7.5 IMPACT OF LOW-LEVEL RADIATION WITH SPECIAL REFERENCE TO TRITIUM IN ENVIRONMENT

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Radiation is invisible, but exists in various types, in the form of particles and/or energy bundles. The effects of low-level radiation seem very abstract since these can not be perceived by our sensory organs. The increase in natural background radiation from various inadvertent sources like tritium has the prospect of altering the entire scenario of billions of years’ slow and steady biogenetic evolution. Mankind, by developing atomic technologies, is unleashing forces which it does understand but not beyond experimental findings. There is no wise sorcerer who can undo the damage we are causing.

Tritium is a radioactive form of hydrogen that is produced in the reactor core. The released tritium replaces hydrogen in water. Tritium in water when gets ingested, causes continuous internal low-level beta radiation exposure over a long period. Proposed presentation will focus on the possible long term damage caused by its low-level exposure is dependent on the length of duration living tissue spends in the radiation field, not on the relative radiation field strength. As internal radiation pulses never stop, impact is continuous by the ambient radiation atmosphere. There is no chance to heal at the molecular level, except small chances of DNA repair since the organically bound tritium has greater severe influence with the slow turnover.

Though the situation needs not be alarming with tritium, the studies on radiation damage on various parameters have given evidence of two compartments of radiation damage; the reparable or potentially lethal and the irreparable or lethal. With emerging new reports on the stochastic effects, those for which the probability, rather than the severity of an effect from tritium occurring as a function of dose also can not be ruled out. Biotoxicity of tritium in the form of induction of cancer, hereditary effects, teratogenesis and life shortening really needs an exhaustive investigation and warrants careful evaluation. However, a positive trend of acclimatization to tritium exposure is always there along with the presence of radiation-induced repair mechanism. But the danger is that the low level exposure may effect in unpredictable ways not only human kind but also its evolving process which may or may not have visible and beneficial (?) influence, what people are calling hormesis. They will act not only on people, but on those biological systems which support us. Because these changes may be beyond our notice and beyond the ability of scientists to judge, and in so many disparate ways, we will not notice the decline in the spiritual and physical quality of our world. When finally the effects of this process are so bad that no one can disagree, it will be too late to put the genie back in the bottle.

In biological systems the same degree of damage has not been produced by the same absorbed dose of different types of radiation. This difference in the radiobiological effectiveness (RBE) needs to be taken into account if we wish to add doses of different radiation to obtain the total biologically effective dose. For this, the absorbed dose of each type of radiation is required to be multiplied by a Quality Factor (QF). For the sake of simplicity, QF for tritium has been assigned a value of unity (ICRP, 1977).
Radiotoxic effects of long term tritium exposure are consistent and apparently higher with those expected from an equivalent absorbed dose from external X-irradiation. Hence, a possibility for a higher RBE for tritium cannot be ruled out.

Four main areas of tritium studies are proposed for the education and careful evaluation:

(1) Specific models and their validity and suitability to predict environmental transfer of tritium released from various sources especially from thermonuclear devices.

(2) The organically bound tritium (OBT) in the food chain and its possible biological consequences

(3) The need for evaluation of the chemical form of tritium in environmental samples and their fate after interaction/dissociation from microorganisms

(4) The studies on effects at low doses and low dose rates were urgently needed; and doubts were expressed on the validity of extrapolating not only between species but between specific strains in one species.

(5) The need for continuing collaboration in educating low level radiation exposure between scientists in Europe, Canada, USA and Japan. European scientists had concentrated their efforts in ecology; the North American scientists on large scale animal experiments; and Japanese scientists on molecular and cellular studies.

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1. Tritium, a problem for radiation protection

With the introduction of nuclear energy, an additional consideration outside the existing radiation protection framework has appeared i.e. the need to assess the radioecological and radiobiological impact of radionuclides of long half life existing in the environment for longer duration. Tritium, a radioactive by-product of power reactors also, is one of the such major radionuclides of concern. In fact, this radionuclide besides having longer life disperse more rapidly and represents a significant risk to the population exposed.

There is now the growing emphasis on tritium in radiation protection as the challenge of nuclear fusion comes nearer. From many varied reports from different laboratories, it appears that projected levels for fusion reactors may produce deleterious and detectable effects. The degree of concern over tritium problem is evidenced by a rapid increase in publications on the health implications of environmental tritium during the eighties. Keeping many such considerations in view, this monograph has been prepared which reviews the work on the behaviour of tritium in its various forms in the environment with an emphasis on the release from various sources, its world inventories and present levels, its transfer in the various compartments of ecosystems. Besides this, its metabolism in the biosystem and the possible implications of low doses of tritium in present and future generations have also been discussed. In this report the question of tritium releases and pathways to man have also been covered with the view of modelling.

