NEWS

Sol gel process for making ceramic fibres*

Ceramic fibres are flexible and lightweight. Being refractory, they are used as insulating materials in high temperature furnaces and they save enormous amounts of energy. They have found considerable applications in domestic heating appliances also. Being very strong and also lightweight, they are slowly revolutionizing aerospace industry. The conventional practice of making ceramic fibres is to extrude ceramics melted at very high temperatures through a set of fine holes approximately 3 µm in diameter. In this process a strict control of the diameter has not been possible. Unfortunately, ceramic fibres less than 1 µm diameter are considered very carcinogenic and those finer than 3 µm diameter can get ingested into the lungs during the manufacturing process and can cause serious respiratory diseases. They can also cause severe skin irritation. As a fair proportion of the fibres manufactured by the conventional process contain these small diameter fibres, they can be dangerous health hazards to those involved in manufacturing and handling them. In both UK and USA, a legislation is being introduced to phase out these small diameter fibres.

Recently, a team from Warwick University led by Robert Pullar, with Ashok Bhattacharya as a member in it, has developed a 'sol gel blow spinning technique' which produces fibres of very even diameters. The process uses a sol – a microsuspension of material particles which consolidate to form the ceramics when finally heated to moderately high temperatures (much lower than the melting point). The sol gel can have a simple composition containing iron and aluminium or can be very complex containing 5 or 6 elements, when one wants to make ceramic fibres for piezoelectric and magnetic applications. In the Warwick process, the sols are made more concentrated and viscous by the addition of a small amount of organic polymer which will help the sol to form fibres. This sol is blown by air through a small hole (3 µm diameter) which turns into the gel fibre. This gel fibre is then raised to moderately high temperatures to form the required ceramics. The Warwick group claims that fibres manufactured by this sol gel process have properties identical to those made by the conventional melt process.

S. Ramaseshan, Raman Research Institute, C. V. Raman Avenue, Sadashivanagar, Bangalore 560 080, India.

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RESEARCH NEWS

New elements discovered and the island of stability sighted

K. R. Rao

During the past sixty years, a large amount of work has been devoted to producing elements that do not occur in nature; this is the subject matter of artificial nucleosynthesis. In fact, the story goes back to the thirties when Enrico Fermi produced lead by β-decay, after bombarding thallium with neutrons. Elements up to atomic number 94 occur naturally; elements of atomic number larger than 94 are produced either in nuclear reactors or by using accelerators. These artificial or synthetic elements are not stable and decay fast. In an article dating back to 1950, Seaborg and Pearlman[1] stated: 'Let us make it clear at the beginning what we mean when we say that the synthetic elements are missing in nature. Actually tiny amounts of some of them, such as plutonium, have been detected in the Earth, and all of them doubtless existed in considerable amounts at the primordial creation of the elements. But without exception they are so unstable that the original atoms must have disappeared long ago; any such atoms now found in nature are created only rarely by spontaneous nuclear reactions due to cosmic-ray bombardment or natural radioactivity.' It was 'wartime studies in the chemistry of fissionable materials that led to a wholesale synthesis of unknown elements' followed by study of chemicals in the thermonuclear debris at oceanic atolls.

Following the initial success of Fermi, elements with atomic numbers 93, 94, 99 and culminating in element with atomic number 100 were produced by neutron absorption and subsequent β-decay. The last of this series of elements, namely, element with atomic number 100 was stable against β-decay and is named as fermium. Another series of elements with atomic numbers 95, 96, 97, 98 and 101 could be produced by α-particle irradiation. All these elements are neutron rich, for example, fermium with mass number 257 has 157 neutrons and 100 protons.

It is interesting to note that there are only three nuclei heavier than Bi sufficiently long-lived to have survived geological time scales; they are ^{232}Th, ^{235}U and ^{238}U. These isotopes are responsible for the fact that the Earth still has small amounts of the elements with atomic numbers between 83 and 92, these coming from the decay of U and Th. Hence there is an 'island' of relative stability at Th and U which prevents the termination of the periodic table at Bi, the end of the 'mainland' of elements.

