC particles show substantial variability in homogeneity and refractive indices.

Typically, BC is released into the atmosphere through incomplete combustion of biomass and fossil fuels and is fundamentally anthropogenic in origin. A wide range of activities contribute to global emissions, such as open burning of biomass (forest fire) (42%), burning of domestic biomass (18%), diesel engines used in transport (14%), industrial diesel engines (10%), industrial activities and energy production, typically from low-capacity boilers (10%), and residential coal burned (6%), among others.

Compared to other greenhouse gases in our environment, BC is complex in nature and is not a single molecule or gas. It indicates a group of chemicals that substantially absorb solar radiation on earth

Further, the relative contributions of BC sources vary from region to region. For instance, in Western Europe, traffic-related emissions appear to be the primary contributor, as elevated BC concentrations are frequently observed in areas with intense motorised traffic and major roadways, but in South Asia, a majority of soot emission is caused by the biomass combustion for cooking purposes, and in East Asia, the combustion of coal for residential and industrial purposes seems to contribute more. Whereas the United States contributes more from industrial and vehicular emissions. There are many countries located in high-emitting zones that neither have proper measurements nor have stringent regulations regarding emissions. Many developing countries primarily lean on open uncontrolled biomass burning and the continued use of conventional energy sources (such as wood, coal, and kerosene) for normal day-to-day activities such as cooking, heating, and lighting.

ROLE OF BC IN GLOBAL WARMING AND CLIMATE CHANGE

An important characteristic of atmospheric BC aerosols is their strong ability to absorb terrestrial solar radiation across the entire wavelength spectrum and re-emit it as low-frequency radiation, thereby warming the atmosphere.

In particular, in areas with high BC concentrations, the warming of both the atmosphere and the Earth's surface is intensified which results in disrupted weather patterns and natural ecological cycles. In addition, BC is often released alongside other hazardous air pollutants including organic carbon (OC), carbon monoxide (CO), volatile organic compounds (VOCs), and other toxic organic

Image Courtesy: Kimberly Vardeman/Flickr

Margerie Glacier, Alaska, showing recession, particularly on its northern side, exposing bedrock since around 2017

carbon (OC) which all together significantly contribute to the degradation of air quality.

BC particles significantly alter the regional meteorology and normal weather patterns that are vital for agriculture and human well-being or health. With the blocking of the sunlight by BC and thus dimming of the Earth's surface, the evaporation rates get lower which ultimately disrupt cloud formation. Further, when these particles settle on plant leaves, they cause the surface to heat up which can damage the cells, thus limiting the plant's ability to absorb carbon dioxide through photosynthesis.

The present research studies on direct global radiative forcing of BC asserts that after the carbon dioxide and methane gases, BC is either the second or third most prominent anthropogenic greenhouse factor. Though these studies on radiative forcing present a comprehensive understanding of the effects of climate change due to enhancing BC concentration in our environment, it is difficult to represent the strong and localised impacts of BC aerosols in view of its highly uncertain or dynamic behaviour.

Present research on direct global radiative forcing of BC asserts that after carbon dioxide and methane, BC is either the second or third most prominent anthropogenic greenhouse factor

Owing to its short atmospheric lifetime, BC exerts highly concentrated warming effects in specific areas, creating localised climate 'hot spots'. To accurately assess the warming effects of BC, it is important to focus on its regional impacts, rather than relying on uncertain global estimates. The overall impact of BC on the regional climate is quite a difficult and complex problem to understand since it depends on several factors. These factors mainly include the source of emission and the life period of BC in the atmosphere along with its interaction with other pollutants and clouds.

BLACK CARBON IN THE CRYOSPHERE

The Himalayan range, referred to as the water tower of Asia as well as the Third Pole, directly or indirectly feeds the majority of the world's population. Due to the present scenario of climate change, it is a well-known fact that Himalayan glaciers are shrinking. Extreme weather events in these regions are increasing. Air pollution is one of the major contributing factors for disturbing the fragile Himalayan ecosystem. The presence of BC in the fragile Himalayan cryosphere is an alarming concern. By darkening the surface of the snow and ice, BC contributes to accelerating their melting rates and disturbs the energy equilibrium of the cryosphere. Research indicates that the BC concentrations in snow and ice are significantly higher in mid-latitude locations relative to polar areas. The BC accounts for around 20% of the drop in albedo during the glacier melt season.

As a result, the melting of glaciers has accelerated with diminished snow cover ultimately affecting available water resources and disturbing climate stability.

ENVIRONMENT AND HEALTH HAZARDS

Owing to nanoscale size of BC aerosol particles, they can infiltrate deep into lungs and enter the bloodstream, spreading toxic compounds, causing inflammation and oxidative stress throughout the body, which can worsen the pre-existing respiratory and cardiovascular problems.

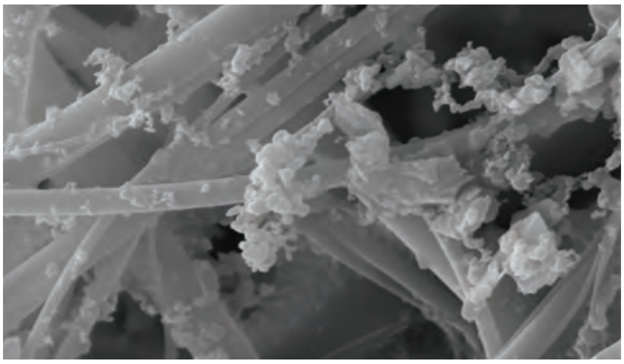
Chronic exposure to BC is associated with numerous health problems including lung cancer, heart diseases, and respiratory infections. Infants are particularly vulnerable since extended exposure to air pollutants, including BC, can severely impair lung development. Pregnant women also face increased risk of low birth weight and preterm birth. Chronic exposure, especially to BC, has also been linked to neurological effects, such as reduced cognitive function.

Over 15% of deaths in Delhi-NCR were attributed to air pollution and the situation is more alarming today as Delhi is currently grappling with extremely poor air quality with Air Quality Index (AQI) frequently in severe range. To safeguard public health particularly for children, the elderly and those with pre-existing health disorders, the lowering of toxic air pollutants is vital.

MITIGATION STRATEGIES

Due to the challenges in quantifying the warming impact of BC precisely, it still remains underrepresented in international climate policy. As of 2025, only nine nations have included explicit targets for reducing BC emissions in their Nationally Determined Contributions (NDCs) in order to fulfil their commitments, set forth in the Paris Agreement. Seven other nations have included BC in their overall climate goals.

Addressing the BC pollution can only begin with a clear understanding of its behaviour after release into the atmosphere. Preventing those emissions at their first source is the important next step. It is necessary to have a comprehensive understanding of the numerous sources that contribute to the production of BC, as well as the numerous strategies that can be utilised to reduce these emissions. Further, localised efforts to reduce BC emissions will provide the greatest benefits in terms of reducing regional warming and improving public health outcomes.



Images Courtesy: fightclimatechange.earth

From Top: Scanning Electron Micrograph; Depleting atmospheric aerosols including Black Carbon; Most common sources of BC pollutants

Urban air quality plans need to be developed to regulate city-specific pollution sources, including road and soil dust, vehicular emissions, domestic fuel, community-generated waste combustion, building materials, and industrial operations. These initiatives establish time-bound targets and are supported by annually updated implementation strategies with detailed micro-level planning for effective implementation of city plans.

Transitioning brick kilns to zig-zag technology aims to mitigate pollution levels and the transition of industrial units to piped natural gas for reduced emissions is further recommended.

Implementing initiatives that inform the public about the detrimental impacts of BC is a necessity for mitigating emissions. It is important to engage communities in discussions and projects that promote the use of low-emission cooking fuels and technologies. Disseminating information on BC and its effects on health and the environment, using various media platforms, can play a vital role. Building partnerships between public and private entities, including enterprises and diverse organisations, should be undertaken to curb BC emissions. We must also encourage policies that support the use of cleaner technology, while also reducing reliance on traditional biomass for heating and cooking purposes. Applying these strategies can considerably raise

Aerial view of Svinafellsjokull Glacier in Vatnajokull National Park in Iceland covered in black carbon

public awareness, which in turn will encourage more people to work towards lowering BC emissions and improving air quality.

INDIAN INITIATIVES FOR BC MONITORING AND MITIGATION

The government of India has implemented various measures to regulate BC emissions, including the flagship programme, the Pradhan Mantri Ujjwala Yojana by Prime Minister Narendra Modi, which promotes the use of clean cooking fuels in households. The metro rail network for public transport has been expanded to include additional cities, introduction of cleaner and alternative fuels, such as gaseous fuels (CNG, LPG, etc.), has led to the launch of a new initiative titled 'Sustainable Alternative towards Affordable Transportation (SATAT)'. This initiative aims to establish 5,000 Compressed Bio-Gas (CBG) production plants and facilitate the availability of CBG in the market for utilisation.

The Central Sector Scheme for the Promotion of Agricultural Mechanization for in situ Management of Crop Residue in Uttar Pradesh, Haryana, Punjab, and NCR Delhi provides a 50% incentive for individual farmers on agricultural machines, and equipment for in situ crop residue management, and an 80% incentive for setting up Custom Hiring Centres. The Union Government is executing the National Clean Air Programme as a long-term, time-bound strategy at the national level to address air pollution comprehensively, aiming for a 40% decrease in particulate matter concentrations by 2025-26.

The Central Pollution Control Board (CPCB) has identified 131 cities that exceed quality standards based on ambient air quality levels and population size of over one million. The 'Clean Air Action Plans' tailored to specific cities have been developed and are now in the process of implementation. Achieving the goal of a healthy and clean environment requires strict adherence to the enacted regulations.

CONCLUSION

BC, which is a transient air pollutant, degrades air quality and thus significantly contributes to global warming and climate change on earth. The BC particles present in the air can be inhaled with deep penetration into the human body leading to serious health risks. BC is therefore at the intersection of climate change, environmental impact, and public health. The accumulation of BC particles on Himalayan glaciers substantially accelerates the melting of snow, thereby changing regional climatic conditions. This in turn affects the fragile Himalayan ecology in diverse ways and water availability for populations residing downstream. The targeted monitoring of BC concentrations along with the implementation of well-designed mitigation strategies is important to minimise its harmful effects. Initiatives to reduce BC emissions and the use of cleaner combustion technologies can not only function as a proactive measure to protect our environment and public health but also effectively lessen the adverse effects of climate change.

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COP30: From a ‘COP of Truth’ to a ‘Theatre of Delay’

In the prolonged global search for a fair path for tackling climate change, India’s position is grounded in arithmetic and a call for responsibility to be allocated honestly

Image Courtesy: PIB

PM Narendra Modi addressed the session on ‘Environment, COP 30 and Global Health’ at the 17th BRICS Summit in Rio de Janeiro in July 2025

■ **Uday Kumar Varma**

When the world’s climate negotiators assembled in Belém, at the threshold of the Amazon rainforest in Brazil, the moment seemed laden with historical and moral significance. COP30 was heralded as the “COP of Truth”—a forum where science, urgency, and political will would finally converge. The choice of Belém was deliberate: few places embody the stakes of the climate crisis as starkly as the Amazon, a living regulator of the planet’s climate now under unprecedented stress.

Yet as the conference drew to a close, a sense of unease lingered. What many had hoped would be a decisive turning point appeared instead as a familiar choreography of restraint and postponement. Activists and analysts described COP30 as a ‘Theatre of Delay’, a phrase that captured the widening gap between scientific clarity and political caution. Inside the conference halls, disappointment hung thick in the air—an irony heightened by the hum of diesel generators powering pavilions devoted to decarbonisation.

Even the moral appeals of Pope Francis, urging delegates to act with compassion for both the Earth and its poorest inhabitants, failed to dislodge entrenched negotiating positions.

FROM RIO TO PARIS TO BELÉM: THE LONG ARC OF CLIMATE DIPLOMACY

The dissonance of COP30 becomes clearer when viewed against the broader evolution of climate negotiations. The COP process, inaugurated by the 1992 Rio Earth Summit, was founded on a deceptively simple premise: climate change is a global challenge requiring collective action, but responsibility must be differentiated according to historical emissions and economic capacity.

Early COPs grappled with recognition and obligation. The Kyoto Protocol attempted binding commitments for industrialised nations but faltered under geopolitical resistance. The Doha Amendment sought to revive Kyoto’s architecture, yet its impact remained limited.

The Paris Agreement of 2015 marked a conceptual shift. Instead of top-down mandates, it relied on Nationally Determined Contributions (NDCs)—voluntary pledges shaped by national circumstances. Paris succeeded in inclusivity, but flexibility came at a cost. Ambition became uneven, enforcement elusive, and accountability diffused.

Subsequent COPs oscillated between urgency and hesitation. Glasgow’s qualified reference to coal “phase-down,” Sharm el-Sheikh’s recognition of loss and damage, and Dubai’s cautious acknowledgment of fossil fuels all pointed to incremental progress. Belém was expected to convert these acknowledgments into firmer commitments.

It did not—at least not decisively.

THE POLITICS OF LANGUAGE AND THE RETREAT FROM CLARITY

The clearest signal of COP30’s limitations lay in its final text. Early drafts had explicitly called for a transition away from fossil fuels—coal, oil, and gas. In the negotiated outcome, this specificity vanished, replaced by the carefully neutral statement that the global transition toward low-emission, climate-resilient development is "irreversible."

For climate scientists, this omission was not rhetorical; it was consequential. Every major assessment by the Intergovernmental Panel on Climate Change underscores that limiting warming to 1.5°C requires a rapid, managed decline in fossil fuel use. Without timelines or sectoral pathways, ambition risks dissolving into abstraction.

Colombia's refusal to endorse parts of the final decision underscored this anxiety. Accusing negotiators of ignoring scientific evidence, its delegation briefly disrupted the plenary, exposing the fragility of consensus when truth itself becomes negotiable.

