Comparative Biological Hazards of Chemical Pollutants and Radiation

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In a discussion on the hazardous biological effects of ionizing radiation and chemicals, one most essential prerequisite is to clearly enunciate the actual context and the specific criteria involved in order to enable the assessment of the problems in their real perspectives. Both ionizing radiation as well as many chemicals are known to produce hazardous health effects on man and other organisms. Both categories of agents further exhibit dose-response relationships in the production of their biological effects. This leads to the prediction that by minimizing the extent of exposure as far as achievable their harmful effects could be greatly reduced or even altogether avoided.

In applying radiation and chemicals for some specified beneficial purposes of man, it should therefore be an essential requirement to develop a good protection programme. The philosophy underlying the programme should be that all unnecessary exposures of people be avoided and that any necessary exposure whether of workers or of members of the general public, should be minimized. It is, however, an additional requirement that even such necessary exposures should not exceed certain stated limits These principles are based on the possibility that even the smallest exposures may involve some risk of harm, that any risk of harm should be justifiable by the circumstances necessitating it and that risk should always be limited to an appropriately low level. This concept is vital and instrumental behind any efforts for controlling the emission of such hazardous agents.

The peaceful applications of radiation are well supported by such health protection programmes. It is indeed heartening to recall that even when the first nuclear reactor went critical some 35 years ago, there was already a background based upon several decades of close critical study on the types of harmful effects that might be caused by radiation and the information on the frequency of their induction by a given radiation exposure. The International Commission on Radiological Protection (ICRP) was already set up at that time with recommended standards of exposure dose limits and guidelines.

In sharp contrast to the fields of peaceful uses of nuclear energy and industry, which were reared in an atmosphere of caution since inception, there was no early effort towards the critical understanding of the risks of toxic chemical substances released to the atmosphere from fossil-fuelled power stations and other installations for chemical and petrochemical industries. It is only during the last decade that a world-wide trend of growing awareness has been noticeable and attempts made to safeguard man and his environment against the deleterious effects of environmental chemical pollutants originating through human activities.

The United Nations' sponsored conference in Stockholm in 1972 on "Man and His Environment" and the subsequent establishment of a specialized agency of the United Nations (United Nations Environmental Programme or UNEP) testify to this growing

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concern for the preservation of a clean, viable environment. Concurrently, several national, regional and inter-regional scientific societies set out to identify, monitor and help prevent possible further exposure of man to noxious and toxic substances. The magnitude of the problem of man's exposure to chemical pollutants in the environment may be appreciated against the fact that about 500 000 to 600 000 chemicals (the number growing at an annual rate of about 500) are produced and utilized in the United States alone. Similar figures may be shown for the other industrialized regions.

In this article further discussions on the comparative biological hazards of chemical pollutants and radiation will be carried out under the following headings: (i) their sources, including relative abundance in the environment, (ii) their mechanisms of action for biological effects, (iii) their relative impacts on man's health and environment; and (iv) the status of the current and proposed regulatory measures and steps to safeguard human health against those pollutants.

ENVIRONMENTAL CHEMICAL POLLUTANTS OF HEALTH SIGNIFICANCE

The initiation of an unfavourable alteration in natural environment through man's own activities dates back to when man first learnt to produce fire. From then on, combustion products continued to gain entry into the atmosphere and pollute the environment. A significant landmark in the history of environmental pollution coincides with the industrial revolution a couple of centuries ago. Concomitant with the increasing availability of coal and fossil-fuel energy sources, and their utilization in the multifarious industrial processes to meet the growing demands of urbanization and rising living standards, the rate of pollution of the environment has been dramatically aggravated.

Table 1: Production of synthetic organic chemicals (millions of pounds per year)

	1938	**1958**	**1966**	**1980** (estimated)
Plastics	130	4 500	13 585	75 000
Synthetic rubber	5	2 200	3 929	10 000
Surface active agents	–	1 355	3 321	8 500
Insecticides and agricultural chemicals (excluding fertilizers)	8	540	1 013	6 350

Source USA Tariff Commission Report

Table 1 shows the growth in the production of some representative chemicals in the USA. One aspect of this exuberance is illustrated by the fact that there are now more than 55 000 pesticide formulations registered with the Department of Agriculture. The Food and Drug Administration (FDA), which by law in the USA is required to certify the safety of pesticides and food additives, receives on the average roughly one new petition every working day in the year. A similar situation is found in other industrialized countries, with some variations in the details and quantities. These chemical and petrochemical industries release as effluents large quantities of toxic and noxious substances into the atmosphere. Human populations located far and wide, not to mention the occupational populations in those industries, thus receive chronic exposures and consequent health hazards.

