mid-1970s. This type of pollution appears to have levelled off or even decreased since then as a result of a decrease in the volume of oil transported along these routes. In any case, vigilance is required to control such pollution.

Summary

The preceding sections have reviewed the main sources of marine pollution around India. The list is by no means complete. For instance, it does not mention the impacts of (i) soil erosion and land reclamation, (ii) disposal of solid wastes (litter), (iii) mining, (iv) modification of the hydrocycles of rivers by dams, and (v) the siting of nuclear power plants on the coast. Similarly, the impact of this pollution on sensitive environments such as estuaries, coral reefs and mangrove forests is not discussed. It is however clear that this is a major problem. The main areas where offshore pollution occurs in India have already been identified and initial work needs to concentrate in such areas.

It has been argued that environmental contamination is the inevitable consequence of human civilization and a natural phenomenon[4]. While this is true, the fact is that we now produce and discard huge volumes of material much of which is synthetic in origin and not biodegradable. It can be argued that India with its 3000 years of civilization based mainly on agriculture, always was a throwaway society. This was perfectly legitimate when biodegradable wastes were being discarded. However, the widespread use of plastics and chemicals, particularly over the last 50 years, has changed the situation drastically necessitating a radical revision of ideas on waste management.

In particular, it is essential to install and upgrade sewage treatment plants in the large cities and would probably result in the biggest single improvement of the environment in India. For industrial wastes, industrial sewers need to be installed. However, modern industrial plants in the west are making major efforts to reduce the discharge of pollutants into the environment and major cutbacks can be achieved by the installation of appropriate technology. Of course, this approach is capital-intensive but it also requires a different mindset in considering the problems involved.

One argument is that the disposal of untreated wastes to the environment is essentially free and that pollution control is an unwarranted expenditure which erodes industrial competitiveness. However, much effort in the West is directed precisely along these lines and it is found that, where operations are optimized, cost savings can be made. Furthermore, the former communist countries of Eastern Europe, where rapid industrialization was accompanied by minimal pollution controls, are now faced with enormous bills for their folly. For instance, it has been estimated that the costs of cleaning up the Baltic Sea and the Vistula River in Poland will be of the order of US $ 18 billion and US $ 3 billion, respectively, over a 20-year period.

The implication of all this is that, in the long term, a policy of indiscriminate discharge of waste into the environment is not necessarily the cheapest option and that environmental clean-ups can be extremely expensive when forced on society, for example, by regulation or in response to health threats such as epidemics or metal poisoning. The real task facing India therefore is to reduce the present throwaway culture which pervades the society and to upgrade waste management systems which are presently well below acceptable levels in order to minimize the future problems. Particular emphasis should be placed on the development of new ways of thinking about the use and disposal of chemicals and wastes. Otherwise, the costs of environmental clean-ups in the future may be much greater than ever anticipated.

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SCIENTIFIC CORRESPONDENCE

Localized chaos on periodic orbits

Boldrini[1] has referred to classification and common noun as two cornerstones of science. He has added that one undesirable effect of classification is to suppress mathematically the variability ubiquitous in the events in the physical world. Classification and common noun impose a subjective reality which leads to inadequate or improper description and one must be alert to the necessity of reconsidering the linguistic expressions so that the underlying concepts are suitably modified. Another argument[2] against 'nomenclatural stasis' has a similar rationale.

More recently, Gould[3] (pp. 8–9) has cautioned us against the uncritical use of dichotomies: 'Dichotomies are useful or misleading, not true or false. They are simplifying models for organizing thoughts, not ways of the world'. His caution applies to classifications and nomenclature (as the latter has the former implicit in it) and he has given serious thought to corrections which 'might provide an amplitude of proper intellectual space without forcing us to forego our most comforting tool of thought'. He has illustrated the occasionally fearful failure of conventional and deeply entrenched categories by discussing the case of Rita–Christina, the Siamese twin Sardinian girls. Was she one or were they two? He has concluded as follows: 'The boundaries between oneness and twoness are human impositions, not nature's taxonomy. Rita–Christina, formed from a single egg that failed to divide completely in twinning, born with two heads and two brains but only one lower half, was in part one, and in part two – not a blend, not one-and-a-half, but an object embodying the essential definitions of both oneness and twoness, depending upon the question asked or the perspective assumed' (p. 200).

