Health Dangers of Tritium Emissions
~ Part 1 ~

Excerpts from Source Documents

WHY TRITIUM?

Tritium is radioactive hydrogen. It is created and released into the environment in far greater quantities from CANDU reactors than from other nuclear power reactors, such as the American "light-water" designs.

Like all radioactive substances, tritium is a carcinogen, a mutagen, and a teratogen. Laboratory work with mice and rats has clearly shown that tritium is particularly potent as a mutagen and teratogen.

The first document in this series was written in 1981 at the request of Marion Dewar (then Mayor of Ottawa) following a deliberate dump of 3500 curies of tritium into the Ottawa River upstream of Ottawa, with no warning to the population or to municipal authorities. The other documents in this series are part of a dossier sent to Mayor Dewar at that time; they are verbatim excerpts from documents on tritium produced by various authoritative bodies.

Gordon Edwards

VERBATIM EXCERPTS FROM

1. Tritium Dumping: Who Should Decide?
   Comments on Tritium Dumped into the Ottawa River
   from the NPD nuclear reactor at Rolphton, Ontario (1981)

2. The US National Academy of Science's BEIR-III Report
   "Effects on Populations of Exposures to Ionizing Radiation" (1980)
   Comments on Tritium

3. The Safety of Ontario's Nuclear Reactors
   Report of the Select Committee on Ontario Hydro Affairs
   Tritium and Carbon-14

4. Testimony of Dr. Edward Radford
   to the Select Committee on Ontario Hydro Affairs
   Tritium Dangers

5. Genetic Effects of Radiation
   from Annex H of the 1977 UNSCEAR Report
   Effects of Tritium Exposure

6. Developmental Effects of Radiation
   from Annex J of the 1977 UNSCEAR Report
   Effects of Tritium Exposure

Reference #1:

TRITIUM DUMPING:
WHO SHOULD DECIDE?

COMMENTS ON THE DUMPING OF

3500 CURIES OF TRITIUM

INTO THE OTTAWA RIVER
FROM THE NPD NUCLEAR POWER REACTOR

ON JULY 19 1981

by Dr. Gordon Edwards, President,
Canadian Coalition for Nuclear Responsibility.

- **What happened to the NPD reactor on July 19, 1981?**

A 200,000 gallon reservoir of emergency cooling water (consisting of ordinary water) was accidentally drained when a rubber sleeve connecting two pipes came loose, flooding the boiler room of the NPD reactor (a prototype CANDU reactor at Rolphton Ontario with a capacity of 22 megawatts) to a depth of 25 feet.

- **Was it a dangerous reactor accident?**

No. Since the regular cooling was uninterrupted during this incident, there was no danger of the reactor core overheating. The emergency cooling water is only needed when the regular cooling is lost, which has never happened in a CANDU reactor as yet. However, the incident does raise some important questions as to how reliable the emergency cooling system would be in the event of a genuinely serious reactor accident.

- **How did the NPD cooling water become radioactive?**

The flooding incident shorted out two heavy water recirculating pumps. As a result, radioactive heavy water ["tritiated" water] leaked out from the core area of the reactor through the pump seals and mingled with the emergency cooling water, contaminating it with 3,500 curies of radioactive tritium.

- **What is a curie?**

A curie is a unit of radioactivity, corresponding to 37 billion disintegrations per second. Thus 3,500 curies corresponds to 129.5 trillion disintegrations per second (1.295×10^{14} dps, or 129,500,000,000,000 dps). That is a great deal of radioactivity.

> One disintegration per second (dps) is called a "becquerel".
> Thus one curie is 37 billion (37,000,000,000) becquerels.
> A microcurie is one millionth of a curie, or 37,000 becquerels.
> A picocurie is a trillionth of a curie; that is, 0.037 becquerels.

- **What is tritium?**

Tritium is a weakly radioactive form of hydrogen, with a half-life of 12.3 years. The radiation emitted by tritium is not penetrating; it is a very low-energy form of radiation. About 99 percent of all tritium occurs in the form of "tritiated water" (HTO or DTO); see the explanation given below.