Images Courtesy: COP30 Brasil

Brazilian president Luiz Inácio Lula da Silva calls for stronger greenhouse gas reductions and emphasises broad social participation at COP30

INCREMENTAL GAINS AND THE LIMITS OF CONSENSUS

Yet COP30 was not devoid of achievement. Two developments stood out. First was tangible movement toward operationalising the Loss and Damage Fund, a mechanism long demanded by climate-vulnerable countries bearing the brunt of extreme weather events. Though modest relative to need, the fund marks an ethical acknowledgment that climate impacts impose real, uncompensated losses. Second was progress on a just transition framework, aimed at ensuring that workers and communities are not abandoned as economies decarbonise. Former Irish President Mary Robinson described these outcomes as imperfect but meaningful—evidence that multilateralism, while strained, remains functional. Brazilian negotiators repeatedly invoked the indigenous concept of 'mutirão'—collective, voluntary action undertaken for the common good. It became both a metaphor and a quiet rebuke: climate action cannot succeed through compulsion alone; it must be cooperative.

INDIA'S CLIMATE POSITION: DEVELOPMENT AS AN ETHICAL IMPERATIVE

For India, the core debate at COP30 was not merely about fossil-fuel phrasing. It was about the ethical architecture of global climate action. India's stance has remained consistent since Rio: climate ambition must be inseparable from equity.

India reiterated that poverty eradication, industrial growth, and universal energy access are non-negotiable foundations of development. For hundreds of millions, energy is not a lifestyle choice but a prerequisite for dignity, health, and opportunity. Climate action that undermines these goals risks becoming socially unsustainable.

This perspective explains India's persistent emphasis on adaptation. For much of the Global South, climate change is not a future projection but a lived reality—manifest in heat stress, water scarcity, agricultural disruption, and coastal erosion. Adaptation, therefore, is not secondary to mitigation; it is existential.

INDIA'S NDCS: SUBSTANCE OVER SYMBOLISM

India has faced criticism for the timing of its updated NDCs. Yet such critiques often miss the deeper context. India's climate commitments are tightly interwoven with domestic transformations—energy markets, infrastructure lifecycles, employment patterns—that cannot be recalibrated overnight.

More importantly, India's climate credibility rests less on announcements than on outcomes. Over the past decade, India has emerged as one of the world's fastest-growing clean-energy markets, consistently aligning policy with execution.

INDIA'S LEADERSHIP IN CLEAN ENERGY: ACTION AS COMMITMENT

Nowhere is India's climate seriousness more evident than in its clean-energy trajectory. India today hosts one of the world's largest renewable-energy expansion programmes. Solar power has become a cornerstone of this transition. Through ambitious initiatives such as large-scale solar parks, rooftop solar deployment, and the International Solar Alliance—conceived and led by India—solar energy has moved from peripheral to central in India's energy planning.

Wind energy, both onshore and offshore, has complemented this growth, while grid modernisation and battery storage initiatives are addressing intermittency challenges. India is also exploring tidal and ocean energy, recognising its long coastline as an untapped resource for future decarbonisation.

Perhaps most consequential is India's strategic push toward green hydrogen. Recognising hydrogen's potential to de-

COP30 is the annual United Nations Climate Change Conference, which brings together nations to discuss global climate action

carbonise hard-to-abate sectors—steel, fertilisers, shipping—India has launched a national mission to scale clean hydrogen production using renewable power. This effort positions India not merely as a consumer but as a potential global supplier of affordable green hydrogen.

Equally significant are gains in energy efficiency, electric mobility, and emissions-intensity reduction. India has already met—and exceeded—several of its climate targets ahead of schedule. These achievements are not symbolic; they reshape the emissions trajectory of a country still in the midst of development.

HISTORICAL RESPONSIBILITY AND CLIMATE JUSTICE

India's insistence on fairness is grounded in arithmetic, not rhetoric. Its per capita emissions remain well below the global average and a fraction of those in industrialised economies. The atmospheric concentration of greenhouse gases reflects over a century of fossil-fuel-driven growth elsewhere.

For developed countries to now demand uniform decarbonisation—without commensurate financial and technological support—risks perpetuating inequality. India's position is not an abdication of responsibility, but a call for responsibility to be allocated honestly.

FINANCE, TECHNOLOGY, AND THE TRUST DEFICIT

The credibility of global climate action hinges on finance and technology—areas where delivery continues to lag behind promise. The long-standing commitment to mobilise $100 billion annually remains unmet and inadequate. Adaptation finance, despite being critical for vulnerable populations, receives a fraction of mitigation funding.

Technology transfer remains constrained by intellectual-property regimes that restrict access to advanced solutions. Without addressing these structural barriers, calls for accelerated transition risk sounding hollow.

MUTIRÃO AND INDIA'S QUIET TRANSFORMATION

The Brazilian idea of mutirão finds a natural resonance in India's transition. India's climate action is not solely state-driven; it is cumulative—shaped by entrepreneurs, engineers, farmers, researchers, and local communities. It is decentralised, adaptive, and pragmatic.

This quiet transformation underscores a central truth: development and decarbonisation need not be opposing forces.

WHAT COP30 ULTIMATELY REVEALED

COP30 may not have fulfilled its promise as the 'COP of Truth', but it revealed truths the world can no longer ignore—about the limits of consensus, the costs of delay, and the urgency of cooperative courage.

COPs move slowly by design. Consensus rarely produces bold language. Yet this is the grammar of multilateralism. Progress emerges incrementally, negotiated word by word.

INDIA'S ROAD AHEAD

India stands at a confluence of great opportunity and massive responsibility. Its development aspirations—to lift millions out of poverty, power its growing economy, modernise infrastructure—must now coexist with the imperative of climate stability, global equity, and durable sustainability.

For India, the path forward is demanding but hopeful: expanding renewables, scaling green hydrogen, strengthening adaptation, deepening innovation, and ensuring that the poorest benefit first. Internationally, India will continue to argue for equity and realism—while demonstrating, through action, what balanced low-carbon development can look like.

WAITING, BUT NOT IDLY

In the end, the world waits for COPs to deliver clarity.

But the climate does not wait.

And neither, increasingly, does India.

**The writer, a Harvard educated civil servant, is a former Secretary to the Ministry of Information and Broadcasting, Government of India. He also served on the Central Administrative Tribunal and as Secretary General of ASSOCHAM. He commands extensive expertise in the fields including Media and Information, Industrial and Labour Reforms, and Public Policy.*

Earth's Growing Heat Imbalance Driven More By Clouds Than Air Pollution

Study reveals how aerosols affect cloud formation and how aerosol changes also affect the climate in opposite ways in the two hemispheres of the earth

■ **Science India Bureau**

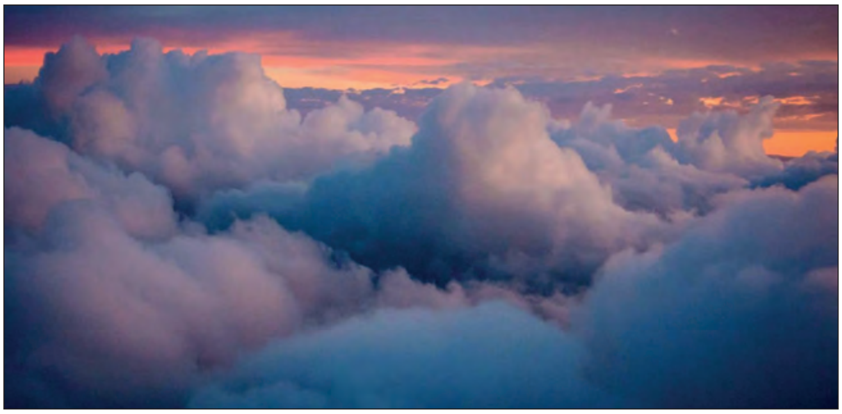


Image Courtesy: Twitter

Scientists have warned that the Earth is absorbing more energy than releasing; a new study links this growing imbalance to changing clouds

A concerning rise in 'energy imbalance' is fuelling global warming, as the Earth is taking in more energy than it releases back into space.

A new study led by scientists at the University of Miami Rosenstiel School of Marine, Atmospheric, and Earth Science finds that recent changes in air pollution are not the main reason for an increase in this imbalance.

Aerosols—tiny airborne particles from sources such as pollution, wildfires, and volcanoes—can affect how clouds form and how much sunlight Earth reflects back to space. While aerosols can influence climate regionally, the new research shows their recent global impact has been small.

Published in the journal *Science Advances*, the study—titled 'Negligible Contribution from Aerosols to Recent Trends in Earth's Energy Imbalance', analysed nearly two decades of satellite observations combined with modern atmospheric reanalysis data. The researchers found that aerosol changes have affected the climate in opposite ways in the two hemispheres.

In the Northern Hemisphere, cleaner air in heavily industrialised regions has reduced the number of particles that help clouds reflect sunlight, allowing more solar energy to reach the Earth's surface. In contrast, the Southern Hemisphere has seen large increases in natural aerosols from events such as the 2019–2020 Australian wildfires and the 2022 Hunga Tonga–Hunga Ha'apai volcanic eruption. These particles made clouds brighter and more reflective, sending more sunlight back to space. Together, the opposing effects largely cancel each other out, resulting in little net global influence from aerosols on the Earth's rising heat imbalance.

The study also shows that the recent increase in Earth's energy imbalance is driven mainly by changes in reflected sunlight, rather than by changes in heat escaping to space. From 2003 to 2023, Earth gained heat at a rate of about half a watt more energy per square meter each decade, largely because the planet is absorbing more sunlight.

To track how aerosols are changing over time, the researchers used two independent indicators. One came from satellites that observe how aerosols in the air affect the passage of sunlight through the atmosphere. The other came from reanalysis data, which combine observations and models to estimate sulphate particles produced by pollution, volcanoes, and wildfires. Despite their different approaches, both methods revealed the same pattern—declining aerosols in the Northern Hemisphere and increasing aerosols in the Southern Hemisphere—indicating that aerosols have had little overall effect on the global energy trend.

The findings also highlight a potential limitation in some climate modelling studies, which focus mainly on pollution reductions in the Northern Hemisphere and may underestimate the growing influence of natural aerosol events in the Southern Hemisphere.

"Earth's energy imbalance tells us how fast heat is building up in the climate system," said Brian Soden, a co-author of the study and a professor in the Department of Atmospheric Sciences at the Rosenstiel School.

"Many earlier studies suggested that cleaner air might explain much of the recent increase, but our results show that aerosol changes largely cancel out between the Northern and Southern Hemispheres. That means we need to look more closely at changes in clouds and natural climate variability to understand why the planet is continuing to gain heat," he added.

The authors of the study include Chanyoung Park and Brian Soden of the University of Miami Rosenstiel School of Marine, Atmospheric, and Earth Science.

**Curated from the study in* Science Advances *journal and various news sources.*

CSIR and ISRO jointly organised the CSIR–ISRO Space Meet 2025 in Bengaluru in November

■ Dr Manish Mohan Gore

India's Scientific Dreams for Space Exploration

Besides ISRO, many CSIR laboratories play an active role in India's quest to achieve excellence in its space missions

Space has always been a centre of curiosity and wonder for humankind. The shining sun during the day and the moon and millions of twinkling stars in the night sky have filled us with awe. In our childhood, we all heard stories about the moon and stars from our grandmothers. While listening to and pondering on these stories, the human mind has always harboured the imagination and desire to travel through space, to journey far from Earth to the moon, stars, and other planets, and observe them up close. Modern science and technology have greatly helped in fulfilling this age-old human desire. The journey of space exploration began in 1957 with the Soviet Union's artificial satellite Sputnik 1, a milestone that led to another in 1961 when the first human, Yuri Gagarin, set the record for reaching space. The next significant global milestone came in 1969 when the US space mission Apollo 11 reached space and Neil Armstrong landed on the surface of the moon. This single step by a man on the moon was, in fact, a giant leap for mankind in the realm of science. Following this, initiatives such as the establishment of the International Space Station, powerful telescopes like Hubble, and robotic explorers like Voyager and the Mars Rover have proven to be remarkable steps in the direction of space exploration.

MAJOR MILESTONES IN INDIAN SPACE EXPLORATION

India has also not lagged behind in space exploration. Under the guidance of the visionary scientist Dr Vikram Sarabhai, India formed the Indian National Committee for Space Research (INCOSPAR) in 1962, which later evolved into the Indian Space Research Organisation (ISRO) on 15 August 1969. ISRO's primary objective is to conduct space exploration and research for communication, broadcasting, and resource management to support the country's progress. In 1972, the Department of Space (DOS) was formed, and ISRO was made an integral part of it. ISRO has given a robust structure to India's space programme and has many historical achievements to its credit. These achievements include the development of the first Indian satellite, Aryabhata, in 1975, which was successfully launched into space using a Soviet rocket. In 1975-76, the Satellite Instructional Television Experiment (SITE) was launched, which initiated satellite-based television broadcasting in India. In the 1980s and 1990s, ISRO developed indigenous satellite launch vehicles, the Polar Satellite Launch Vehicle (PSLV) and the Geosynchronous Satellite Launch Vehicle (GSLV). And who can forget the successful launches of India's lunar mission Chandrayaan and the Mars Orbiter Mission (Mangalyaan)! Now, India is preparing for its human space mission, Gaganyaan.

Gaganyaan is a highly ambitious Indian space mission being implemented by ISRO under the leadership and inspiration of the current central government which is targeted for launch in 2027. Four Indian Air Force officers (Group Captain Prasanth Balakrishnan Nair, Group Captain Ajit Krishnan, Group Captain Angad Pratap, and Wing Commander Shubhanshu Shukla) have been selected as Gaganyaan astronauts (Gaganyatris) and are undergoing rigorous training for space travel before the Gaganyaan mission launch. Shubhanshu Shukla was given the opportunity to travel to the International Space Station (ISS) during 26 June to 15 July 2025, becoming the first Indian astronaut to visit the ISS. The first Indian space traveller ever was Rakesh Sharma, who traveled to space on 3 April 1984, aboard the Soviet Soyuz T-11 spacecraft (a joint ISRO-Soviet space mission).