Here, Rita–Christinas between the categories of periodicity and chaos are presented with the same interest in illustrating the inadequacy of the nomenclature or categorization. In the field of deterministic chaos[4] one talks of the evolution of periodic orbits into chaos through mechanisms such as period-doubling or Hopf bifurcation[4] as one or more control parameters are varied. In the two examples discussed here, a part of the orbit is periodic (almost) and a part of it is definitely chaotic.

The first example is of a discrete system:

$$\begin{aligned} x(n+1) &= (1+a)\,x(n) + a\,[y(n) - x(n)\,y(n) + bx^2(n)], \\ y(n+1) &= (1-c)\,y(n) + c\,[dz(n) - x(n)\,y(n)], \\ z(n+1) &= ex(n) + (1-e)\,z(n), \end{aligned} \tag{1}$$

where n is the index which can be identified with discrete time, x, y and z are variables, and a, b, c, d and e are control parameters. The physical meaning of the system is not of particular interest here. However, if the conditions that x, y and z cannot be negative were additionally imposed, the same equations would represent a discrete version of Belousov–Zhabotinsky reaction[5]. Figure 1 shows the solution of (1) for particular parameter values. Figure 1 *a* shows the behaviour in the x–z plane. The solution consists of a periodic orbit except for a bulb

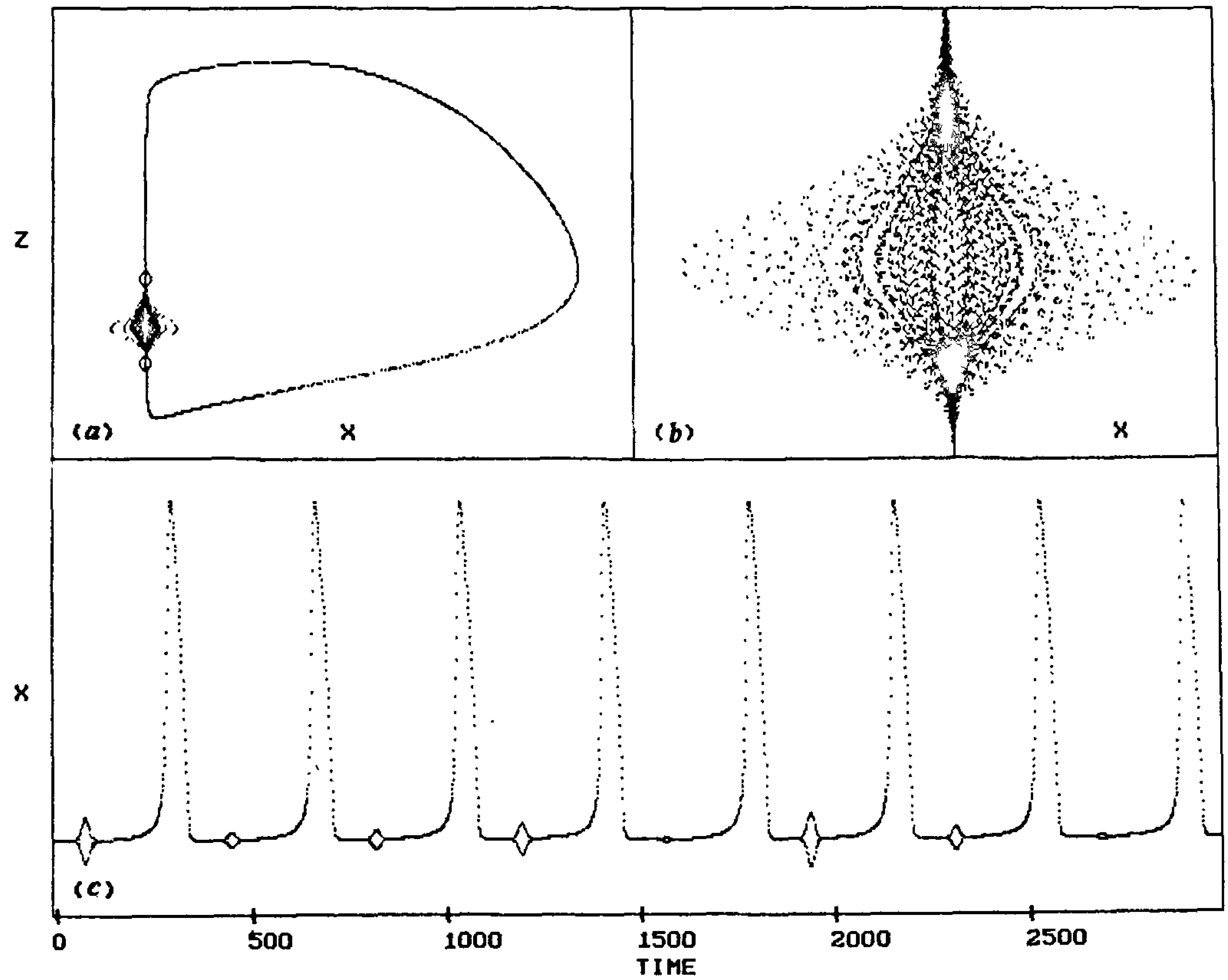

Figure 1. ***a***, The solution of (1) in the x–z plane for $a = 0.458$, $b = 0.015$, $c = 0.0098$, $d = 1.38$ and $e = 0.01$. The initial conditions are $x_0 = 2$, $y_0 = z_0 = 1$. The frame scales are $-10 \leq x \leq 60$ and $2 \leq z \leq 18$. ***b***, An enlarged version of the inset between the two circles in (*a*), the frame scales being $-4.5 \leq x \leq 6$ and $5 \leq z \leq 8.5$. ***c***, x versus time, or rather the index n. The system can be called periodo-chaotic.