Table 2: Forecasts of installed total electric and nuclear capacity (in thousands of MW)

	1976	1977	1980	1985	1990	2000
Total electric	1 700	1 800	2 200	2 800–3 000	3 600–3 900	5 900–6 600
Total nuclear	85	95	170	300–400	500–700	1 300–2 000
Percentage nuclear	5	5.3	8	11–13	14–18	22–30

Source IAEA Annual Report 1977

Table 2 illustrates trends in power sources estimated till the end of the current century. Two of these energy sources, namely fossil fuel and nuclear, are believed to pose environmental health problems. Combustion of fossil fuels poses severe air pollution problems. Nuclear power sources, although with a potential for radiation pollution, have succeeded in maintaining a clean, safe record for more than three decades – thanks to the continuous improvements in technologies and strict surveillance and monitoring during operations.

Coal, oil and other fossil-fuel energy sources pollute the environment with sulphur oxides and other sulphur-containing products. Carbonaceous particulates, excessive quantities of fly ash, carbon dioxide, some heavy metals such as mercury are among the pollutants which enter the atmosphere from the operation of conventional energy installations. Manufacturing factories for chemicals, petrochemicals, rubber, plastics, pesticides, and dyes for textiles continue to overburden man's environment with a plethora of noxious chemical pollutants.

To these are added pollutants such as carbon monoxide, carcinogenic hydrocarbons and metallic lead from automobile exhausts. At present more than 3500 food additives are in use throughout the world. The use of polyphenols for the preservation of foodstuffs may be another potential health hazard. Chlorinated hydrocarbon insecticides such as DDT, dieldrin, endrin, persist in the soil and may be transmitted into man's food chain.

This inventory of harzardous chemicals in man's environment may be regarded as representing only a fraction of the total to which current human populations are chronically exposed Generally, there has been little world-wide public concern for health hazards from these chemical pollutants until very recently. In many instances there has been concern shown only after a catastrophe, such as the mercury poisoning in Minamata, Japan, and the "itai itai" disease caused by cadmium pollution.

Furthermore, chemical pollution of air and water respects no boundaries. The art and historical treasures of the ancient civilizations of Rome and Athens are damaged by the acids and gases of automobile exhausts and industrial smog. Snow falling on Norwegian forests comes down gray with soot and mineral wastes from industrialized areas far from the nation's frontiers. Residues of insecticides such as DDT, chemical fertilizers, vinyl chloride from plastic factories, heavy metals such as mercury, lead, cadmium and vanadium, and spilled crude oils and petroleum move in ever growing volumes through the hemispheres with wind and ocean currents. Many environmental chemical pollution problems are thus more than national in scope and qualify as a "global problem", to be solved by appropriate international action.

RADIATION AND THE ENVIRONMENT

Discussion of ionizing radiation in the environment must start with the natural background sources. Mankind has since time immemorial been bathed in low levels of gamma radiation and cosmic rays and exposed to radioactive nuclides in the earth's crust. In addition, radioactive substances leached or absorbed from soil and ingested with food or water have irradiated man from within. The average dose of ionizing radiation from these natural sources, also called "background", on a world-wide basis is about 100 millirems per year, the usual variation being less than a factor of two.

At the current stage of development of nuclear technology, two main sources for exposure of general population to man-made radiation may be recognized: (a) sources for medical uses of radiation and (b) radioactive wastes from nuclear installations. To this a third category could be added — fall-out from nuclear tests (which nowadays have progressively lessened in significance).

The largest increment to the natural background level of radiation (100 millirem per year) is the 25 to 50 millirem from diagnostic uses of X-rays. Recent developments in technology, including the use of high-speed films and limiting exposed areas through collimation, give further promise of reduction of this exposure dose by as much as 75%. Industrial sources of ionizing radiation, including the rapid growth of nuclear power programmes, have contributed only a negligible addition to the general population exposure dose. The safety accomplishments of nuclear technology are primarily attributable to the high standards in the technologies involved as well as prudent implementation of the strict management and surveillance practices.

