DEVENDRA LAL
14 February 1929 — 1 December 2012
Devendra Lal was an Indian nuclear physicist who began his career studying particle physics while a student at the Tata Institute of Fundamental Research (TIFR) in Bombay, using tracks in nuclear emulsions to study cosmic ray particles and their interactions. He soon moved on to the search for radionuclides produced in the atmosphere by cosmic ray bombardment, independently (with colleagues) discovering radioisotopes of Be, P and Si and using them as geophysical tracers for atmospheric, meteorological and oceanographic processes. His career revolved principally around multiple aspects of cosmic rays, employing theory and experiment to examine their flux, chemical composition and energy spectrum, both at present and in the past through (for example) studies of particle tracks in the minerals of meteorites and lunar samples. He played a major role in developing approaches for the use of terrestrial cosmic-ray-produced isotopes as dating tools and tracers for a wide range of Earth processes, from biological cycles in the ocean to landscape evolution and ice ablation in the Antarctic. At various stages of his career Lal was professor at TIFR and led the geophysics group there, was professor and director of the Physical Research Laboratory in Ahmedabad, India, and was professor at the Scripps Institution of Oceanography, University of California San Diego. He was elected fellow of numerous scientific organizations and academies internationally, and was the recipient of many scientific awards and prizes.
EARLY LIFE

Devendra Lal was born in Banaras (Varanasi), India, the fifth child in a large family (he had seven brothers and four sisters). From a young age he was inquisitive. The story goes that when he wanted to buy a camera his postmaster father told him he would have to find the money himself, so he learned to make fireworks, vanishing creams, fountain pen ink and several other commodities to sell in the local market (K. Gopalan, personal communication). Those of us who knew Lal later in life suspect that he would have done such things even if he hadn’t needed to raise funds for a camera (Lal was universally known by his surname, a practice we will follow here). Even as a senior professor he continued to tinker with a range of side projects, perhaps most notably his quest for the perfect ‘white out’, the commercial product used to paint over errors in typewritten manuscripts. Several of Lal’s colleagues and graduate students recall being bomburred over many years with requests and questions related to this quixotic project. Lal’s early fascination with the hands-on chemistry required to make fireworks and other products was a foretaste of his later scientific work. Although he always considered himself to be first and foremost a nuclear physicist, much of his work in both cosmic ray geophysics and particle track studies of minerals depended on his chemical knowledge and skills. One of the many awards he won was the Goldschmidt Medal of the Geochemical Society.

Lal’s early education was in the city of his birth, first at Harishchandra High School, then Queen’s Intermediate College and, finally, Banaras Hindu University (BHU), where he obtained his BSc in 1947 and MSc in 1949. Both BHU degrees were in physics, a subject that fascinated him, and he was determined to pursue postgraduate work in the same field. But he did not want to stay in Varanasi, setting his sights instead on obtaining a place at the then newly founded Tata Institute of Fundamental Research (TIFR) in Bombay. His family were opposed, but he prevailed and in 1949 was admitted to the new institute, along with a small cadre of other students making up TIFR’s very first group of PhD students. He immediately began research in particle physics, using nuclear emulsions to study cosmic ray particle interactions under the tutelage of H. J. Taylor, a noted English physicist and nuclear emulsion expert who at that time supervised the cosmic ray group at TIFR and also served as professor of physics at nearby Wilson College. Lal’s first scientific paper appeared in 1950 (1); co-authored with Taylor, it is a short note in Nature describing an unusual particle decay track detected in an emulsion plate that had been exposed to cosmic rays in a high-altitude (90,000 feet) balloon flight near Bangalore in southern India.