which is shown enlarged separately in Figure 1 *b*. The portion enlarged is demarcated by two circles externally put on the plot in Figure 1 *a*. The bulb is clearly chaotic, tracing a different trajectory on every round, but the rest of the trajectory is a limit cycle. Obviously, the differences in the bulb must be there, greatly attenuated, on the rest of the trajectory also. In other words, the relevant Lyapunov exponent is positive over the top half of the bulb, which is a small portion in every period, and is negative or zero everywhere else. Figure 1 *c* shows the same information in a different format. The variable x is plotted against time, or more explicitly, the index n. It is obvious that but for a small bulb of variable amplitude appearing once in every period, the waveform is almost periodic. Thus, the phenomenon is different from intermittency, which is defined as 'the occurrence of a signal that alternates randomly between two regular (laminar) phases (so-called intermissions) and relatively short irregular bursts[4]'. In the example above, the alternation is not random and the durations of the two phases are also almost constant and not irregular as in the examples of intermittency (e.g. Figures 48 and 54 in ref. 4).

Another example is of a continuous system:

$$\dot{x} = -(1-\lambda)\ \sigma(x-y) - \lambda(x+y),$$
$$\dot{y} = (1-\lambda)\ (-xz + rx - y) + \lambda(x + ay),$$
$$\dot{z} = (1-\lambda)\ (xy - bz) + \lambda(b - cz + xz), \qquad (2)$$