The letters in parentheses are based on a kind of chemical shorthand:

H = an atom of normal hydrogen (hydrogen-1), known as "protium".
Hydrogen is the lightest and most abundant element in the universe.
It is essential to life, forming an integral part of every organic molecule.

D = an atom of heavy hydrogen (hydrogen-2), known as "deuterium".
D behaves exactly like H, except that it's twice as heavy as H.
For technical reasons, it is used in the CANDU reactor.
("**CANDU**" means "**CAN**adian **D**euterium **U**ranium".)

T = an atom of radioactive hydrogen (hydrogen-3), known as "tritium".
It behaves like H, but it's three times as heavy, and it is also radioactive.
When a deuterium atom (D) absorbs a neutron it becomes a tritium atom (T); this happens often inside every CANDU nuclear reactor.

H_2O = a molecule of ordinary water (or "light water").
An ordinary water molecule is formed when two ordinary hydrogen atoms (H + H = H_2) combine with one oxygen atom (O).

D_2O = a molecule of heavy water.
In every molecule of "heavy water", both of the ordinary hydrogen atoms in ordinary water have been replaced by heavy hydrogen atoms.
Heavy water is used in the core of a CANDU reactor as a "moderator" (to slow down the neutrons) and as a "coolant" (to remove the heat produced by the nuclear fuel).

HTO or DTO = a molecule of tritiated water.
If one of the ordinary hydrogen atoms (H) in ordinary water (H_2O)
-- or one of the heavy hydrogen atoms (D) in heavy water (D_2O) --
is replaced by a tritium atom (T) , "tritiated water" is created.
This happens when one or two neutrons are captured.

- **Where did the contaminated NPD cooling water get dumped?**

The tritium-contaminated water was eventually pumped from the boiler room back into the reservoir from which it came, but it was contaminated with grit and oil as well as with radioactivity. In order to clean out the reservoir, Ontario Hydro officials decided to dump the dirty water into the Ottawa River. Many communities downstream from the reactor site draw their drinking water from the Ottawa River. Tritium cannot be filtered or otherwise removed from drinking water by any standard water-treatment processes.

- **Is this kind of radioactive dumping allowed?**

According to the United Nations Scientific Committee on the Effects of Atomic Radiation, radiation protection policies are supposed to be based on "the principle of **eliminating any exposures which are not necessary** and of keeping all doses as low as is reasonably achievable" (UNSCEAR 1977 p.14). Evidently, the Atomic Energy Control Board (AECB) does not enforce this principle rigorously; instead, it sets limits and establishes guidelines on how much radioactivity can be released by the nuclear industry into the environment, wehether it is necessary or not. In this particular case, the resulting radiation exposure of people downstream was clearly unnecessary, but was nevertheless allowed.

- **Do the radiation guidelines prevent biological damage?**

No. In the case of cancer, leukemia, and genetic damage, the scientific consensus is that every additional exposure to radiation adds to the total risk and therefore to the incidence of these diseases in exposed populations. In the case of developmental damage to unborn babies exposed in the womb, scientists have so far found it impossible to determine what level of exposure to tritium constitutes a "damaging dose".

According to a 470-page report published by the British Columbia Medical Association (BCMA) in 1980, existing AECB standards for public exposure to another radioactive substance -- radon -- "may well be viewed as tantamount to allowing an industrially-induced epidemic of cancer". Chapter XXII of the BCMA Report is entitled "Atomic Energy Control. Board -- Unfit to Regulate", based on the AECB's poor record of protecting the public health and safety (BCMA p.283).

- **What is the AECB limit for tritium emissions from NPD?**

According to the AECB, the maximum permissible release limit from the NPD reactor into the Ottawa River is 220,000 curies of tritium per month, or 2.64 million curies per year. As an operating target, the AECB tries to keep releases to within 1 percent of this limit; that is, 2,200 curies of tritium per month or 26,400 curies per year (equivalent to an average of 7.3 curies per day).

- **Did the NPD dumping meet the AECB operating target?**

Obviously not. Since 3,500 curies is larger than 2,200 curies, the dumping exceeded the AECB operating target by about 60 percent (if calculated on a monthly basis). However, since the 3,500 curies were dumped in less about five days, at an average rate of more than 700 curies per day, the AECB operating target was exceeded by about 1000 percent if calculated on a daily basis.