AT TIFR WITH BERNARD PETERS

Barely a year after Lal arrived at TIFR, an event that would set the stage for much of the rest of his career occurred: a visit to India by the nuclear physicist Bernard Peters, who at that time was working at the University of Rochester in the United States. Like Taylor, Peters was interested in cosmic rays and their interactions in the atmosphere, and he visited India to participate in the low-latitude balloon flight programme that TIFR was already running as part of its cosmic ray research programme. Peters duly arrived in Bombay with his equipment at the end of August 1950, and for the next few months immersed himself in the balloon experiments. Lal participated in all aspects of the work, and he would later say
that the experience was a revelation for him, opening his eyes to how basic research was
carried out, from concept to implementation (37). The experiments were so successful, and
Peters was so impressed by the facilities and talent at TIFR, that he accepted an invitation
from Homi Bhabha, then director of TIFR, to join the institute in a more permanent capacity
the following year. Peters moved his family from Rochester to Bombay, and Lal became
his student.

During the first few years of their collaboration, Lal’s work with Peters concentrated on
research into the nature of the high-energy component of cosmic rays, and their interactions
with other nuclei, again using nuclear emulsions flown to high altitudes in balloons. India’s
geographical location was ideal for such studies because at low latitudes the geomagnetic
field shields the atmosphere from low-energy particles, drastically reducing the density of
background tracks in the emulsions. Peters had the idea of using emulsion stacks—up to a few
dozen emulsion layers fastened together in a block—which allowed the tracks of particles,
and the tracks of their interaction products, to be traced over long path lengths. With this
method the TIFR group were able to study particles of far higher energy than could be
produced at the time by laboratory accelerators. A series of papers documenting this work,
most first-authored by Lal, appeared between 1952 and 1954 (e.g. 2–6). They described
the production and interaction of mesons at high energy, the properties of heavy, unstable
particles, as revealed from their decay in the emulsions, and, perhaps most interesting, the fact
that the primary cosmic radiation has essentially constant chemical composition up to high
energies (over a factor of at least 1000 in energy per nucleon, encompassing at least 95% of
the incident energy). The cosmic ray group at TIFR, with Peters as its leader and Lal as a
leading researcher, had quickly established Bombay as an important world centre for particle
physics research.

However, around the world accelerators were increasingly becoming larger and more
powerful, capable of producing particles of higher and higher energy. Peters realized that
the advantage the TIFR group had for studying high-energy particles was fast eroding, and
he decided to focus his attention on another area of cosmic ray physics: the radioisotopes
produced by cosmic ray interactions in the atmosphere. Several years earlier, Willard Libby
had discovered $^{14}$C produced in the atmosphere by cosmic rays and had begun to use it
as a dating tool. Cosmic-ray-produced tritium had been detected in 1951. Peters wanted to
investigate whether there were additional cosmic-ray-produced radioactive isotopes in nature
that might be useful as tracers or dating tools, and he told Homi Bhabha that he would like to
start a new group at TIFR devoted to that task: a geophysics group. Bhabha gave him a free
hand and said he should not worry about the cost. Although several of Lal’s TIFR colleagues
tried to persuade him that he would be crazy to leave the cosmic ray group, he decided to
follow Peters into this new area of research. He later recounted that his friends had told him he
should stick with particle physics because it was a prestige discipline, while ‘geophysics [was]
zero physics’ (Kohl 1997). However, he was not dissuaded and quickly immersed himself in
the new field.

The geophysics investigations were an entirely different experience from studying
nuclear emulsions with a microscope. The expected quantities of most cosmic-ray-produced
radioisotopes were vanishingly small; the newly established geophysics group had to learn
how to process very large samples chemically in order to separate the elements in question,
and they also had to build, from scratch, detectors with very low backgrounds so that they
could measure the feeble radioactivity of the samples. They were successful in both tasks. Lal
was deeply involved in building the low-background counters; with his characteristic vigour and enthusiasm he enlisted the help of both TIFR technicians and silversmiths in the Bombay markets to get the job done. When Peters sent him to Harwell and several other laboratories to learn more about low-level counting he discovered to his surprise that the TIFR counters actually had lower backgrounds, by a factor of three or four, than those he saw abroad. He reported back to Peters that they were doing fine.