2 Properties

In order to examine the various perspectives of impacts of tritium in the environment, it is necessary to take a detailed look at a number of endpoints such as the physical characteristics of tritium, its natural and artificial sources, world inventory, distribution routes from the environment to man, metabolism, and several other related factors. This would enable one to evaluate whether or not tritium in the environment is a potential hazard, now or in the future. Besides a detailed analysis of the many papers relating to the tritium research a reference has also been made to some those papers which appear indirectly but pertinent to the specific aspects of the tritium question. Hopefully the present document will help the committees charged with the responsibilities of setting the standards permissible dose limits and determining an acceptable level of exposure from such radionuclides, particularly considering accidental situation which involves a release of large inventories of radioactivity.

3 Behaviour in the environment

The chemical form in which tritium is released determines greatly its radioecological behaviour. Tritiated water, becomes rapidly distributed in a given environment and is diluted as light water. Tritium incorporated in
organic material behaves differently and may be accumulated in biological system.

3.1 Speciation of Tritium: Tritium has appeared as an occupational hazard mainly as tritiated water of high specific activity or as tritium gas. The speciation of tritium in the environment is another focal area of interest. Most tritium is released into the environment as HTO, elementary HT or, rarely and as a small fraction, tritiated methane gas. Certain liquid effluents containing tritiated compounds may constitute a peculiar risk due to their preferential incorporation by living organisms.

Several mechanisms intervene in the conversion of HTO or HT to organic tritium like exchange with organic hydrogen, metabolic reduction, photosynthesis etc. The surprisingly high T/H ratio in atmospheric methane raises questions as to its origin and its fate. At least 80% of this methane is of
biological origin; it can also be a by-product of laboratory or industrial processes where tritiated organic matter is present. A particular problem in that respect may be the shallow burial of low level tritiated organic material. Tritium might initially be absorbed at sites capable of absorbing hydrogen at the surface of plants.

Tritium can form organic compounds

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\begin{align*}
\text{C}_6\text{H}_{12} & + \text{T} \rightarrow \text{"Benzene"} & \text{C}_6\text{H}_{11} + \text{HT} \\
\text{CH}_4 & + \text{T} \rightarrow \text{"Methane"} & \text{CH}_3 + \text{T} + \text{HT}
\end{align*}
\]

Tritium can be captured in metallic compounds called "Hydrides" and then released by heating

3.2 Factors affecting Metabolism: Tritium as a gas or as tritiated water can reach the body tissues of animals and man through several routes. However, the absorption time and passage time of tritium from various compounds in and through various tissues to blood depend on the various factor as studied in different animals and human, viz., basal metabolic rate of the animal, habitat, physiological status, season etc, which are yet to be investigated fully. Tritium can be absorbed in either form by way of the skin or the lungs, or it can be ingested in the form of food as organically bound tritium or as drinking water. Organically bound tritium (OBT) has the form of tritium bound to one or more constituents of food which is consumed.

3.3 Fixation: Tritium gets fixed in skin and transmitted to body fluids when intact skin is brought into contact with surfaces that have been exposed to tritiated H gas (HT or T₂). There have indications that the hazards associated with the route of tritium uptake are probably small in laboratories handling small quantities of T₂ but could be significant when large quantities are being processed, particularly during repair or maintenance of process of equipment. The significance of T₂ contaminated surfaces in terms of dose to skin and to body tissues showed that the significant uptakes of HTO and OBT could also occur from skin contact with T₂ concentrations.
3.4 Organically bound tritium: OBT is formed in microorganisms, plants or animals; the relative contribution of these pathways to the dose to man depends on site and food habits. Considerable information on transfer of HTO and OBT to milk and meat and on that to the growing organism have been obtained. A few data are available on transfer of tritium from soil organic matter to plants showing that tritiated water as well as organic matter from tritiated organic compost is incorporated into various parts of plants. Tritium in liquid effluents released in aquatic environments can come from several sources and occur in different physico-chemical forms. Certain organic compounds may constitute a particular risk due to their preferential absorption by aquatic microorganisms. This fraction was however small (<1%) in the case of effluents from a radiochemical laboratory and for OBT of high specific activity formed in purification resins in the primary loop of PWR.