- **Does it matter if tritium is released slowly or quickly?**

According to Dr. Edward Radford, Chairman of the U.S. National Academy of Sciences' Third Committee on the Biological Effects of Ionizing Radiation (BEIR-III), a sudden burst of tritium in the drinking water may be much more dangerous to a female embryo in the early stages of pregnancy than the same amount of tritium spread out over a longer period of time (testimony to the Select Committee on Ontario Hydro Affairs, July 10 1979).

- **Where does tritium come from?**

Tritium is produced in nature by the action of cosmic rays from outer space. It is also produced by atomic explosions and by nuclear power plants. Each CANDU reactor produces from 30 to 100 times as much tritium as a comparable American light water reactor, because the heavy water in a CANDU "breeds" tritium while the reactor is operating.

- **How much tritium is produced globally?**

Before the advent of nuclear energy, it is estimated that the global inventory of naturally-occurring tritium was about 34 million curies, of which 22.2 million curies were contained in the oceans and 9.2 million curies were present in inland areas (UNSCEAR p.55).Nuclear weapons testing has added about 3,600 million curies of tritium in the northern hemisphere. By 1970, only about 2,900 million curies was left, mostly in the oceans; the rest had undergone radioactive disintegration to become helium-3 (UNSCEAR p.117).

American light-water reactors generate about 15 to 23 curies of tritium per megawatt-year, of which no more than 1 curie is normally released into the environment. CANDU reactors generate about 620 curies per megawatt-year, of which about 20 curies are normally released into the environment (16 curies to the air, 4 curies to the water -- UNSCEAR p.180).

At that rate, one would expect the Pickering nuclear complex (2,000 MW) to release about 32,000 curies of tritium into the air each year, yet in 1978 only 26,000 curies were released. One would expect the NPD reactor (20 MW) to release about 80 curies of tritium into the Ottawa River each year.

- **Is tritium a biological hazard?**

The radiological significance of tritium is not related to its inherent toxicity, as it is a very low energy form of radiation, but to its easy incorporation into all parts of the body that contain water (Select Committee Report p.15).

Tritiated water can be ingested in the liquid form. It can also be inhaled or absorbed through the skin in the form of water vapour or steam, which makes tritium an occupational hazard in CANDU nuclear power plants. In pregnant females, tritium ingested by the mother can cross the placenta and be incorporated directly into the foetus.

Like all radioactive substances, tritium can cause cancer, genetic mutations, or developmental defects in unborn children (the latter following pre-natal exposure of the foetus). No threshold or "safe dose" of tritium has been scientifically established for any of these effects.

- **What scientific evidence is available?**

"There is now experimental evidence, both in terms of changes in the developmental effects on foetuses in utero in animals and also in studies of cancer induction, that tritium [is] four or five times more effective than would be predicted just on the basis of its energy alone" (Dr. Edward Radford, testimony to the

Select Committee on Ontario Hydro Affairs, July 10 1979).

"Concerning the passage of tritium administered under the form of tritiated water from the mother through the placenta and into the foetus ... several statistically significant effects were found at various HTO levels, in no apparent relationship with dose. These included microcephaly [shrunken heads, also observed at Hiroshima], sterility, stunting, reduction of the litter size, ..." (UNSCEAR p.695 -- these are, of course, animal studies).

"During the past few years, there has been a growing interest in the study of the biological effects of radio-isotopes, particularly of plutonium-239 and tritium. A number of genetic and cytogenic [i.e. cellular] studies that have so far been carried out in mice demonstrate that these isotopes are capable of inducing dominant lethal mutations, chromosome aberrations and point mutations (for the last category, only the effects of tritium have been studied)" (UNSCEAR p.477).

Bibliography

1. **BEIR III** (National Academy of Sciences: Third Committee on the **B**iological **E**ffects of **I**onizing **R**adiation). **The Effects on Populations of Exposure to Low Levels of Ionizing Radiation.** Academy Press. Washington: 1982.