In about 1954 Peters concluded that two radioisotopes of beryllium, $^7\text{Be}$ and $^{10}\text{Be}$, would be the best candidates for initial investigation. Both are produced by spallation reactions on N and O in the atmosphere, and, based on Be chemistry, were expected to attach themselves to atmospheric dust particles and/or be washed out by rain. Peters was particularly interested in $^{10}\text{Be}$ because its relatively long half-life (1.5 million years) promised to make it especially useful for chronology and as a tracer ($^7\text{Be}$ has a half-life of only 53 days). But the question was: where should they search for this rare isotope? The answer the TIFR group came up with was Himalayan snow. So, in the spring of 1955 Peters, Lal and two other TIFR scientists set off on an expedition to Kashmir in pursuit of $^{10}\text{Be}$. It would be a massive undertaking. In order to separate a detectable amount of the isotope, they calculated they would need about 200,000 gallons of meltwater. The idea was that the meltwater would be processed—in a series of steps—through ion exchange columns and in the final step all of the $^{10}\text{Be}$ atoms would be collected on a single resin bead, which could then be placed on a freshly prepared nuclear emulsion sheet in order to detect radioactivity. Some TIFR scientists were convinced that the newly formed geophysics group had collectively gone mad.

Peters did not stay at the field camp for long; after less than a week he returned to Bombay to organize collection of the first monsoon rains of the year in order to search for the shorter-lived beryllium isotope, $^7\text{Be}$, leaving his young colleagues to continue the heroic task of melting vast quantities of Himalayan snow and separating $^{10}\text{Be}$. With them was a young TIFR technician, Aruna Damany. She and Lal had been married just a week earlier, and the working trip to Kashmir was their honeymoon. From that moment on, until her untimely death in 1993, Aruna was a constant and indispensable aid to Lal’s scientific endeavours. It is no exaggeration to say that she played a significant part in his many scientific successes (figure 1).

In the end, the experiment with Himalayan snow did not lead to unambiguous detection of $^{10}\text{Be}$; that occurred about a year later when the TIFR group separated the isotope from deep sea sediments. But his experience in Kashmir gave Lal an appreciation for large-scale experiments and the confidence throughout his career to tackle problems that others dismissed as impossible. A good example was his quest for a technique to separate extremely low concentration elements and isotopes from seawater. His solution was to load a framework consisting of a large volume of sponge, jute fibre or acrylic fibre with ferric hydroxide, which has the ability to efficiently scavenge many elements, and tow this material behind ships (13, 21). In this way he was able to collect cosmic-ray-produced isotopes as well as a variety of trace elements from many hundreds of tons of seawater without having to process the water directly.

When Lal and his colleagues returned from Kashmir they immediately set about separating Be from the monsoon rainwater that Peters had collected, in order to look for $^7\text{Be}$. This time they were successful (7), and they believed they were the first to measure the isotope in nature. However, they soon learned that the US scientist Jim Arnold had recently published a paper announcing the detection of the isotope in Chicago rainwater (Arnold & Al-Salih 1955). Arnold had actually made the discovery a year and a half earlier, after collecting
and processing the rainwater during the winter of 1953–1954, but blanket US government classification of all work dealing with radioisotopes of any kind had delayed publication of his paper.

For the next few years Lal and the TIFR geophysics group forged ahead with their investigations of naturally occurring cosmic-ray-produced isotopes. In 1956 they detected and measured $^{10}$Be in deep sea sediments collected from the eastern Pacific Ocean during the Swedish Albatross expedition (8). Essentially simultaneously Jim Arnold (then at Princeton University) also reported detecting $^{10}$Be in Pacific sediments (Arnold 1956). In 1957 Lal and his colleagues reported measurements of two short-lived isotopes of phosphorus, $^{32}$P and $^{33}$P (half-lives of approximately 14 and 25 days, respectively), in Bombay rainwater and discussed the potential of using this pair of isotopes with the same chemical properties but different half-lives for tracing large-scale atmospheric processes (9).