The method of choice to create elements beyond atomic number 100 was to fuse nuclei of heavier elements with nuclei of lighter elements. Elements up to atomic number 99 were available in sufficiently large quantities. The nuclei of these elements were accelerated to sufficiently large energies to overcome nuclear Coulomb repulsion that prevents fusion (the so-called fusion barrier) and made to collide with nuclei of the lighter elements. Elements with atomic numbers

102 to 106 were synthesized in this way by 1974. But the game came to a grinding halt with synthesis of the element with atomic number 106. In general, as the atomic number increases the nuclei tend to become more and more unstable; half lives decrease from thousands of years to millionth of a second (Figure 1). However, it was soon realized that in these 'cold fusion' reactions (not the recent notorious chemical one!) masses of the projectiles and those of the targets and the bombarding energy have to be carefully chosen to minimize excitation of newly formed nuclei in the nuclear reactions. Brute force methods to coalesce, say, the heaviest man-made radioactive nuclei with lightest elements would not continue to succeed: it was rather a gentler coercion at the lowest possible bombardment energies that would induce a heavy nucleus to coalesce with a nucleus of a less massive target. While fusion of heavy actinides like ^{249}Cf, ^{249}Bk with ^{12}C or ^{15}N, etc. would end up in excitation of the compound nucleus with about 50 MeV energy, fusion of ^{208}Pb or ^{209}Bi with ^{54}Cr or ^{58}Be would result in an excitation energy of about 20 MeV only. The lesser the excitation energy and the more aspherical the ground state configuration, the lesser the chances of fission of the cooler compound nucleus that is formed. The experimental research in this fascinating field of creation of new elements has been a saga of an adventure in an unknown territory so much so that the subtlety involved in the technique can take one from a deep ravine of no reaction to one of fission of an unstable excited nucleus instead of reaching the glorious heights of observing a relatively stable state; it is like walking on the edge of a sharp sword.

As understanding of nuclear structure and dynamics progressed, theoretical predictions were made that elements around atomic number 114 would be more stable than those either lower or higher in atomic number. Beyond the element with atomic number 106, the element with atomic number 114 is expected to be at another stable 'island' in the ocean of unstable nuclei. Specifically, $^{298}X_{114}$ is expected to survive because it is doubly lucky to be associated with the magic number 114 of protons and the magic number 184 of neutrons – a nucleus with a complete shell of protons and a complete shell of neutrons. In spite of lack of promise in the intervening region which was more like an ocean of instability, researchers at the Institute for Heavy Ion Research (GSI) at Darmstadt, Germany had laid claim to synthesis of elements with atomic numbers 107 to 112 since the eighties. The element with number 112 is said to last for about 300 μs. According to Ambruster and Munzenberg[2], elements 107 to 109 lie on the dike between the island around element number 114 and the mainland.

In December 1998, researchers at the Joint Institute of Nuclear Research (JINR) at Dubna, Russia (in collaboration with scientists of Lawrence Livermore National Laboratory (LLNL), USA) announced synthesis of the element with atomic number 114 that was evading discovery till then[3]. One atom is said to have been produced that seemed to possess a halflife of nearly 30 s. Comparing this lifetime with that of others synthesized so far, it would appear that one has landed on the peak of the island of stability in the midst of a large sea of instability. However, the technique that was used was hot fusion. The team led by Dubna's Yuri Oganessian and Vladimir Utyonkov bombarded a target of ^{244}Pu by a beam of ^{48}Ca isotopes. From the data it was inferred that there was a decay chain starting with $^{289}X_{114}$, lasting for about 30 s, before the decay chain ended with an α-particle to form an isotope of element 112.

