High Effects at Low Doses?  
The Internal/External Dose problem and Tritium  

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The big question
What is the answer?

No they are not dangerous

If low doses of radiation were unsafe, then people who were having X-rays or medical radiation treatment with moderate doses would all be getting sick, developing cancer: They are not.

If low doses of radiation were unsafe, then cancer rates in high background areas would be greater than cancer rates in low background areas: They are not.
What is the answer?

Yes they are dangerous

If low doses were safe there would be no health effects like those associated with:

Chernobyl effects, Sellafield leukemias, Fukushima Thyroid cancer, Santa Susana cancer cases, Atmospheric Test Veterans, Irish Sea, Baltic Sea, Nuclear site downwinders at Hinkley Point, Bradwell, Aldermaston, Trawsfynydd, Uranium in Iraq and Balkans, Uranium miners and workers, sex ratio changes after exposures, global fallout infant mortality, cancer epidemic etc etc.
Sherlock Holmes says:
Something wrong here!

What is wrong is the question.
What is wrong is at the very heart of the whole issue, something that has been overlooked, either by error or on purpose since 1952 when radioprotection began with the International Commission on Radiological Protection.
Absorbed Dose

- The concept of **absorbed dose** is the primary problem.
- It is the basis of all radiation risk legislation.
- It is a mis-applied scientific concept adopted by the military in the 1950s and now employed to justify nuclear energy and to argue that LOW DOSES OF RADIATION ARE SAFE.
Dose the key issue in radioprotection

The misunderstandings about the quantity “Absorbed Dose” are fundamental to the understanding of the health effects of exposure to radioactive contamination, from Hiroshima to Fukushima, from Atmospheric Test fallout effects to Nuclear plant releases to Chernobyl. To understand the problem of Tritium, we must first understand what “dose” is and how it is calculated and applied to radiation protection.
<table>
<thead>
<tr>
<th>Activity</th>
<th>Dose (mSv)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dental X-ray</td>
<td>0.005</td>
</tr>
<tr>
<td>Transatlantic flight</td>
<td>0.07</td>
</tr>
<tr>
<td>Nuclear worker annual average</td>
<td>0.18</td>
</tr>
<tr>
<td>CT scan of head</td>
<td>1.4</td>
</tr>
<tr>
<td>UK average annual</td>
<td>2.7</td>
</tr>
<tr>
<td>CT chest scan</td>
<td>6.6</td>
</tr>
<tr>
<td>Blood cell changes are measurable</td>
<td>100</td>
</tr>
<tr>
<td>No cancer detectably predicted</td>
<td>100</td>
</tr>
<tr>
<td>Acute deterministic effects</td>
<td>1000</td>
</tr>
<tr>
<td>Death in 50% exposed</td>
<td>5000</td>
</tr>
</tbody>
</table>
But these doses are based on EXTERNAL EXPOSURE. ICRP phantom: body is modelled as a bag of water and radiation is assumed external. ABSORBED DOSE is ENERGY divided by MASS, Joules/Kg = Gray.

This method gives same dose for warming yourself in front of a fire or eating a hot coal.
This 50 page article reviews the problem of external and internal doses discussing the evidence and citing the previous literature. This has had more than 3600 downloads in the three months after its publication in May 2013.
INTERNAL EXPOSURE
A hot coal- Alpha particle decays- micron diameter particles of Plutonium in a rat lung: ‘alpha stars’ This local high energy effect is called ‘anisotropy’.
Edible mussel (mytilus edulis) Irish Sea; this is a hot particle example of the failure of dose as a measure of harm.
LOW DOSES? Doses to 10μ cell from internal α– decay (5MeV per decay)

<table>
<thead>
<tr>
<th>event</th>
<th>mSv</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>Single decay</td>
<td>385 mSv</td>
<td>Any alpha emitter</td>
</tr>
<tr>
<td>Sequential decays</td>
<td>1540 mSv</td>
<td>Th-228, Ra-224, Rn-220, Po-216</td>
</tr>
<tr>
<td>Hot particle 1μ diameter</td>
<td>570 mSv</td>
<td>Pu-239</td>
</tr>
<tr>
<td>Warm particle 1μ</td>
<td>4.4 mSv</td>
<td>U-238 ignoring β daughters</td>
</tr>
</tbody>
</table>
It is now universally acknowledged that radiation effects are due to DNA damage. So the target is not even the cell, but is mainly the chromosomal DNA. It is therefore the dose to the DNA that is relevant for radiation protection. There are specific mechanisms that enhance the ionisation at the DNA. All cellular DNA including bound water is $1/87^{th}$ of the cell by mass.
All radiation effects are delivered as ionisation tracks. Probability of ionisation track intercepting chromosomal DNA bases is function of distance of radionuclide; $P$ increases rapidly for radionuclides within $0.5\mu m$ of DNA.