Wg Cdr Rakesh Sharma (retd), India's first astronaut, reflected on his 1984 Soyuz mission & acknowledged NAL's long-standing aerospace contributions

India's space ambitions continue to expand, and ISRO's future goals reflect a strategic vision for scientific leadership, national development and global collaboration. Key priorities include the successful execution of the Gaganyaan human spaceflight mission and development of a sustained human space programme, including space stations. ISRO aims to deepen planetary exploration through upcoming missions to the Moon, Mars and Venus, along with advanced solar studies. Strengthening satellite constellations for communication, navigation and Earth observation will support climate resilience, agriculture, disaster management and governance. ISRO is also working on reusable launch vehicles, heavy-lift capabilities and next-generation propulsion to reduce mission cost. Increasing private sector participation through space-tech start-ups and promoting international partnerships remain core goals to build a robust space ecosystem for a self-reliant and globally competitive India.

India's space ambitions continue to expand, and ISRO's future goals reflect a strategic vision for scientific leadership, national development and global collaboration. Key priorities include the successful execution of the Gaganyaan human spaceflight mission

CSIR-ISRO SPACE MEET FOCUSED ON INDIA'S HUMAN SPACEFLIGHT MISSION

Topics related to space exploration are discussed within the intellectual and scientific fraternity, but the general public often remains unaware of these discussions. Another point of concern that emerges is that while ISRO is the only organisation mentioned when it comes to space-related missions and research in India, the contributions of several other scientific organisations in the country to space research often go unnoticed. Many a time, information about significant contributions is not shared with the general public, and these roles remain unknown. A similar kind of silent and unacknowledged scientific and technical contribution has been made by the Council of Scientific and Industrial Research (CSIR) to ISRO in its various space missions. Considering India's human spaceflight mission, the CSIR-ISRO Space Meet was held on 17 November 2025, at CSIR's Bengaluru-based laboratory, the National Aerospace Laboratories (NAL), in which ISRO and CSIR brainstormed on India's Human Spaceflight Mission. It is worth considering that CSIR is one of India's largest scientific organisations,

CSIR-National Aerospace Laboratories (NAL) provides critical testing infrastructure to ISRO for space missions

established in 1942, and currently operates 37 national laboratories across the country, conducting research in cutting-edge S&T fields such as oceanography, metallurgy, genomics, materials science, energy, engineering, environment, medicine, and agricultural technology. Several CSIR laboratories also develop technologies and equipment related to space science, which have been used in ISRO's space missions. The aforementioned meet focused on the key issue of how CSIR laboratories will strategically provide technical support to India's upcoming human spaceflight mission.

By 2025, approximately 90% of the Gaganyaan mission's development will be complete, including the human life support system and crew safety technologies. At a space meet in Bengaluru, Dr N Kalaiselvi, Director General of CSIR,

All Images Courtesy: Dr Manish Mohan Gore

Dr N Kalaiselvi (left), Secretary, DSIR & DG CSIR, and Dr V Narayanan (right), Secretary, Department of Space & Chairman, ISRO, at CSIR-ISRO Space Meet

highlighted CSIR's contributions to space technologies, including advanced materials and life support systems, and emphasised knowledge exchange and the use of indigenous innovations. ISRO Chairman and Secretary of the Department of Space, Dr V Narayanan, spoke about CSIR's role and collaboration in India's human spaceflight mission. He also proposed a Joint Steering Committee to give a new push and direction to this collaborative relationship. Dr Abhay Pashilkar, Director of CSIR-NAL, highlighted his laboratory's capabilities in space technologies, materials research, and testing facilities. NASA astronaut Jean-François Clervoy, through a video message, emphasised the role of international collaboration in the progress of human spaceflight. Indian astronaut Prashanth Balakrishnan Nair also attended the meeting and shared his training insights related to Gaganyaan, including microgravity simulations, operational protocols, and recovery frameworks.

CSIR LABS: CLOSE PARTNERS IN ISRO'S SPACE RESEARCH

CSIR-National Aerospace Laboratories (NAL) provides critical testing infrastructure to ISRO for space missions. Its 1.2m Trisonic Wind Tunnel, operational since 1967, validates aerodynamics for HLVM3 and Gaganyaan's orbital module. NAL's Acoustic Test Facility (ATF) simulates intense launch noise to qualify satellites and vehicle subsystems before flight. NAL also contributes through aero-elastic and structural testing, advanced composites and materials research, and collaborative R&D that enhances propulsion and aerospace systems used in space missions. These contributions have been crucial in successful ISRO missions, including Chandrayaan and Gaganyaan preparations.

Ceramic Matrix Composites (CMCs) developed by CSIR-Institute of Minerals and Materials Technology (IMMT) offer ablation resistance above 1600°C for Gaganyaan's heat shield, outperforming imported phenolics by 30% in erosion tests. It developed silica-phenolic ablators for re-entry vehicles and carbon-phenolic nozzles for solid rocket motors.

CSIR-National Physical Laboratory (NPL) ensures precision metrology. NPL calibrated sensors for the Environmental Control and Life Support System (ECLSS). NPL's atomic clock standards synchronise mission timing to 10^-12 seconds is vital for orbital rendezvous.

From left: Dr Abhay A Pashilkar, Director, CSIR–NAL, Wg Cdr Rakesh Sharma (retd), India's first astronaut, Dr N Kalaiselvi, Secretary, DSIR & Director General, CSIR, Dr V Narayanan, Secretary, Department of Space (DoS) & Chairman, ISRO, and Group Captain Prasanth B Nair, ISRO astronaut, at CSIR-ISRO Space Meet in November 2025

CSIR-Centre for Cellular and Molecular Biology (CCMB) has contributed to space research endeavours that align with the Indian space programme, including collaborations with ISRO in life science and space biology experiments. Records show that CCMB worked with ISRO on proposals and documentation to conduct life science experiments associated with NASA's Spacelab missions, reflecting CCMB's role in studying biological processes in microgravity alongside space agencies. CCMB's involvement in space biology underlines the interdisciplinary contributions of life science institutes to space research objectives linked with ISRO and broader international space projects.

Mysuru based CSIR lab, Central Food Technological Research Institute (CFTRI) formulates space nutrition. CFTRI's retort-pouched meals (thermo-stabilized biryani, dal) and 3D-printed nutrient bars provide 2500 kcal/day, preserving 95% vitamins after six months via high-pressure processing. CFTRI supplied specially formulated Indian space food for Group Captain Shubhanshu Shukla's Axiom-4 mission to the International Space Station in June-July 2025. Shubhanshu carried items like gajar ka halwa, moong dal halwa, vegetable biryani, dal, rajma-rice, khichdi, roti, and mango nectar, designed for long shelf life and nutritional density in microgravity. CFTRI developed these via high-pressure processing and retort packaging, ensuring 95% vitamin retention after months and 2500 kcal/day intake in compact form. Shubhanshu noted missing authentic home tastes post-mission, informing CFTRI's Gaganyaan refinements like millet tablets (4 pills = 1 meal) and reformulated sambar-rice or paratha equivalents. These address sensory satisfaction alongside nutrition for psychological well-being.

CSIR-National Chemical Laboratory (NCL) synthesises liquid crystal polymers for spacesuits, offering breathability (MVTR >500 g/m²/day) and puncture resistance. Additional contributions include CSIR-Indian Institute of Chemical Technology (IICT) refining hypergolic propellants with 2% higher density; CSIR-Structural Engineering Research Centre (SERC) conducting seismic and hypervelocity impact tests on habitats.

We have seen how Indian scientific institutions are doing remarkable work in space research. A major driving force behind this is the fact that space is a boundless resource for human existence in the near future. The significant milestones India has achieved in space exploration clearly demonstrate that we are among the world's most powerful nations in the field of space research. Our space capabilities not only strengthen socio-economic development but also ensure global leadership. The country's space research is making a remarkable contribution to communication, navigation, weather forecasting, agriculture, Earth observation, and disaster management. Besides Gaganyaan, the development of the Venus Orbiter, Chandrayaan-4, and the Indian Space Station are key objectives of the Indian space programme in the coming years. All these efforts related to space exploration will make the lives of the country's citizens easier and also help realise the dream of a Viksit Bharat by 2047.

**The writer is Senior Scientist, CSIR-National Institute of Science Communication and Policy Research, New Delhi.*

NEW FRONTIERS OF SCIENCE

From Idea to Impact: The Journey of Innovation

The TRL and IRL frameworks can help Indian science accelerate its shift from knowledge creation to tangible societal impact

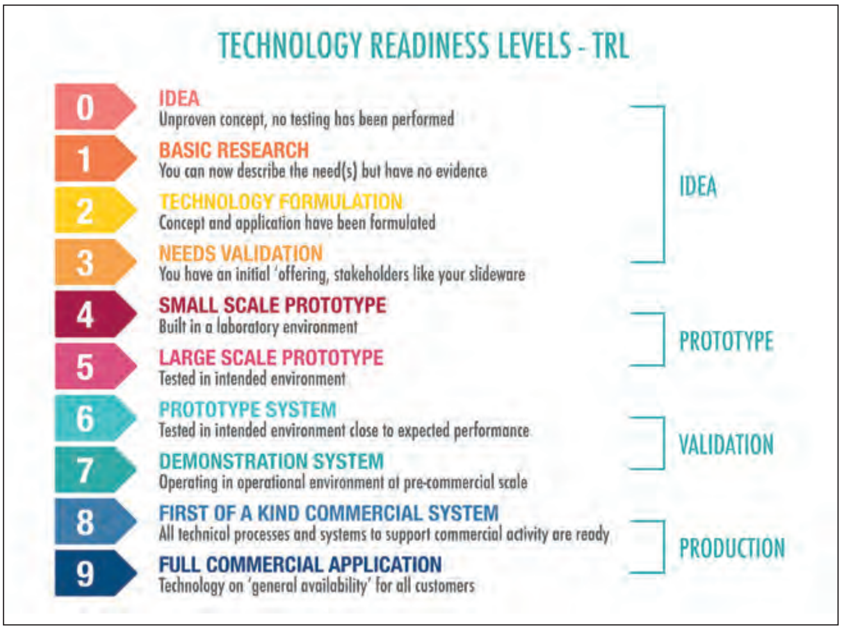
 

■ Prof Joydeep Dutta and Prof Kishore Paknikar

Every innovation begins as a quiet possibility. A researcher notices an unexpected laboratory result, an engineer identifies a long-standing societal problem, or a student imagines a better way to complete a routine task. At this earliest stage, nothing is written, tested, or demonstrated. There is only thought. This informal beginning, sometimes called TRL 0 (Technology Readiness Level), is where most ideas remain, and that is natural. Imagination must always exceed what is built, for it is the source of originality. Yet when a particular idea refuses to fade, it must begin the long journey from possibility to proof, and from proof to practice.

That journey is rarely linear. It loops

All Images Courtesy: Shutterstock



through setbacks, redesigns, failures, renewed attempts, and slow realisations. To navigate this uncertainty, NASA introduced the Technology Readiness Level framework in the 1970s; in the 1990s, John C Mankins formalised its definitions and evidence expectations. TRLs have since travelled far beyond space missions. They are now used in energy, water, agriculture, and healthcare to give innovators a shared vocabulary and to anchor maturity claims to evidence gathered under increasingly realistic conditions. Instead of vague statements about progress, TRLs offer a clear map from insight to impact.

THE TRL JOURNEY

TRL 1 begins with scientific observation. Imagine a materials scientist who discovers that a certain natural surface can adsorb heavy metals from contaminated groundwater. At TRL 2, the idea becomes a concept. The scientist imagines a low-cost water purification device, writes down hypotheses, and sketches possible configurations. TRL 3 demands proof of concept through controlled experiments. The material is tested repeatedly to confirm its behaviour. If results are consistent, confidence grows.

TRL 4 builds a prototype and tests it in controlled laboratory conditions. These early stages can feel comfortable, as conditions are controlled and progress is legible to peers. Research papers are written and prototypes are demonstrated, yet the device still exists in an environment that behaves perfectly. As many innovators admit, TRL 1 to TRL 4 are also the stages where technology remains in the laboratory. The purifier works in glass beakers and polished rigs, but life outside the laboratory is untidy, imperfect, and unpredictable.

TRL 5 marks a turning point. The prototype must now perform in relevant environments. Real groundwater carries unpredictable impurities, suspended solids, and fluctuating pH. TRL 6 requires pilot testing in the field. A small unit is installed in a community, where researchers observe flow rates, clogging, maintenance needs, and user interactions over several days or weeks. TRL 7 demands sustained performance in real settings. The purifier must tolerate inconsistent cleaning, irregular usage, seasonal variation, and unpredictable behaviours. When problems arise, the design must adapt, because reality does not follow laboratory schedules.

If the system endures these trials, it reaches TRL 8, where it is considered mature and ready for deployment at scale. TRL 9 represents full integration into daily life. Many filtration systems and disinfection units used in low-resource settings travelled this path over years before earning widespread trust. A parallel journey unfolds in healthcare. A point-of-care diagnostic begins with biomarker discovery at TRL 1, reaches prototype validation at TRL 4, enters clinical testing at TRLs 6 and 7, and only reaches TRL 9 after regulatory approval, manufacturing readiness, supply chain preparation, and training for frontline workers. Rapid diagnostic kits for infectious diseases, now used widely across continents, followed this long arc.

Most innovations never reach TRL 9. Studies frequently describe a valley of death between TRL 4 and TRL 7, where promising technologies collapse despite scientific merit

Despite such successes, most innovations never reach TRL 9. Studies frequently describe a valley of death between TRL 4 and TRL 7, where promising technologies collapse despite scientific merit. One example is a low-cost arsenic filter that worked in laboratories and early pilots but failed during scale-up because maintenance behaviour was misunderstood, supply chains for consumables were thin, and willingness to pay was overestimated. In diagnostics, validated devices stall when certification is slow, distribution networks are weak, or health systems are unprepared to adopt new workflows. These cases show that technical readiness is necessary but not sufficient.