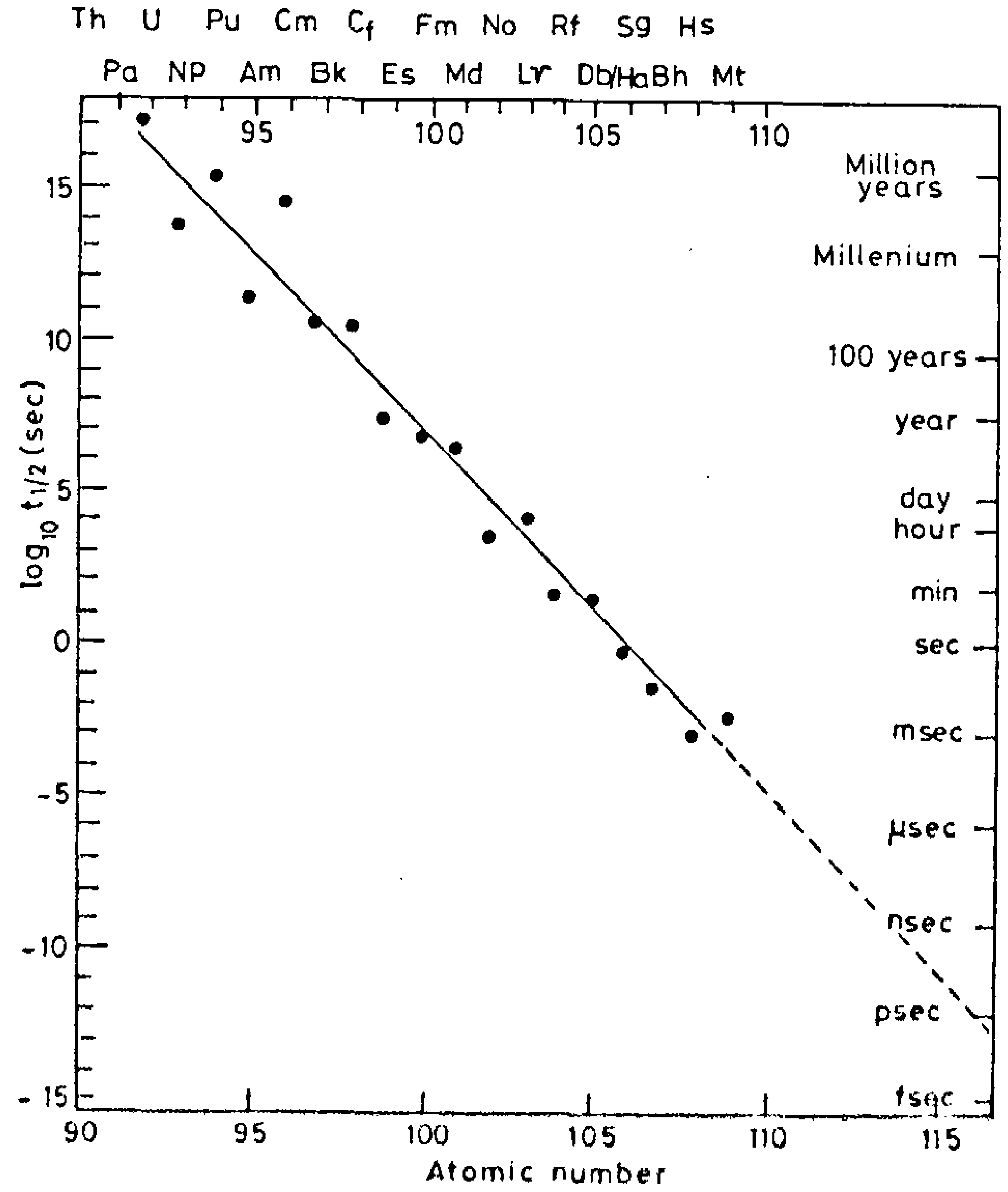

Figure 1. Variation of half life in the region of super heavy elements.

Naming the elements is also a part of this competitive game. Table 1 gives the atomic numbers of the super heavy elements, the year of their discovery, the laboratory where they were discovered and the name of the elements. Some names may not be officially accepted by the international community because of the controversy regarding claims/claimants' choice of name. In fact, it is stated that pending publication of further evidence element with atomic number 114 will be called by the provisional name ununquadium given by IUPAC!

Impetus to create heavier super heavy elements came from this Dubna announcement of the creation of the element with atomic number 114 and now comes the news[4] that a team at the Lawrence Berkley Nuclear Laboratory (LBNL) at Berkeley, USA, Oregon State University and others led by Ken Gregorich observed 'indications of production of three atoms of element with atomic number 118' along with other interesting results. The route followed was that of cold fusion. The fusion of two nuclei is hampered by the need to overcome the

Table 1. Data on synthetic elements

Atomic number	Year of discovery	Laboratory where the element was discovered	Element
43	1936	In Italy using sample from Berkeley	technetium
85	1940	LBNL	astatine
93	1940	LBNL	neptunium
94	1940	LBNL	plutonium
95	1944	In Chicago by Berkley team	americium
96	1944	– do –	curium
97	1949	LBNL	berkellium
98	1950	LBNL	californium
99	1952	LBNL	einsteinium
100	1952	LBNL	fermium
101	1955	LBNL	mendelevium
102	1958	LBNL	nobelium
103	1961	LBNL	lawrencium
104	1969	LBNL	rutherdfordium
105	1970	LBNL	hahnium
106	1974	LBNL	seaborgium
107	1981	GSI	bohrium
108	1981	GSI	hessium
109	1982	GSI	meitnerium
111		GSI	
112		GSI	
114	1999	JINR and LLNL	
116	1999	LBNL	
118	1999	LBNL	