Approximate probability of a track interception of a DNA target modelled as a strip of $0.1 \times 1 \mu m$ by distance in $\mu m$ from target. In this model, the maximum probability is $0.5$ for a nuclide located on the surface of the flat DNA strip.

From Busby  InTech 2013
Genetic damage enhancement mechanisms for DNA ionisation from internal exposures (see Busby Intech 2013)

<table>
<thead>
<tr>
<th>Mechanism</th>
<th>Nuclide of concern</th>
<th>Enhancement of ICRP (dose to DNA)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. DNA affinity</td>
<td>Sr-90, Ba-140, Uranium</td>
<td>300-10,000</td>
</tr>
<tr>
<td>2. Transmutation</td>
<td>Tritium, C-14, S-35, all DNA bound</td>
<td>10-100 reported, poss. higher</td>
</tr>
<tr>
<td>3. Secondary photoelectron SPE</td>
<td>Uranium, Bismuth, Lead, platinum, Iodine</td>
<td>&gt; 80; depends on fifth power of atomic number</td>
</tr>
<tr>
<td>4. Second Event and dose $^2$</td>
<td>Sr-90, Te-132, Tritium</td>
<td>10-300</td>
</tr>
<tr>
<td>5. Auger</td>
<td>Cs-137, U-238, OBT (tritium)</td>
<td>10-100</td>
</tr>
<tr>
<td>6. Hot particles</td>
<td>Uranium weapons, Pu, Actinides</td>
<td>10 to 10,000</td>
</tr>
</tbody>
</table>
**Transmutation**: internal elements in the DNA or key enzymes change identity and create ionisation; many studies in 1960s showing effects as high as 100-fold vs dose. Discussed with references in Busby InTech 2013

<table>
<thead>
<tr>
<th>Nuclide examples</th>
<th>Change to</th>
<th>Key molecules</th>
</tr>
</thead>
<tbody>
<tr>
<td>C-14 (β)</td>
<td>N-14</td>
<td>DNA bases: purines, pyrimidines, amino acids, proteins</td>
</tr>
<tr>
<td>H-3 (β)</td>
<td>He-3</td>
<td>DNA bases, enzymes, membranes</td>
</tr>
<tr>
<td>S-35 (β)</td>
<td>Cl-35</td>
<td>Enzymes, proteins</td>
</tr>
<tr>
<td>I-131 (β)</td>
<td>Xe-131m</td>
<td>Thyroid proteins, hormones, components of blood</td>
</tr>
<tr>
<td>P-32 (β)</td>
<td>S-32</td>
<td>DNA, RNA</td>
</tr>
</tbody>
</table>
The effects of *Transmutation* are greater than the dose effects of the decay; this has been known since the 1960s but ignored by ICRP and the risk agencies. One example:

Apelgot and Latarjet [1962] incorporated C-14 into the cells of the bacteria *e.coli* by culturing in a medium containing 2-14C-thymidine. The samples were stored at -196 C for one year. To evaluate the role of the β-radiation, a control non-radioactive bacteria sample was stored in the presence of 2-14C thymidine in such a way that the radioactivity per cm3 of this suspension was the same as the study sample. From a comparison of the results, the authors concluded that the *predominant lethal effect* was from transmutation with an efficiency of **160-times** that which was obtained from the β-radiation.
Tritium H3

- Tritium H3 is a radioisotope of hydrogen H1 with a half life of 12.3 years. It decays with the emission of a beta particle to an isotope of Helium He3.
- The beta emission is of unusually low energy the average and maximum energies being 5.7 and 18.6 keV.
- It is both man made and naturally occurring.
- The average range in water of the beta particle is 0.5 microns, compared with cell diameters of 10 microns.
- Therefore the location of the tritium atom is critical in assessing its effects.
Tritium H3 (2)