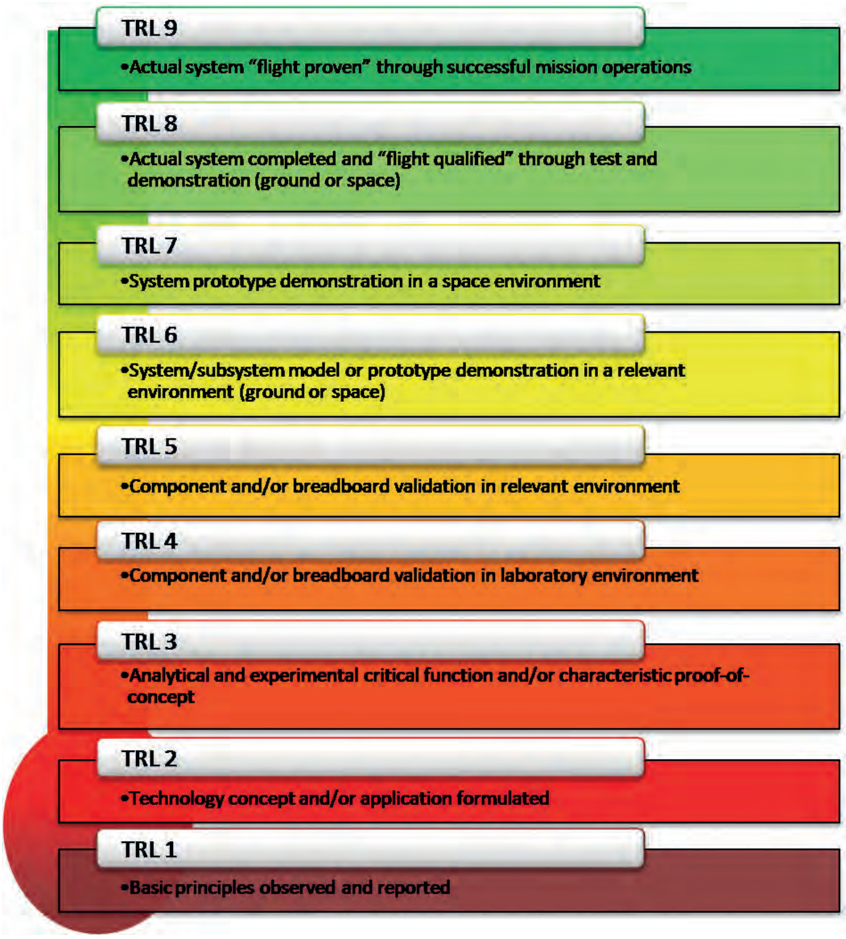
Field observations reinforce this lesson. During neutral, observation-driven pilots, teams may find that households skip periodic cleaning to save time, which undermines performance. In another setting, spare parts are unavailable locally, so devices sit idle after a minor failure. Elsewhere, water chemistry changes between seasons, saturating filter media faster than expected. Such outcomes confirm why TRL 6 and TRL 7 must include behavioural and logistical evidence, not only technical metrics. Funding calls increasingly require a stated TRL with traceable evidence, a practice formalised in European programmes where target TRLs are specified. This creates comparability but also demands honesty and rigour from innovators.

BEYOND TECHNOLOGY: THE IRL LENS

Technical maturity alone does not guarantee real-world adoption. The KTH Innovation Readiness Level (IRL) framework makes this explicit by extending readiness beyond the device into the human, organisational, and economic dimensions. IRL incorporates Customer Readiness Level, Business Readiness Level, Intellectual Property Readiness Level, Team Readiness Level, and Funding Readiness Level. Where TRL asks whether a technology works, IRL asks whether the innovation is understandable, adoptable, financeable, protectable, and operable in its intended context.

The two ladders complement one another. In early stages, customer readiness protects teams from building elegant solutions to the wrong problems. Around TRL 4 and TRL 5, business readiness becomes essential because prototypes, however clever, require a path to affordability, distribution, and service. TRL 6 and TRL 7 align with intellectual property readiness and deeper customer validation so that pilots generate real adoption insights. By TRL 8 and TRL 9, funding readiness and team readiness reduce execution risk by aligning capital and capability with the demands of scale. Each dimension has its own proofs, and gaps among them are early warning signals.

Interdisciplinary work is the quiet engine behind such transitions. Scientists contribute depth on mechanisms. Designers reduce cognitive load and improve usability. Social scientists uncover norms, incentives, and behavioural frictions. Entrepreneurs build models for scale. Policymakers and regulators clarify standards and certification pathways that convert performance into trust. When disciplines work in silos, blind spots multiply and readiness plateaus.



Policy and standards matter concretely at upper readiness levels. In water, national standards often require durability tests, removal efficiencies, and clear operating instructions, while international frameworks shape expectations for safety and quality. In health, diagnostics may need prequalification or approval before procurement, along with evidence that supply chains and training plans exist so devices do not gather dust. These processes take time, but they convert performance into trust, and trust sustains adoption.

What distinguishes projects that cross the valley of death from those that do not? Successful teams run technical maturation and market learning in parallel, instead of waiting for a perfect prototype before engaging users

THE ROAD TO REAL IMPACT

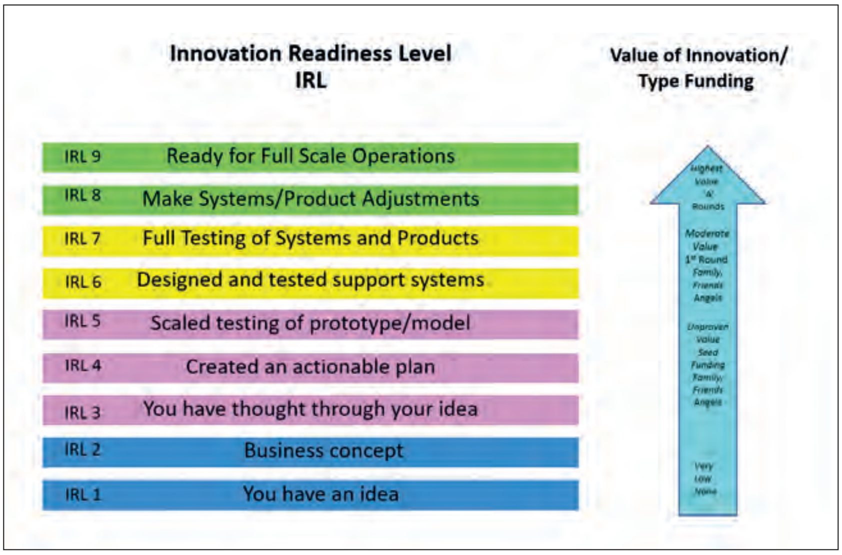
What distinguishes projects that cross the valley of death from those that do not? Successful teams run technical maturation and market learning in parallel, instead of waiting for a perfect prototype before engaging users. They use stage-gated funding tied to transparent evidence. They measure total cost of ownership, not just sticker price. They choose early markets where the need is strong and switching costs are manageable. They generate decision-grade evidence packs that make it easy for buyers, partners, and regulators to proceed.

Another distinguishing trait is respect for human behaviour. Adoption grows when benefits are clear, frictions are low, rituals are acknowledged, and trust is earned. In our water example, a visible flow indicator or a simple cleaning guide can improve adherence. In diagnostics, a clear readout can shorten training time for health workers. These small design choices accumulate into large differences in adoption.

Research bodies and funders increasingly recognise that readiness is multidimensional. Discussions now emphasise pairing TRLs with agile, responsible mechanisms so that public funding supports not only invention but also translation and uptake. This aligns with practical experience, which shows that innovation succeeds when evidence accumulates across technical, social, and economic dimensions simultaneously. Adoption is sustained by trust. Trust is sustained by proof. And proof must be gathered in the environments where life actually happens.

In the Indian context, where a vibrant higher education system coexists with a rapidly growing startup ecosystem, understanding TRL and IRL frameworks can help academicians, researchers, and students better align their work with real-world needs. For faculty and research supervisors, these frameworks provide structured pathways to design projects that go beyond publications toward technology demonstration and deployment. For students, they clarify how an idea develops—from hypothesis to prototype to field validation—and foster deeper collaboration with industry and user communities. For research institutions and innovation centres, TRL and IRL offer a common language that simplifies evaluating maturity, planning translational milestones, and attracting funding. In short, these frameworks can help Indian science accelerate its shift from knowledge

In the Indian context, where a vibrant higher education system coexists with a rapidly growing startup ecosystem, understanding TRL and IRL frameworks can help researchers better align their work with real-world needs



creation to tangible societal impact.

There is also a caution. TRLs can be misused if teams overclaim levels without matching evidence, or if funders treat levels as labels rather than learning tools. The remedy is straightforward. Attach each claim to transparent tests, share protocols openly, invite independent verification, and allow levels to move backwards when new facts emerge. Pre-registering key tests and sharing protocols raises confidence without slowing teams.

The journey from TRL 0 to TRL 9 is never merely technical. It is also ethical and human. A purifier that works only in a laboratory is a technical outcome. A purifier that works in remote schools, clinics, relief camps, and rural homes is a societal outcome. The same is true for diagnostics. It is not enough that a test detects disease. It must reach the clinician's hand in time to change a decision. Responsible innovation therefore weighs affordability, maintainability, end-of-life handling, and the total cost of ownership over time.

Many technologies that enrich lives today exist because someone stayed steady through uncertainty. Rapid diagnostics, biosand filters, solar lighting systems, satellite-based crop tools, and community water solutions all endured detours and redesigns before gaining trust. They advanced because teams blended scientific discipline with empathy, used readiness frameworks to see blind spots early, and gathered the right evidence at the right time.

When a scientist sees clean drinking water flowing from a device that began as an untested thought at TRL 0, there is quiet fulfilment. Innovation becomes a public good shaped by evidence and care. New ideas will be born tomorrow, once again at TRL 0. With thoughtful readiness and steady collaboration, many will rise to TRL 9 and beyond, touching lives, widening opportunity, and strengthening collective hope.

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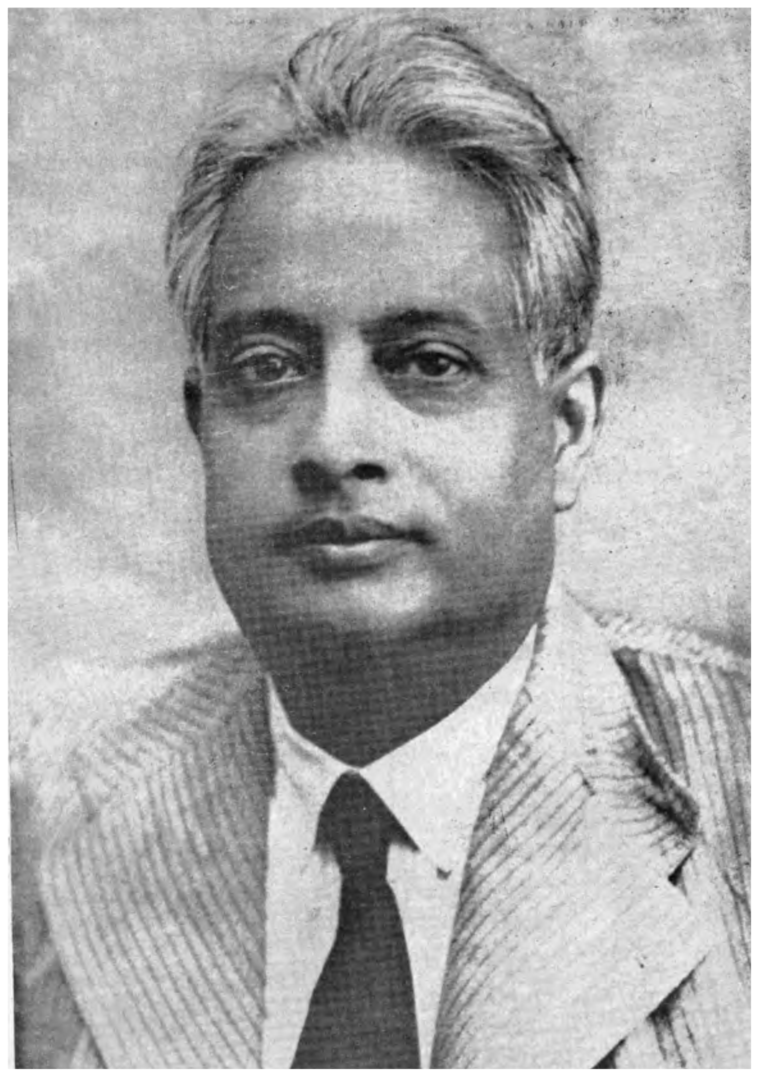
BIRTH ANNIVERSARY:
1 JANUARY / PROF SN BOSE



Remembering One of India's Most Potent Geniuses

Half of the fundamental particles in the universe—the bosons—are named after Prof Satyendranath Bose, who remains one of India's most influential scientific brains, and also one of the most under celebrated

■ **Sreeprasad M Kuttan**

At 22, Iswar Mill Lane in North Calcutta, a quiet home awoke to destiny on the first dawn of 1894. Laughter and light filled its rooms—not for the turning of the calendar, but for a far deeper miracle. Surendranath Bose and Amodini Devi were no longer just husband and wife; they had become parents. In their arms rested a newborn son, whom they named Satyendranath Bose. In that tender moment, no one could have known that the child cradled so gently would one day reshape humanity's understanding of nature itself. Surendranath Bose could not have foreseen that his humble family surname would one day echo across the cosmos. Through the brilliance of his eldest son, the hidden laws of the quantum world would unfold, and the scientific community would honour that legacy by naming half of the fundamental particles in the universe—bosons. Thus, from a small house in North Kolkata, it was the starting of the journey of Father of Bosons—Satyendranath Bose.

Time flew, from the year of 1894 to 2026. Last year—2025—the world celebrated International Year of Quantum Science and Technology, when several programmes, deliberations, discussions and conferences were arranged by the scientific community to celebrate100 years of quantum science, and to try and understand the new area of opportunity put forward by quantum science, mainly in the most celebrated technological application called quantum computing. As citizens of Bharat, we became part of these discussions and brainstorming as we had an icon in this field. But how much did we celebrate his name and were inspired by his works? We can

Prof S N Bose delivering a speech

All Images Courtesy: S. N. Bose National Centre for Basic Sciences

revisit the works of Satyendranath, and the hardships he faced on the road to success, which will be an inspiring story to anyone.