LBNL – Lawrence Berkeley National Lab,USA.
GSI – Institute for Heavy Ion Research at Darmstadt, Germany.
JINR – Joint Institute of Nuclear Research, Dubna, Russia.
LLNL – Lawrence Livermore National Laboratory, USA.

fusion barrier. In this context, Armbruster and Munzenberg[2] had noted that 'for a given product nucleus the probability of overcoming the fusion barrier is smallest when the lightest possible ions bombard the heaviest possible targets (although it has ease of fusion) because of the high probability of fission on deexcitation. Best chances are offered by the more symmetric combinations with target nuclei in the vicinity of lead'. Robert Smolancjuk, a visiting Polish theorist to Berkeley, based on his calculations, suggested recently that the element with atomic number 118 may be produced by bombardment of lead by krypton ions. Smolancjuk's suggestion was followed at Berkeley's nearly 40 year old but upgraded third generation 88″ cyclotron (its predecessor, the remarkable 60″ cyclotron built by E. O. Lawrence in 1939 which had helped in the first creation of nearly six transuranic elements retired in 1962), a high current (a trillion ions/s) high energy accelerator, using a high performance electron–cyclotron resonance ion source which hurled the most neutron-rich stable isotopes of krypton, namely ^{86}Kr ions at nearly 450 MeV. The newly created super heavy elements decayed almost instantaneously and the chain of radioactive decay resulted in landing on the island of stability around the element with atomic number 114 and proceeding downhill to the element with atomic number 106, all this happening via six successive α-particle emissions within a second. During the eleven days of experimentation, three such α-decay chains were produced indicating production of element with atomic number 118.

The newly constructed Berkeley Gasfilled Separator (BGS) played a crucial role in the success of the experiment. According to Gregorich, the BGS has unsurpassed efficiency and background suppression that allows the researchers to investigate nuclear reactions with production rates smaller than one atom per week. One atom of element number 118 is said to have been made once in a trillion reactions; so it was like looking for a needle in a haystack! The strong magnetic field of BGS could separate ions of element with atomic number 118 from the debris of all other interfering reaction products. The BGS operated with 75% efficiency to capture atoms of element with atomic number 118 and then these atoms were implanted into a solid state silicon strip detector. The α-decays were observed in this detector, which was placed behind a parallel plate avalanche counter that helped to suppress background due to the beam and other products. The detector could distinguish the signature of the events of interest with 99% efficiency.

Gregorich says, 'Our unexpected success in producing the super heavy elements opens up a whole world of possibilities using similar reactions; new elements and isotopes, tests of nuclear stability and mass models and a new understanding of nuclear reactions for production of heavy elements'.

Noting that four members of the discovery team are German citizens, the US Secretary of Energy, Bill Richardson said: 'This stunning discovery . . . underscores the value of foreign visitors and what the country would lose if there were a moratorium on foreign visitors at our national laboratories. Scientific excellence does not recognize national boundaries, and we will damage our ability to perform world class science if we cut off our laboratories from the rest of the world.'

The most important outcome of the production of elements 118, 116 and 112 at this stage is that it has established that the island of stability around element number 114 is reached. The days of conducting study of even chemical properties of these and other elements and isotopes may not be too far in the future. Unfortunately, Glenn Seaborg who was codiscoverer of nearly a dozen transuranic elements did not live long enough to witness this spectacular achievement; he passed away recently on 25 February 1999.

1. Seaborg, G. T. and Pearlman, I., *Sci. Am.*, 1950, **182**, 38; see also Seaborg, G. T. and Ghiorso, A., *ibid*, 1956, **195**, 66; and Seaborg, G. T. and Fritsh, A. R., *ibid*, 1963, **208**, 68.
2. Armbruster, P. and Munzenberg, G., *Sci. Am.*, May 1989, **260**, 36.
3. Richard Stone, *Science*, 1999, **283**, 474.
4. (a) Robert F. Service, *Science*, 1999, **284**, 1751 and several web pages in the Internet;. (b) Ninov, V. *et al.*, *Phys. Rev. Letts.*, to appear on 23 August 1999, **83** (8).

K. R. Rao lives at 'Gokula', 29/2, 11th Cross, III Main, Malleswaram, Bangalore 560 003, India.