in which x, y and z are variables, the overhead dot denotes differentiation with respect to time and σ, r, β, a, b, c and λ are parameters. For the sake of completeness, it may be stated that if $\lambda = 0$, (2) is a Lorenz system, and if $\lambda = 1$, it is a Rössler system. If $0 < \lambda < 1$, it defines an interpolation between Lorenz and Rössler systems. Otherwise, i.e. for $\lambda < 0$ and $\lambda > 1$, it defines an extrapolation beyond Lorenz or Rössler, respectively. The extrapolation beyond Lorenz is with respect to Rössler and that beyond Rössler is with respect to Lorenz. Therefore, if $\lambda < 0$, the system is called contra-Rössler infa-Lorenz, and if $\lambda > 1$, it is called contra-Lorenz ultra-Rössler. The system (2) has been solved by using fourth-order Runge–Kutta integration. Figure 2 *a* shows the trajectory in the x–y plane. It has a straight line on which the system moves relatively slowly from right to left. If the rest of the trajectory was also a line closing on to this straight line from the right, the trajectory would have been a limit cycle. However, on the left the trajectories evolve as different growing spirals followed by shrinking spirals which bring them on the right and again the straight line commences. Thus, this too is an example of a periodo-chaotic orbit, though the spread of the chaotic part is relatively much larger here in the x–y plane than in Figure 1. Figure 2 *b*