A BRILLIANT COHORT

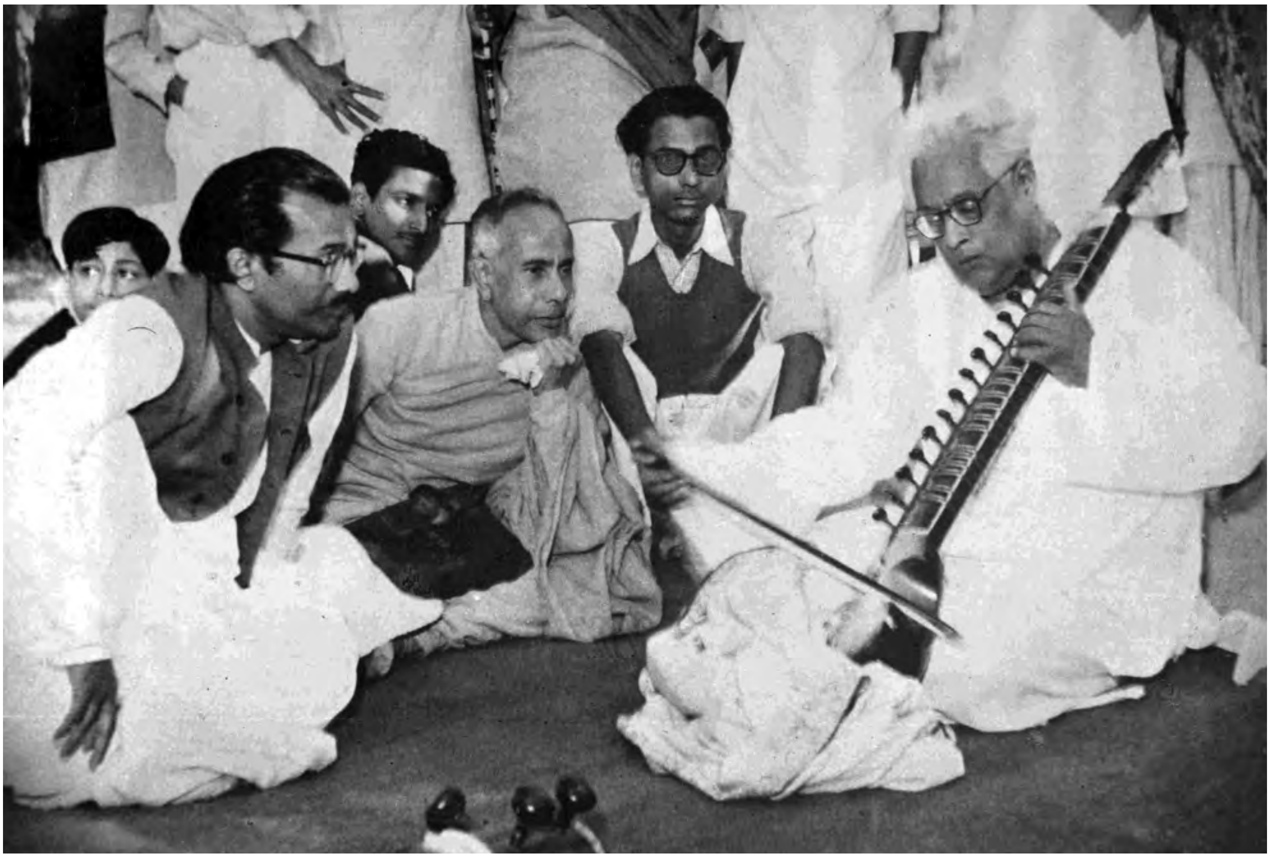
Back in the early 20th century, our country was struggling to break free of colonial rule. Bengal was the epicentre of all freedom movements, from young children to elderly citizens, students to professors, and artisans to masters, everyone had joined the fight for independence. At the same time, scientific thoughts and newly introduced modern science education were illuminating the minds of aspiring Indians. Calcutta was the hub of modern science education in India during that era. The British, using science as a tool to rule India, were met with a response from the Indians. The college streets of Kolkata were filled with brilliant minds, we can imagine classrooms where brilliant students sat on the benches, while the greatest minds of science in history stood and delivered lectures to them. Satyendranath Bose was one of the fortunate students at Presidency College who was in this dream class room. He joined the college in 1909 and was part of a remarkably brilliant cohort. His most prominent classmates and contemporaries included Meghnad Saha, a lifelong friend, collaborator, and celebrated astrophysicist; Jnanchandra Ghosh, later a renowned chemist; J N Mukherjee, a distinguished chemist; and Nikhilranjan Sen, a mathematician. With these brilliant minds sitting in classrooms, their teachers had to be of a much higher stature. As a blessing to these students, their teachers were the likes of Acharya Prafulla Chandra Ray and Acharya Jagadish Chandra Bose, under the visionary leadership of the vice chancellor Ashutosh Mukherjee. SN Bose learned modern chemistry from Acharya Prafulla Chandra Ray in the first year and the basics of modern physics from Acharya Jagadis Chandra Bose in the third year. SN Bose graduated from Calcutta University with a record mark sheet that remains unbroken in the University till this day.

Bose's first significant work was his collaborative effort with Meghnad Saha to translate Einstein's theory of relativity. This monumental task was further propelled by the historic foreword by Prashanta Chandra Mahalanobis. The book, a joint endeavour of three eminent Indian scientists, was published by the University of Calcutta in 1920.

At Presidency College, Bose studied with Meghnad Saha, later a celebrated astrophysicist, and their teachers were Acharyas PC Ray and JC Bose

Prior to this, Bose's first paper, co-authored with Saha, was published in a philosophical magazine in 1918. Subsequently, his next two papers were based on pure mathematical problems and were published in The Bulletin of the Calcutta Mathematical Society. In 1920, his paper on the deduction of the right-hand rule from the quantum theory of spectral emission in the same philosophical magazine gathered the attention of appreciative physicists.

On 15 June 1924, Bose sent his second paper to Einstein, marking the beginning of their communication. In that letter, Bose attempted to address a flaw in quantum theory that Einstein had been trying to solve for several years. Einstein understood that Bose had provided a better solution. The problem concerned a fully satisfactory derivation of Max Planck's law, which describes the spectrum of radiation from a black body. This law showed that the radiation does not rise to infinity at ever-shorter wavelengths as classical physics suggests, but



Prof Bose playing the Esraj for the Mahalanobises on the occasion of a wedding anniversary

instead peaks before falling back.

Einstein then translated Bose's paper into German and published it in the *Zeitschrift für Physik*. This kind gesture by Einstein helped Bose's paper gain acceptance and was published in the journal in August 1924. However, before Einstein's intervention, Bose had been attempting to publish his paper in various journals through different publishers, but unfortunately, no one recognised the importance of his work and it was not published.

IN LIKE-MINDED COMPANY

Bose embarked on a journey from Bombay on 1 October 1924, aboard a ship. He arrived in Paris on October 18th and set out on a mission to visit the cutting-edge laboratories of Europe, particularly those specialising in radioactivity and x-ray crystallography. Initially, he worked in the x-ray laboratory with Maurice de Broglie. However, his primary objective was to collaborate with Madame Curie at the Radium Institute. Upon meeting Curie, she advised Bose to spend several months learning French before commencing work in her laboratory. Despite his proficiency in French, Bose was too humble to correct her and followed her advice. He spent months honing his language skills while simultaneously conducting measurements on the piezoelectric effect in her lab. After a year in France, Bose journeyed to Berlin, where he immersed himself in German culture, attending seminars and engaging in intellectual discussions with prominent physicists. Max Planck and Walther Nernst were present during a seminar where Bose presented his groundbreaking work, marking a significant milestone in the history of quantum physics. Werner Heisenberg and other physicists also shared their ideas and perspectives with Bose during his stay in Germany. Bose's frequent visits to Albert Einstein allowed him to engage in discussions beyond physics, exploring various other subjects.

In 1945, Bose resigned from Dacca University and joined Calcutta University, where he held the prestigious chair Khaira professor of Physics. The Khaira Laboratory refers to a research facility at Calcutta University, where Satyendranath Bose served as the professor from 1945 to 1956. He began his experimental investigations in crystallography and radiation physics, and soon, the Khaira laboratory was developed into a well-equipped centre for crystal structure analysis.

A GENIUS SCIENCE COMMUNICATOR

All these achievements were overshadowed by Bose's growing commitment to science communication. He became the president of the Indian Physical Society from 1945 to 1948, the president of the National Institute of Sciences from 1948 to 1950, and was also nominated a member of the Rajya Sabha from 1952 to 1954 by the President of India. In 1954, he was honoured with the title of Padma Vibhushan and became the president of the Asiatic Society in 1959.

Potraits of Prof SN Bose inspecting a telescope (top) and with children (above)

Throughout these periods, Satyendranath Bose strongly advocated the study of science in one's own mother tongue. He believed that this approach would attract more youngsters from diverse social backgrounds to science. His dream was partially realised when he founded the Bangiya Bijnan Parishad in 1948, with the primary objective of popularising science in Bengal. On the same day, the Parishad was founded, Bose launched *Jnan-O-Bijnan*, a monthly popular science journal in Bengali. It was one of the first journals of its kind in a vernacular Indian language.

Bose maintained close relationships with individuals from diverse social circles. His social circle included singers, musicians, actors, filmmakers, and many more. Their interactions extended beyond literature, as they engaged in discussions about science and technology. Consequently, the renowned poet of Bharat, Rabindranath Tagore, wrote his only book on science, titled *Biswa Parichay*, and dedicated it to Satyendranath Bose.

Nobel laureate Rabindranath Tagore wrote only one book on science, a collection of essays titled *Biswa Parichay,* in 1937, and he dedicated it to Prof Satyendranath Bose

Bose actively worked with the organisation to translate complex scientific concepts into easy-to-understand Bengali. He published science books and magazines specifically designed for school and college students. Bose used the Parishad as a platform to deliver scientific lectures and keynote addresses in classic Bengali, completely avoiding foreign technical terms where possible. He even extended this practice to academic settings, teaching postgraduate classes on subjects like Relativity and X-ray crystallography in colloquial Bengali.

Bose's work with the Parishad was very different from the usual academic practice of his time, when English was preferred for scientific communication. He strongly believed that using Indian languages was not an elitist idea, but essential for national development and the spread of scientific thinking. Such was his commitment that his colleagues observed him carefully writing even complex scientific calculations in Bengali script so that his students could understand them better. While celebrating the genius of Satyendranath Bose the physicist, we should also remember what a great science communicator he was as well.

**The writer is Regional Organising Secretary, Vijnana Bharati, Western Region, and Coordinator, Science India Forum–Gulf Countries.*

HERB HERITAGE: **SHILAJATU (SHILAJIT)**

Ayurveda's Ancient Elixir of Strength, Longevity, and Transformation

This naturally occurring bioactive exudate that emerges from rock crevices of high mountain ranges, such as the Himalayas, during warmer months, enhances efficacy of other medicines

■ **Vaidya Preeti Bhosle**

Among the many remarkable substances described in Ayurveda, Shilajatu—popularly known today as Shilajit—occupies a place of exceptional reverence. Classified as a *Rasayana dravya* (rejuvenative substance), Shilajatu is neither a simple herb nor a mineral in isolation. It is a complex, naturally occurring bioactive exudate that emerges from rock crevices of high mountain ranges, especially the Himalayas, during the warmer months.

In classical Ayurvedic texts, Shilajatu is celebrated as "destroyer of weakness and disease" and "promoter of longevity, intellect, and strength." Modern interest in Shilajit has surged globally, often framed around testosterone, stamina, or fitness. However, Ayurveda offers a far deeper, holistic understanding—one rooted in dhatu nourishment, agni regulation and systemic rejuvenation.

The classical texts describe Shilajatu as a *yogavahi*—a substance that enhances the efficacy of other medicines by carrying them deep into tissues without losing its own potency. This property alone distinguishes it from most herbal drugs.

According to *Charaka Samhita*, Shilajatu possesses:

• Rasa (Taste): Tikta (bitter), Katu (pungent)
• Guna (Qualities): Laghu (light), Ruksa (dry)
• Virya (Potency): Ushna (hot)
• Vipaka: Katu
• Dosha Karma: Tridoshahara (especially pacifies Vata and Kapha)

Charaka states:

"*Shilajatum yogavahi, sarva-vyadhi-vinashanam* |
Vayah sthapanam medhyam balyam pushtikaram param ||" *(Charaka Samhita, Chikitsasthana 1)*

Translation:

"Shilajatu is a yogavahi that destroys diseases, stabilizes age, enhances intellect, strength, and nourishment."

This single verse encapsulates its role as a Rasayana—not merely symptomatic relief, but restoration of vitality and resilience.

ORIGINS AND NATURE: A SUBSTANCE BORN OF TIME

Ayurvedic scholars recognised Shilajatu as a product of long-term geological and biological transformation. It is described as the essence of plant matter compressed and transformed over centuries within mountain rocks—symbolically representing time, pressure and natural alchemy.

This aligns remarkably with modern findings, which identify Shilajit as rich in fulvic acid, humic substances, trace minerals and bioactive compounds. Ayurveda, however, understood this complexity intuitively—recognising Shilajatu as a *samyoga dravya* (compound substance) rather than a single entity.

IMPORTANCE OF PURIFICATION AND AUTHENTICITY

A critical aspect emphasised in classical texts is *shodhana* (purification). Raw or improperly processed Shilajatu is considered unsuitable for therapeutic use. This caution is especially relevant today, given widespread commercial availability.

HOW TO ASSESS THE PURITY OF SHILAJATU (PUBLIC AWARENESS)

While laboratory analysis remains the gold standard, Ayurveda and traditional knowledge systems describe certain observational indicators that may help

Images Courtesy: Wikimedia Commons

identify authenticity:
• Solubility test: Pure Shilajatu dissolves completely in warm water, imparting a brownish-golden hue without leaving gritty residue.
• Heat response: When gently warmed, it softens and becomes pliable rather than burning or producing fumes.
• Taste and smell: It has a bitter, slightly pungent taste and an earthy odour—not sweet or perfumed.
• Residue check: Ash content after combustion should be minimal, indicating low contamination with soil or fillers.