Well over 99.9% of the radioactivity generated in the power reactors is retained within the casings of the fuel elements until they are subjected to reprocessing. Because of this and the fact that one fuel reprocessing plant may serve a large number of power reactors, no major impact of this radioactivity on the environment is anticipated. Systematic study on the characteristics of effluent discharged to the environment from an operating boiling water reactor indicated ^{3}H, ^{58}Co, ^{89}Sr, ^{90}Sr, ^{131}I and ^{137}Cs in the liquid wastes would account for an average contribution of the total activity of 0.189×10^{-7} u Ci/ml over a one year period. In addition the gaseous effluent consists of noble gas fission products ^{85}Kr and ^{133}Xe.

BIOLOGICAL ACTIONS OF CHEMICAL POLLUTANTS AND RADIATION

Soon after the discovery of X-rays and radioactivity, research into the biological effects of ionizing radiation demonstrated its lethal effects on individual cells as well as on whole organisms. About this time, by the end of the first quarter of the current century, H.J. Muller discovered the mutagenic actions of ionizing radiation. This discovery while providing a valuable tool for genetic research simultaneously raised the spectre of an entirely new kind of health hazard, that of injury to future generations yet to be born.

Studies on biological systems (using radiation doses much higher than those to be potentially encountered by the general population in the environmental context) have shown that genetic effects of ionizing radiation increase in direct proportion to the dose received. In addition, it is assumed there is no threshold dose below which genetic effects are not expected to be produced. This conservative approach, based on the concept of "no threshold for genetic injury" has been used by the various international and national recommending bodies, such as ICRP and the U.S. Federal Radiation Council, in the establishment of doses permitted for the general population and for the radiation workers.

About ten to fifteen years after the initiation of research on the biological effects of ionizing radiation, studies on the genetic actions of chemical agents on biological systems started through the pioneering efforts of C. Auerbach in the U.K. The rapid advances in the cell biology and genetic research with the enunciation of DNA as the chemical and molecular basis of heredity and cell functions furthered the understanding of the basic mechanisms of the biological effects of radiation and chemicals. Leaving aside the differences in the detailed mechanisms of chemical actions on DNA, the end biological effects produced by most of the chemical agents closely **resembled** those of ionizing radiations. In other words, many chemical effects "mimicked" radiation effects and were thus designated as "radiomimetic agents".

COMPARATIVE ENVIRONMENTAL IMPACTS OF CHEMICALS AND RADIATION POLLUTANTS

Although an increasing number of chemical pollutants are suspected to give rise to cancers of different types, still there is a lack of systematic human data which can be used for numerical risk analysis as are available in the case of ionizing radiations. Such carcinogens include inorganic substances like asbestos, arsenic, chromium, nickel and organic substances such as benzo(a)pyrene, benzidine, vinyl chloride and coal tar among others.

Benzo(a)pyrene is produced in substantial quantities in the burning of coal and is also present in automobile exhaust fumes. Benzo(a)pyrene concentrations in different big cities of the world lie in the range of 1 to 4 ng/m^3 (excluding the areas with high industrial concentrations). The radiation dose equivalent for 1 ng/m^3 benzo(a)pyrene in the air has been calculated as 240 millirem/year. From this it can be inferred that the current risk of benzo(a)pyrene inhalation alone is nearly 100 times the risk of projected radiation dose of a large nuclear power programme.

Some of our recent knowledge of the health hazards from low-level chronic exposures to suspected specific chemical pollutants are based on epidemiological studies. A classic example is provided by surveys of plastic industry workers exposed to vinyl chloride effluents. Significant increase in the incidence of specific liver cancer, angiosarcoma, in the exposed workers has been reported from different countries, and these studies have established the carcinogenic properties of vinyl chloride. Similar epidemiological and experimental studies on certain therapeutic agents, such as halothane used for anaesthesia, hycanthone for control of schistomiasis, and diethylsilbestrol used for treatment of cervical cancer, have revealed carcinogenic and mutagenic side effects in the treated patients and in some cases even in their progeny. Experimental screening of a wide range of chemical agents from our daily utility list and from our immediate environment have shown that some have potent mutagenic and carcinogenic properties.