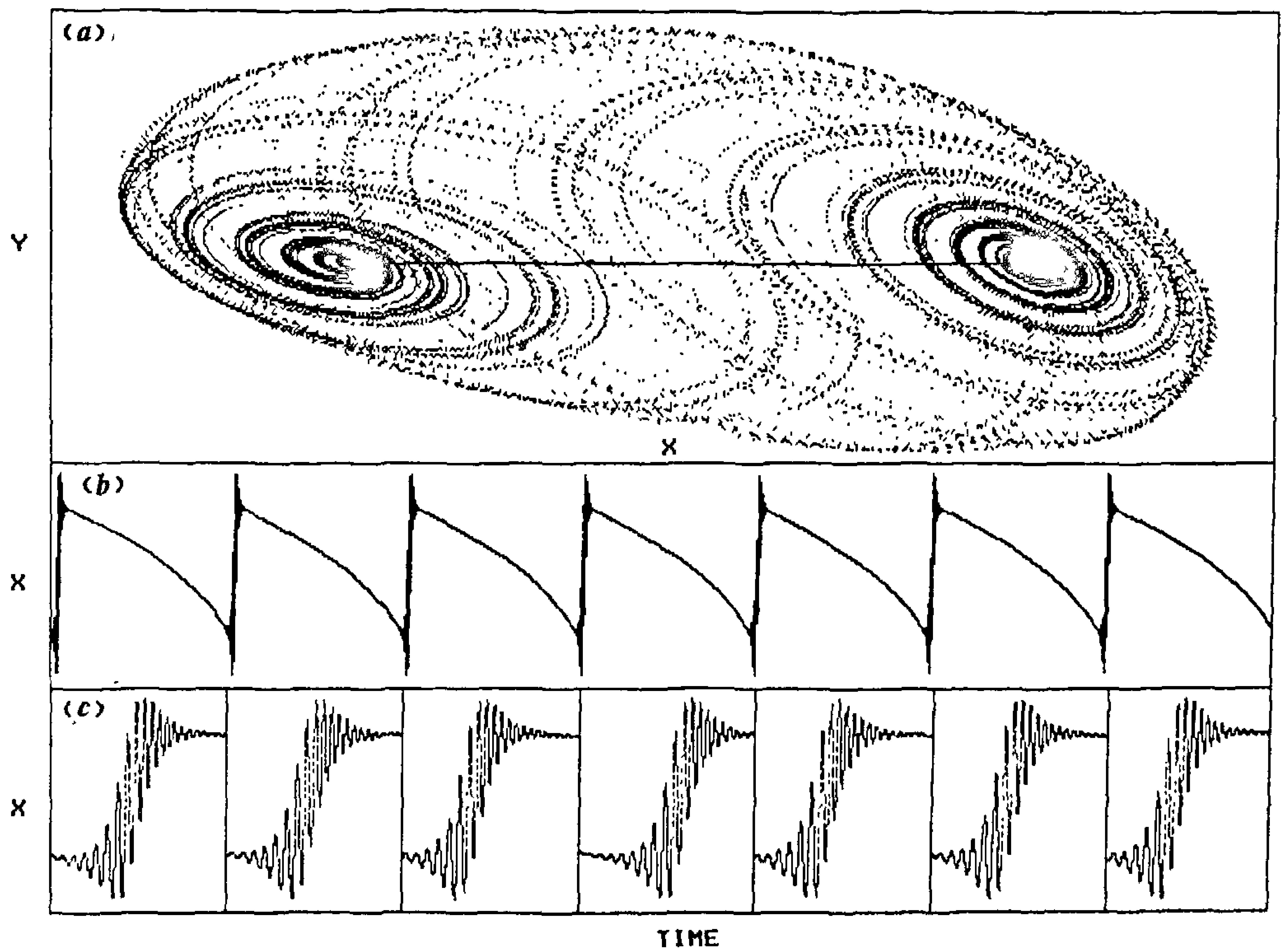

Figure 2. ***a***, Solution of (2) in the x–y plane. It represents a contra-Rössler infra-Lorenz attractor for $\lambda = -5$. The Lorenz parameters are $\sigma = 0.85$, $r = 350$ and $\beta = -180$. The Rossler parameters are $a = 9.8$, $b = 37.5$ and $c = 175$. The initial conditions are $x_0 = 300$ and $y_0 = z_0 = 1$. The frame scales are $250 \le x \le 500$ and $-16000 \le y \le 20000$. The discretization interval is $\delta = 0.00002$. Again, a part-periodic, part-chaotic orbit is witnessed. ***b***, Variable x as a function of time, or rather the iteration number. ***c***, The vertical flyback in (*b*) is shown captured during 7 such transitions for showing the details.

shows the variable x as a function of time. It can be regarded as a negative ramp with upward flyback. The flyback has a structure which is shown by capturing it by manual intervention 7 times and plotting only those segments in Figure 2 *c*. Again, there are two distinct phases but their alternation is not as random as intermittency would seem to require. The flyback occupies a small portion of time in the total period, as does the bulb in Figure 1. That no two flybacks are exactly identical is seen more convincingly in Figure 2 *a* rather than in Figure 2 *c*.

The part-periodic, part-chaotic orbits illustrated here would represent systems in which over some time or phase-space region there is very good predictability provided by periodicity and elsewhere it is unpredictable due to chaos. The transitions from one of these behaviours to another are also predictable, i.e. there is a fairly regular alternation between predictable and unpredictable modes, indicating that these are not cases of intermittency as normally understood. The earlier discussion on terminological rigidity is entirely relevant in such cases.

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GC–MS evidence of dimethyl isocyanurate and 2,4-dione in the blood of Bhopal victims

It has been reported earlier by us that apart from methyl isocyanate many other reaction products, reformulated and reconjugated due to the high pressure and temperature developed in the tank, had escaped from the tank E-610 of Union Carbide India Limited, Bhopal, on 2/3 December 1984 (ref. 1–3). Some of these compounds were inhaled by the victims[4,5].

Materials corresponding to the peaks representing DMI and 2,4-dione of the compounds described earlier[1–3,6] with a common molecular weight of 157 amu were investigated. The 'reference compounds' were isolated and purified by column chromatography from the tank residue material obtained through the Central Bureau of Investigation (CBI), New Delhi.

The identity of these compounds was established on Varian model 3400 capillary gas chromatograph (GC) interfaced with ion trap detector (ITD) model 800 of Finnigan MAT Ltd., UK. This system was used to obtain GC retention time data as well as mass spectral data (GC–MS). Ultraviolet spectral analysis was carried out on Beckman simulated spectrophotometer.

One hundred and twenty-four randomly selected cryo-preserved blood samples of the gas victims, for the period 1984–1990, were studied. Fifty-two clinical samples of the blood collected during the same period were also exposed to this study. These were processed and analysed on GC–MS according to the earlier described method[4].