**Interlude in La Jolla**

By this time, because of their parallel interests in cosmic-ray-produced isotopes, Jim Arnold at Princeton and Bernard Peters at TIFR were in frequent communication. But Arnold was about
to move from Princeton to the Scripps Institution of Oceanography in La Jolla, California, and
at about the same time the director of the institution, Roger Revelle, invited Lal to visit as a
postdoc. The informality of the invitation letter surprised Lal. There were no strings attached;
he would be free to pursue any avenue of research he desired. However, Revelle noted that
Jim Arnold would soon be coming to Scripps and in light of their similar interests Lal could
‘work with Arnold if [he] wanted to’. He jumped at the opportunity.

Lal arrived at Scripps in November 1958, just a few months after Arnold, and remained
in La Jolla for the next year and a half. He later remarked that this period was one of
the most intense and productive of his life in science. It was, he said, ‘like being shot by
hundreds of guns’ (Kohl 1997), a strange metaphor but one that underlines the uniqueness
of his postdoctoral experience. It was the beginning of a long association with the Scripps
Institution that would last until his death in 2012.

At the time of Lal’s postdoctoral stay, Scripps was a dynamic, interdisciplinary centre for a
broad spectrum of science. Director Revelle had grand ambitions: from the nucleus of a then
relatively small oceanographic institution, he was in the process of developing a new campus
of the University of California. It would eventually become the University of California San
Diego (UCSD). Revelle began by recruiting founding faculty in the sciences, physics and
chemistry in particular. Jim Arnold, with whom Lal worked closely while in La Jolla, was one
of the first (Revelle recruited him as head of the chemistry department for the new university);
Nobel Prize winning chemist Harold Urey was another. The focus for the new university
was to be excellence above all else. Because buildings and facilities for the nascent campus
were still under construction, the early faculty worked in the seaside buildings of the Scripps
Institution, many of them living in small cottages on the institution grounds. The atmosphere
was egalitarian, and they lived and breathed science. For a young scientist from India it was a
dream come true.

As Revelle’s invitation letter had promised, Lal quickly discovered that he could conceive
and carry out virtually any research he wanted while at Scripps. Many decades later he still
expressed amazement at the freedom—and the absence bureaucratic restrictions—of those
times. In the 1997 oral history interview (Kohl 1997), he recounted an example: he and
Masatake Honda, a Japanese chemist who was also visiting Scripps and working with Arnold,
devised an experiment to measure cosmic ray production rates for various radionuclides by
exposing water and argon at high altitude on Mt Evans, in Colorado (an easily accessible peak
that had long been used for cosmic ray studies). However, Arnold did not have enough extra
funding to cover the costs of the experiment; he suggested that Lal should send a request to the
National Science Foundation. Lal had no previous experience with funding applications, but
he sat down and composed a brief letter—he says it was just one and a half pages long—and
sent it off. Within a few months they had the necessary funds.

Lal’s work during this period resulted in a series of important papers. Working with Arnold
and Honda, he measured production rates of a variety of cosmic-ray-produced radioisotopes,
including $^7$Be, $^{32}$P, $^{33}$P and $^{35}$S, based on data from the experiment at Mount Evans (11).
With the same colleagues he became involved in the measurement of cosmic-ray-produced
radioisotopes in meteorites, in particular through a major study of an iron meteorite in which
they compared calculated and measured amounts of a wide range of isotopes and concluded
that cosmic ray intensity had been broadly constant over periods up to millions of years (12).
As might be expected, interaction with colleagues at an oceanographic institution led Lal to
recognize the potential for using cosmic-ray-produced radioisotopes in oceanography. With
Ed Goldberg and Minoru Koide he set out to detect and investigate $^{32}\text{Si}$ (half-life 710 years) in the oceans by analysing sponges dredged from the Gulf of California (had they worked directly with seawater, up to hundreds of tons would have been necessary to obtain enough Si for their measurements; by focusing on sponges that extract the silicon for their skeletons from seawater they let nature do the concentration for them). In the *Science* paper on this discovery Lal and his colleagues discussed how the isotope could be used to study mixing of oceanic water masses, sediment accumulation rates and the silicon geochemical cycle (10).