2. **UNSCEAR** (**U**nited **N**ations **S**cientific **C**ommittee on the **E**ffects of **A**tomic **R**adiation). **Sources and Effects of Ionizing Radiation.** Report to the UN General Assembly. United Nations, New York: 1977.
   - Annex H: Genetic Effects of Radiation. Part 2: Tritium.
   - Annex J: Developmental Effects of Radiation. Part V-B: Tritium

3. **Select Committee on Ontario Hydro Affairs. The Safety of Ontario's Nuclear Reactors.** Ontario Legislature, Toronto: 1980.

4. **BCMA (British Columbia Medical Association). Health Hazards of Uranium Mining.** BCMA, Vancouver: 1980.
   - Chapter XXII: AECB -- Unfit to Regulate.

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Reference #2:

The Effects on Populations of Exposure to Low Levels of Ionizing Radiation

published in 1980 by

The U.S. National Academy of Sciences' BEIR-III Committee

(BEIR = Biological Effects of Ionizing Radiation)

Excerpt from pp. 485-486:
"Somatic Effects Other Than Cancer"

Because tritium (hydrogen-3) is a potential pollutant from nuclear-energy production, it's effect on development [of unborn babies] **has been the subject of a number of studies.**

Tritiated water (HTO) is a common chemical state of tritium, and it has **easy and rapid access to living cells, including those of the embryo or foetus**.

HTO administered in the drinking water to rats throughout pregnancy produced **significant decreases in relative weights of brain, testes, and probably ovaries**, and increases in norepinephrine concentration, at doses of 10 microcuries per millilitre (estimated at 3 rads per day), and produced weight decreases in a number of [other] organs at higher doses.

Because the length of the critical period [of vulnerability to damage] for various organs is not known, the **total damaging dose cannot yet be estimated**. Relative brain weight was found to be reduced at only 0.3 rads per day (one microcurie per millilitre of drinking water) when exposure began at the time of the mother's conception.

Even lower exposures (0.003 rads per day and 0.03 rads per day) have been implicated in the induction of **behavioral damage, such as delayed development of the righting reflex and depressed spontaneous activity**. However, because the data fail to show a clear dose dependence, there is some doubt about the validity of this suggestion.

Tritiated drinking water has been used to study the effects of radiation on development of a sensitive cell type, the oocyte. Oocyte counts were made in serial sections of exposed and control animals. In squirrel monkeys continuously exposed from conception to birth, the LD-50 was 0.5 microcuries per millilitre of body water, giving a foetal dose rate estimated at 0.11 rads per day. Because the sensitive period for oocyte development is probably the last trimester, the LD-50 was calculated to be 5 rads. In the mouse, the sensitive period occurs during the first two weeks after birth, and, by a similar calculation, the LD-50 from tritiated drinking water at that time is slightly below 5 rads.

. . . from the Summary section, page 493

Until an exposure has been clearly established below which even subtle damage does not occur, it seems prudent not to subject the abdominal area of women of child-bearing age to quantities of radiation appreciably above background, unless a clear health benefit to the mother or child from such an exposure can be demonstrated.

Ed. note: This does not refer to tritium only, but to any form of radiation exposure.

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Reference #5:

Sources and Effects of Ionizing Radiation

1977 UNSCEAR Report
to the U.N. General Assembly

[UNSCEAR = U.N. Scientific Committee on the Effects of Atomic Radiation]

ANNEX H

Genetic effects of radiation

2. Tritium

(a) Induction of dominant lethal [mutations] in mice

Paragraph 372.

Carsten and Commerford and Carsten and Cronkite have published the results of their studies on the induction of dominant lethals [dominant lethal mutations] in mice (random-bred, Hale-Stoner-Brookhaven strain) fed with tritiated water (HTO).

The HTO test animals were first-litter mice resulting from breeding of eight-week-old animals that had been maintained on HTO (3 microcuries per millilitre) since weaning at four weeks of age. The control animals were first litter mice taken from the colony and maintained on tap water.

From the second generation animals, four experimental groups were established for dominant lethal tests.

- Group 1 consisted of animals
  where both the male and female were on HTO.
- Group 2 females received HTO,
  males, tap water.
- In Group 3, the situation
  was the reverse of that in Group 2, and
- Group 4 received only tap water
  (both males and females).