Table 3: Comparative health effects associated with alternative energy sources*
(data standardized for total fuel cycle to produce 10^{10} KWh electric power)

Fuel	Estimated deaths	Estimated disabilities
Coal	10–200	300–500
Oil	3–150	150–300
Gas	0.2	20
Nuclear power	1–3	8–30

*Estimate based on 1975 U S data
Source L.D Hamilton and A.S. Manne

Table 3 shown the comparative estimates of health effects associated with the total fuel cycle including the currently available alternative energy sources as computed by the Biomedical and Environmental Assessment Division (BEAD) at Brookhaven from 1975 U.S. data. The implications of these data on the comparative health effects of radiation from nuclear power sources and fossil fuel sources are self-evident. Air pollution from fossil fuels is by far the largest contributor to the deaths recorded.

STEPS FOR CONTROL OF ENVIRONMENTAL POLLUTANTS

Research on the identification of suspected chemical pollutants and the evaluation of their carcinogenic and mutagenic effects at the lowest dose levels of exposure have been instituted by the various regional centres of the world These activities have taken into account the hazardous indigenous chemicals of significance which are locally used in industry, foods, agriculture and public health care. In the course of this investigation, if a chemical agent is found to have mutagenic and/or carcinogenic effect on the biological test system(s), the agent is recommended for withdrawal from the market and if available, a substitute non-carcinogenic alternate form is introduced instead. Such activities have been sponsored by the national and regional scientific societies for the investigation on environmental carcinogens and mutagens and co-ordinated by the International Association for Environmental Mutagen Societies (IAEMS) and the U.S. National Institute for Environmental Health Sciences (NIEHS), among others.

The international scientific experts in the field of environmental studies have further recommended the establishment of an "International Commission on Protection against Environmental Mutagens and Carcinogens" – somewhat along the pattern of the International Commission on Radiological Protection (ICRP). It is further recognized that the problems relating to the protection of man against chemical pollutants could have much benefit from the extensive relevant experiences of the nuclear fields and from successful protection record against radiation in particular. Attempts are now being made to "equate" the hazardous biological effects of specific chemical pollutants in terms of the "rad-equivalent chemical" units or REC units (i.e. equivalent biological effects, in terms of say, mutagenicity or carcinogenicity produced by certain dose-level of a chemical agent and the ionizing radiation expressed in rad units). Implicit in such an attempt is the objective of expressing the overall "health risk commitment" from the combined exposures to chemical pollutants and radiation in the environment Needless to say such attempts are in their preliminary stages and are still fraught with many technical uncertainties.

In keeping with its objectives, the IAEA promotes the practical applications of nuclear techniques to help solve the environmental pollution control problems. For example, through research support and co-ordination, the techniques of neutron activation analysis have been elaborated into suitable methods applicable for the epidemiological survey of heavy metal contamination in human hair samples. Activation analysis has also been extended for the detection of pesticide residues, and for the correlation of metallic pollution with the incidence of cardiovascular diseases. Genetic (biological) control of insect pests of agricultural crops ("sterile male technique" using gamma radiation) keeps the environment from being burdened with hazardous chemical pesticides. The programme activities of the Agency's Division of Nuclear Safety and Environmental Protection deal with the formulation of the radiation health safety standards and guidelines in the various practices of handling of the nuclear materials for peaceful uses, including the safe disposal of radioactive waste materials from nuclear installations.

Useful current information in these areas of peaceful nuclear applications are disseminated to Member States through scientific meetings and training courses, the provision of technical assistance, fellowships and expert services, and the publication of proceedings, manuals and technical reports. In all these activities, co-operation is maintained with the corresponding programme activities of UNEP, WHO and FAO.

CONCLUSIONS

Chemical pollutants from conventional energy and industrial sources released to the environment presumably pose a hazard to man's health and environmental resources. Insufficient knowledge of their detailed mechanisms of interaction with the biological systems seems to provide the greatest drawback in current attempts for realistic assessment of the health risks of chemical pollutants in the short and long terms. Nevertheless, their detrimental health consequences are becoming more and more apparent as a result of recent epidemiological surveys of workers in conventional energy installations and of the chronically exposed general public.

So far nuclear power has succeeded in achieving a remarkable health safety record. In view of its projected expansion, research on biological effects of low-level radiation and radionuclides should continue to re-evaluate the health safety consequences. However, a projection from past experiences together with continued efforts for improvements of health safety aspects seem to justify an expectation that the proposed expansions in the nuclear power programme should not have an unfavourable impact on the environment. The potential hazards and challenges from the associated radiation in man's environment have proved manageable. More attention now needs to be paid urgently to safeguard human health and environment against the chemical pollutants.

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