These indicators are not substitutes for quality control testing but serve as preliminary checks for consumers and practitioners.

ROLE IN DHATU POSHANA (TISSUE NOURISHMENT)

Shilajatu's therapeutic brilliance lies in its ability to nourish all seven dhatus, particularly:
• Rasa & Rakta: Improves nutrient assimilation and circulation
• Mamsa & Meda: Supports muscle tone and metabolic balance
• Asthi & Majja: Strengthens bones and nervous tissue
• Shukra: Enhances reproductive vitality and *ojas*

This makes Shilajatu invaluable in conditions of chronic fatigue, premature ageing, infertility, osteoporosis and neurodegenerative states—conditions Ayurveda attributes to *dhatu ksaya* rather than isolated pathology.

SHILAJATU IN RASAYANA THERAPY

In Rasayana *chikitsa*, Shilajatu is recommended both as a standalone rejuvenative and as an anupana (adjuvant) with herbs like Ashvagandha, Gokshura, or Amrita.

Sushruta mentions:

"Na rogo jayate tasya, na jara na ca klamah"

"One who consumes properly purified Shilajatu does not succumb easily to disease, ageing, or exhaustion."

Importantly, the texts emphasize *shodhana* (purification). Unpurified Shilajatu is considered toxic and unsuitable for consumption—an often-overlooked warning in today's supplement-driven marketplace.

INDICATIONS IN CLASSICAL AYURVEDA

Ayurveda prescribes Shilajatu in a wide spectrum of conditions:
• Prameha (metabolic disorders, including diabetes)
• Kshaya and Daurbalya (emaciation and weakness)
• Vata-vyadhi (neuromuscular disorders)
• Mutrakrcchra (urinary disorders)
• Medha-kshaya (cognitive decline)

Notably, Charaka places Shilajatu among the foremost drugs for Prameha, indicating its role in improving *dhatu* agni rather than merely reducing blood/urine sugar levels.

SHILAJATU AND DHATU-LEVEL ACTION

Unlike agents that act superficially, Shilajatu is believed to act at multiple tissue levels. Classical texts note its supportive role in strengthening *rasa*, *rakta*, *mamsa*, *asthi*, *majja*, and *shukra dhatus*. This multi-layered action explains its traditional use in chronic fatigue, metabolic disorders (prameha), neuromuscular weakness, and age-related degeneration.

Importantly, Ayurveda emphasises that Shilajatu works by improving dhatvagni—the metabolic mechanism of each tissue—rather than forcing physiological outcomes.

RELEVANCE IN MALE AND FEMALE HEALTH

While Shilajit is frequently marketed for male vitality, Ayurvedic literature does not restrict its benefits by gender. Its Rasayana action supports fundamental physiological processes relevant to both men and women.

In male health, Shilajatu is traditionally used to support *shukra dhatu*, contributing to reproductive vitality, physical endurance and recovery from debility.

In female health, its role is subtler but equally significant. By improving *rasa* and *rakta dhatu*, Shilajatu supports nutritional status, energy levels and resilience—particularly in states of chronic fatigue, post-illness weakness and age-related decline. Classical physicians also used it cautiously in conditions involving metabolic imbalance and bone health, recognizing its action on *asthi* and *majja dhatus*.

Ayurveda, however, strongly advises individualised prescription, especially in women with predominant *pitta prakriti* or inflammatory conditions.

RELEVANCE IN CONTEMPORARY TIMES

In an era marked by chronic stress, metabolic disease and premature ageing, Shilajatu offers an Ayurvedic lens to resilience—not as a stimulant, but as a systemic restorer. Its growing popularity should invite responsible integration, rooted in classical wisdom rather than commercial exaggeration.

Shilajatu reminds us that Ayurveda's strength lies not in quick fixes, but in deep nourishment, balance and longevity. When understood in its true Ayurvedic context, it stands as a testament to how ancient sciences anticipated modern integrative health paradigms—quietly, comprehensively and sustainably.

A WORD OF CAUTION: CONTEXT MATTERS

Ayurveda never advocates indiscriminate use. Shilajatu is contraindicated in:
• Acute pitta disorders
• During high fever or active inflammation
• Without proper purification or medical supervision

Dose, *anupana* and patient constitution (*prakriti*) are crucial determinants of benefit.

Shilajatu stands as a reminder of Ayurveda's sophisticated understanding of health—where longevity is not pursued through force but through balance, nourishment, and metabolic harmony. When interpreted through its classical framework and applied judiciously, it continues to offer insights relevant to modern health challenges.

Rather than viewing Shilajatu as a supplement trend, Ayurveda invites us to see it as a symbol of how traditional medical systems approached vitality—holistically, patiently, and with deep respect for nature's processes.

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Dr Debala Mitra, the first woman director general of the Archaeological Survey of India, 1981-1983

Image Courtesy: Internet

SPOTLIGHT: DR DEBALA MITRA (14 DECEMBER 1925 – 2 DECEMBER 2003)

The Life and Legacy of Dr Debala Mitra

On her recent centenary, we remember the ASI's first woman director general who made immense contributions to Buddhist studies

■ Dr Navneet Kumar Gupta and Dr Biju Dharmapalan

Too often, the dedicated scholars who painstakingly reclaimed India's past fade into the background. Among such unsung heroes, the remarkable life of archaeologist Debala Mitra warrants a closer examination.

Born in pre-independence Bengal, she defied the constraints of a patriarchal society and entrenched feudal traditions to become a luminous figure in Indian archaeology. Mitra was a woman who made the crumbling stone speak. She rose to become the first woman Director General of the Archaeological Survey of India (ASI), shattering glass ceilings in a male-dominated field.

A century after her birth, it's fitting that we pause to honour her monumental achievements, which continue to inspire a new generation of researchers, conservators, and historians.

Her story is at once historical irony and elegy. A woman in a field dominated by men, she became Director General of the Archaeological Survey of India. What she discovered in Ratnagiri, Tilaurakot, and through other excavations, her interpretations of Buddhist art and architecture were not only a reflection of the past but also a mirror through which we see our present more clearly. She was a gifted scholar, with patience, curiosity, and an impeccable analytical rigour.

EARLY LIFE AND EDUCATION IN BENGAL

Debala Mitra was born on 14 December 1925 in the Bengal Province, now part of Bangladesh, into a middle-class Kayastha household that prized learning and art. Her early schooling took place in Calcutta and Khulna, where she quickly distinguished herself through an inveterate thirst for knowledge and an uncommon precision of thought. The period into which she was born was marked by both intellectual ferment and nationalist agitation, yet the opportunities for women's education remained circumscribed. Mitra overcame these limitations asserting that intelligence could occasionally surpass social expectations.

She demonstrated diligence and analytical acuity right away. By 1940, she had attained first place among all female students in the Bengal Presidency matriculation examination, securing star marks and five letters. She maintained her academic excellence and ranked 19th in merit on the Intermediate of Arts examination. Even within the competitive and factionalised environment of higher education, Mitra maintained an unswerving commitment to historical and linguistic studies, cultivating skills that would become indispensable in archaeological research.

She graduated from Ashutosh College in 1944 before completing her M.A. in Ancient Indian History and Culture from the University of Calcutta in 1946, winning the silver medal and the Rai Radhika Prasanna Mukherjee gold medal for exceptional scholarship. Her academic curiosity led her beyond the subcontinent. She studied French language courses in Paris and explored the Art of Cambodia at the École du Louvre. Her doctoral research on the temples of Telkupi in West Bengal earned her a PhD from the University of Calcutta in 1975. She learned to organize fragmented evidence chronologically, and to approach ideas analytically. These formative experiences and cultural sensitivity would facilitate her lifelong contributions to archaeology.

Images Courtesy: Wikimedia Commons

Telkupi, situated on the southern banks of the Damodar river near Panchet in West Bengal, was once famous as Tailakampa, the ancient capital and riverine port of Shikharbhum

A TRAILBLAZING ENTRY INTO THE ARCHAEOLOGICAL SURVEY OF INDIA

In December 1952, she walked all the way into the corridors of the Archaeological Survey of India, taking her place in an institution that oscillated the weight of colonial legacy and nationalist promise. The ASI of that era was old, crumbling in parts, and desired galvanisation of a new approach to indigenous history. It had inherited Alexander Cunningham's vision, but also the British bureaucracy.

She recognised the patriarchal dominance in her environment and proceeded with quiet competence rather than vociferous confrontation. From the outset, her work involved documentation, cataloguing ancient finds, and conducting field surveys. Colleagues recognised that she was a researcher capable of reading bones, potsherds, and crumbling frescos.

Through her tenure at ASI, she rose methodically through the ranks, serving first as Superintendent of the Eastern Circle and subsequently as Additional Director General, before ultimately assuming the office of Director General. She participated in excavations at Rupar, Nohar, Sothi, Maski, and Tamluk, and later undertook independent excavations at Jaugada, Udaygiri, Khandagiri, Ratnagiri, Tilaurakot, Kodan, and various sites in north-east India. Her responsibilities extended to conservation and preservation, including the mosques of Murshid Quli Khan at Murshidabad, tombs and mosques at Gaur and Pandu-as in West Bengal, temples at Bishnupur in Manipur, and earthquake-damaged temples in Assam.

After joining the ASI in 1952, Dr Mitra recognised the patriarchal dominance in her environment and proceeded with quiet competence rather than confrontation

Mitra's administrative and advisory roles were extensive. She chaired the National Committee for the Lumbini Development Project and ICOMOS, served on the Central Advisory Board of Archaeology, the Asiatic Society, and the National Council for Science Museums. She represented the Indian government at international conferences and symposiums across multiple countries, and contributed as a consultant to the cultural triangle in Sri Lanka. In May 1986, she attended the international conference in Berlin on the development and chronology of Buddhist and Hindu sculptures in early medieval art.

Dr Mitra made an enduring contribution to Indian archaeology through her extensive research and excavations at key Buddhist sites, including Ratnagiri, Jaugada and Udaygiri in Odisha, as well as Tilaurakot, Lumbini, Kodan and Nigali Sagar in Nepal, among others. Snapshots of her at work from archives.

EXCAVATIONS IN BUDDHIST SITES AND RECLAMATION

Debala Mitra's most concrete contributions to Indian archaeology were her systematic excavations, which clarified longstanding questions about Buddhist religious practice, architectural evolution, and regional socio-cultural aspects. Among the sites she investigated, Ratnagiri in Odisha and Tilaurakot in Nepal were of peak importance. In her book Buddhist Monuments, Dr Mitra offers details on the development of stupas. She emphasises differences across regions and the symbolic meanings they hold. She also examines lesser-known monasteries, highlighting their distinctive architecture and situating them within their historical context. Her interpretations of inscriptions provided data on patronage and sociopolitical conditions, while comparative studies across multiple Buddhist centres illustrated the diffusion of artistic and ritual forms.

A notable episode occurred in Bodhgaya. In February 1987, she observed an eighth-century Buddha statue within the Maṭ ha complex. Upon returning in March 1989, she noted the statue was missing and learned that the Maṭ ha authorities had not reported the loss. Cross-referencing a published photograph from the Metropolitan Museum of Art, Dr Mitra confirmed that the missing Bodhgaya statue had appeared in the museum's collection. She reported the matter to the Archaeological Survey of India in May 1990. Investigations traced the statue's registration to Shri Shatanand Giri of the Bodhgaya Maṭ ha, dated 4 October 1976. Consultations between the ASI, the Indian Embassy in New York, and the Metropolitan Museum verified the identification, and the museum consented to return the statue without compensation. The object was formally repatriated on 23 March 1999.

One of the first recoveries of a stolen Bihar sculpture from a foreign collection happened during this episode. Dr. Mitra's hard work and commitment to scholarly verification highlighted the practical and procedural needs to deal with art theft. This approach was much needed.

RECOGNITION FOR HER PIONEERING WORK AND SCHOLARSHIP

Debala Mitra oversaw the Archaeological Survey of India's excavations at Ratnagiri, Odisha, between 1958 and 1961. Her team uncovered Monasteries No. 1 and No. 2, a colossal stupa, numerous smaller votive stupas, temples, and a profusion of sculptures, including Buddha heads and bronze artifacts. With its complex carved doorways and rows of cells encircling a central shrine, Monastery No. 1 was a prime example of the period's artistic sophistication.

Dr Mitra's meticulous documentation of these finds, published in the ASI's Memoirs of the Archaeological Survey of India in Ratnagiri (1958-61), remains an essential research on the site. She measured pottery shards, traced stylistic and iconographic developments, and connected local artistic expressions to broader Buddhist centres across Asia. She demonstrated how monastic life, sanctuaries, and religious art evolved over the fifth to the thirteenth centuries, cultural exchange, and artistic cross-fertilisation that bound these monasteries together.

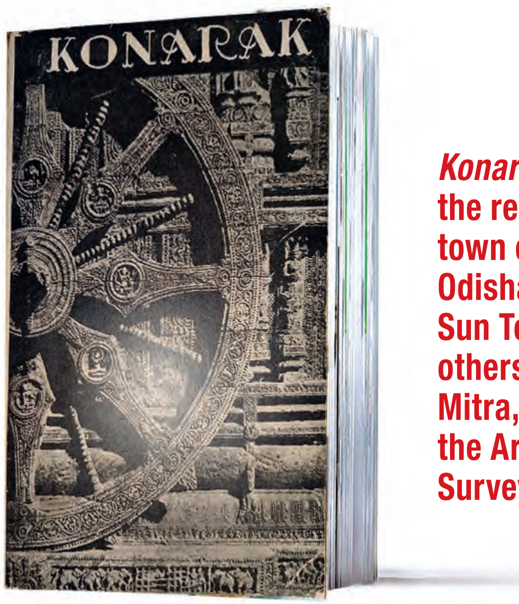
Early 2025 excavations have confirmed Dr Mitra's groundbreaking research. Three enormous Buddha heads and a vast shrine complex were found by archaeologists, demonstrating Ratnagiri's historical and cultural significance as a flourishing Buddhist centre. These discoveries expand on her initial interpretations and offer more context for the site's artistic evolution and monastic traditions.