Lal’s relatively short postdoctoral stay in La Jolla was highly productive. As already mentioned, the timing of his visit coincided with an interval of high intellectual excitement at the Scripps Institution and the new university. In a 1985 interview about the founding of UCSD, Roger Revelle commented on the stellar accomplishments of several of the early faculty recruits during that time. He also singled out the work of Devendra Lal, who had then been at Scripps not as a new faculty member but as a postdoc. He went on to say that Lal was now (at the time of the interview) a full professor at UCSD (Ringrose 1985).

At TIFR

At the end of his postdoctoral stay in California, and at Homi Bhabha’s urging, Lal returned to TIFR in 1960. Peters, who in a few short years had made an indelible impression on science at the institute and in India generally, was no longer there, having left to take up a position in Denmark at about the same time Lal departed for his California postdoc. With Peters gone, Lal now had his own research group at TIFR, and with his students and colleagues he quickly branched out into several new applications of cosmic ray geophysics. Notably, this was when he began what would be one of his signature achievements: guiding and nurturing bright young scientists who would go on to highly successful careers of their own in India and abroad. He set up India’s first $^{14}\text{C}$ laboratory, primarily with archaeological applications, and launched a programme to use tritium as a groundwater tracer. With his students he pursued applications of various cosmic-ray-produced isotopes in oceanography and atmospheric circulation. He also published several important papers stemming from both his earlier work with Peters and his postdoctoral research at the Scripps Institution—perhaps most importantly the still heavily referenced Lal and Peters paper on terrestrial cosmic-ray-produced radioactivity that appeared in *Handbuch der Physik* in 1966 (14). The production rates of a large range of radioisotopes calculated in this paper were the foundation for much subsequent research by Lal and others.

Buford Price, then at General Electric’s research laboratory in Schenectady, New York, visited TIFR as a Fulbright Fellow in 1965–1966. Price, together with his GE colleagues Bob Walker and Bob Fleischer, was developing the field of nuclear particle tracks in solids. Lal’s background in nuclear emulsion work, coupled with Price’s expertise, quickly led them to develop methods for revealing cosmic ray and solar flare tracks in the minerals of meteorites. Much of this work depended on Lal’s chemistry skills coupled with his curiosity, energy and enthusiasm: his group tested hundreds of ‘recipes’ for just the right solutions and conditions to effectively reveal the tracks of heavy nuclei in various minerals by etching away the damaged regions without significantly affecting the minerals themselves (15). Based on microscopic studies of these tracks, Lal and his students were soon publishing papers on the chemical composition and energy spectrum of the prehistoric cosmic ray flux (16, 25). They also published details of how individual crystals in gas-rich meteorites had been irradiated in
space prior to incorporation into the matrix of the meteorites (17). These investigations had implications not only for cosmic ray physics, but also for the history of meteorites. The nuclear track studies of meteorites led naturally to Lal’s research group at TIFR being approved for studies of the Apollo lunar samples.

