Tritium
The Overlooked Nuclear Hazard

by
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More tritium is released from nuclear installations than any other radioactive contaminant. The nuclear industry insists that such releases, which are largely unregulated, pose no risks to the public; but the models used to assess its radiotoxicity are suspect, and there is mounting evidence linking tritium emissions with birth defects and cancers.

Although tritium, a radioactive form of hydrogen, occurs in nature — formed by the action of cosmic rays on the earth's atmosphere — nuclear installations are by far the greatest source of tritium in the environment. Emissions from civil nuclear reactors, reprocessing and storage facilities in Western industrialized countries now equal natural sources[1] — approximately 7.4×10^4 terabecquerels per year[2] (TBq/a), one terabecquerel being 10^{12} becquerels. Still larger quantities are released from nuclear weapons facilities: the two massive US nuclear weapons plants at Savannah River and Hanford, when they were both working, alone released ten times more than the combined emissions from all the West's civil nuclear installations — some 1.1×10^5 TBq/a.[3] Worldwide, nuclear weapons manufacturing, up until recently, released 2.8×10^6 TBq/a.[4] Testing of nuclear weapons, in particular from 1954 to 1962, released even larger amounts into the atmosphere — a report[5] by the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) put the figure for 1977 at 1.6×10^8 TBq.

In the UK, the largest tritium emissions to atmosphere are from the Chapelcross plant in Dumfriesshire, Scotland, which makes tritium for nuclear weapons. Other major sources are the Sellafield reprocessing plant in Cumbria, and other nuclear weapons and production facilities. The table opposite shows these facilities ranked according to the volume of atmospheric emissions.

If nuclear fusion is ever developed commercially, it is expected that tritium discharges will increase considerably, since the core of each fusion reactor will contain an estimated 10 kilogrammes (100 million curies) of tritium.[6] Should the lithium, also used in the reactor, catch fire and burn with sufficient intensity, a substantial fraction of the reactor's tritium could be released. It has been estimated that for every 1,000 megawatts of future fusion capacity, 110 TBq/a of tritium will be released into the environment in the form of "routine" discharges.[7] "Accidental" releases could add a further 3.7×10^4 TBq/a.[8]

In Britain, atmospheric emissions of tritium from most nuclear power stations are neither monitored nor limited (current figures for releases being estimates). It is expected, however, that limits will be imposed under revised authorizations to be issued by the Ministry of Agriculture Fisheries and Food (MAFF) and the Department of the Environment (DoE). Such atmospheric releases are more hazardous than tritium discharges to the sea, which are currently monitored and subject to limits, because airborne tritium is more readily incorporated into the human food chain, and can be directly inhaled and absorbed through the skin.

Hard to Detect

All nuclear reactors produce tritium in their fuel elements as a by-product of the fission of uranium and plutonium. Tritium is also formed by neutron activation of deuterium, lithium and boron in the moderator, coolant and control rods. With Magnox reactors and Advanced Gas Reactors (AGRs), the main activation source is lithium impurities in the graphite moderators.

Tritium does not readily diffuse through the magnox and zircalloy fuel cladding of Magnox and Pressurized Water Reactors (PWRs), whereas it diffuses easily through the stainless steel cladding of AGRs. Consequently, the tritium formed in AGRs is released on site, while that formed in Magnoxes and PWRs is not released until their fuel elements are reprocessed. Larger amounts of tritium are therefore emitted from AGRs than from other reactors in Britain.

Discharges of tritium from nuclear plants occur mainly in two forms: tritium gas (HT) and tritiated water (HTO). In its elemental form (HT), tritium is invisible, odourless and pervasive, permeating most materials, including rubber and most grades of steel, with relative ease. Tritiated gas is converted to tritiated water in dry indoor conditions at the rate of about one per cent per hour, faster in humid conditions.[9] Tritiated water is more hazardous than HT, since, being chemically identical to ordinary water, it diffuses rapidly throughout the hydrosphere and biosphere. All people living downwind of large nuclear facilities can thus be expected to be tritiated to ambient HTO levels. HTO is considered by the International Commission on Radiological Protection (ICRP) to be 25,000 times more hazardous in air than HT, because of its mobility and uptake.[10]

Because of its low energy, tritium's beta radiation is difficult to detect in air without expensive US-made equipment, not widely used in the UK. *In situ*, it is impossible to detect in air with most hand-held portable instruments, and all thermoluminescent dosemeters, film-badges or other personal dosemeters. Separating, detecting and measuring environmental concentrations of organically-bound

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tritium in food or in our bodies is even more difficult, and requires expensive, dedicated equipment and/or techniques not normally used outside specialist labs.