TILAURAKOT: IN SEARCH OF KAPILAVASTU

From the late 1960s through the 1970s, Debala Mitra led the Archaeological Survey of India in excavating Tilaurakot in Nepal. Many considered this site to be the ancient Kapilavastu, the childhood home of Prince Siddhartha. Her work focused on fortified urban structures, revealing defensive walls, gateways, residential areas, and artefacts that dated from the Maurya to Kushan periods. Although there was no clear evidence confirming Tilaurakot as Kapilavastu, her investigations significantly reduced the likelihood of such possibilities.

She employed careful stratigraphic analysis, meticulously recording details with precision, much like an ophthalmologist examines retinal information. Her thorough documentation created a framework that allowed later scholars to build on strong archaeological foundations. The excavations discovered material culture and urban planning that linked Nepal's Terai region to the more expansive Gangetic plains. This offered insights into trade, rituals, and population movement during the early historical period.

Her work at Tilaurakot shows a careful balance of field skills and scholarly interpretation. While the exact location of Kapilavastu remains uncertain, Mitra's efforts transformed the site from a place of doubt into a well-documented archaeological case study.



Konarak, a book on the renowned temple town of Konarak, Odisha (home to the Sun Temple, among others), by Dr Debala Mitra, published by the Archaeological Survey of India

SCHOLARSHIP AND PUBLICATIONS: A PROLIFIC LEGACY IN PRINT

Dr Debala Mitra was a prolific archaeologist and scholar whose work extended beyond field excavations into rigorous documentation and analysis. Her major publications include *Buddhist Monuments, Ajanta, Konarak, Telkupi: A Submerged Temple-Site in West Bengal*, *Ratnagiri: 1958-61*, and numerous articles in *Indian Archaeology – A Review* and other journals. In Buddhist Monuments, Mitra examined Buddhist architecture, sculpture, and painting, covering sites from Ajanta and Ellora to Nalanda, Vikramashila, Sanchi, and Amaravati. She provided detailed descriptions of stupas, monasteries, sculptural iconography, and inscriptions, establishing chronological and stylistic frameworks. Her articles in *Indian Archaeology – A Review* documented new excavations, analysed artefacts, and interpreted epigraphic evidence. She combined field data with art-historical analysis, creating systematic records of significant sites.

Mitra's scholarship also included comprehensive studies of Ratnagiri, Telkupi, and other Buddhist and temple sites, thereby contributing to an understanding of the architecture, culture, and chronology.

AS DG OF THE ARCHAEOLOGICAL SURVEY OF INDIA: LEADING THE NATION'S HERITAGE

In 1981, she became the first woman to serve as the Director General of ASI, overseeing excavations, conservation, bureaucratic challenges, and national heritage. Many saw her appointment as a victory of merit over entrenched patriarchy. She transformed ASI from an institution of mere custodianship to one of interpretation and vision. Buddhist archaeology, under her guidance, ceased to be dry cataloguing and became a living history. When she retired on 31 December 1983 she left behind not only a strengthened organisation and an ethical legacy, she had also opened doors for other women, scholars, and those who dared question prejudice.

AWARDS AND RECOGNITION: A DULY HONOURED SCHOLAR

Dr Mitra's contributions did not go unnoticed. She was awarded the Dr B C Law gold medal by the Asiatic Society for her work on art, architecture, iconography. She travelled widely: Rome, Athens, London, Cairo. She represented India at international symposia, sat on committees like Central Advisory Board of Archaeology and Asiatic Society.

As we honour her on her birth centenary we do more than remember dates. We celebrate a woman who showed us that intellect, courage, persistence can surmount obstacles. Her century-long legacy shows us that the past is not a fixed relic. It is fluid, contested, and alive. Her life encourages us to dig deeper, listen more closely, and question more boldly.

**Dr Navneet Kumar Gupta is a New Delhi-based freelancer, while Dr Biju Dharmapalan is the Dean-Academic Affairs, Garden City University, Bangalore. and an adjunct faculty at the National Institute of Advanced Studies, Bangalore.*

India's Breakthrough That Makes Gene Editing Visible

Scientists at Kolkata's Bose Institute have engineered a glowing version of the CRISPR-Cas9 protein, allowing researchers for the first time to watch gene editing unfold inside living cells

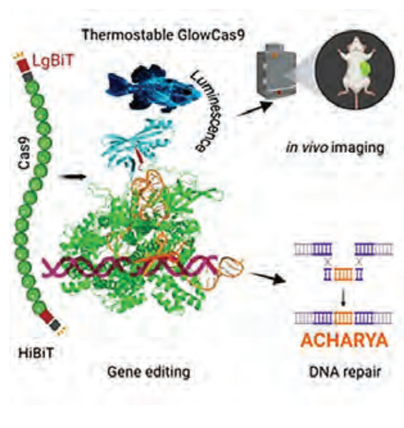
■ **Science India Bureau**

For decades, gene therapy has held the promise of curing some of humanity's most devastating hereditary diseases. Yet, while CRISPR-Cas9 revolutionised genome editing by making DNA cuts with extraordinary precision, one major limitation persisted: scientists could not observe the Cas9 enzyme at work inside a living cell. Traditional methods required breaking open or fixing cells destroying the system they hoped to study. Real-time tracking remained out of reach.

A team at the Bose Institute, Kolkata, led by Dr Basudeb Maji, has now solved this long-standing problem by developing GlowCas9, a bioluminescent version of Cas9 that produces light when active. Their findings, published in Angewandte Chemie International Edition, represent a significant leap forward in both fundamental biology and applied genetic therapy.

GlowCas9 was designed by PhD researcher Arkadeep Karmakar, who fused Cas9 with two inactive halves of a split nano-luciferase enzyme. This luciferase, originally derived from deep-sea shrimp proteins, only lights up when its two pieces come close enough to reassemble. When Cas9 folds correctly and initiates gene editing, the luciferase fragments reunite and emit a glow—a molecular signature that marks the precise timing and location of DNA cutting. The effect is subtle but powerful: a measurable burst of light that allows scientists to track CRISPR activity without harming the cell.

This bioluminescent behaviour solves a fundamental challenge in genome engineering. For the first time, researchers can watch the 'molecular scissors' at work, cutting DNA, engaging repair pathways, and completing edits, in living cells, tissues, and even intact plant leaves. The ability to visualise the process as it happens opens new possibilities in understanding CRISPR's efficiency, its stability inside complex biological environments, and the timing of DNA repair mechanisms.



Presentation of engineered thermostable reporter GlowCas9 development for theratracking applications

GlowCas9 is not merely a visualisation tool. Early studies show that it is more stable than conventional Cas9, maintaining structure and activity even at higher temperatures. This is important for therapeutic applications, where enzymes must remain robust inside the body. The researchers also found that GlowCas9 improves the efficiency of homology-directed repair (HDR), the high-precision DNA repair mechanism used to correct mutations responsible for diseases like sickle-cell anaemia and certain muscular dystrophies.

In a symbolic demonstration of its accuracy, the team programmed GlowCas9 to insert the DNA sequence for 'ACHARYA' into a genome— an homage to Acharya Jagadis Chandra Bose, the institute's founder and one of India's pioneering scientists. This precise, efficient insertion highlights the tool's potential in corrective gene therapy, where targeted edits must be carried out without introducing off-target damage.

Another promising application lies in agriculture. Because GlowCas9 can be visualised in plant systems without introducing foreign DNA, it may facilitate non-transgenic gene editing in crops, offering safer and more publicly acceptable avenues for improving plant traits.

GlowCas9 also represents a major step toward what scientists call 'thera tracking', the ability to simultaneously deliver gene therapy and track its success in real time. Current CRISPR-based therapies often rely on delayed or indirect markers to confirm whether a gene edit was successful. With GlowCas9-like systems, clinicians could one day map when Cas9 reaches the target tissue, observe when it cuts DNA, and monitor whether repair proceeds correctly. This would dramatically improve safety in clinical trials and personalisation of treatments.

More broadly, GlowCas9 highlights India's growing contributions to frontier biotechnology. As global research groups race to develop safer, more controllable gene-editing platforms, the Bose Institute's innovation positions Indian scientists at the forefront of next-generation genetic tools.

By merging gene editing with light, GlowCas9 turns a once-hidden process into something observable, measurable, and ultimately more controllable. In doing so, it brings gene therapy closer to a future where doctors can not only correct faulty genes but literally watch healing begin.

Recognition for Research in Systems Chemistry

Dr Dibyendu Das has been honoured with the Vigyan Yuva Shanti Swarup Bhatnagar Award 2025 for research on life-like properties in simple chemical systems

■ Science India Bureau

Dr Dibyendu Das, Associate Professor in the Department of Chemical Sciences at the Indian Institute of Science Education and Research (IISER) Kolkata, has been selected for the Vigyan Yuva Shanti Swarup Bhatnagar Award 2025. He is the sole recipient of the award in Chemistry, under the Rashtriya Vigyan Puraskar (RVP) scheme. This honour, among the nation's highest recognitions for scientific achievement, acknowledges his pioneering research and global impact in the rapidly growing field of systems chemistry.

Trained as an organic and supramolecular chemist with a deep interest in molecular self-organisation, Dr Das has established an internationally visible research programme aimed at understanding how life-like properties can emerge from simple chemical systems. His work interrogates fundamental questions concerning the chemical origins of life, the emergence of catalytic networks, and the possibility of constructing 'Life 2.0'; synthetic matter that exhibits the fundamental characteristics of living systems.

Dr Das is widely regarded as a leading figure in systems chemistry, particularly for elucidating how non-equilibrium chemical self-assembly processes give rise to emergent functions. His laboratory has also demonstrated how short peptide-based assemblies can form amyloid structures that catalyse multiple reaction pathways, offering a plausible mechanism for primitive enzymatic evolution under early-Earth conditions. These studies have influenced origin-of-life research by introducing chemically robust, experimentally tractable models of early enzymes and protometabolic emergence.

Image Courtesy: PIB

Dr Dibyendu Das received the Rashtriya Vigyan Puruskar 2025 (Vigyan Yuva category) in Chemistry

A hallmark of his work is the creation of synthetic non-equilibrium assemblies that mimic key features of living matter, adaptation, transient behaviour, chemotaxis, and signal response. His group has engineered chemical systems capable of spatiotemporal control over structure and function, where materials grow, transform, and dissipate only when supplied with energy. This far-from-equilibrium design strategy is redefining how dynamic functional materials are conceptualised within chemistry.

Dr Das's contributions extend beyond fundamental science to translational innovation. His laboratory is developing self-destructing catalytic systems for security applications, oscillatory hydrogels for dermal drug patches, adaptive diagnostic kits, and programmable non-equilibrium materials with real-time decision-making capabilities. This interdisciplinary approach positions his group at the cutting edge of chemistry, materials science, and bioinspired engineering.

His leadership and international standing are reflected in several major honours. He was featured in '75 Under 50 Scientists Shaping Today's India' (Vigyan Prasar, 2021), recognised for his role in shaping the trajectory of modern Indian science. He has been elected Vice Chair (2026) and Chair (2028) of the Gordon Research Conference on Systems Chemistry; an exceptional distinction for an India-based scientist. He served as a mentor at the 2024 Gordon Research Seminar, guiding early-career researchers on the scientific and societal impact of systems chemistry. His earlier recognitions include the prestigious Swarnajayanti Fellowship (2020) and election as an INSA Associate Fellow (2025).

Dr Das's long-term vision is to create synthetic matter that blurs the boundary between inanimate and living systems, uncovering the origins of biological complexity while developing future-ready adaptive materials. His laboratory aims to construct autonomous chemical networks, evolve primitive catalytic pathways, and engineer life-inspired materials with transformative applications spanning healthcare, diagnostics, energy, and security.

Through his exceptional scientific contributions, visionary leadership, and sustained excellence, Dr Dibyendu Das has positioned his laboratory as a global leader in systems chemistry. The Vigyan Yuva Shanti Swarup Bhatnagar Award 2025 stands as a recognition of his pioneering role in advancing one of the most dynamic frontiers of contemporary chemical science.

Tejas Gets Indigenous Brake Parachute Boost

India has strengthened the landing safety of its Light Combat Aircraft (LCA) Tejas with the induction of an indigenously developed Hybrid Brake Parachute manufactured by Gliders India Ltd (GIL). The system enhances safety during high-speed recoveries and emergency landings, marking another step in modernising India's frontline fighter fleet. Officials said the lightweight parachute significantly shortens landing distance, improving operational flexibility at both forward and established air bases. The parachute uses a Uni-Cross main canopy measuring 5.75 metres, with a total surface area of 17 square metres. This design ensures stable and efficient deceleration, a critical requirement during adverse weather or high-speed landings.

Hybrid Brake Parachute to assist the safe landing of Tejas has been indigenously developed

Chillai Kalan Begins as Kashmir Enters Deep Freeze

The Kashmir Valley entered Chillai Kalan on 21 December, the harshest phase of its winter cycle, which will last until 29 January. Temperatures across Srinagar, Gulmarg and Pahalgam have already dropped below freezing point, accompanied by heavy snowfall in higher reaches. Rain in the plains and snowfall in the mountains caused a rise in minimum temperatures in parts of Jammu and Kashmir, while Punjab and Haryana experienced cold-day conditions. Dense fog reduced visibility in Delhi and Uttar Pradesh. Chillai Kalan, meaning "the great cold" in Kashmiri, is rooted in centuries-old climatic observation. It coincides with the winter solstice, when reduced solar heating and polar air intensify cold across the Himalayas. This phase is followed by Chillai Khurd from 30 January to 18 February, and Chillai Bachha from 19 February to 1 March, though neither matches Chillai Kalan in severity. Daytime temperatures typically remain between 2°C and 5°C, while night temperatures in higher valleys can fall well below freezing point.