- Because of its low beta energy and short range of 0.5\(\mu\)m, the average density of ionisation in the track is high, 12keV/\(\mu\)m compared with beta particle tracks from Strontium-90 of 0.5keV/\(\mu\)m.
- This makes a Tritium beta track 24 times more ionising than an average beta or photoelectron track originating from natural background radiation.
- It is thus half way between a low LET track and a high LET alpha particle track for which a Relative Biological Effectiveness RBE of 20 has been assigned.
- ICRP originally assigned Tritium a QF of 1.7 for this reason, although a RBE of 10 would be more reasonable.
Karl Z Morgan, who served on the main committee of the ICRP between 1951 and 1971 was originally Chair of Committee 2 which provided advice on internal exposures.


“The ICRP also prostituted itself regarding the dangers of Tritium, an essential component of the fusion bomb. [our] desperate attempt to increase the RBE of Tritium from 1.7 to 4 or 5. . . . Made it too costly for industry. . . . Shortly after I left ICRP in 1970 they solved the problem by reducing it from 1.7 to 1.0.”
Chemical Transmutation effects

Radiation is not the only way that Tritium (and other biological radionuclides, C-14, S-35, P-32) can introduce ionisation. Tritium, as a form of hydrogen, exchanges with hydrogen atoms on DNA, on proteins and other key elements in the cell. When the Tritium decays to He3 in immediately introduces an ionisation by breaking the hydrogen oxygen, hydrogen nitrogen or covalent hydrogen-carbon bond, destroying the molecular structure of the parent molecule.
Multiple tracks; Second Event

- Cells function for their normal lifespan, which depend on the cell type. Blood cells fast; liver cells slow; brain cells never
- Cells which become damaged or when aged make a decision to repair and replicate
- They are most sensitive to mutation in the repair replication cycle
- If both DNA strands are broken locally there is no repair template and there is a mutation introduced.
- This can occur if there are two tracks which cause lesions within the cell repair cycle period of 12 hours.
- Tritium produces many more tracks per unit dose than usual beta emitters like Sr-90 or Cs-137. (120 times).
Sources of Tritium

- **Natural:** formed by interactions of cosmic rays in the upper atmosphere; occurs principally in the form of water vapour HTO
- Increased during atmospheric weapons tests 240pBq/Mt
- Tritiated water has a higher freezing point than normal water and will preferentially form fog as the temperature falls
- Is produced by and is released by nuclear power reactors
- Is used as tracers in research and is normally discarded to local watercourses.
The Jha experiments

- Dr Awadhesh Jha in Plymouth carried out a series of experiments in the early 2000s on the effects of Tritiated water on the development of invertebrates.
- Results showed that there were serious developmental effects at very low doses, around 1 mSv.
- I brought these results to CERRIE but they were dismissed as impossible by the committee.
- Jha’s researcher found significant increase in chromosome damage at “doses” below 1 mSv.
- There is no reason why such effects would not occur in human embryonic development. SWITCH TO JHA PPT.
The Painter experiments

- Painter et al (1974) studied the degree of preparative replication and the degree of repair of such damage depending on the dose of Tritium and external X-rays.

- It was shown that one decay of H3 leads to incorporation of the newly synthesized (repair) genetic material in DNA in the same quantity as during X-radiation in the dose of 3.4mSv.

- Similar values were obtained in experiments on the induction of single strand breaks (4.8mSv/decay) and in calculation of the mean energy of beta particles of H3 for the nucleus of mammalian cells (4.7mSv/decay).
Conclusions

- Tritium is a hazardous material which is not safely modeled by the ICRP “absorbed dose” methodology.
- Because of its equivalence to hydrogen it easily passes into living systems and exchanges with the natural element.
- There is sufficient evidence for it to be considered harmful for embryonic development.
The ICRP model must be abandoned as a matter of urgency

Releases of fission product radionuclides and uranium to the environment must be strictly regulated on the basis of the ECRR2010 risk model,

The BSS Directive cannot be approved and the Parliament must demand re-justification of all practices under Article 20

This is a Public Health and Human Rights Issue