Faulty Dosimetry?

Nuclear authorities insist that tritium is not hazardous: indeed its releases are either not discussed in official UK reports on radioactive discharges, or are relegated to brief discussion in appendices. So how radiotoxic is tritium?

To answer this, one has to calculate the internal doses received from tritium inhaled, or absorbed through the skin, or ingested as tritiated food or tritiated water. The dosimetry of internally deposited radionuclides from concentrations released to the environment is complex. Environmental transport models have to be used to estimate tritium concentrations to which the public is exposed. Biokinetic models are then used to estimate the body's uptake, retention and excretion of tritium. From these concentrations absorbed doses can be calculated, which in turn are converted to equivalent doses so that different kinds of radiations can be measured on a common scale, a Radiation Weighting Factor, or Q factor.

These transport and biokinetic models may involve unproven assumptions and the Q factor chosen for tritium is subject to strong differences of view. Most importantly, the above models ignore the ingestion and uptake of organically-bound tritium (see below p.230). As a result, the real level of tritium doses near nuclear facilities is likely to be significantly underestimated

Political considerations have played a large part in the setting of standards. In 1963, for example, the ICRP[11] assigned a Q factor for tritium of 1.7, but in 1969 reduced it to 1.0.[12] This was despite evidence, even then, suggesting that tritium was more harmful than previously thought.[13] Dr. Karl Morgan, past chair of one of the main committees of the ICRP, recently stated that in the 1950s and 1960s, during which he was a full member of the ICRP, "there was constant pressure to set the RBE [Relative Biological Effectiveness, a scale similar to Q value] at 1.0 instead of 1.7." He added: "One ICRP member even went so far as to lament the difficulties they were having in keeping down to the tritium Maximum Permissible Concentrations (MPC) in their weapons production plant, and our lowering the RBE to one would be a great help . . . Thus the way of reducing risk in a weapons production plant has been to get the ICRP and the US National Council on Radiation Protection (NCRP) to relax radiation protection standards, raise the MPC values, and have them adopted by the US Department of Energy and the US Nuclear Regulatory Commission."[14] Since then, many other scientists[15] have questioned the wisdom of setting the low Q value of 1.0 for tritium, in view of various studies which suggest that tritium has Q values four to five times higher than the value of 1.0 still used by the ICRP.

Tritium Emissions from UK Nuclear Plants

NUCLEAR FACILITY	TRITIATED WATER VAPOUR ADMISSIONS TO ATMOSPHERE TBq/a*	TRITIATED WATER DISCHARGES TO SEA TBq/a
Chapelcross[1]	1900	0.28
Sellafield[1]	593	1699
Amersham Int'l (Cardiff Plant)	180[2]	601[3]
AWRE Aldermaston[4]	100	0.1
AERE Harwell	46[1]	1.8[4]
UKAEA Dounreay[5]	18	9.9
Amersham Int'l (Amersham Plant)	14[2]	6[3]
Wylfa Magnox	13[2]	3[3]
UKAEA Winfrith	8.4[2]	149[3]
Hunterston B AGR	8.2	333[3]
Dungeness B AGR	3.2[5]	7.3[6]
Hartlepool AGR	3.2[5]	166[6]
Heysham 1 AGR	3.2[5]	95[3]

*One TBq/a = 27 curies.

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The "Weak" Radionuclide

Tritium's beta emissions are weak, indeed they are unable to penetrate intact human skin. But this relative weakness outside the body is reversed when tritium is inhaled, ingested or absorbed into the body.

For example, when tritium is incorporated into chromosomes in cell nuclei, it deposits all its energy within the chromosome because the electron emitted by tritium's decay has a short range of about 0.6 micrometres, less than the width of a human chromosome. Tritium's very "weakness" is thus the source of its danger, since its low energy and short track result in considerable damage to the DNA macromolecule, the critical site for the effects of radiation. Other internally-deposited radionuclides with larger beta and gamma energies (gamma radiation having greater penetrating power than beta radiation) have much longer tracks: their effects are thus diluted throughout organs or the whole body.

Many studies[16] indicate that ingested tritium is incorporated into cell nuclei and specifically into their DNA. Nuclear magnetic resonance studies suggest it may be selectively taken up by DNA's water of hydration.[17] Other studies show that tritium from tritiated food finds its way into DNA rather than other cell nuclei

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Chapelcross nuclear power station, in Dumfriesshire, Scotland, emits more than three times as much tritium into the atmosphere as any other UK plant. It produces tritium for nuclear weapons.

constituents[18] and that the ingestion of tritiated protein results in "a standard nucleus containing four times more tritium in the form of nuclear proteins than in the form of water".[19] The key point here is that the ICRP and other radiation authorities make no allowance for these possible dangers to DNA in their dose conversion factors for tritium.[19]

Organically-Bound Tritium

The incorporation of tritium into DNA is the most important of several ways in which tritium may become bound to organic material. The behaviour of such organically bound tritium (OBT) is, in general, neglected by the nuclear industry.