Kashmir has entered the coldest phase of its winter, locally known as Chillai Kalan or 'the great cold'

Maharashtra Labyrinth Hints at Ancient Trade Links

Archaeologists have uncovered a massive circular stone labyrinth in the Boramani grasslands of Solapur, Maharashtra, believed to be nearly 2,000 years old and the largest of its kind found in India. The structure consists of 15 concentric stone rings carved with remarkable precision and measures approximately 50 feet by 50 feet. It's perfectly circular form is unique in India, where earlier discoveries, such as the labyrinth at Gedimedu in Tamil Nadu, were square. Until now, the largest known circular labyrinth featured only 11 rings, making this discovery exceptional. Experts have linked the site to the Satavahana period, suggesting cultural and trade connections extending beyond the subcontinent, possibly towards the Roman world.

A labyrinth of 15 concentric rings discovered in Maharashtra is likely to have been a navigational marker

Agnikul Tests Indigenous 3D-Printed Rocket Engines

Indian private space startup Agnikul Cosmos has successfully test-fired two fully indigenous 3D-printed rocket engines, marking a major milestone in India's private launch vehicle programme. The company released footage showing both electric motor-driven, pump-fed, single-piece engines achieving thermal stability and sustained performance for 49 seconds. Conducted with support from ISRO and IN-SPACe, the test validates the engines' reliability under real firing conditions and brings Agnikul closer to the launch of its Agnibaan orbital rocket. The achievement underscores India's growing capabilities in private-sector propulsion technology.

IN-SPACe Launches Antariksh Prayogshala Initiative

The Indian National Space Promotion and Authorisation Centre (IN-SPACe) has announced plans to establish advanced space laboratories, named Antariksh Prayogshala, in academic institutions across the country. A Request for Proposal (RfP) has been issued to eligible institutions, aiming to bridge the gap between classroom learning and industry-ready space technology skills. Described as a first-of-its-kind national programme, the initiative will provide students with hands-on exposure to space systems and applications, while promoting collaboration between academia and the space industry. The effort aligns with India's long-term goal of emerging as a leading global space power.

All images courtesy: Internet

South Korea's Private Rocket Fails After Liftoff

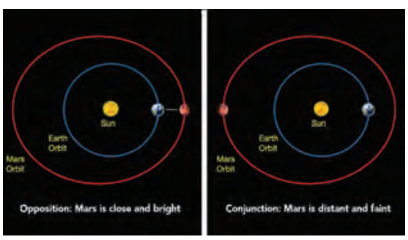
South Korean space startup Innospace suffered a major setback when its Hanbit-Nano rocket crashed roughly one minute after launch from Brazil's Alcantara Space Centre. The mission, launched at 20:13 EST on December 24, was intended to mark the first orbital launch attempt by a South Korean private company, a milestone for the country's commercial space ambitions. Tracking data showed the 57-foot-tall rocket experiencing an

South Korean rocket Hanbit-Nano collapsed back to Earth after liftoff

anomaly shortly after liftoff before falling back to the Earth. Innospace confirmed the failure but did not immediately disclose the cause, ending its live broadcast soon after the incident. Hanbit-Nano is a two-stage launch vehicle designed for the small satellite market, one of the fastest-growing segments of the global space economy.

Mars Missions to Go Silent During Solar Conjunction

NASA and other space agencies will temporarily lose all communication with spacecraft operating on Mars due to a solar conjunction, a recurring alignment that occurs roughly every two Earth years. During this period,



The current solar conjunction will peak around 9 January 2026

All images courtesy: Internet

which will take place from late December 2025 to mid-January 2026 and peak around 9 Januray 2026, the Sun will position itself directly between the Earth and the Mars, blocking line-of-sight communication. Charged particles from the Sun can interfere with radio signals, corrupting data sent from Mars and distorting commands transmitted from the Earth. To keep spacecrafts safe, mission controllers suspend active operations during this period. NASA compares the phenomenon to trying to communicate across opposite sides of a massive bonfire.

Interstellar Comet 3I/ATLAS Captured Near Earth

Astronomers have released the first detailed image of interstellar comet 3I/ATLAS as it passed closest to the Earth, offering a rare glimpse of a visitor from beyond the Solar System. The image was captured from a remote observatory in Utah, while precision measurements from the ATLAS survey in Chile confirmed its interstellar origin. This makes 3I/ATLAS only the

Interstellar comet 3I/ATLAS recently passed closest to the earth

third known object of its kind, following Oumuamua in 2017 and Borisov in 2019. The comet reached perihelion on 29 October 2025, passing 1.36 Astronomical Units from the Sun. Its closest approach to the Earth occurred on 19 December 2025, providing astronomers with a unique observational window.

Artificial Womb Shows Promise for Preterm Infants

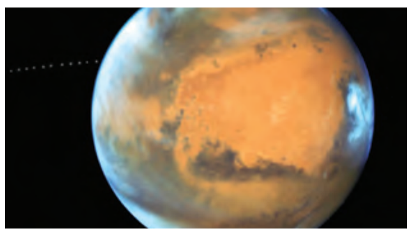
Scientists have developed an artificial womb system that could significantly improve survival chances for extremely premature babies. The technology is designed for infants born between approximately 24 and 28 weeks of gestation, a critical stage when organs, particularly the lungs, are not fully developed. By recreating conditions

Artificial womb recreates natural conditions to help preterm babies

inside the uterus, the artificial womb allows babies to continue developing in a protected environment, offering vital time that conventional neonatal care cannot provide. Premature birth remains one of the leading causes of newborn mortality worldwide. Juntendo University of Japan has been at the forefront of research in this field.

ESA Captures Phobos Crossing Mars

The European Space Agency has released striking new images of Phobos, Mars' innermost moon, appearing to glide across the face of the Red Planet. Captured by the Mars Express orbiter



ESA's Mars Express orbiter captured Phobos gliding across the Red Planet

and processed by imaging specialist Andrea Luck, the images show the small, irregularly shaped moon silhouetted against the dramatic surface of Mars. In one image, Phobos is seen passing between the Tharsis volcanic region and the vast canyon system spanning Noctis Labyrinthus and Valles Marineris, one of the most geologically striking landscapes of Mars.

Quiz

Q1. Which country's private space startup Innospace recently saw its Hanbit-Nano rocket explode shortly after launch from Brazil?
A. South Korea
B. Japan
C. India
D. None of the above

Q2. The James Webb Space Telescope (JWST) recently detected complex organic molecules primarily in:
A. Neutron star remnants
B. Protoplanetary disks
C. Cometary tails
D. None of the above

Q3. Which country announced a significant advance in controlled nuclear fusion by sustaining high-temperature plasma for record durations in 2025?
A. United Kingdom
B. China
C. France
D. None of the above

Q4. The asteroid sample-return mission that brought pristine material from asteroid Ryugu back to Earth was conducted by:
A. NASA
B. ESA
C. JAXA
D. None of the above

Q5. 'Frontier', often cited as the world's most powerful supercomputer in recent reports, is primarily used for:
A. Military encryption only
B. Financial market simulations
C. AI research and climate modelling
D. None of the above

Q6. Which emerging technology is expected to render current public-key encryption methods obsolete, prompting global cybersecurity concerns?
A. Blockchain hashing
B. Quantum computing
C. Optical data storage
D. None of the above

Q7. Research aiming to restore traits of extinct species using CRISPR and synthetic genomics is best described as:
A. Molecular archaeology
B. Evolutionary genetics
C. Zoological engineering
D. None of the above

Q8. Conclusive confirmation of water ice near the Moon's south pole in recent years came from which mission?
A. Artemis-I
B. Luna-25
C. Chandrayaan-3
D. None of the above

Q9. The 'Blue Economy', frequently discussed at international science and policy forums, primarily focuses on:
A. Naval modernisation
B. Sustainable use of ocean resources
C. Deep-sea warfare technology
D. None of the above

Q10. Recent breakthroughs allowing paralysed patients to communicate via direct neural signals are linked to:
A. Brain–computer interfaces
B. Neural stem-cell transplants
C. Artificial spinal cords
D. None of the above

GOOD TO KNOW

Infosys Prize 2025

- The Infosys Prize is a prestigious annual award presented by the Infosys Science Foundation (ISF) to honour exceptional research contributions across multiple disciplines.
- It is awarded in six fields: Economics, Engineering and Computer Science, Humanities and Social Sciences, Life Sciences, Mathematical Sciences, and Physical Sciences.
- Each laureate receives a gold medal, a formal citation, and a prize purse of USD 100,000.
- Economics Winner 2025–Nikhil Agarwal. Awarded for his pioneering contributions to market design, including empirical insights into complex allocation systems like school choice and kidney exchanges. He is Paul A. Samuelson Professor of Economics at MIT.
- Engineering & Computer Science – Sushant Sachdeva: Recognised for deep theoretical advances in mathematical optimization and algorithms. He is an Associate Professor at the University of Toronto.
- Humanities & Social Sciences – Andrew Ollett: Honoured for his scholarship on Prakrit languages and Indian poetics. He teaches at the University of Chicago.
- Life Sciences – Anjana Badrinarayanan: Awarded for innovative work on genome maintenance and DNA repair mechanisms. She is an Associate Professor at the National Centre for Biological Sciences, Bengaluru.
- Mathematical Sciences – Sabyasachi Mukherjee: Recognised for his original mathematical research linking group dynamics and complex systems. He is an Associate Professor at TIFR, Mumbai.
- Physical Sciences – Karthish Manthiram: Won for pioneering sustainable electrochemical methods to produce essential chemicals. He is a Professor of Chemical Engineering at the California Institute of Technology (Caltech), Pasadena, California.

Answers : 1 (A); 2 (B); 3 (B); 4 (C); 5 (C); 6 (B); 7 (D); 8 (C); 9 (B); 10 (A)

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LVM3-M6 / Bluebird Block-2 Mission

Image Courtesy: ISRO

LVM3 is the operational heavy lift Launch Vehicle of ISRO and has a spectacular pedigree of completing eight consecutive successful missions. LVM3-M6 is the Sixth Operational Flight of LVM3 and third dedicated commercial mission to launch the BlueBird Block-2 spacecraft, which is the heaviest payload (~6100 kgs.) in the LVM3 launch history, into Low Earth Orbit (LEO).

Celebrating Science This Month

JANUARY 1
Satyendra Nath Bose, best known for his work on quantum mechanics, was born in 1894. He collaborated with Albert Einstein in developing the foundation for Bose-Einstein statistics and the theory of the Bose-Einstein condensate.

Shanti Swarup Bhatnagar, the father of research laboratories in India, passed away in 1955. He was the first DG of CSIR, first chairman of UGC, a colloid chemist, academic and scientific administrator.

Subramanian Kalyanaraman, an Indian neurosurgeon, was born in 1934. He was known for his pioneering techniques in stereotactic surgery.

JANUARY 2
Physicist Deb Shankar Ray was born in 1954.

Nil Ratan Dhar, the Father of Indian Physical Chemistry, was born in 1892. He discovered thermal and photochemical fixation of atmospheric N_2 in the soil.

JANUARY 3
Bhabha Atomic Research Centre (BARC) was established in 1954. BARC was first instituted as the Atomic Energy Establishment, Trombay (AEET), with Homi Jehangir Bhabha, who conceived India's nuclear programme, as its first director.

JANUARY 5
Nil Ratan Dhar passed away in 1986.

JANUARY 6
The founder-president of the Indian Academy of Forensic Medicine, Idupuganti Bhooshana Rao, was born in 1914. He was a leading figure in the field in India.

JANUARY 7
The Indian National Science Academy (INSA), earlier called The National Institute of Sciences of India, was founded in 1935 in Calcutta. It was shifted to New Delhi in 1951 and got its present name in 1970.

JANUARY 9
Har Gobind Khorana, an Indian American biochemist, was born in 1922. He shared the 1968 Nobel Prize for Physiology or Medicine with Marshell W Nierenberg and Robert W Holley.

JANUARY 10
Haffkine Institute, named after Dr Waldemar Mordecai Haffkine, who invented the plague vaccine, was established in 1899 in Bombay.

JANUARY 12
National Youth Day is celebrated every year to commemorate the birth anniversary of Swami Vivekananda, the great philosopher, religious teacher, monk, and scientific visionary, who was born in 1863.

Yellapragada Subbarow, the Indian biochemist, who discovered the function of adenosine triphosphate as an energy source in the cell, was born in 1895

JANUARY 13
Rakesh Sharma, the first Indian to travel to space aboard a Soviet rocket in 1984, was born in 1949.

JANUARY 14
Raghunath Dhondo Karve, who initiated the family planning and birth control for masses in Bombay, was born in 1882.

JANUARY 16
Subhash Mukhopadhyay, an Indian scientist and physician who created the world's second and India's first child using in-vitro fertilisation, was born in 1931.

JANUARY 20
Hindoo College was established in 1817 in Calcutta. Today, it is known as the Presidency University.

JANUARY 24
The University of Calcutta was established in 1857.

Homi Jehangir Bhabha, Indian nuclear physicist also known as the father of the Indian nuclear programme, passed away 1966. He was the founding director of the Atomic Energy Establishment, Trombay (AEET), which was named after him posthumously as the Bhabha Atomic Research Center (BARC).

JANUARY 26
T C Anand Kumar, the creator of the second scientifically documented test tube baby in India, passed away in 2010.

Central Agricultural University was established at Lamphelpat, Imphal, Manipur, in 1993.

Gopinath Kartha, an Indian crystallographer, was born in 1927. He determined the structure of the enzyme ribonuclease.

JANUARY 28
Raja Ramanna, Indian physicist known for his role in India's nuclear programme, was born in 1925. India's first nuclear reactor, Apsara, was designed under his guidance. He served as the Director of BARC, and director general of DRDO.

JANUARY 31
Royal Society, UK, honoured Acharya Prafulla Chandra Ray's work with the Chemical Landmark Plaque in 2012. This was the first-ever Landmark Plaque awarded to anyone outside Europe.

**Compiled by Surbhi Agarwal and Dr Rajeev Singh, University of Delhi.*

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