At eight weeks of age, in each group, each male was mated to five females for a 5-day period, the females were killed and their uterine contents examined for assessing dominant lethality.

Paragraph 373.

The results, based on 366 pregnant females in the controls, 764 in Group 1, 315 in Group 2, and 316 in Group 3, clearly demonstrated that **dominant lethals are induced by HTO in both sexes.**

Significantly fewer viable embryos were found when either both mating partners or only the female was maintained on the tritium regimen. Similarly, when both the partners were on tritium, **the incidence of early death (dark mole) is significantly higher** than in the control group. Treatment of the males only gave similar effects, but these were not [statistically] significant.

When post-implantation mortality (early plus late deaths in the authors' terminology) is used as the basis for comparison, the **increased mortality due to HTO** in Groups 2 and 3 is of the same magnitude in both sexes, and in Group 1 (both sexes on HTO) the effect is nearly twice that in Groups 2 or 3.

Current experiments are directed at repeating these studies with a lower concentration of 1.0 microcuries per millilitre.

(b) Induction of specific-locus mutations in male mice

Paragraph 374.

Cumming et al. (128) have completed the first series of **experiments on tritium-induced specific locus mutations in mice, providing the only data available on such gene mutations in any mammal.**

In view of possible levels of tritium release, not only from existing nuclear installations but also from contemplated controlled thermonuclear reactors, these data are of great relevance.

A total of 14 groups of males was used. Two groups were injected with 0.75 millicuries , and the 12 others with 0.50 millicuries , of tritiated water per gram of body weight.

The results demonstrate that **beta radiation from the decay of tritium can induce specific-locus mutations** in spermatogonia as well as in post-meiotic stages: 16 mutations have been recovered among a total of 20,626 offspring derived from germ cells irradiated as spermatogonia and 11 in 7,943 offspring from irradiated post-meiotic stages.

The mean absorbed dose to the spermatogonial cells has been estimated to be 700 rad and that to post-meiotic cells, 430 rad. These data thus permit mutation-rate estimates of 1.58×10^{-7} per rad per locus for spermatogonia and 4.60×10^{-7} per rad per locus for the other stages. These rates are within the statistical limits of what would have been expected from a comparable external dose of x [-irradiation] or gamma irradiation.

The point estimate of the RBE [Relative Biological Effectiveness] for post-spermatogonial stages is close to 1, with fairly wide confidence intervals; that for spermatogonia is slightly above 2, with confidence intervals that include 1.

There are some indications that the distribution of mutants among the seven loci may differ from that produced by gamma rays; noteworthy is the observation that only one of the mutations was at the s locus (the expectation would be about 5 or 6).

In more recent studies, currently in progress at Oak Ridge, Cumming and W.L. Russell (129) are engaged in collecting more extensive data on tritium irradiation, focusing attention on the induction of mutations in spermatogonia.

(c) Induction of chromosome aberrations in human lymphocytes by tritiated water (HTO)

Paragraph 375.

Hori and Nakai (233) and Bocian et al. (39) have reported on the induction of **chromosome aberrations in human lymphocytes exposed to tritiated water** in vitro. Exposures were carried out by the addition of whole blood to the culture medium containing tritiated water.

In the work of Hori and Nakai, the concentration of tritium ranged from one millionth of a microcurie per millilitre to one hundredth of a microcurie per millilitre, and the cells were exposed during their entire period in culture (48 hours).

Bocian et al., used two regimens: in one ("acute exposures" in the authors' terminology), the lymphocytes were exposed for a 2-hour period prior to PHA stimulation (range of concentrations, 1.71 to 14.36 millicuries per millilitre), after which they were washed and cultured (53-hour cultures); in the other ("protracted series") the cells were exposed during 53 hours (concentration range, 0.063 to 0.51 millicuries per millilitre).

Paragraph 376.

The results indicate that with protracted exposures (48 or 53 hours) the [chromosome] aberrations produced were mostly of the chromatid type, such as gaps, deletions and fragments, and there were relatively few chromatid exchanges.