In calculating the concentrations of tritium in the body, the ICRP uses a metabolic model of the body's uptake, retention and excretion of tritium. Unfortunately, the ICRP ignores the fact that tritium over time will bind with the body's organic molecules. It also ignores the ingestion of tritiated food. These omissions are the most serious of all the ICRP's errors, for three reasons. First, OBT delivers radiation doses for much longer periods of time than tritiated water — 280 to 550 days as compared to 10 days.[20] Second, it delivers doses to specific organs and cells rather than being diluted throughout the 40 kilograms of water in the average human body. Third, the dangers of radiation are thought to be particularly acute where rapid cell replication occurs, for example in embryos, and in sperm-producing and bone-marrow cells. Uptake of high concentrations of OBT from tritiated food by the DNA of these cells could result in birth defects, genetic effects and childhood leukemias respectively. These are the adverse health effects being reported near nuclear reactors around the world producing large amounts of tritium.

Organically-bound tritium was overlooked by radiation authorities for many years, and even now, relatively little is known about the details of OBT uptake, metabolism and excretion in humans. This situation is changing slightly; in 1989, the ICRP issued a report[21] acknowledging OBT's uptake for the first time. In 1989, the National Radiological Protection Board (NRPB) followed suit and issued dose conversion factors for OBT which gave it further recognition, but they still have not taken the next vital steps of recommending limits for OBT intake, or suggesting how to measure OBT in humans. Also, in 1990, four scientists from health research institutes in Germany, France, Sweden and the US issued a report[22] drawing attention to OBT, stating "the radiation dose delivered to specific tissues, for example bone marrow, may be greater following the ingestion of organically-bound tritium by almost an order of magnitude as compared to HTO [tritiated water]." Unfortunately, UK monitoring authorities, including MAFF, the Department of the Environment and the NRPB, still consider only tritiated water in their measurements and dose calculations, and ignore OBT.

Lax Limits

It can be seen from the above that the factors which shaped tritium's limits were determined in the late 1960s and 1970s when cold war imperatives and the need for maximum tritium production for nuclear weapons were considered more important than today. These same limits, though out of date, are still in force.

The crucial point about tritum's faulty dosimetry is that it results in annual limits for tritium which are very lax. The maximum amount of a radionuclide which a worker may safely ingest or inhale in one year is termed the Annual Limit on Intake (ALI). The ICRP now recommends an ALI for ingested tritiated water of $1x10^9$ Bq/a.[23] This is the amount of tritium which, if ingested, would result in the ICRP's recommended maximum radiation dose for workers in one year. This limit is 660 times more lax (for ingestion) than that for caesium-137, and 1,000 times more lax than iodine-131, both of which are commonly discharged from nuclear sites and may be compared with tritium. Also, the Derived Generalised Limit for members of the public for tritium in green vegetables is 40 times higher than that for carbon-14 and 2,400 times than for strontium-90.[24]

Recent Reports Concerning Tritium

Several recent epidemiological studies and other reviews have added fresh evidence about tritium's toxicity, linking tritium emissions from nuclear reactors in Canada, India, the US and Britain to birth defects and possibly to cancers. Three of these studies — the findings of which are set out below — specifically discuss tritium. Several others (listed in the Box, p.231) do not single out tritium, but may be significant.

- **AECB Canada Report**

The most recent and directly relevant report is an Atomic Energy Board of Canada study[25] which analysed birth de-

near Toronto, Ontario. The Pickering heavy water reactors emit 2,500 TBq/a of tritium, about the same amount as is emitted from Sellafield, but, and this may be important, it is the only radionuclide emitted in any quantity by the Canadian reactors. The study found an 80 per cent (Observed 24; Expected 12.9) increased birth prevalence of Down's syndrome at the nearby town of Pickering, and a 46% (Observed 14; Expected 9.6) increase at Ajax, a town further away. These were correlated with airborne tritium releases in the case of Pickering, and ground monitored tritium levels in the case of Ajax. The report also found an association between high airborne tritium release levels and central nervous system anomalies in births at Pickering.

