tion than the atmosphere. CO_2, SO_2 and HCl are readily converted into soluble ions which are natural constituents of sea water. In fact the composition of sea water may reflect absorption of these gases by the oceans from the primordial atmosphere and volcanic eruptions over the geological timescale.

The work carried out to date demonstrates that sea water is a suitable recipient for SO_2 pollution. Clearly more research is needed to find suitable solutions to the problem of CO_2 emissions. It should, however, be borne in mind that the two pollutants are usually present together and a solution to both problems using one method would be desirable.

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Chromosomal instability

SIR — Kadhim *et al.*[1] studied clonal descendants from murine haematopoietic stem cells irradiated with α-particles from plutonium-238 (linear energy transfer, LET = 121 keV μm^{-1}). They observed a high frequency of nonclonal chromosomal aberrations after 10–13 cell divisions following the initiation of proliferation, even though this proliferation was clonal. Most of the anomalies were of the chromatid type, resulted in breakages and were assumed to affect chromosomes or chromosome sites at random. The authors interpreted their results as a *de novo* occurrence of transmissible chromosomal instability, and assumed that this instability, which was not observed after X-ray irradiation under the same conditions, characterized the biological effects of high LET radiation.

We began our investigation of radioinduced chromosomal anomalies by characterizing the complex rearrangements induced by heavy ions in human lymphocytes[2], and then focused on the transmissibility of radioinduced chromosomal rearrangements in human dermal fibroblasts (see table). For this purpose, fibroblasts were irradiated by neon (E=10.74 MeV per a.m.u., LET=386 keV μm^{-1}; E is energy), argon (E=10.52 MeV per a.m.u., LET=1,207 keV μm^{-1}) and lead (E=9.5 MeV per a.m.u., LET=13,600 keV μm^{-1}). At the earliest passages studied (1–3), a high percentage of metaphase cells carried chromosomal aberrations directly induced by irradiation, most of which disappeared after a few subcultures. At passages 5–10, almost all karyotypes were normal except in the cultures irradiated by neon ions, in which transmissible chromosomal rearrangements persisted. This was obviously due to the low dose of irradiation delivered by these ions (0.62–2.48 Gy).

CYTOGENETIC ABERRATIONS IN HUMAN FIBROBLASTS EXPOSED TO HEAVY IONS

Radiation	Fluence (particle per cm^2)	Dose (Gy)	Subculture	Metaphases with aberrations	Metaphases with at least 1 dicentric	Metaphases with clonal rearrangement	Metaphases with clonal rearrangement and at least 1 dicentric
Neon	10^6	0,62	P20	22/23	16	0	0
	2×10^6	1,24	P25	17/19	12	0	0
	4×10^6	2×48	P25	12/12	1	3	4
Argon	10^6	1,93	P25	11/12	7	0	0
	2×10^6	3,86	P25	21/22	8	10	0
	4×10^6	7,72	P23	20/20	3	14	2
Lead	2×10^6	44	P20	15/24	9	0	0

Human dermal fibroblasts from a normal donor were irradiated at confluence at the G.S.I. (Darmstadt). Fluences ranged from 106 to 4,106 particles per cm^2, which corresponded to the passage of 0.4 to 1.6 particles through the cell nucleus (equatorial area, 40 μm^2). They were then cultured up to the twentieth or twenty-fifth subculture (about 40 cell divisions). R-banded karyotypes were established for each of the five subcultures. Almost 25% of the chromosomal breakpoints detected at the fifteenth to twenty-fifth subcultures were located on chromosome 13. See text for radiation exposures.

Around the fifteenth subculture, a high percentage of dicentrics, resulting from end-to-end translocations, was observed. The location of the corresponding breakpoints were not random but specific, as they were found mainly in the two telomeric regions of chromosome 13, and were also observed, in decreasing order of frequency, in that of chromosome 16, of the short arm of chromosome 1 and of other chromosomes.

Therefore, this nonrandom chromosomal instability, which affected more than 50% of metaphase cells, can be considered as a late consequence of radiation by high LET particles. It further led to clonal aberrations which were frequently unbalanced, and in particular to the loss of chromosome 13. Consequently, a period of chromosomal instability induced by heavy ions, followed by the formation of clones with unbalanced karyotypes, could constitute early steps towards cellular transformation.

These results for normal human fibroblasts confirm those of Kadhim *et al.* for murine haematopoietic stem cells with respect to the induction of chromosomal instability after high LET irradiation. However, we studied the effects of particles with a wide range of high LET radiation (386–13,600 keV μm^{-1}), whereas Kadhim *et al.* used only Pu-238 (LET=121 keV μm^{-1}). In addition we found, in contrast to Kadhim *et al.*, that the chromosomal instability, mainly reflected by the appearance of dicentrics, which are nontransmissible chromosomal rearrangements, does not appear at random but affects certain specific telomeric regions. We further observed that this instability persisted from at least the fifteenth to the twenty-fifth passage; and that it led to clonal chromosome imbalances and rearrangements, as frequently observed in human solid tumours.

These results may help to explain why high LET radiations are so potent in causing cell transformation[3] and radiocarcinogenesis[4].

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