OBT could exist in exchangeable and nonexchangeable forms and the presence of minute traces of residual HTO in soil after its apparent removal may falsify the results. The need for standardising procedures for measuring
OBT should be stressed. Enrichment of tritium in organic material compared with water should be viewed with suspicion if the source of the tritium exposure and details of the exposure conditions. As an example, enrichment could be caused by discontinuous release. Thus one must verify that equilibrium conditions have been attained since enrichment may have been simulated by the different metabolic behaviour of various compartments under conditions of discontinuous exposure.

As long as OBT is exchangeable with water, its behaviour may be unpredictable and the simulation with the way tritium will behave in different metabolic pathways face difficulty. Although it is pointed out that in tissue and cell preparations, all exchangeable tritium can be removed easily. It was generally agreed that non-exchangeable tritium should be equated with OBT. The importance of reversible reactions in living organisms should also be underlined. Some studies are also necessary to determine whether catalytic oxidation of HT could occur in air.

Environmental tritium from atmospheric testing will be at natural levels by about 2030

The world inventory of tritium from atmospheric testing is approximately 400 million curies (approximately 41 kg).
### 3.5 Waste Management

The waste management of tritium needed to be addressed before undertaking a massive tritium production programme for fusion.

Tritium containment is necessary in the first few years because of its high mobility in the biosphere if buried. Most tritium waste could be adequately managed but it should be kept in mind that tritium-contaminated aqueous effluents from reprocessing plants which could not be disposed of in rivers or the sea; and the high temperature treatment processes where tritium could be released.

### 3.6 Modelling

A need for improved model development now mainly relates to accidental releases. Improved data on environmental behaviour are needed for the development of such models and a great with establishing a programme of reliability testing. The data available are still too fragmentary on the models which could predict distribution from source data. For the realistic models are to be realistic, their parameters need to be tested experimentally and it also demands a continuous feed-back must exist between experimentalists and modeler. Hitherto known worked out models are relatively insensitive to changing activity concentrations and accidental situations. They are more likely to overestimate dose to people, particularly if HT was present. As per Linsley's remark* in the specific activity model, to predict the consequences of atmospheric releases of tritium, the specific activity of tritiated water taken in by man has been equal to that in atmospheric water at the location of interest. However this situation is rarely achieved in practice.

### 3.7 Doses

Doses to the localised critical group resulting from routine releases of tritium are usually a very small fraction of the dose limit; in such situations, the conservative approach of the specific activity method is acceptable. When estimating collective doses for use in optimisation studies, a more realistic assessment is required in principle. However, these doses are generally low when considering tritium dispersion on a regional scale. Thus the specific approach may be adequate at such levels. More sophisticated models are

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* Linsley's remark: "To predict the consequences of atmospheric releases of tritium, the specific activity of tritiated water taken in by man has been equal to that in atmospheric water at the location of interest."
however required to predict the consequences of accidental releases, where equilibrium conditions are not anticipated, for example after a pulsed release. Such models are needed to analyse safety aspects at the design stage and in planning the likely scale of events on an exposed population. Under these circumstances, information is required about the spatial distribution of the tritium deposit and the time dependent behaviour of the nuclide in the environment. The model must take into account factors such as the interaction between tritium in the atmosphere and soil, HT to HTO conversion, evaporation and subsequent dispersion; and finally transfer through a food chain to man and the consequences of intakes of OBT. The problem arises in testing the validity of these models against actual environmental measurements.

4 Metabolism and Radiotoxicity

Though tritium exposure in the form of HTO has been considering not very toxic, yet the metabolism of tritium in mammals and man needs a careful evaluation when all forms of tritium had to be taken into account in terms of effects. Information on elementary tritium is limited but for the other forms the incorporation into various molecules of the cell need to be looked into. For long-term effects metabolic incorporation into cellular macromolecules is most important, and prime among these is DNA and associated proteins. In fact, the short range of the tritium beta particles label in the cell nucleus is decisive for the biological effects. Tritium activity can also be very high in lipids, whereas it is relatively low in carbohydrates which mostly have a rapid turnover and thereby can release their label into tritium water.

A better information on tritium localisation inside the cell is required. The studies performed on many proliferating and renewal tissues have given some indications, but most of them have a relatively rapid turnover of its OBT and it appears that large variations in turnover of OBT can occur. A better information on turnover in different tissues and in different molecules is thus needed. It may not be enough to study molecular species such as lipids or proteins, to have a comprehensive picture, an information on specific molecules would be needed. For example, the turnover of histones differs from that of proteins in the cytoplasm and that of proteins in muscle or skin is much slower than that in liver or intestine. All this information would be quite useful to obtain better metabolic models.