In 1985, Beral conducted a mortality study[26] of 40,000 United Kingdom Atomic Energy Authority employees, some of whom were monitored for tritium exposure (but whose precise levels of tritium exposure were not recorded). The study found that the only cause of death showing a clear relation with radiation exposure was prostatic cancer and the relationship was particularly marked for those who were monitored for tritium exposure. However other workers not monitored for tritium also died from this form of cancer. The study indicated that these unmonitored cases were almost exclusively linked to the Winfrith heavy water reactor, which produced relatively large amounts of tritium.

Laboratory Report

In 1991, the US Lawrence Livermore Laboratory, a nuclear research facility funded mostly by US nuclear agencies, comprehensively reviewed[27] the carcinogenic, mutagenic and teratogenic risks of tritium — ie. the risks for cancer, genemutation and birth defects. The report assembled RBE estimates for tritium which were judged to be 1.5 to 5 times greater than RBE estimates for gamma and X-rays. This alone raises serious doubts about the ICRP's recommended Q factor of 1.0 for tritium. Interestingly, both this laboratory and the US Oak Ridge National Laboratory have abandoned any further work with tritium, for unstated reasons.

A Common Factor in Cancer and Deformity Clusters

Several reports have appeared of adverse effects associated with nuclear facilities which discharge tritium. They do not identify tritium as a causative agent; nevertheless all of these facilities emit large amounts of tritium, and the adverse effects that they report, principally leukemias and birth defects, are similar.

- **United Kingdom**

The 1990 Gardner Report[28] found an association between externally-measured radiation doses received by nuclear workers at the Sellafield reprocessing plant and the likelihood that they would father a leukemic child. The specific cause of these leukemias is still a matter of debate in scientific circles. Nevertheless the report mentioned tritium as one of two possible internal radionuclides in workers at Sellafield. The other was plutonium, a bone-seeker which emits powerful alpha radiation in the bone marrow where white blood cells are formed. This was thought to be the link with the leukemia found near the nuclear plants. But the Gardner report appears to cast doubt on this theory, and has shifted the focus of attention from somatic to genetic effects, from bone marrow to testes, and from plutonium to tritium, as plutonium is not , at present, thought to accumulate in testes.

- **United Kingdom**

The second and third reports[29] of the Committee on Medical Aspects of Radiation in the Environment (COMARE) discuss the raised incidence of childhood leukemias near the nuclear reprocessing plant at Dounreay, and near the nuclear facilities at Harwell, Aldermaston and Burghfield. At both areas, relatively large amounts of tritium were and are routinely emitted.

- **Ontario, Canada**

From 1989 to 1991, the AECB in Canada carried out a study[30] of childhood leukemia around Ontario nuclear plants which found a 40% (Observed 40; Expected 28.5) increase in childhood leukemia deaths near the Bruce and Pickering reactors, with a 94% level of confidence.

- **Rajasthan, India**

On 2 April 1991, the UK Channel 4 TV programme "The Price of Power" revealed high levels of congenital malformations among babies born in the villages downstream and downwind of the heavy water reactors at Kota in Rajasthan.

- **Washington State, USA**

In February 1988, at the Hanford nuclear military complex in Washington State, Sever[31] reported a statistically significant association between the paternal pre-conception radiation dose to Hanford workers and neural tube birth defects in their children, ie. anencephaly and spina bifida . Sever also reported a statistically significant elevated rate of the same birth defects among the general population near the Hanford site. Hanford, which reprocesses spent fuel for nuclear weapons purposes, discharges large amounts of tritium.

- **South Carolina, USA**

The Savannah River Plant (SRP) in South Carolina contains plutonium-producing reactors, tritium-producing plants and nuclear fuel reprocessing plants, all for nuclear weapons purposes. These are now closed but the US Government is trying to restart some of these facilities. The SRP's tritium discharges in the 1970s and 1980s were massive: according to the US National Council on Radiation Protection,[32] in the 1970s the SRP emitted 24,000 TBq of tritium a year. Statistically significant findings by the 1990 US National Cancer Institute (NCI) report of adult leukemias and especially of lung cancers in the counties surrounding the plant, and unreported higher perinatal mortality statistics for Barnwell County in South Carolina.

The Future for Tritium

The associations suggested in the above health reports raise questions about tritium's dangers. This is being matched by an increasing recognition, at least in some quarters, of tritium's toxicity, especially that of organically-bound tritium. Considerable research is now being carried out into the uptake and retention of nuclides, including tritium, during pregnancy, and studies may soon be initiated into OBT concentrations near some UK nuclear facilities. These perceptions of the increased dangers of tritium may not augur well for any expansion of the UK nuclear industry. They certainly will dampen hopes that fusion would provide a non-radioactively polluting source of electricity. It may be wiser to address these newly-perceived dangers of tritium while we still have energy policy choices ahead of us, rather than face expensive nuclear cleanups and retrofits for health reasons later.

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