### Appointment to UCSD Faculty

In 1967, Lal was appointed professor at the Scripps Institution at UCSD on a part time basis. He remained a professor at TIFR as well, and from that point onward he began making regular trips between the two institutions. This was also the time when Aruna’s support became especially crucial to his career. The couple had already decided not to have children in order to focus on Lal’s science, and Aruna’s help in smoothing over the disruption of periodically moving their household half way round the world and her aid with administrative work, library searches and other day-to-day activities were invaluable. This was especially true at Scripps, where professors had less ready access to such help from institution staff than they did at TIFR.
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With his appointment at Scripps, Lal’s lunar sample studies, and much of his other research, were carried out both in India and in southern California, and he had students and scientific collaborators in both places. As might be expected, his joint appointments facilitated extensive and fruitful exchanges in both directions. Several of his Indian students became deeply involved in marine geochemistry, spending time at Scripps and using the expertise in low-level counting that had been developed at TIFR to investigate a range of radioisotopes in the marine environment beyond those produced by cosmic rays. At the same time several of Lal’s American students and colleagues made research visits of varying duration to TIFR. During the late 1960s and early 1970s Lal’s numerous publications spanned an eclectic range of subjects, from laboratory experiments to study ion implantation in metals with the aim of finding suitable material for space experiments to study the solar wind composition (18), to theoretical studies of the size distribution of particulate matter in the oceans (24), investigations of the dynamics of the lunar regolith (19), examinations of trace element budgets in seawater (22), measurements of the long-term variability of cosmic ray heavy nuclei flux at 1 AU (20), studies of low-energy solar cosmic ray nuclei in a Skylab experiment (27), chronology of marine sediments using $^{10}$Be (23), and more. Much, but not all, of this work incorporated Lal’s expertise in low-level radioisotope measurements or particle track studies.

At the Physical Research Laboratory
And the Scripps Institution

In 1972 Lal was appointed Director of the Physical Research Laboratory (PRL) in Ahmedabad, a position he held until 1983 (figures 2 and 3). He took his entire TIFR research group with him, bringing a new area of investigation, geophysics, to PRL. With typical energy and force of personality, Lal restructured programmes at the laboratory and started new ones—in plasma physics, in infrared astronomy and in climatology—not always to the approval of some long-term members of PRL. But, like his determination as a young student to follow Bernard Peters into geophysics rather than stay in particle physics, his vision and determination paid off. The new areas thrived. In spite of the increased burden of administrative duties, he continued to be immersed in both theoretical and experimental work with his students and colleagues, and he also maintained his appointment at the Scripps Institution, typically spending part of each year in La Jolla. During this time his work primarily revolved around using particle track studies in lunar samples and meteorites to examine the flux variations, energy spectra and charge compositions of heavy cosmic ray nuclei, and also using terrestrial cosmic-ray-produced radionuclides to address problems in oceanography (e.g. 26, 28). He also continued his long-term interest in $^{14}$C, working extensively on the terrestrial distribution of cosmic-ray-produced radiocarbon and its implications for understanding temporal variations in solar activity, secular variations in the geomagnetic dipole field and variations in the carbon cycle over the past 40–50 thousand years (e.g. 29, 30).

After giving up the PRL directorship in 1983, Lal began to spend more time at the Scripps Institution, although he remained senior professor at PRL until 1989 when he reached the retirement age of 60. During this time—the late 1970s into the 1980s—advances in accelerator mass spectrometry (AMS) made possible the quantitative measurement of extremely small amounts of individual isotopes. Applied to the radioisotopes produced by cosmic rays, the
gain in sensitivity relative to traditional counting techniques was enormous, about three orders of magnitude. Direct counting was soon supplanted, especially for the longer-lived (and therefore more difficult to measure by direct counting) isotopes. With his extensive background in cosmic ray investigations, Lal was ideally placed to take advantage of the new approach. But characteristically he did not limit himself to the kinds of studies he had done in the past. He realized that with the hugely increased sensitivity it might be possible to detect radioisotopes produced by cosmic rays \textit{in situ} at the Earth’s surface, not just those produced in the atmosphere. The production rates in materials such as surface rocks or glacial ice would be much lower than in the atmosphere, resulting in correspondingly smaller quantities for measurement, but even so it quickly became apparent that even these tiny amounts would be measurable using AMS. Soon, Lal and his students and colleagues were extracting and measuring a large range of isotopes produced \textit{in situ} in surface rocks and minerals ($^3$He, $^{37}$Ar, $^{39}$Ar, $^{10}$Be, $^{26}$Al) as well as in glacial ice ($^{14}$C and $^{10}$Be). They also conducted laboratory experiments to measure production rates in these materials. This work spawned an entirely new way of investigating Earth surface processes, and showed that
these isotopes could be used to track glacial erosion, illuminate geomorphological processes, calibrate erosion surfaces, examine soil dynamics, study the ablation of glacial ice and much more, as summarized in Lal’s 1988 review paper in the *Annual Review of Earth and Planetary Sciences* (32).