The isolated and purified DMI showed a melting point between 208 and 210°C. It exhibited 99.9% purity on GC-ITD and showed principal mass fragmentation peaks at m/z = 58, 157, 70, 43, 128, 100, 85 (Figure 1) and matched with fragments reported in the literature[6]. Its ultraviolet spectrum showed a maximum at 214 nm.

The isolated and purified 2,4-dione showed a melting point of 80–82°C; the literature values of the prepared compound were slightly variable. D'Silva *et al.*[6] observed 87–92°C and Etienne and Bonte[7] reported 95°C. The principal mass fragments on GC-ITD were at m/z = 42, 156, 56, 99, 113, 72 (Figure 2). The ultraviolet spectrum showed its maximum at 237 nm.

Some representative chromatograms with their respective mass spectra in the inset clearly show the presence of dimethyl isocyanurate and dione in the victims of the disaster (Figures 3 and 4).

Dimethyl isocyanurate (DMI) (1,3-dimethyl-1,3,5-triazine-2,4,5(1H,3H,5H)-trione) and 2,4-dione (dihydro-1,3,5-trimethyl-1,3,5-triazine-2,4(1H,3H)-dione) were found to be present in the blood of the victims. DMI was positive in the blood of 12 post-mortem and 2 clinical samples of December 1984, while it was absent in the samples for the years 1985–

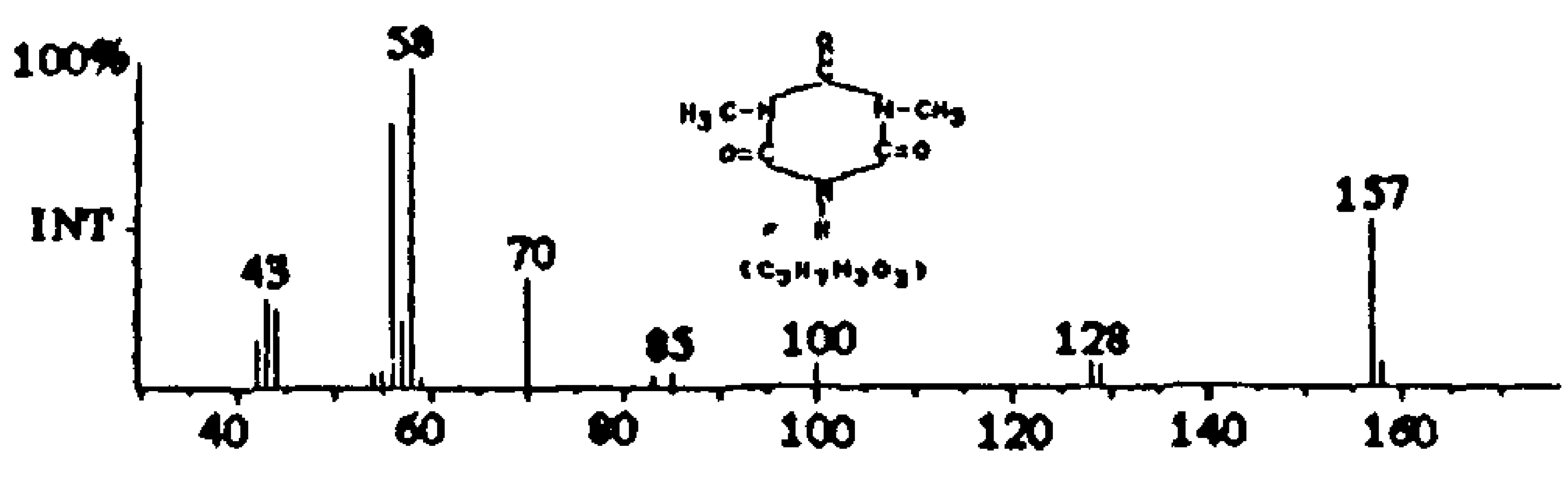

Figure 1. Mass fragmentation pattern of purified dimethyl isocyanurate