In the concentration range used by Hori and Nakai, the dose-effect curve for the number of [chromosome] breaks induced was quite complex at low concentrations. In the work of Bocian et al. and with the range of concentrations they used, the frequency of chromatid aberrations increased linearly with dose.

A quantitative comparison of the frequencies between the two groups of authors is, however, not possible because each group used only one (but different) fixation time, and in addition, the ranges of concentration were different.

Paragraph 377.

In the 2-hour exposure experiments of Bocian et al., chromosome-type aberrations were found to be induced (dicentrics, centric rings, terminal and interstitial deletions). The data for dicentrics plus rings, as well as those on deletions, gave a good fit to a linear plus quadratic model.

Using the data obtained in x-irradiation experiments (acute doses of 50 to 300 rad), Bocian et al. have estimated that the RBE [Relative Biological Effectiveness] for the induction of dicentrics plus centric rings is about 1.2 .

3. Summary and conclusions
[Annex H: Genetic Effects]

Paragraph 378.

During the past few years, **there has been a growing interest in the study of the biological effects of radioisotopes, particularly of plutonium-239 and tritium.**

A number of genetic and cytogenetic studies that have so far been carried out in mice demonstrate that **these isotopes are capable of inducing dominant lethals [i.e. lethal mutations] , chromosome aberrations and point mutations (for the last category, only the effects of tritium have been studied) .**

Paragraph 379.

Autoradiographic studies have shown that in mice, intravenously injected plutonium-239 (as citrate solution) is inhomogeneously distributed in the testis and is largely localized in the interstitial tissue outside and between the seminiferous tubules. A consequence of this is that the alpha-irradiation dose rate to the spermatogonial stem cells is from 2 to 2.5 times greater than the average for the testis as a whole.

Paragraph 380.

When plutonium-239-injected males are mated to females, there is a significant excess of intra-uterine mortality relative to controls and the effect persists in matings up to five weeks after injection (post- and peri-meiotic stages sampled). In addition, the effect appears to be unrelated to the amount of plutonium-239 injected (in the range of 0.05-0.5 microcuries per mouse).

Paragraph 381.

Dominant lethal [mutation] tests performed on F1 males sired by fathers which received plutonium injection (and derived from matings during the ninth, fourteenth and sixteenth weeks) showed that here again there was an increase in intra-uterine mortality relative to controls.

Paragraph 382.

Relative to chronic gamma irradiation, alpha particles from plutonium-239 seem to be more than 20 times as effective in inducing dominant lethality (post-implantation) in meiotic and post-meiotic stages.

Paragraph 383.

In male mice exposed to alpha particles from plutonium-239 (intravenously injected citrate solution) for a duration of 6 to 34 weeks, reciprocal translocations (in spermatogonia) and chromosome fragments (in spermatocytes) are induced.

Relative to chronic gamma irradiation, alpha-particle irradiation from plutonium-239 is more than 20 times as efficient for the induction of these effects. This finding is similar to that recorded for the induction of dominant lethals in meiotic stages.

These calculations do not take into account the inhomogeneous distribution of plutonium-239 in the testis.

Paragraph 384.

Male and female mice fed on tritiated water, show, in dominant lethal tests, an increased amount of intra-uterine death.

Paragraph 385.

In specific-locus tests, **mutations have been found to be induced in male mice fed with tritiated water.** The data currently available suggest that the rate of induction [of mutations] per unit dose of irradiation with beta particles from tritium is about the same as that of x-irradiation. The estimates are 1.58 x 10^{-7} per rad per locus for spermatogonial mutations and 4.60 x 10^{-7} per locus for post-spermatogonial stages. These estimates have wide confidence limits. There is some evidence that the distribution of mutants among the seven loci may be different from that after x-irradiation.

Paragraph 386.

In human lymphocytes exposed to tritiated water in vitro, both chromosome- and chromatid-type aberrations are induced, depending on the concentration of tritium and the duration of exposure.

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[Tritium Dangers ~ Part 2]

[Nuclear Accidents at Chalk River -- The Human Fallout]

[No Safe Dose of Radiation -- Nuclear Authorities]

[CCNR SHORT DIRECTORY] [CCNR COMPLETE DIRECTORY]

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