At the same time as he pursued studies of *in situ* produced isotopes using AMS, Lal continued to be involved in both direct investigations of cosmic rays and experiments using conventional counting methods to investigate short-lived cosmic-ray-produced radioisotopes in the ocean. As principal co-investigator, working with colleagues at TIFR, he played an integral part in the Indian Anuradha (IONS) experiment, flown on Spacelab-3 aboard the space shuttle *Challenger* in late April and early May 1985. The aim of the experiment was to investigate the ionization states, flux and compositions of heavy, low-energy ions of the ‘anomalous cosmic rays’ (ACR). The equipment operated successfully, and the first results were reported in 1986 (31). Many other papers followed. A major finding was the confirmation of the presence of singly ionized ACR in near-Earth space.

Working with students at the Scripps Institution, he conducted experiments using two short-lived radioisotopes of P ($^{32}$P and $^{33}$P, with half-lives of 14.3 and 25.3 days, respectively; as described earlier, Lal had been a key player in the discovery of these isotopes in Bombay rainwater in the 1950s) to investigate nutrient recycling in the upper ocean (figure 4). The experiments were carefully designed: at oceanographic stations off southern California, Lal collected dissolved inorganic phosphorus by passing large quantities of filtered seawater through Fe(OH)$_3$ coated acrylic fibres, and dissolved organic phosphorus by running similarly
large amounts of filtered seawater through activated charcoal columns. Particulate-associated phosphorus was extracted from plankton collected in net tows. The experiments produced data that permitted calculations of the mean residence time of dissolved inorganic phosphorus in the mixed layer, gave detailed information about phosphorus transfer across the thermocline and (because collections were made both at night and during the day) provided information about the diurnal cycling of phosphorus caused by the vertical migration of plankton (33). Typical of Lal’s approach to science, once he had demonstrated the utility of this new way of examining nutrient cycling, he did not mount a campaign to employ the method at other locations in order to work out a more detailed description of the process, as some might have done. He was always looking for new challenges, and moved on to other investigations.

From the late 1980s until his death in 2012, Lal worked permanently at the Scripps Institution (figure 5), although he retained a home in Ahmedabad and returned to India for a month or more each year to interact with colleagues and give lectures around the country. He continued to be very active, characteristically working with students and multiple collaborators, focusing primarily on applications of cosmic-ray-produced isotopes to a wide

Figure 5. Lal in his laboratory at the Scripps Institution of Oceanography, October 2010. (Photograph courtesy of Tim Jull.) (Online version in colour.)
range of problems in the earth sciences, from oceanographic processes to soil dynamics and the ablation rates of glacial ice in the Antarctic (e.g. 34–36, 38–44).

**SOME GENERAL OBSERVATIONS ON LAL’S CAREER**

Throughout his life Lal was intensely curious and inventive. He was forever asking colleagues, students, friends, children of friends—scientists or not—what new thing they had learned that day. He loved jokes and often asked friends to tell him a new joke, although—in spite of his long residence in the United States—he was sometimes puzzled by American humour. He had a seemingly endless and ever-changing supply of games and puzzles, and he was constantly trying them out on friends and colleagues. Because he and Aruna had no children of their own, both of them doted on and spoiled the children of Lal’s colleagues—and in return were much loved by those children. Once, Lal suggested to a colleague that instead of sending his child to school, he should simply teach him quantum mechanics. It would be a great experiment, he said.