For a one-generation study the course of tritium incorporation and its turnover becomes of importance, however, it is of less consequences in the case of multigenerational studies when the animals are chronically (continuously) exposed to HTO. In such a situation the maximum activity in the organism should remain constant. Organically bound hydrogen in an animal may arise from an incorporation from the hydrogen of body water during the metabolic synthesis of the compounds in tissues. Tritium content of the tissues thus indicates the extent to which hydrogen has been derived from each of the two available sources. The organically bound hydrogen pool consists of many...
compartments, the hydrogen of which will not usually equilibrate with each other.

4.1 RBE: A consideration on the radiosensitivity of the tissues involved and the RBE need to be looked into. The RBE seem to differ from 1 to 3 compared to X-rays. This must be better defined for radiation protection purposes. The mechanisms of action in order to judge better the RBE in different systems needs to be studied. There has been also the question whether we can extrapolate from animals to man. We can certainly do this for the same defined effect such as myeloid leukaemia but one cannot in general, extrapolate from one effect to another, for example, from the RBE of leukaemia to that of another cancer. One cannot extrapolate quantitatively from animals to man except on general principles (Streffer*).

4.2 Radiotoxicity: The toxic effects of tritium administered in various forms, especially as water and labelled thymidine have been adequately demonstrated at various levels of biological organization. The radiotoxic effects of tritium on embryos and fetuses seem consistent and apparently higher than those expected from an equivalent absorbed dose from external X- or gamma-irradiation. However, there have been a few other studies where no such difference is evident. It appears to be dependent on many factors viz. the organ or cellular system studied, doses and dose rates etc.

4.3 Human studies: About 20 years ago Silini et al (1973) in the EUR 5033 e report on radiotoxicity of tritium in mammals stated that 'the data available are of little use for public health protection because the effects measured are not of immediate practical application. For example systemic studies of the lethal action of tritium in vitro and in vivo which are probably the most significant, even on a practical level, have only been conducted fragmentarily and without practical objectives.' Since then the situation has changed a lot and several new studies with prime aim on the dose dependent response, on human tissue has made and appeared in the literature. In this context the contribution from Japanese researchers on the in vitro studies on the human tissues and delayed effects studies by Brookhaven National Laboratory are worth drawing attention, besides from several fragmentary but specific reports.

4.4 Carcinogenesis: With emerging new reports the "stochastic effects", those for which the probability, rather than the severity of an effect from HTO occurring is a function of dose also can not be ruled out. Biotoxicity of tritium in the form of induction of cancer, hereditary effects, teratogenesis and life shortening really need an exhaustive investigation and warrant careful evaluation. Though the situation need not be alarming with tritium, the studies on radiation damage on various parameters have given evidence of two compartments of radiation damage; the reparable or potentially lethal and the irreparable or lethal. However, a positive trend of acclimatization to HTO-exposure is always there along with the presence of radiation-induced repair mechanism.

Several reports from the literature indicate that tritiated thymidine may be potentially carcinogenic depending on the amounts of tritium incorporated into
the cell nuclei and on the time of life at which the tritium was introduced into the cells. In this context the effect of organically bound tritium needs yet to be explored which may be quite different in magnitude than those of HTO.

The aspects of carcinogenic actions of tritiated water merit careful attention in view of the data showing the incorporation of tritium from tritiated water (HTO) into DNA and other macromolecules, and the significance of nuclear fraction of tritiated water. The potential carcinogenic effects at low doses of tritium remain a controversial subject. Further studies involving the effects of tritiated water on different processes in cultured cells under controlled laboratory conditions can provide much useful basic information.

5 Future Research Needs

Four main areas of tritium research can be envisaged for a careful evaluation.

(1) the chemical form of tritium in environmental samples and their fate after interaction/dissociation from microorganisms

(2) the organically bound tritium (OBT) in the food chain and its possible biological consequences

(3) Development of specific models and their the validity and suitability to predict environmental transfer of released tritium in an accidental situation as well in commercial use of tritium.

(4) The studies on effects at low doses and low dose rates on the validity of extrapolating not only between species but between specific strains in one species.

Gerber* rightly remarked that the need for continuing collaboration between scientists in Europe, Canada, USA and Japan should be stressed. European scientists had concentrated their efforts in ecology; the North American scientists on large scale animal experiments; and Japanese scientists on molecular and cellular studies.