Lal’s driving force in science was to learn how things worked. He thrived on ‘quick and dirty’ experiments and back of the envelope calculations to check an idea. No experiment was too far-fetched. And if something didn’t work, well, make some changes and try again. He was one of those ‘larger than life’ figures and his energy and enthusiasm were infectious, although sometimes, when sustained, wore down lesser mortals.

His brilliance as a scientific innovator was recognized worldwide, both in a formal sense—he was the recipient of prestigious awards and medals, and was elected fellow of numerous societies and academies—and in a less quantifiable but equally important way through the admiration of and often direct collaboration with a wide range of high profile scientists from around the globe. In addition to being elected Fellow of the Royal Society, Lal was a Foreign Associate of the US National Academy of Sciences, an Associate of the Royal Astronomical Society and a fellow of the Indian National Academy of Sciences, the American Association for the Advancement of Science, the Geochemical Society, the Indian Geophysical Union and the Meteoritical Society. He was the recipient of the Pandit Jawaharlal Nehru Award for Science and the Goldschmidt Medal of the Geochemical Society, among others.

Lal loved to work with young people, and for those willing to learn he was a wonderful teacher. He expected his students to work at least as hard as he did, and he was very generous toward those who did. At UCSD, in addition to graduate-level courses, he often taught in the undergraduate seminar programme, in which a single topic was explored with a small group of students over the course of a 10-week academic quarter. Any undergraduate could enrol in these seminars; the programme was designed to give students access to a wide range of topics outside their own academic focus, and also give them the opportunity to interact with faculty members in a more intimate setting than the typical large university class. Lal sometimes complained that many of the students in these seminars had inadequate training in mathematics, but he would nevertheless spend hours in his office talking them through complex ideas. He would also work late into the evening with his graduate students and colleagues, in the lab, in his office or sometimes at home, with Aruna supplying coffee and food and Hindi movie music playing quietly in the background. He worked tirelessly to ensure that talented young scientists received recognition—especially those with whom
he worked closely, although not limited to them. In perfect harmony with his lifelong immersion in science, Lal willed his body to science so that it could be used for research and education.

HONOURS AND AWARDS

1963 Fellow, Indian Geophysical Union
1964 Fellow, Indian Academy of Sciences
1965 Krishnan Medal for Geochemistry
1967 S. S. Bhatnagar Memorial Award for Physics
1971 Fellow, Indian National Science Academy
1975 Foreign Associate, National Academy of Sciences, USA
1979 Fellow, Royal Society of London
1975 Fellow, Meteoritical Society
1981 DSc (Hon Causa) Banaras Hindu University
1981 K. S. Krishnan Memorial Lectureship
1983 Founder member, Third World Academy of Sciences
1984 Associate, Royal Astronomical Society of London
1986 Pandit Jawaharlal Nehru Award for Sciences
1988 Fellow, National Academy of Sciences, India
1989 Foreign Honorary Member, American Academy of Arts and Sciences
1992 Honorary Fellow, Geological Society of India
1997 Fellow, The Geochemical Society
1997 Fellow, American Association for the Advancement of Science
1997 Goldschmidt Medal of the Geochemical Society

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The portrait photograph is from the Royal Society's collection and is © Godfrey Argent (1979).

AUTHOR PROFILES

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J. D. Macdougall

Doug Macdougall is a geoscientist and writer based in Edinburgh. Born in Toronto, he was educated at the University of Toronto and McMaster University before pursuing a PhD at the Scripps Institution of Oceanography, where Devendra Lal was co-advisor (with G. Arrhenius) for his thesis. After a postdoc at Berkeley he returned to Scripps on
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the faculty, and throughout his career collaborated and co-taught courses with Lal. He is currently Emeritus Professor of Earth Sciences at Scripps/UCSD.

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